The Energy Consumption and Economic Growth Nexus in Top Ten Energy-Consuming Countries: Fresh Evidence from Using the Quantile-on-Quantile Approach

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Abstract: This paper empirically examines the inter-linkages between energy consumption and economic growth in top ten energy-consuming countries i.e. China, the USA, Russia, India, Japan, Canada, Germany, Brazil, France and South Korea. We use the quantile-on-quantile (QQ) approach of Sim and Zhou (2015) to explore some nuanced features of the energy-growth nexus and to capture the relationship in its entirety. The results show a positive association between economic growth and energy consumption, with considerable variations across economic states in each country. A weak effect of economic growth on energy consumption is noted for the lower quantiles of economic growth in China, India, Germany and France, which suggests that energy as an input has less importance at low levels of economic growth. A weak effect of economic growth on energy consumption is also noted for the highest quantiles of income in the United States, Canada, Brazil and South Korea, which indicates that energy demand decreases with the increase in economic growth as these countries have become more energy efficient. The weakest effect of energy consumption on economic growth is observed at lower quantiles of energy consumption in China, Japan, Brazil and South Korea. The results of the present study can help in the design of energy development and conservation policies for sustainable and long-term economic development.

Keywords: Energy Consumption, Economic Growth, Quantile-on-Quantile Approach
JEL Classifications: C22, Q43

1. Introduction

The wave of globalization has not only integrated the countries socially, politically and economically but also intensified the growing competition among developing and developed countries of the 21st century. The tendency of rising competition among developed and developing countries is widely understood via higher economic growth that often comes with massive usage of energy. The environmental consequences of rising energy consumption bring climate change and global warming. The rising climate change and global warming are detrimental to the quality of natural environment and human being living on the planet. To reduce global warming, governments and policy makers of high pollution-emitting countries are planning to cut their energy use by enhancing energy innovation development and are also exploring the energy-growth relationship. Many empirical studies have previously been conducted on the energy-growth linkages (Kraft and Kraft 1978, Ozturk 2010, Payne 2010, Shahbaz et al. 2011, 2013, Belke et al. 2011, Magazzino 2015, Shahbaz et al. 2017). However, these studies have flaws, especially with regard to their estimation techniques used (discussed in detail in the next section). Moreover, the time series estimation techniques used in the previous studies have failed to capture the true dependency relationship between energy consumption and economic growth at lower and higher quantiles of the time series data. The failure of these time series-driven cointegrating techniques may misguide the policy makers and governments of high energy consuming countries especially at the time of energy and economic growth policy making. Under such circumstances, one research question arises here: what kind relationship that we have for most energy consuming countries when we tend to study the dependency pattern between the series both at lower and higher quantiles of the time series data? Therefore, there is a need to reinvestigate the energy-growth nexus using more sophisticated estimation techniques which is the main innovation of the study apart from effectively guiding the policy makers and governments of top ten energy consuming countries. In this vein, our study is motivated and contributes to the rich energy economics literature in two different ways. On the one hand, to assess the dependency pattern between energy consumption and economic growth for top ten energy consuming countries, we use the Quantile-on-Quantile (QQ) approach, as recently proposed by Sim and Zhou (2015). Our second innovation stems from choosing top ten energy consuming countries within a time series framework, i.e. China, the USA, Russia, India, Japan, Canada, Germany, Brazil, France and Korea. These countries account for

64.6 percent of the world's primary energy consumption.[1] The QQ approach was developed by Sim and Zhou (2015). It combines quantile regression and nonparametric estimation techniques and regresses the quantile of a variable on the quantile of another variable. Further, the QQ approach takes into account the nonlinear relations between energy consumption and economic growth. Therefore, QQ analysis represents a very useful method, as it enables one to estimate the effect that the quantiles of economic growth (energy consumption) have on the quantiles of energy consumption (economic growth), thus providing a comprehensive and precise picture of the overall dependence of both variables. By its very nature, the QQ framework allows one to identify complexities in the relationship between energy consumption and economic growth that would be difficult to detect using conventional econometric models. To the authors' best knowledge, this is the first paper to apply the QQ approach to study the energy-growth nexus. The results can help in the design of energy development and conservation policies for sustainable and long-term economic development for top ten energy consuming countries.

However, energy consumption is indispensable for economic development. In addition to labor and capital, energy is also an important input for economic growth. The association between energy consumption and economic growth gained momentum after the energy crisis of the 1970s. Kraft and Kraft (1978) were the first one to empirically examine the energy-growth nexus. The theoretical literature has categorized the energy-growth nexus into four types, which are known as the growth hypothesis, the conservation hypothesis, the neutrality hypothesis, and the feedback hypothesis. The *growth hypothesis* states that energy consumption inputs contribute directly to economic development and work as a complement to labor and capital in the production process (Ebohon 1996, Templet 1999, Apergis and Payne 2009a, b). The *growth hypothesis* is supported if an increase in energy consumption increases economic growth i.e., gross domestic product (GDP). The policy implications of the growth hypothesis suggest that energy conservation-oriented policies may have a detrimental effect on economic growth (GDP) because the underlying country is energy dependent, and measures to conserve energy such as energy pricing or rationing may hamper economic growth because economic growth largely depends on energy consumption (Karanfil 2009, Ozturk 2010). In turn, if an increase in energy consumption decreases economic growth, it may be because the growing economy has shifted to production in less energy-intensive sectors that require less energy consumption. Furthermore, the growing economy may have

[1] These data are for the year 2014 and are taken from US EIA Historical Statistics.

become highly fuel efficient, meaning that it requires less energy to produce the same level of output. In addition, an adverse effect of energy consumption on economic growth may be the result of the excessive use of energy inputs in unproductive sectors of the economy, capacity constraints, or inefficient energy supply, among others (Squalli 2007). The *conservation hypothesis* suggests that a country is less dependent on energy inputs and that conservation-oriented policies may not impede economic growth. This hypothesis is supported if an increase in economic development increases energy demand (Apergis and Payne 2009a, 2009b, Jalil and Feridun, 2014). The *neutrality hypothesis* postulates that energy inputs play a minor role in the economic development of a country and do not significantly affect economic growth. Therefore, energy conservation policies do not adversely affect domestic income (GDP). Thus, according to this hypothesis, energy consumption and economic growth are not dependent on each other (Squalli 2007, Yu and Choi 1985, Jalil and Feridun, 2014). Finally, the *feedback hypothesis* stipulates that energy consumption and economic growth are interdependent and serve as complements to one another. In this case, an increase (decrease) in energy consumption results in an increase (decrease) in economic growth, and likewise, an increase (decrease) in economic growth results in an increase (decrease) in energy consumption. This relationship suggests that energy exploration policies should be prioritized over energy conservation policies, which impede economic growth (Yang 2000, Squalli 2007, Belloumi 2009, Payne 2009, Oztuk 2010, Tiba and Omri, 2017).

The rest of the paper is organized as follows. Section 2 provides an overview of literature review. Section 3 presents the energy consumption profiles of the selected countries. Section 4 describes the data. Section 5 elaborates the methodology. Section 6 provides the estimated results. The final section 7 concludes the paper and discusses policy implications.

2. An Overview of Literature Review

2.1. Energy-Growth Nexus Controversies

Many researchers have explored the determinants of economic growth. In this respect, several economic growth theories have been proposed. However, it is interesting to note that none of these theories has included energy as an important determinant of economic growth. For instance, the Solow growth model shows that technological progress is an important factor in economic growth. The AK model stipulates that a high savings rate is important for economic growth. Similarly, the Schumpeterian growth models highlight the importance of capital accumulation and innovation as determinants of economic growth. The growth models developed by Romer (1990) and Grossman and Helpman (1990) show that research & development is an important factor in economic growth.

In their seminal work, Kraft and Kraft (1978) were the first to empirically examine the relationship between energy and economic growth by considering energy consumption as an important factor of production, like capital and labor. Numerous empirical studies have since been conducted to examine the energy-growth nexus. Different studies have been conducted in different countries over different time periods using different econometric techniques to examine the relationships among energy, income and other macroeconomic variables. Ozturk (2010) and Payne (2010) and later Shahbaz et al. (2011, 2013) and Magazzino (2015) provided detailed surveys of the previous studies that have examined the energy-growth relationship. Additionally, Belke et al. (2011) using panel data of 1981 to 2007 for 25 OECD countries indicated the presence of bidirectional causality between energy consumption and economic growth. However, these prior studies have found conflicting and controversial results regarding the energy-growth nexus (Ozturk, 2010). The results differ both in the direction of causality and in short-run versus long-run effects. The differences in the results can be attributed to differences in the types of models used, the model specifications, the econometric techniques, the types of data, the countries selected, the measures of energy, the sample sizes, and the countries' resource endowments, among others (Karanfil 2009, Payne 2010, Stern 2011). These differences in the results may also occur because different countries have different climatic conditions and energy conservation policies.

The previous studies have mainly used three types of models to examine the energy-growth relationship i.e. bivariate models (e.g., Kraft and Kraft 1978, Akarca and Long 1980, Chontanawat et al. 2008, Hu and Lin 2008), multivariate models (e.g., Shahiduzzaman and Alam 2012, Stern 1993, 2000, Oh and Lee 2004, Apergis and Payne 2009c, Lee and Chien, 2010), and energy demand models (e.g., Asafu-Adjaye 2000, Fatai et al. 2004, Belke and Dreger 2013, Belke et al. 2011, 2014a).[2] In bivariate models, the relationship between two variables is examined i.e. energy consumption and economic growth/income. In multivariate production function models, energy inputs are included in the production function along with labor and capital. According to Lee et al. (2008), if labor and capital stock variables are not considered in the analyses of the energy-growth nexus, the role of energy inputs in economic growth may be exaggerated. Energy demand models

[2] Suganthi and Samuel (2012) provided a review of energy demand models.

include energy prices as important determinant in addition to income. The advantage of a multivariate model is that it decreases the possibility of omitted variable bias. Therefore, it examines the additional channels through which energy consumption and economic growth variables are inter-linked.

With regard to the specification of econometric models, some studies have used linear models to study the energy consumption and income growth relationship, while others have used nonlinear models, as it has been argued that energy consumption and income in developed countries increase linearly, while income and energy consumption in developing countries increase exponentially. Further, the EKC hypothesis, which was first proposed by Grossman and Kruger (1991, 1995), describes an inverted U-shaped relationship between environmental pollution and economic development. It stipulates that at the early stage of economic development, environmental pollution increases and then starts decreasing as economic development continues. Because most pollutants are closely related to energy consumption, energy consumption is often treated as a proxy for environmental stress. Thus, it is necessary to capture a possible nonlinear relationship in the estimation. Thus, the quadratic term of income is introduced to the regression of energy consumption on economic growth in addition to any other necessary control variables (e.g., Ang 2007, Apergis and Payne 2009c, and Lean and Smyth 2010, Suri and Chapman 1998, Luzzati and Orsini 2009, Yoo and Lee 2010).

With regard to econometric techniques, different studies have applied different estimation techniques to explore the energy-growth nexus. The most commonly used techniques are Granger/Sims causality tests, Engle-Granger/Johansen-Juselius cointegration and error-correction models. The conventional (Granger) causality tests have been criticized on the grounds that they can only be employed in time-dependent processes such as stock-adjustment processes, where a shock has inter-temporal effects. Such tests are inappropriate for time-invariant dependent processes (Bernard et al. 2010). According to Bernard (2010), the current period's energy consumption cannot predict/cause the next period's economic growth. Similarly, the conventional unit root and cointegration tests have been criticized due to their low power and size properties for small samples (Harris and Sollis, 2003). Therefore, more recent studies have used autoregressive distributed lag (ARDL) models, as introduced by Pesaran and Shin (1999), Pesaran et al. (2001), Toda and Yamamoto (1995) and Dolado and Lutkepohl (1996). These tests do not require a pre-test of unit root for cointegration and causality. They can be applied irrespective of whether the variables have the same or different unit roots. Recently, Carmona et al. (2017) examined the causality between energy consumption and economic growth by decomposing both series into two components, a non-stationary natural component and a stationary (transitory) cyclical component. The study finds bidirectional causality between energy consumption and economic growth.

Initially, studies used time series data to explore energy-growth inter linkages. However, the use of short data spans reduces the power and size properties of conventional unit root and cointegration tests. To overcome these issues, researchers have started to use panel unit root and panel cointegration tests, as proposed by Pedroni (1999, 2004). With the advent of panel techniques, some studies have examined the nexus between these two variables using panel data (e.g., Lau et al. 2011, Lee 2005, Lee and Chang 2007, Lee et al. 2008, Huang et al. 2008, Lee and Chang 2008, Antunano and Zarraga 2008, Apergis and Payne, 2009c, Lee and Chien 2010, Belke et al. 2011, Mohammad and Parvaresh 2014). Because panels merge cross-section and time-series data, the estimations have significantly enhanced reliability and robustness. The use of panel data significantly increases the degrees of freedom and allows some advanced econometric methods for panel data to be utilized, such as full-modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS), to estimate the cointegration vector for heterogeneous cointegrated panels, which corrects the bias in traditional OLS estimators induced by the endogeneity and serial correlation of the regressors. An important drawback of most of the previous studies is that they have estimated the energy-growth nexus without considering structural break(s) in the analysis. Energy consumption and economic growth may have some structural break(s) due to domestic and global economic shocks (business cycle), changes in energy policy and fluctuations in energy prices (e.g., Altinay and Karagol 2004, Lee and Chang 2005, Chiou-Wei et al. 2008, Clemente et al. 2017). In addition, considering only one or two breaks may not capture changes in the energy-growth relationship in their entirety. Furthermore, the asymmetry in the relationship, i.e., a positive change in one variable may have a different impact on the other compared to a negative change, has remained unexplored so far. The present study intends to fill this gap because it will examine the association between energy consumption and economic growth using the quantile-on-quantile (QQ) approach, which takes into account structural breaks, nonlinearity, asymmetry, and regime shifts, among others. It captures all of these effects because it shows distribution-to-distribution effects, which has not been done before (Shahzad et al. 2017, Saidi et al. 2017).

2.2. Energy-Growth Nexus in the Top10 Energy-Consuming Countries

The existing energy economics literature on the energy-growth nexus provides ambiguous empirical evidence. For example, in the case of the **USA**, Kraft and Kraft (1978) investigated the association between energy consumption and gross national product (GNP) and reported that energy use is a cause of GNP. Later, Akarca and Long (1980) revisited the energy-growth nexus and reported a neutral effect between energy consumption and economic growth. Yu and Hwang (1984) also reported that energy consumption and economic growth are independent of each other. By incorporating employment as an additional variable Yu and Jin (1992) reported that a causal relationship does not exist between energy consumption and economic growth. Stern (1993) applied bivariate modelling to assess the causality between energy consumption and economic growth and reported that energy consumption leads economic growth. Stern (2000) applied the production function in a multivariate framework to test the effect of energy consumption on economic growth and found that the variables are not cointegrated. By applying Toda and Yamamoto's (1995) methodology, Lee (2006) found that energy consumption leads economic growth and economic growth leads energy consumption.[3] Chiou-Wei et al. (2008) applied linear and non-linear causality approaches and confirmed the empirical findings reported by Akarca and Long (1980). Jin et al. (2009) found an insignificant role of energy consumption in stimulating economic growth. Similarly, Payne (2009) applied the Toda-Yamamoto causality test to examine the relationship between energy (renewable and non-renewable) consumption and economic growth and found that economic growth does not cause energy consumption, nor does energy consumption cause economic growth[4].

By applying a bivariate framework, Gross (2012) found that energy consumption and economic growth stimulate each other, but economic growth has a stronger effect on energy consumption[5]. Ajmi et al. (2013) also reported a feedback effect between energy consumption and economic growth. Aslan et al. (2014) conducted a wavelet analysis to re-examine the direction of causality between energy consumption and economic growth. Their empirical results contradicted the findings reported by Kraft and Kraft (1978), Rodríguez-Caballero and Ventosa-Santaulària

[3] Soytas and Sari (2006) reported that energy consumption causes economic growth in the US.
[4] Narayan et al. (2011) reported that changes in energy consumption and output are sensitive to permanent shocks in the US economy.
[5] Hatemi-J and Uddin (2012) found unidirectional causality running from a negative shock in energy utilization to a negative shock in output per capita.

(2016). The authors applied the Toda and Yamamoto (1995) causality test and found that energy consumption and economic growth are complementary. Conversely, Mutascu (2016) confirmed the empirical evidence reported by Akarca and Long (1980), Yu and Hwang (1984), Yu and Jin (1992), Stern (2000), Chiou-Wei et al. (2008) and Payne (2009) that a neutral effect exists between energy consumption and economic growth. Recently, Koutzidis et al. (2018) reinvestigated the association between energy consumption and sectoral economic growth by applying threshold cointegration approach for long run over the period of January 1991 to May 2016. Their empirical evidence confirms neither sectoral economic growth causes energy consumption or energy consumption causes sectoral economic growth but energy conservation hypothesis is validated at national level.

For the **Canadian** economy, Ghaliand El-Sakka (2004) employed a production function to examine the relationship between energy consumption and economic growth by including labor and capital as additional determinants of economic growth. They found that energy consumption is an important factor in domestic production and that a feedback effect exists between energy consumption and economic growth. Lee (2006) confirmed the presence of unidirectional causality running from energy consumption to economic growth. Conversely, Soytas and Sari (2006) found that energy consumption (economic growth) leads economic growth (energy consumption). Later, Rodríguez-Caballero and Ventosa-Santaulària (2016) supported the empirical findings of Soytas and Sari (2006) that energy consumption causes economic growth, but in addition, economic growth causes energy consumption, which is similar to Ajmi et al. (2013), who confirmed the presence of a feedback effect between the two variables. By applying a bivariate framework, Mutascu (2016) reported that energy consumption causes economic growth.

In case of **France**, Lee (2006) applied the Toda and Yamamoto (1995) causality test to the energy-growth nexus and found that energy consumption is led by economic growth. Similarly, Soytas and Sari (2006) also reported that economic growth leads energy consumption. Ajmi et al. (2013) noted that energy consumption and economic growth are interdependent, i.e., the feedback effect holds. Conversely, Arouri et al. (2014) applied the asymmetric Granger causality to test the direction of the causal relationship between energy utilization and economic growth. Their empirical analysis indicated that energy utilization asymmetrically leads to economic growth. For the **German** economy, Lee (2006) reported a neutral effect between energy consumption and economic growth. However, Soytas and Sari (2006) confirmed the presence of unidirectional causality from economic growth to energy consumption, which was also confirmed by Ajmi et al. (2013). In contrast, Mutascu (2016) found that energy consumption (economic growth) does not cause economic growth (energy consumption).

In the **Chinese** economy, Wang et al. (2011) employed a production function in a multivariate framework by incorporating capital and labor as additional determinants of economic growth to assess the linkages between energy consumption and economic growth. They found that energy consumption plays an important role, like capital and labor, in stimulating economic growth. Their causality analysis indicated that economic growth causes energy consumption. Shahbaz et al. (2013) reinvestigated the association between energy consumption and economic growth by incorporating additional determinants, i.e., financial development and trade in the production function. Their empirical results confirm that energy consumption stimulates economic growth. Furthermore, they reported that energy consumption causes economic growth, but the opposite is not true in a Granger sense. In contrast, Herrerias et al. (2013) reported that energy consumption is a cause of economic growth. Jalil and Feridun (2014) employed a production function by incorporating labor to examine the impact of energy consumption on economic growth. They reported that labor strengthens the relationship between energy consumption and economic growth and that energy consumption leads economic growth. Tang et al. (2016) applied a multivariate framework to re-examine the relationship between energy consumption and economic growth by incorporating exports in the production function. They reported that energy consumption significantly contributes to economic growth. In the case of **India**, Paul and Bhattacharya (2004) applied the Granger causality test and reported that energy consumption causes economic growth and conversely, economic growth causes energy consumption. In contrast, Zhang (2011) found that neither energy consumption causes economic growth nor economic growth leads energy consumption. Yang and Zhao (2014) reported that the growth hypothesis is valid, i.e., economic growth is led by energy consumption. Recently, Nain et al. (2018) applied Toda–Yamamoto causality test and reported that economic growth is cause of energy (electricity) consumption is short run.

In the case of **Russia**, Zhang (2011) examined the relationship between energy consumption and economic growth by including capital and labor as additional determinants of economic growth. The empirical analysis indicated that the two variables are cointegrated and that energy consumption leads economic growth, and in turn, economic growth also leads energy consumption[6]. Faisal et al. (2016) re-examined the causality between energy consumption (electricity consumption) and economic growth over the period from 1990-2011. After confirming cointegration between the variables, their empirical evidence indicated a feedback effect between electricity consumption and economic growth, but a neutral effect was found between energy consumption and economic growth. In the case of **Brazil**, Cheng (1997) employed a trivariate production function by including energy consumption and capital as determinants of gross domestic product. By applying error-correction modelling, the empirical results indicated unidirectional causality running from energy use to economic growth. Zhang (2011) reported a feedback effect between energy consumption and economic growth. Pao et al. (2014) investigated the relationship between energy consumption and economic growth by using a bivariate framework. They found that energy consumption adds to economic growth, but the causality analysis confirmed the presence of a feedback effect between the two variables. Similarly, Rodríguez-Caballero and Ventosa-Santaulària (2016) also reported that energy consumption (economic growth) leads economic growth (energy consumption).

In the case of **Japan**, Cheng (1998) explored the association between energy use and real GNP by including employment and capital as additional determinants of the production function. The empirical results showed unidirectional causality running from employment and real GNP to energy use. By applying Toda and Yamamoto's (1995) methodology, Lee (2006) reported that economic growth leads energy consumption, and later, Soytas and Sari (2006) confirmed the unidirectional causality running from economic growth to energy consumption, but Ajmi et al. (2013) reported a feedback effect between the two variables. In contrast, Mutascu (2016) confirmed the presence of a neutral effect between energy consumption and economic growth. For the **South Korean** economy, Glasure (2002) employed a production function by including oil prices to assess the relationship between energy consumption and economic growth. The empirical results indicated that energy consumption adds to economic growth and that causality runs from energy consumption to economic growth. Conversely, Oh and Lee (2004) reported that energy consumption is a cause of economic growth, but Chiou-Wei et al. (2008) reported that energy consumption does not cause economic growth, nor does economic growth cause energy consumption. Yildirim et al. (2014) applied a bootstrapped autoregressive metric causality test to

[6] Dedeoglu and Pishkin (2014) applied panel causality to test the relationship between energy consumption and economic growth in the Soviet Union. They found that economic growth is a cause of energy consumption.

examine the relationship between energy consumption and economic growth. They found that energy consumption does not affect economic growth, nor does economic growth affect energy consumption. Shahbaz et al. (2016) applied time-varying causality and found that energy consumption and economic growth are complementary.

3. Profiles of the Top 10 Energy-Consuming Countries

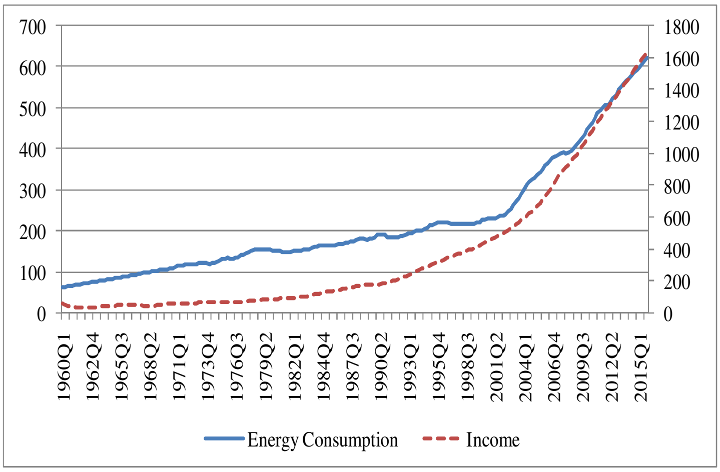
Energy consumption plays a critically important role in determining the outlook for economic development. For the world as a whole, energy consumption is pushing GDP growth higher. However, this relationship has diverged substantially across countries over recent years (Figure-1). For instance, in the United States, economic development (as measured by per capita GDP) is associated with a slight decline in (per capita) energy consumption for the period from 2000 to 2015. The same pattern holds in Japan, Canada and Germany. France has also followed the same pattern since 2009. All of these countries are OECD countries, which indicates that structural economic shifts, saturation effects and efficiency gains have produced a peak in energy consumption in all OECD countries (IEA, 2016). Elsewhere, however, the links between GDP growth and energy consumption are strong.

In 2015, China was the world's highest energy consumer, followed by the United States, India and Russia (Figure-2; values are in metric tons of oil equivalent). All of the other countries, i.e., Japan, Germany, Brazil, Korea, Canada and France, also consumed high amounts of energy in 2015 and remained among top 10 energy-consuming countries. Energy consumption in the OECD countries is declining, however, while energy consumption in the non-OECD countries is increasing, particularly in China and India. According to the IEA (2016), the geography of global energy consumption continues to shift toward India, China and Southeast Asia as well as parts of Africa, Latin America and the Middle East. If we look at the growth pattern of these countries (Figure-3), we find that in 2015, India had the highest growth rate, followed by China. In both the United States and Korea, GDP growth was 2.60 percent in 2015. These disparities again support the notion that energy consumption will continue to shift toward China and India due to their high economic growth rates. However, future energy consumption in China and India depends heavily on their energy efficiency policies, the degree of expansion of their energy-intensive sectors (e.g., iron and steel, cement, petrochemicals), and their ability to shift from an industrial-oriented economy toward a services-oriented economy, which is less energy intensive. Industry's share of

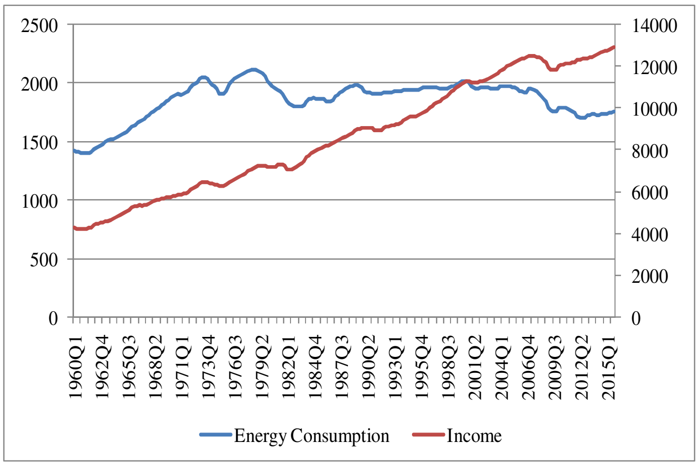
China's GDP is projected to decrease from 42 percent today to 34 percent in 2040 (IEA, 2016). Further, structural changes in these economies, for instance, shifts from the use of solid biomass toward modern fuels, especially for cooking, will also affect the energy consumption patterns in these countries.

Figure 1: Patterns of Energy Consumption and Economic Development in Selected Countries

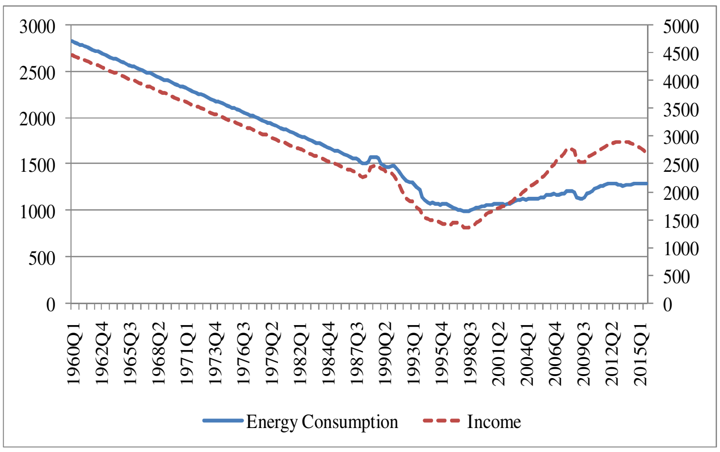
China



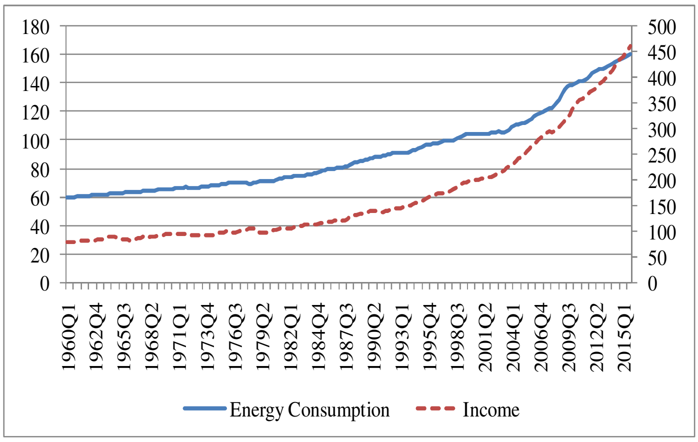
USA



Russia

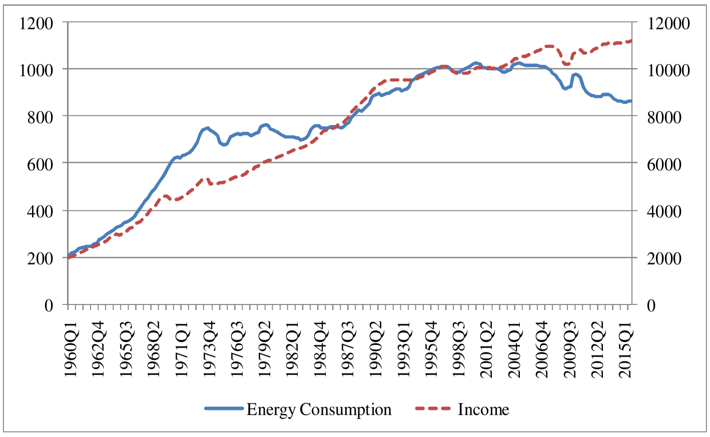


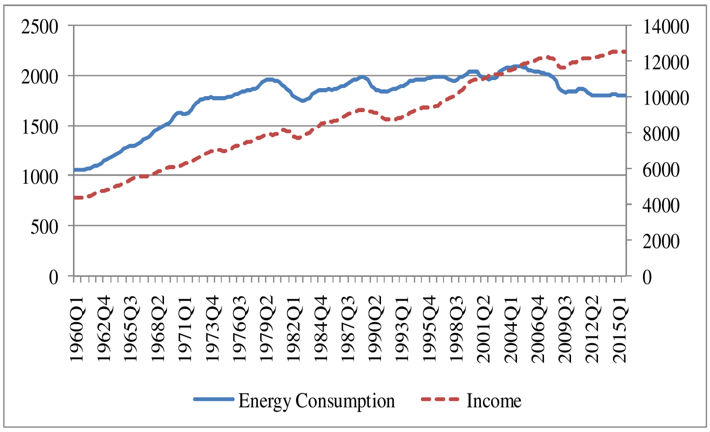
India



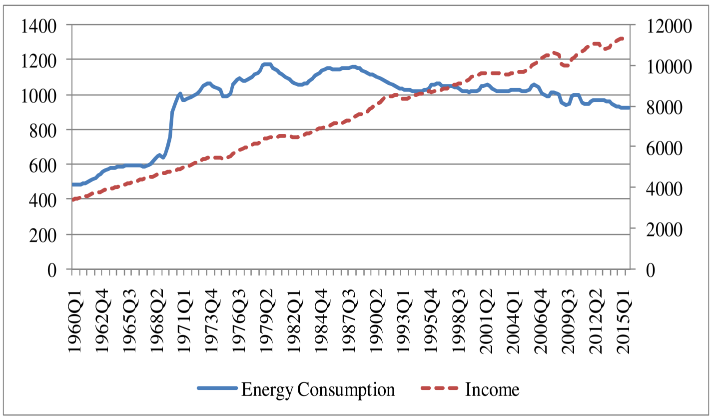
Japan

Canada

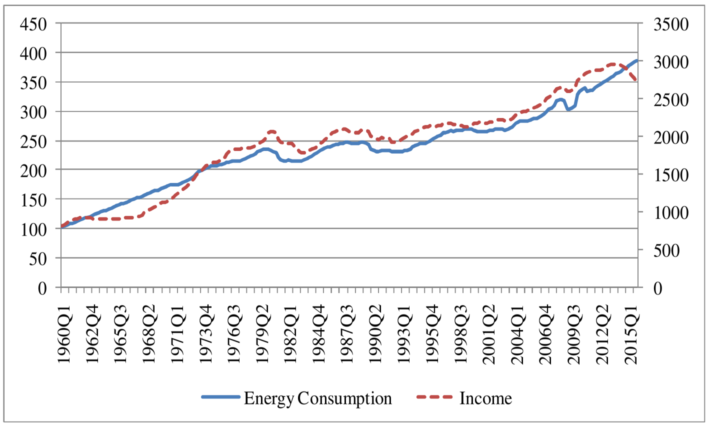




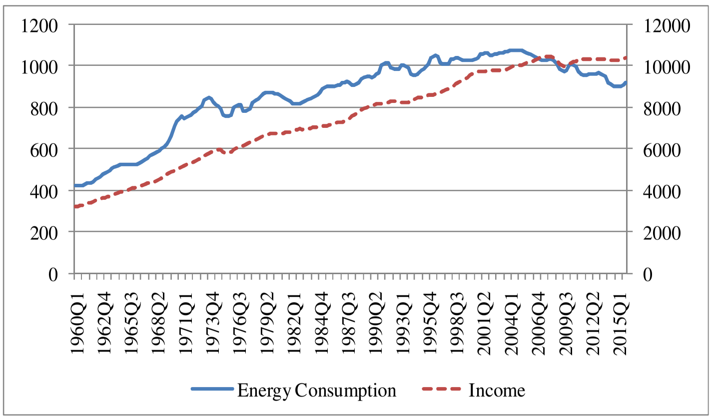
Germany



Brazil



France



Korea

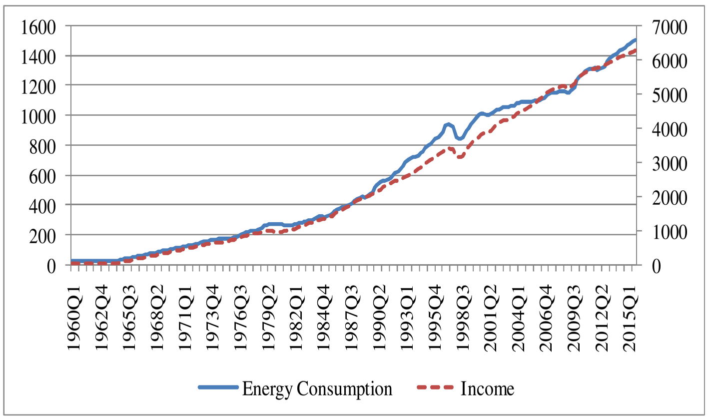
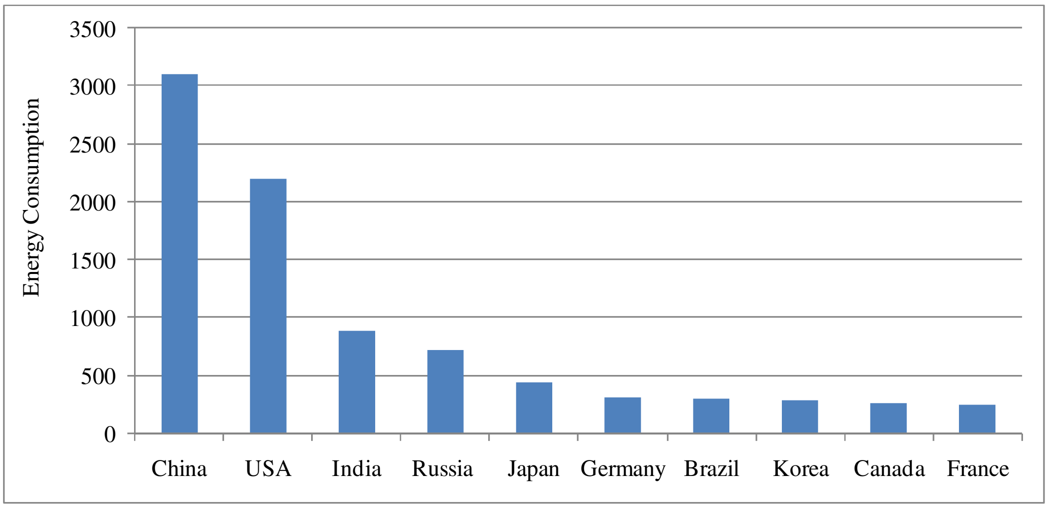
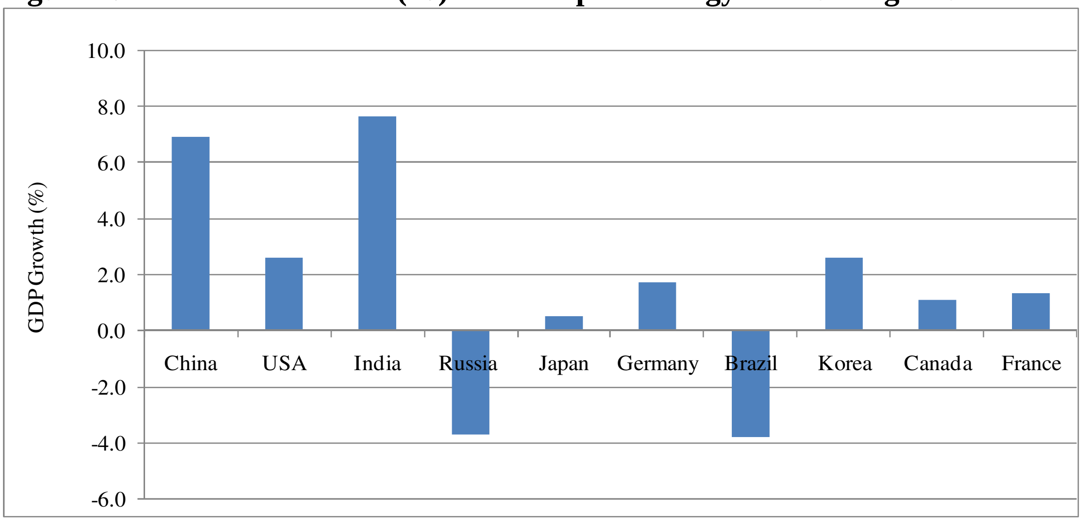


Figure 2: Total Energy Consumption in the Top 10 Countries in 2015 (MTOE)



Source: Global Energy Statistical Year Book 2016

Figure 3: GDP Growth Rates (%) in the Top 10 Energy-Consuming Countries in 2015



Source: World Development Indicators, World Bank

4. Data and its Description

The dataset in this study consists of two variables, that is, per capita energy consumption (kg of oil equivalent) and per capita real Gross Domestic Product (GDP) in constant 2010 US dollars[7], which is used as a proxy for economic growth. For the empirical analysis, quarterly time series data are used for the top ten energy-consuming countries (China, the USA, Russia, India, Japan, Canada, Germany, Brazil, France and Korea) for the period from 1960Q1 to 2015Q4, which

[7] We have taken GDP per capita for all countries in terms of US constant dollar. This is because it is comparable among countries which have single parity (for more similar details, see the recent study of Beckmann et al. 2014). We are thankful to an anonymous reviewer for raising this clarity at the time of revision.

is a total of 224 quarterly observations. Annual data are collected from the World Bank's World Development Indicators (WDI) database. The annual series are then converted into quarterly series using a quadratic match-sum method. This method also makes adjustments for seasonal variations in the data when the data are converted from low frequency into high frequency by reducing the point-to-point data variations (Cheng et al. 2012, Sbia et al. 2014, Shahbaz et al. 2017). The quadratic match-sum method is also preferred to other interpolation methods due to its convenient operating procedure (Shahbaz et al. 2016, 2017).

Table 1 provides the descriptive statistics for economic growth (GDP per capita) and (per capita) energy consumption for each country over the sample period. The mean values for both variables are positive for all countries. Canada is found to be the most highly developed country, as it has the highest mean value for GDP per capita (8,745.19), which ranges from 4,405.18 to 12,512.29. Similar to Canada, the United States also has a high mean value for per capita GDP at 8,651.18, and it fluctuates between 4,243.20 and 12,949.29. Japan, Germany and France also have high per capita incomes; their mean values are 7,559.73, 7,473.94 and 7,456.11, respectively. In contrast, India has the lowest per capita income, with a mean value of 168.85 and a range between 78.63 and 462.02. China also has a low per capita GDP (363.46), which is not surprising because China's economy only gained momentum in the last decade. The standard deviation values show that per capita GDP fluctuated greatly in Japan (2,882.82), followed by the United States (2,697.60).

With regard to energy consumption, the United States has the highest per capita mean energy consumption (1,855.69), followed by Canada (1,782.43) and Russia (1,699.10). These values reflect the fact that the United States, Canada and Russia were the highest energy consumers over the last 56 years. Germany, France and Japan also show high mean per capita energy consumption, at 962.96, 860.36 and 767.05, respectively. India has the lowest mean per capita energy consumption (91.09), and it ranges between 60.15 and 160.69. The standard deviation values indicate that energy consumption remained volatile in Russia (570.24), followed by Korea (462.49). The results of the Jarque-Bera test are statistically significant, which indicates that economic growth and energy consumption are not normally distributed in any of the countries except for Brazil, where energy consumption is normally distributed. In addition, Augmented Dickey-Fuller (ADF) unit root test was performed to determine the order of integration of the time series. The results of ADF test show that all variables are non-stationary at levels, but they are stationary at their first differences. In other words, all of the variables are integrated of order one, i.e., $I(1)$. To account for the issue of structural breaks, we applied the Kim and Perron (2009) unit root test; the results are reported in Table 1. We find that all variables are non-stationary at levels with the intercept and trend in the presence of a structural break. After first differencing, all the series are stationary in the presence of structural breaks. This unit root test also confirms that the variables have a unique order of integration, i.e., I(1). Thus, for the empirical analysis, stationary data are used, and economic growth as well as energy consumption are converted into their first differences.

Table-1: Descriptive Statistics for Energy Consumption and Real GDP Per Capita

	Mean	Minimum	Maximum	Std. Dev.	Jarque-Bera	ADF Level	ADF Δ	Perron Level	Break Year	Perron Δ	Break Year
Panel A: GDP per capita											
China	363.46	32.30	1,640.19	428.28	95.37***	0.576	-3.618***	-0.043	2007Q2	-5.858***	2001Q1
USA	8,651.18	4,243.20	12,949.29	2,697.60	16.55***	-0.553	-4.252***	-2.737	1982Q1	-5.085***	2009Q1
Russia	2,780.65	1,370.06	4,459.66	843.41	7.32*	-1.952	-3.979***	-2.777	1989Q2	-5.607***	1994Q1
India	168.85	78.63	462.02	99.67	70.14***	4.426	-3.399***	3.494	2002Q2	-5.078***	2002Q1
Japan	7,559.73	2,017.96	11,201.21	2,882.82	20.34***	-2.088	-2.919**	-3.116	1983Q1	-4.485**	1991Q1
Canada	8,745.19	4,405.18	12,512.29	2,424.83	11.56***	-1.175	-4.049***	-3.014	1993Q1	-4.921**	2009Q1
Germany	7,473.94	3,427.01	11,327.22	2,329.74	14.62***	-0.748	-4.299***	-1.674	1984Q4	-5.039***	2009Q1
Brazil	1,906.92	819.35	2,954.27	588.31	6.87*	-1.656	-3.550***	-3.045	1983Q2	-5.365***	1983Q1
France	7,456.11	3,207.15	10,451.04	2,251.51	15.29***	-2.148	-3.590***	-2.761	1987Q1	-4.772**	2008Q1
Korea	2,382.80	56.81	6,292.04	1,979.73	21.51***	2.349	-3.231***	-1.176	1998Q2	-6.247***	1985Q2
Panel B: Energy consumption											
China	219.53	62.67	623.37	139.15	73.66***	2.582	-2.436*	0.372	2008Q2	-7.543***	2002Q1
USA	1,855.69	1,398.29	2,112.31	166.17	58.15***	-3.200**	-3.164**	-3.928	2007Q1	-4.920**	1978Q1
Russia	1,699.10	992.43	2,833.01	570.24	20.88***	-1.940	-3.701***	-2.647	1989Q2	-5.347***	1995Q1
India	91.09	60.15	160.69	27.66	33.76***	1.992	-3.725***	-0.367	2003Q2	-4.750**	2003Q1
Japan	767.05	207.50	1,026.66	231.39	33.10***	-2.718*	-3.027**	-3.938	1983Q1	-6.688***	1973Q1
Canada	1,782.43	1,061.78	2,097.75	270.17	79.38***	-3.234**	-3.264***	-3.666	1966Q1	-4.673**	1972Q1
Germany	962.96	487.37	1,175.08	189.94	75.84***	-2.676*	-3.307***	-3.369	1969Q1	-6.077***	1970Q1
Brazil	236.03	103.45	386.49	65.26	0.87	0.349	-3.030**	-2.114	2009Q2	-5.173***	2009Q1
France	860.36	422.19	1,076.93	185.41	35.12***	-2.670*	-3.237**	-3.335	1966Q1	-4.424**	1973Q1
Korea	576.50	23.76	1,503.51	462.49	21.63***	1.293	-3.230**	-0.916	1989Q1	-5.274***	1985Q1

Note: ***, ** and * indicate that the value is significant at the 1%, 5% and 10% levels of significance, respectively.

Table 2 provides the correlation coefficients between energy consumption and economic growth for all countries. The values of the correlation coefficients show that both variables are highly positively correlated with each other in all countries. The highest correlation value is found in Korea (0.99), followed by China (0.98), India (0.98) and Brazil (0.98). The correlation coefficients are also high in Japan (0.93), Russia (0.92) and France (0.92). For Canada, the correlation value is also relatively high, i.e., 0.78. For Germany, the value is 0.53, and for the United States, it is 0.34, which is a low value. This result implies that energy consumption and economic growth are highly correlated in almost all countries. These correlation values are also highly statistically significant, as the p-values of the correlation coefficients are less than 0.01, which indicates that the values are statistically significant at 1 percent level of significance.

Table-2: Correlation between Energy Consumption and Income

Countries	Correlation	*t*-value	*p*-value
China	0.98922	100.6452*	0.00000
USA	0.34990	5.565160*	0.00000
Russia	0.92586	36.50784*	0.00000
India	0.98756	93.58673*	0.00000
Japan	0.93708	39.99424*	0.00000
Canada	0.78305	18.75900*	0.00000
Germany	0.53337	9.395048*	0.00000
Brazil	0.98133	76.02168*	0.00000
France	0.92085	35.18850*	0.00000
South Korea	0.99566	159.3960*	0.00000

Note:* indicates that the value is statistically significant at the 1% level of significance.

5. Methodology

In this section, the key features of the model specification of the quantile-on-quantile (QQ) approach recently suggested by Sim and Zhou (2015) are used to study the relationship between energy consumption and economic growth in the top ten energy-consuming countries of the world. The QQ technique is a generalization of the proposed quantile regression model, and it has been utilized in the field of applied economic growth and energy economics to empirically investigate how the quantiles that emerge from a variable affect the conditional quantiles of another variable. The QQ approach is theoretically believed to be the combined product of a conventional quantile regression and nonparametric estimations. First, the conventional quantile regression technique proposed by Koenker and Bassett (1978) is used to assess the impact of an explanatory variable on different quantiles of a dependent variable. Second, the quantile regression technique is also accepted as an extension of the classic linear regression model (CLRM). Similar to the ordinary least squares (OLS) methodology, the quantile regression approach ideally explores the impacts of an independent variable on a dependent variable at both the top and bottom quantiles of a given distribution, thereby enabling us to judge the comprehensive relationship between the variables across different time periods. Third, the local linear regression technique proposed by Stone (1977) and Cleveland (1979) is used to examine the local effects of a specific quantile of the independent variable on the dependent variable. Additionally, the local linear regression technique strongly avoids the "curse of dimensionality," which is the only problem that is associated with nonparametric model estimations. Moreover, the main aim of this local linear regression technique is to determine a linear regression locally around the neighborhood of each data point in the sample, and it provides higher weights to each data point's immediate neighbors. Thus, the combined use of both approaches enables us to estimate the relationship between various quantiles of the independent and dependent variables, and it therefore provides richer information than alternative estimation techniques such as OLS or conventional quantile regression.

The QQ approach used in this study to model the effects of the quantiles of economic growth (energy consumption) on the quantiles of energy consumption (economic growth) for a country starts with the following nonparametric quantile regression equation:

$$EC_t = \beta^{\theta}(GDP_t) + u_t^{\theta} \tag{1}$$

where EC_t denotes energy consumption per capita (kg of oil equivalent) of a country at period t, GDP_t denotes real GDP growth per capita of a country at period t, θ is the θth quantile of the conditional distribution of energy consumption per capita, and u_t^{θ} is the quantile residual term whose conditional θth quantile is assumed be zero. $\beta^{\theta}(\cdot)$ is an unknown function because we lack prior information on the relationship between energy consumption and economic growth.

This quantile regression model helps us to empirically explore the varying effects of economic growth across different quantiles of energy consumption per capita for the top ten energy-consuming countries of the world. Flexibility is the main underlying advantage of this regression specification, which normally captures the functional form of the dependency relationship between energy consumption and economic growth in the sample countries. However, the quantile regression model does not take into account the nature of large and small positive shocks arising from economic growth that may also influence the inter-relations between energy consumption and economic growth. The effect of large positive economic growth shocks on energy consumption may be different from the effect of small positive economic growth shocks. Finally, the asymmetric effects of economic growth on energy consumption could possibly be responses to both negative and positive shocks arising from economic growth.

Moreover, the local linear regression is used to examine equation-1 in the neighborhood of GDP^{τ} for the purpose of establishing the relationship between the θth quantile of energy consumption and the τth quantile of real GDP per capita. Given the unknown value of $\beta^{\theta}(\cdot)$, the regression function can be expanded via a first order Taylor expansion around a quantile of GDP^{τ} in the following way:

$$\beta^{\theta}(GDP_t) \approx \beta^{\theta}(GDP^{\tau}) + \beta^{\theta'}(GDP^{\tau})(GDP_t - GDP^{\tau}) \tag{2}$$

Where $\beta^{\theta'}$ is the partial derivative of $\beta^{\theta}(GDP_t)$ with respect to *GDP*, describing it as a marginal effect. However, it reflects a similar interpretation to the slope coefficient in a linear regression modeling framework. A telling feature of equation-2 is that it recognizes both θ and τ as dual indexed parameters that are represented in the following form, such as $\beta^{\theta}(GDP^{\tau})$and $\beta^{\theta'}(GDP^{\tau})$. In addition, $\beta^{\theta}(GDP^{\tau})$ and $\beta^{\theta'}(GDP^{\tau})$ are functions of θ and are followed by GDP^{τ} and GDP^{τ}as a function of τ. Hence, this indicates that $\beta^{\theta}(GDP^{\tau})$ and $\beta^{\theta'}(GDP^{\tau})$are both functions of θ and τ. Additionally, $\beta^{\theta}(GDP^{\tau})$ and $\beta^{\theta'}(GDP^{\tau})$can be declared as $\beta_0(\theta,\tau)$ and $\beta_1(\theta,\tau)$, respectively. Accordingly, the modified equation-2 can be represented as:

$$\beta^{\theta}(GDP_t) \approx \beta_0(\theta,\tau) + \beta_1(\theta,\tau)(GDP_t - GDP^{\tau}) \tag{3}$$

By substituting equation-3 into equation-1, we arrive at equation-4 as follows:

$$EC_t = \underbrace{\beta_0(\theta,\tau) + \beta_1(\theta,\tau)(GDP_t - GDP^{\tau})}_{(*)} + u_t^{\theta} \tag{4}$$

The part (*) of equation-4 is the θth conditional quantile of energy consumption per capita. Similar to a standard conditional quantile function, the given formula in equation-4 reflects the true relationship between the θth quantile of energy consumption and the τth quantile of real GDP per capita. The quantile relationship between energy consumption and economic growth is truly established because of the parameters β_0 and β_1, which are doubly indexed in θ and τ. These parameters may vary depending upon the θth quantiles of energy consumption and the τth quantiles of real GDP per capita. Hence, the method establishes only a linear relationship between the quantiles of the variables. Thus, the overall dependence structure between energy consumption and real GDP per capita is also established in equation-4 through the linking of their respective distributions.

Finally, equation-4 claims to replace GDP_t and GDP^{τ} with its estimated counterparts GDP_t and GDP^{τ}. The local linear regression's estimated parameters b_0 and b_1 are the estimates of β_0 and β_1 and are further obtained by estimating the following minimization problem:

$$\min_{b_0,b_1} \sum_{i=1}^{n} \rho_\theta \left[EC_t - b_0 - b_1\left(\widehat{GDP}_t - \widehat{GDP}^{\tau}\right)\right] K\left(\frac{F_n(\widehat{GDP}_t)-\tau}{h}\right) \quad (5)$$

where $\rho_\theta(u)$ is the quantile loss function represented as $\rho_\theta(u) = u\big(\theta - I(u < 0)\big)$, and I is denoted as the usual indicator function. $K(\cdot)$ denotes the kernel function, and h is the bandwidth parameter of the kernel function. Although Gaussian kernel functions are widely used in applied economic and financial applications due to their computational simplicity and efficiency, their main objective is to weigh the observations in the neighborhood of GDP^{τ}. From a theoretical landmark point of view, the Gaussian kernel appears to be symmetric around zero, and it assigns minimal weights to observations that are further away. These weights are inversely related to the distanced observations among the distribution function of $\widehat{GDP}_t$, which is represented by $F_n\left(\widehat{GDP}_t\right) = \frac{1}{n}\sum_{k=1}^{n} I(\widehat{GDP}_k < \widehat{GDP}_t)$, and produces the value of the distribution function that eventually links with the quantile GDP^{τ}, reported by τ.

The use of a nonparametric estimation approach makes the choice of bandwidth more critical. Because the bandwidth approach often determines the size of the neighborhood around the target point, it indicates the smoothness of the resulting estimate. More specifically, a larger bandwidth will produce a strong bias in the estimates, and a smaller bandwidth will lead to estimates with a higher variance. Therefore, the choice of bandwidth is very important for this study, as it often provides a balance between the bias and the variance. Following the recent methodological approach of Sim and Zhou (2015), we use the bandwidth parameter $h = 0.05$ for our analysis.[8]

6. Empirical Results

6.1. Quantile-on-Quantile Estimates

This section presents the main empirical results of the QQ analysis between economic growth and energy consumption for the world's top ten energy-consuming countries. Figure 4 displays the estimates of the slope coefficient $\beta_1(\theta, \tau)$, which captures the effect of the τth quantile of economic growth in real GDP per capita (energy consumption) on the θth quantile of energy consumption (economic growth) at different values of θ and τ for the ten countries under consideration. Figures (1-5) reveal some important results. It is also evident from the figures that the relationship between economic growth and energy consumption is not the same for all countries. Rather, there is considerable heterogeneity among countries regarding the energy-growth nexus.

In **China,** a negative effect of economic growth on energy consumption is found in the area that combines the lower to upper quantiles of energy consumption (0.05-0.80) with the lower to upper quantiles of economic growth (0.05-0.95). A strong positive effect of economic growth on energy consumption is found at the lowest quantiles of economic growth (0.05-0.70) and at the highest quantiles of energy consumption (0.80-0.95). A somewhat strong positive effect is also found at the highest quantiles of both economic growth and energy consumption. The effect of energy consumption on economic growth is positive for all quantiles of both economic growth and energy consumption. The effect of energy consumption on economic growth is very low at low quantiles of energy consumption and low to high quantiles of economic growth. However, this effect is strong at medium quantiles

[8] A number of alternative values of the bandwidth have been also considered, but the results of the estimation remain qualitatively the same.

of economic growth, then becomes weak at middle quantiles and again becomes strong at high quantiles of economic growth. This finding suggests that a sharp decline in energy consumption due to energy conservation policies at high levels of economic growth seems to have an important downward effect on the Chinese overall economy. In general, these results reveal that it is energy consumption that affects economic growth, while economic growth has little effect on energy consumption. Technically speaking, we may conclude that energy consumption leads economic growth. This result supports the findings of Wang et al. (2011), Shahbaz et al. (2013), Jalil and Feridun (2014) and Tang et al. (2016), who reported that energy consumption leads economic growth, although Herrerias et al. (2013) noted that economic growth leads energy consumption.

In the **USA,** the effect of economic growth on energy consumption is positive for all quantiles of both variables. This positive effect is very strong at low quantiles of economic growth (0.2-04) and moderate to high quantiles of energy consumption (0.50-0.95) but becomes very weak at high quantiles of economic growth. This result implies that at high levels of economic growth, demand for energy as an input decreases in the USA. Thus, in the United States, either technology has become fuel efficient or the production of goods has been shifted to less energy-intensive sectors, which has decreased energy demand. The result corroborates the notion that structural economic shifts, saturation effects and efficiency gains have produced a peak in energy consumption in the OECD countries (IEA, 2016). The effect of energy consumption on economic growth is also positive for all quantiles of both energy consumption and economic growth. However, this effect is somewhat strong only at the high quantiles of both variables. These results reveal that there is not such a strong relationship between these two variables in the USA. Previously, Aslan et al. (2014) also found mixed results regarding the association between economic growth and energy consumption in the USA using wavelet analysis. Our results do not support the findings of Ajmi et al. (2013) that there is a feedback effect between economic growth and energy consumption in the USA, but they are consistent with Akarca and Long (1980), Yu and Hwang (1984), Yu and Jin (1992), Stern (2000), Chiou-Wei et al. (2008), Payne (2009) and Mutascu (2016).

In **Russia**, the effect of economic growth on energy consumption is positive and somewhat interesting. The effect is strong only at the middle quantiles of per capita real GDP (0.4-0.6) and energy consumption (0.6-0.8) and at the peak quantiles of both per capita real

GDP and energy consumption. The main exception to the generally poor energy-economic growth nexus is located in the area that combines the lower to middle quantiles of economic growth (0.2-0.6) with the highest quantiles of energy consumption (0.8-0.95). The relatively high positive relationship observed in the remaining region can be interpreted in the sense that a sharp increase in economic growth seems to increase energy consumption in Russia. The effect of energy consumption on economic growth is same as the effect of economic growth on energy consumption. However, the strength of this effect has decreased. The effect of energy consumption on economic growth is moderately strong only at high quantiles of both energy consumption and economic growth. This result implies that conserving energy use at high levels of economic growth will dampen economic development in Russia. In generic terms, the results reveal a feedback effect between energy consumption and economic growth at high quantiles. This finding contrasts with the findings of Faisal et al. (2016), who found no causality between growth and energy consumption and supported the neutrality hypothesis, but the findings are similar to those of Zhang (2011), who reported that energy consumption and economic growth are complementary.

In **India**, the effect of economic growth on energy consumption is very small or even negative at low quantiles of per capita real GDP. This result implies that there is seemingly no significant effect of economic growth on energy consumption at low levels of economic growth. However, this effect becomes positive and very strong at high quantiles of economic growth. This result supports the actual situation in India, which has experienced economic development in recent years that has increased the energy demand. The effect of energy consumption on economic growth is high at medium to high quantiles of both energy consumption and economic growth and becomes moderate at high quantiles of energy consumption. These results indicate that energy consumption is an important input for economic growth in India. This empirical evidence is consistent with Yang and Zhao (2014) but contradicts the findings of Paul and Bhattacharya (2004) and Zhang (2011), who reported a feedback effect and a neutral effect between economic growth and energy consumption, respectively.

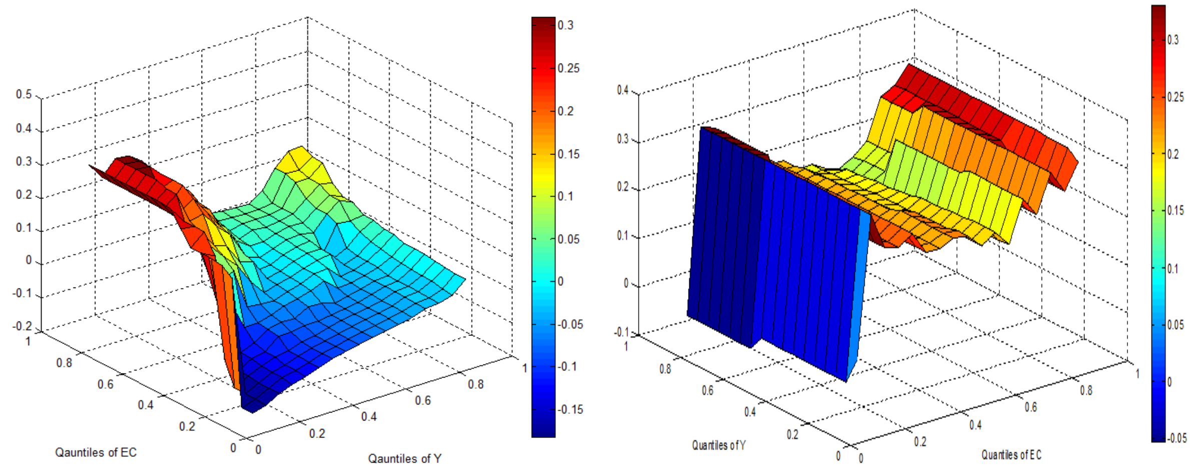
In the case of **Japan**, the effect of economic growth on energy consumption is positive for all combinations of quantiles of energy consumption and real GDP per capita. A weak positive effect of economic development on energy consumption is found in the area that combines low quantiles of economic growth (0.20-0.50) and low to intermediate quantiles of energy consumption (0.20-0.80). However, a strong positive effect is observed in the area combining intermediate to upper quantiles of economic growth (0.6-0.95) and the upper quantiles of energy consumption (0.80-0.95). The findings suggest that energy demand in Japan is decreased during periods of low economic development, while it is high during periods of a booming economy. Thus, the relationship between energy consumption and economic growth in Japan is not stable over time. Rather, it depends on general business conditions and major economic events. These results demonstrate that in Japan, energy consumption and economic growth have positive effect on each other at their upper quantiles, which supports the previous findings of Ajmi et al. (2013) and Mutascu (2016) but contrasts with Cheng (1998), Lee (2006) and Soytas and Sari (2006), who reported that economic growth leads energy consumption and energy consumption leads economic growth.

Interestingly, the effect of energy consumption on economic growth is more or less the same. The effect of energy consumption on growth is positive throughout the sample. This positive effect is weak at low quantiles of energy consumption (0.10-0.40) and intermediate to high quantiles of economic growth (0.50-0.95). However, the effect becomes very strong at upper quantiles of both energy consumption and economic growth. These results indicate that both economic growth and energy consumption are strongly correlated, but only at their high quantiles, and decreasing energy consumption will decrease growth and vice versa.

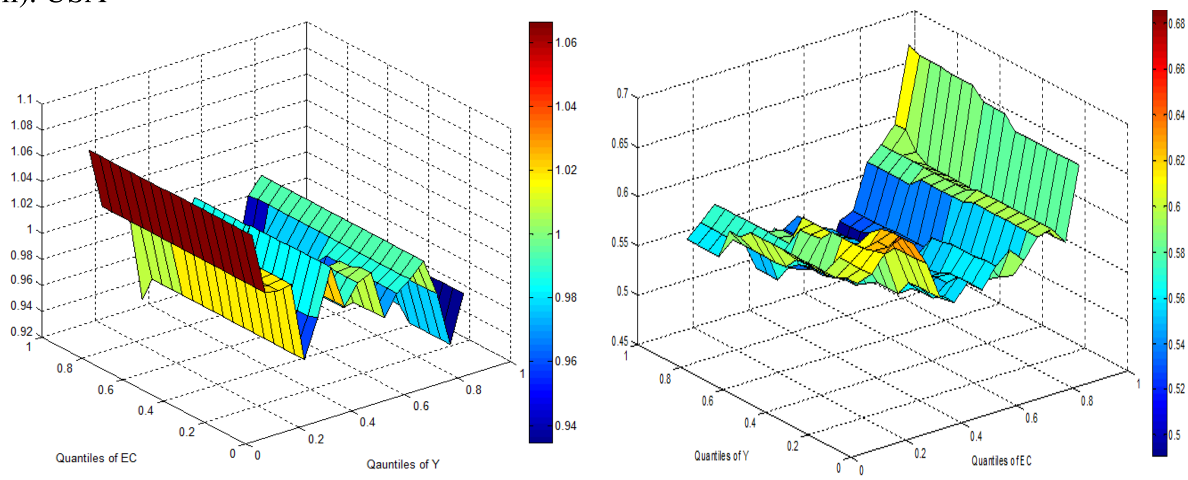
Figure 4: Quantile-on-Quantile (QQ) estimates of the slope coefficient, $\hat{\boldsymbol{\beta}}_1(\boldsymbol{\theta}, \boldsymbol{\tau})$

Impact of economic growth on energy consumption	**Impact of energy consumption on economic growth**

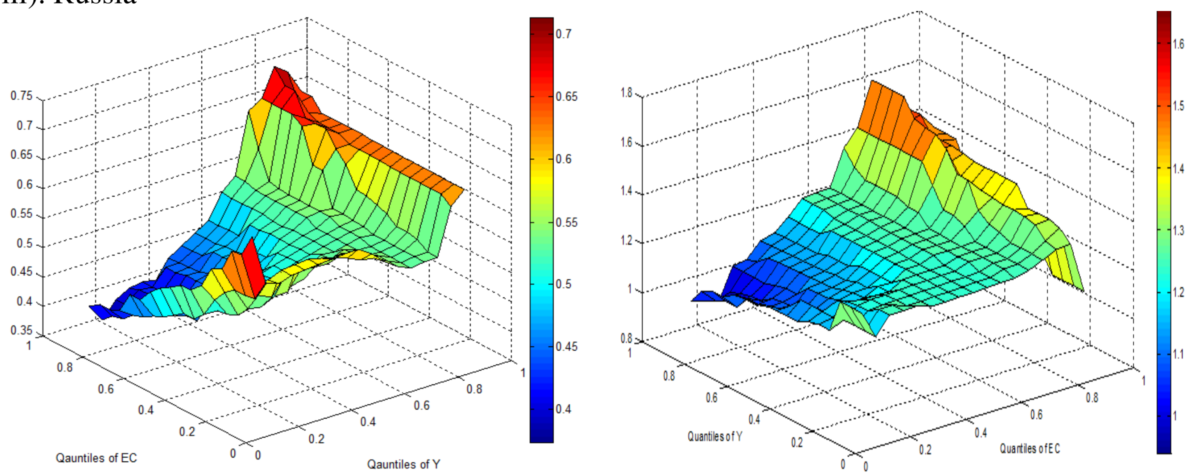
i). China



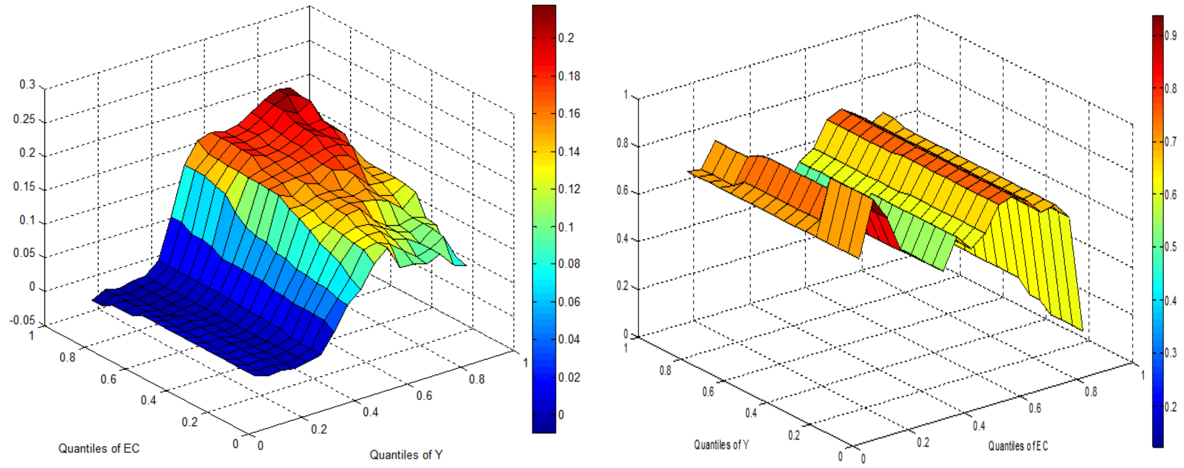
ii). USA



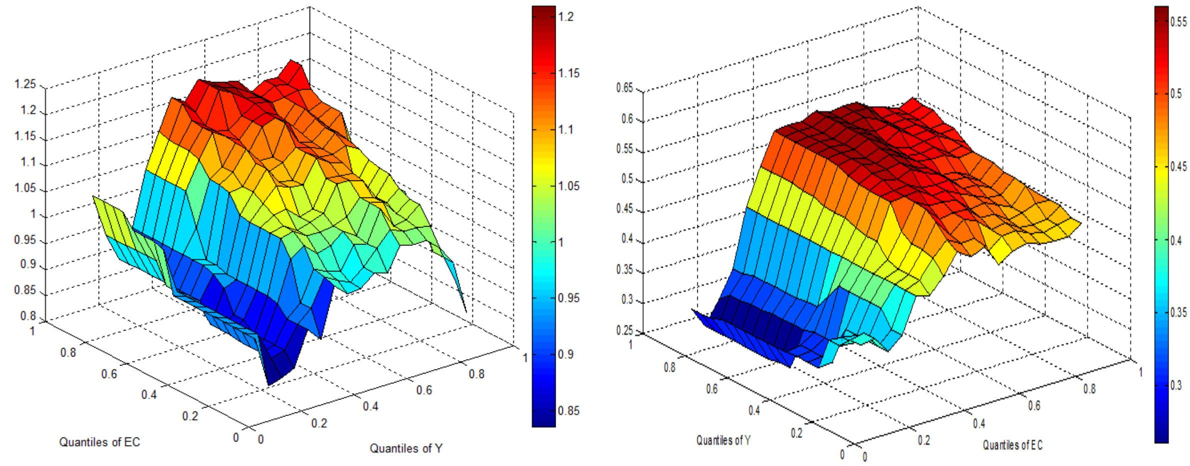
iii). Russia



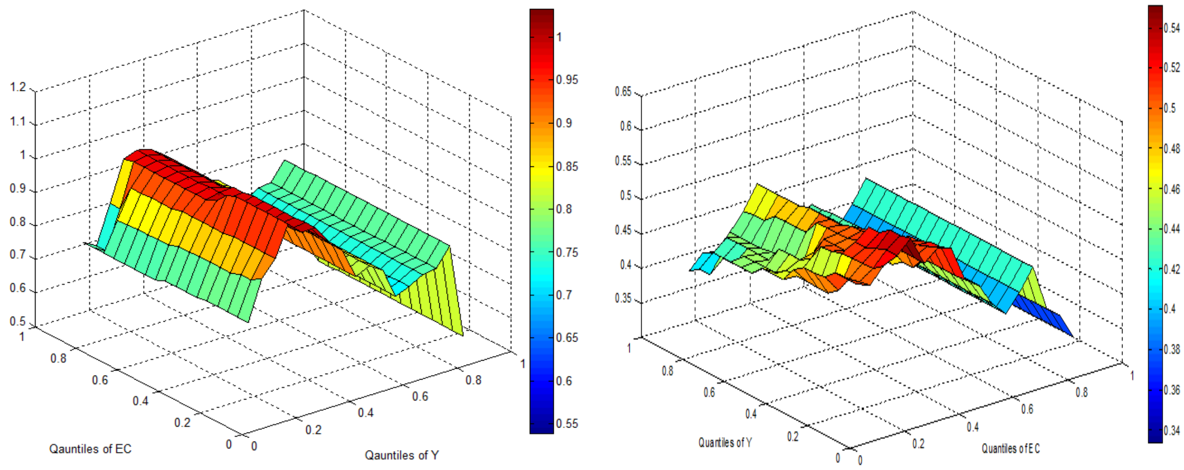
iv). India



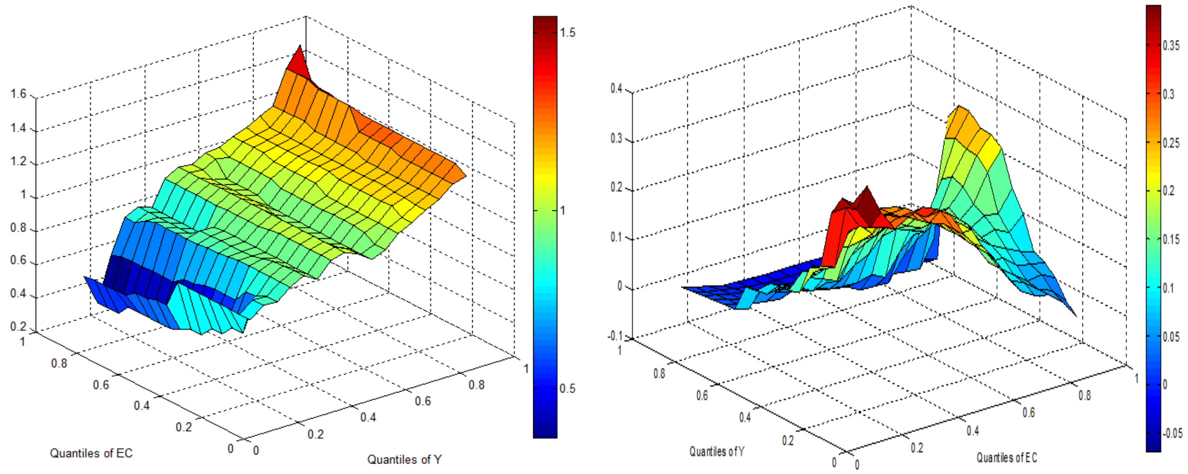
v). Japan



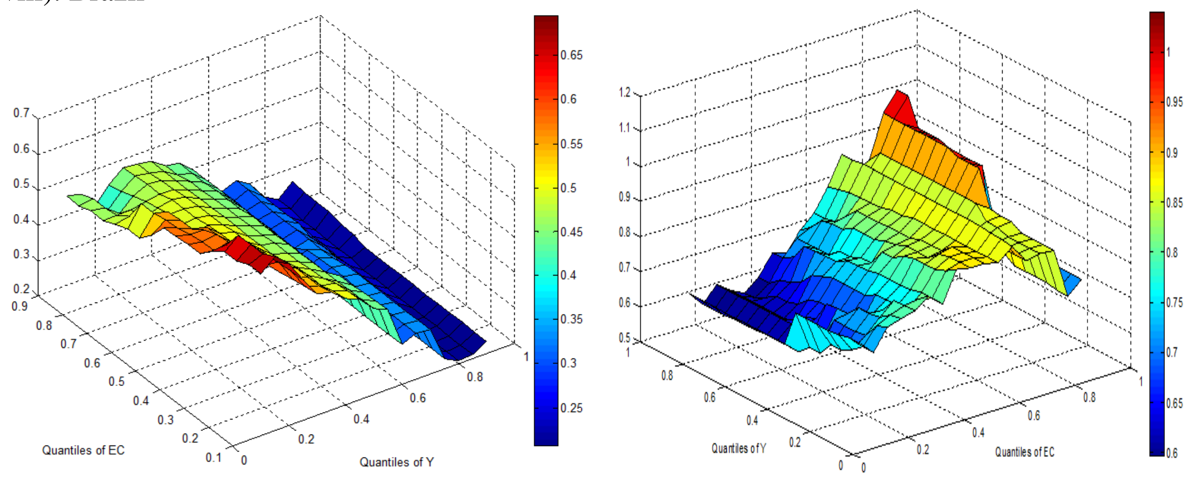
vi). Canada



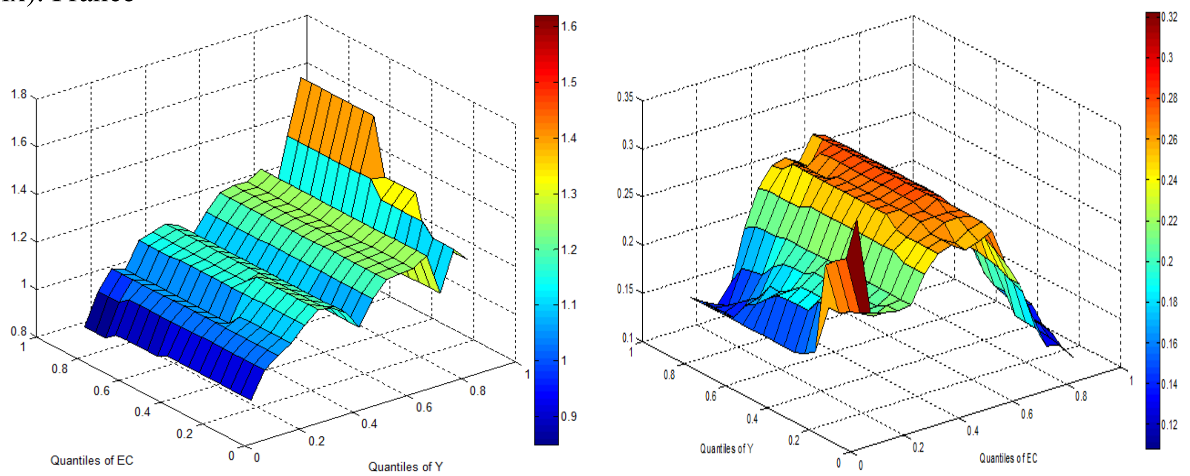
vii). Germany



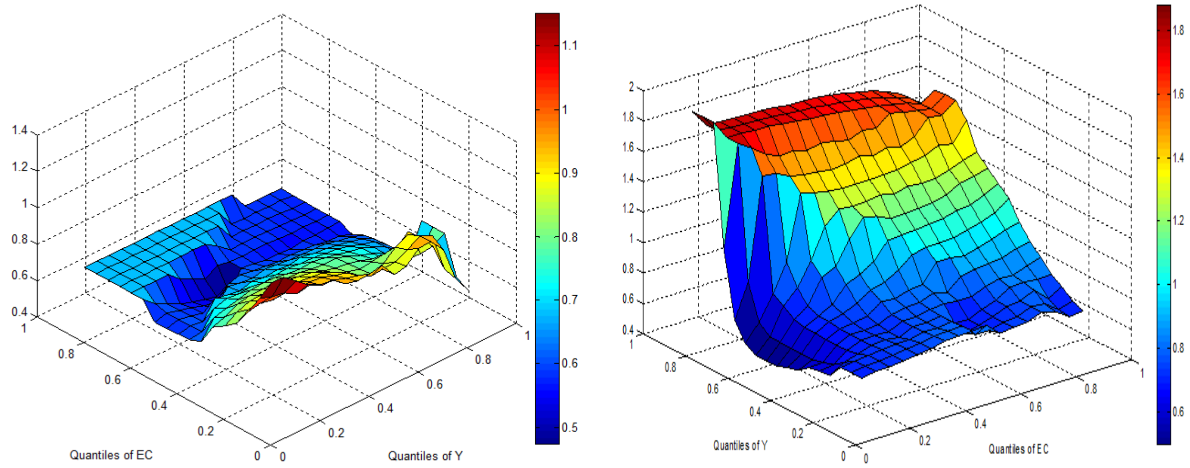
viii). Brazil



ix). France



x). South Korea



Note: The graphs show the estimates of the slope coefficient $\beta_1(\theta, \tau)$ in the z-axis against the quantiles of per capita energy consumption (real GDP) in the y-axis and the quantiles of real GDP per capita (energy consumption) in the x-axis.

For the **Canadian** economy, the effect of economic growth on energy consumption is predominantly positive but weak at middle quantiles of economic growth (0.50-0.60) and middle to high quantiles of energy consumption (0.6-0.95). However, it becomes strong for middle quantiles of economic growth (0.60-0.80) but again becomes substantially weak at high quantiles of economic growth (0.80-0.95). This result means that similar to the USA, Canada has also become a fuel-efficient economy, which has decreased the energy demand. The result again supports the view that structural economic shifts, saturation effects and efficiency gains have produced a peak in energy consumption in the OECD countries (IEA, 2016). The effect of energy consumption on economic growth follows the same pattern as the effect of economic growth on energy consumption. The effect of energy consumption on economic growth is somewhat strong at middle quantiles of both energy consumption and economic growth before becoming weak at the upper quantiles of both variables. This result again validates the previous notion that energy is no longer an important input for economic development in Canada. In generic terms, these results show that economic growth and energy consumption influence each other at their middle quantiles. In other words, there is a feedback effect between these two variables at their middle quantiles. These results support the findings of Ghali and El-Sakka (2004), Soytas and Sari (2006), Ajmi et al. (2013), Rodríguez-Caballero and Ventosa-Santaulària (2016) and Mutascu (2016), who reported a feedback effect between economic growth and energy consumption, but Lee (2006) found that economic growth is a cause of energy consumption and vice versa.

The effect of economic growth on energy consumption is positive in **Germany**. The effect is weak at low quantiles of economic growth and becomes relatively strong at upper quantiles of economic growth, which means that energy consumption has become a major driver of the German economy at high levels of economic growth. The effect of energy consumption on economic growth is very strange. It is not only weak but also negative for low to middle quantiles of energy consumption (0.20-0.70) and high quantiles of economic growth (0.90-0.95). However, a high positive effect of energy consumption on economic growth is found at upper quantiles of both variables, which again supports the notion that energy has become an important input, but only at high levels of growth. Overall, the results show that it is economic growth that mainly affects energy consumption, not the other way around. The results validate the findings of Soytas and Sari (2006) and Ajmi et al. (2013), who confirmed the presence of energy conservation hypothesis. In contrast, Lee (2006) and Mutascu (2016) reported the presence of a neutral effect between economic growth and energy consumption.

There is a positive association between economic growth and energy consumption in **Brazil**. The positive effect of economic growth on energy consumption is strong only at middle quantiles of economic growth (0.55-0.65) and middle to upper quantiles of energy consumption (0.60-0.80). The weakest effect is found at high quantiles of economic growth (0.80-0.95) with all quantiles of energy consumption. In contrast, the weakest effect of energy consumption on economic growth is found at low to middle quantiles of energy consumption (0.30-0.75) and the middle to upper quantiles of economic growth (0.55-0.95). The effect of energy consumption on growth becomes strong at the upper quantiles of both variables. The results suggest that energy consumption loses its status as a key driver of economic growth in times of a buoyant economy in Brazil. The intuition is that Brazil has obtained energy efficiency technology with its economic development, and it has shifted to production in less energy-intensive sectors. This empirical finding contrasts with Cheng (1997), Zhang (2011), Pao et al. (2014) and Rodríguez-Caballero and Ventosa-Santaulària (2016), who reported that energy sources should be explored to sustain long-term economic growth.

The effect of economic growth on energy consumption is the same in **France** as in Germany. The effect of economic growth on energy consumption is weak at low quantiles of economic growth, while a relatively high effect is found in areas combining high quantiles of economic growth and energy consumption. This result suggests that the economy of France does not excessively depend on energy consumption. The effect of energy consumption on per capita real economic growth is weak at low quantiles of energy consumption (0.30-0.40) and at middle to upper quantiles of economic growth (0.60-0.95). This effect becomes somewhat strong at high quantiles of energy consumption (0.80-0.90) and becomes weak at upper quantiles of energy consumption (0.90-0.95). The results again indicate that energy consumption plays little role in economic development in France. These results are dissimilar from the findings of Ajmi et al. (2013) that a feedback effect exists between energy consumption and economic growth in France. This empirical evidence is similar to the findings of Lee (2006) and Arouri et al. (2014), who reported that energy consumption is a major contributor to economic growth.

The association between energy consumption and economic growth is positive in **South Korea**. The effect of economic growth on energy consumption is very weak for all quantiles of economic growth and energy consumption. The weakest relationship is observed in the region that combines intermediate to high quantiles of energy consumption (0.55-0.95) with the lowest to highest quantiles of real GDP growth (0.20-0.95). However, a moderate link is found between these two variables for lower quantiles of energy consumption (0.20-0.45) with the lower to highest quantiles of economic growth (0.20-0.95). The effect of energy consumption on economic growth is weak for the lower to upper quantiles of energy consumption (0.20-0.95) and the lower to middle quantiles of economic growth (0.35-0.80) and becomes strong for the upper quantiles of economic growth. These results indicate that energy as such is not an important input for economic development in South Korea. This empirical finding is similar to those of Chiou-Wei et al. (2008) and Yildirim et al. (2014) but contrasts with Shahbaz et al. (2016), who reported the presence of a feedback effect between the two variables. Furthermore, Glasure (2002) noted that energy consumption plays an important role in stimulating economic growth in South Korea, but Oh and Lee (2004) found that economic growth leads energy consumption.

The differences in the results may be attributed to fact that the different countries are in different phases of economic development. Furthermore, the different countries have different production capacities and energy supply constraints. Moreover, within each country, sizeable variations of the slope coefficient are observed across different quantiles of economic growth and energy consumption. This finding suggests that the linkage between economic growth and energy consumption is not uniform across quantiles, as the relationship depends on both the sign and size of economic growth in a country and the specific phase of the economic cycle the country is experiencing. It is also worth noting that ignoring such heterogeneity across countries could lead to inaccurate inferences.

6.2. Checking the Validity of the QQ Method

The QQ approach can be viewed as a method that decomposes the estimates of the standard quantile regression model, thus enabling specific estimates to be obtained for different quantiles of the explanatory variable. In the framework of the present study, the quantile regression model is based on regressing the θth quantile of real GDP per capita on energy consumption and vice versa; hence, the quantile regression parameters are only indexed by θ. However, as stated earlier, the QQ analysis regresses the θth quantile of energy consumption on the τth quantile of real GDP per capita; therefore, its parameters are indexed by both θ and τ. Thus, the QQ approach contains more disaggregated information about the energy-growth link than the quantile regression model because the relationship is perceived by the QQ method as potentially heterogeneous across different quantiles of economic activity.

Given this property of decomposition that is inherent to the QQ approach, it is possible to use the QQ estimates to recover the estimates from the standard quantile regression. Specifically, the quantile regression parameters, which are only indexed by θ, can be generated by averaging the QQ parameters along τ. For instance, the slope coefficient of the quantile regression model, which measures the effect of real GDP per capita on the distribution of energy consumption and is denoted by $\gamma_1(\theta)$, can be obtained as follows:

$$\gamma_1(\theta) \equiv \overline{\hat{\beta}_1}(\theta) = \frac{1}{S}\sum_{\tau} \hat{\beta}_1(\theta, \tau) \quad (6)$$

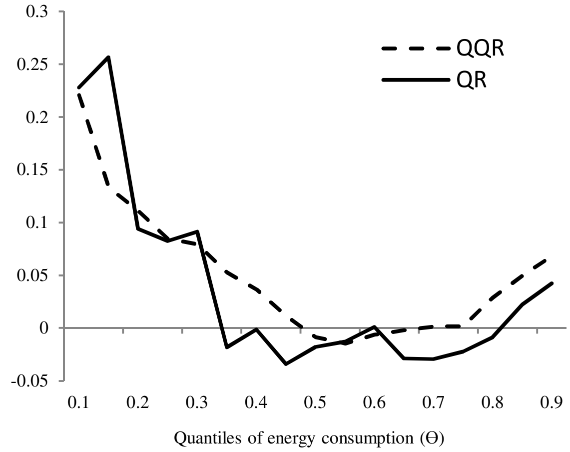
where S=17 is the number of quantiles $\tau = [0.10, 0.15, \ldots, 0.90]$ considered.

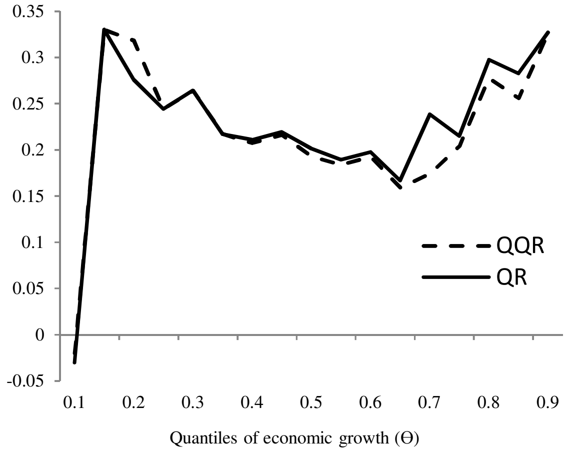
In this context, a simple way to check the validity of the QQ approach is to compare the estimated quantile regression parameters with the τ-averaged QQ parameters. Figure 5 plots the quantile regression and the averaged QQ estimates of the slope coefficient that measures the impact of real GDP per capita on energy consumption and the impact of energy consumption on real GDP per capita for all of the countries under analysis.

Figure 5: Comparison of Quantile Regression and QQ estimates

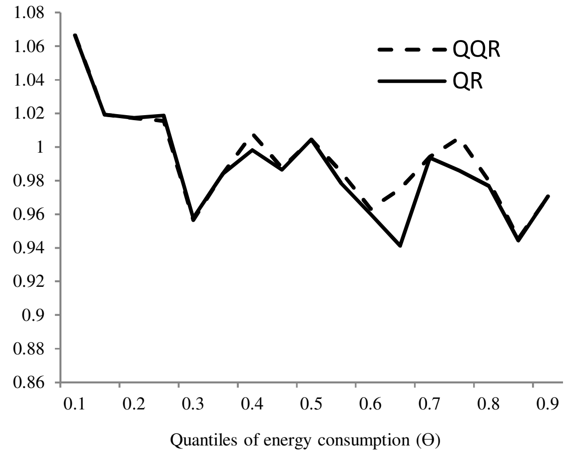
Impact of economic growth on energy consumption | **Impact of energy consumption on economic growth**

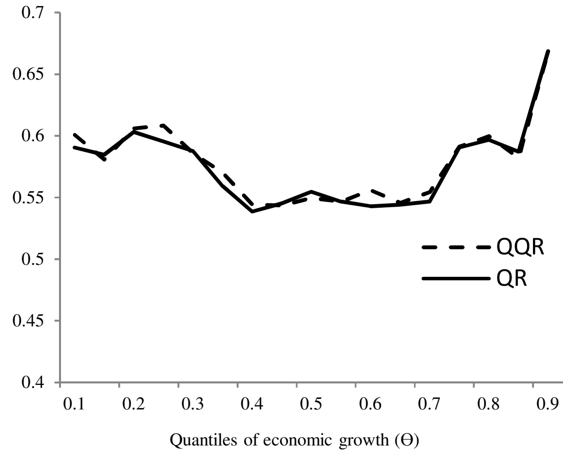
i). China



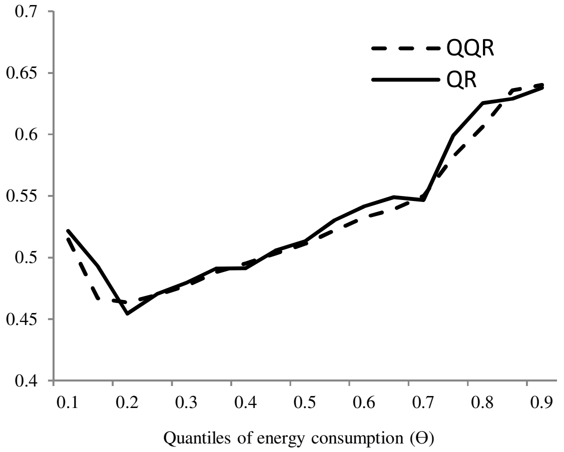


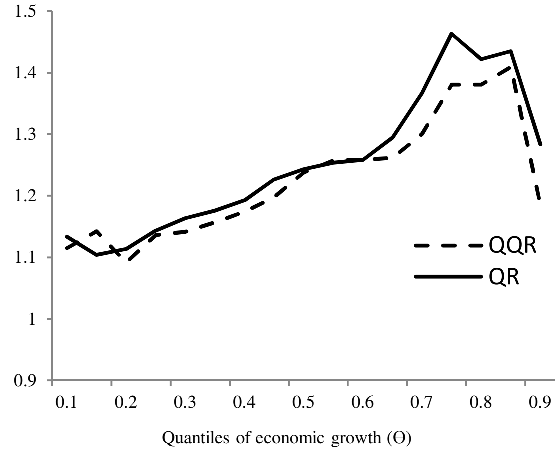
ii). USA



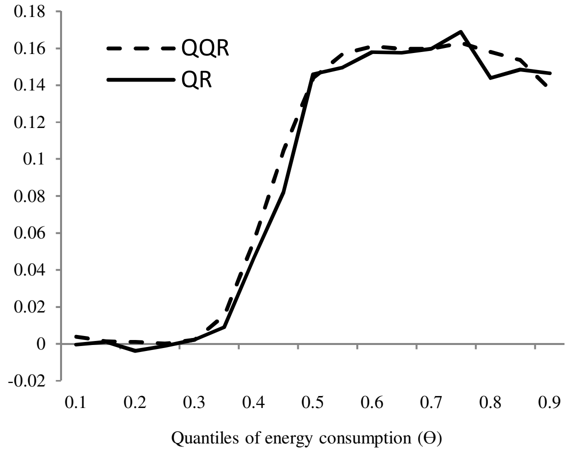


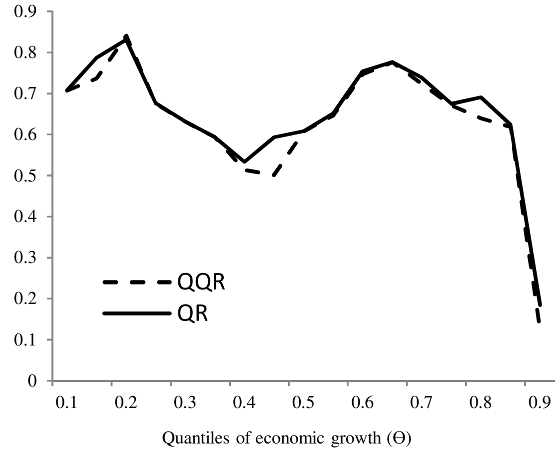
iii). Russia



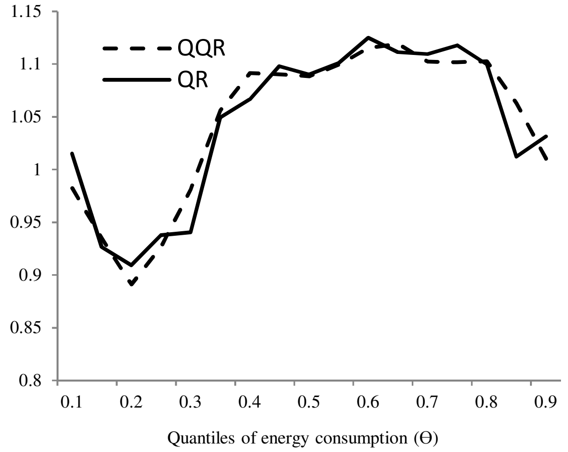


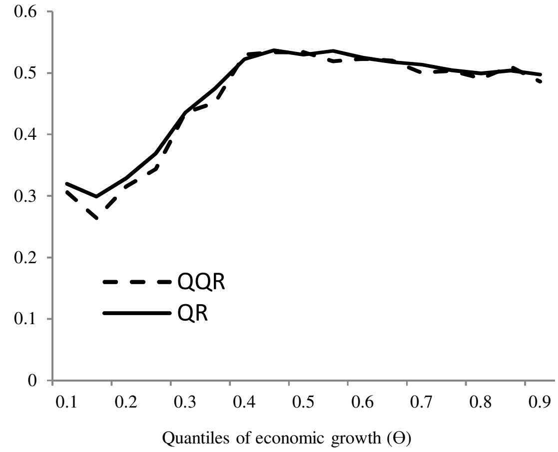
iv). India



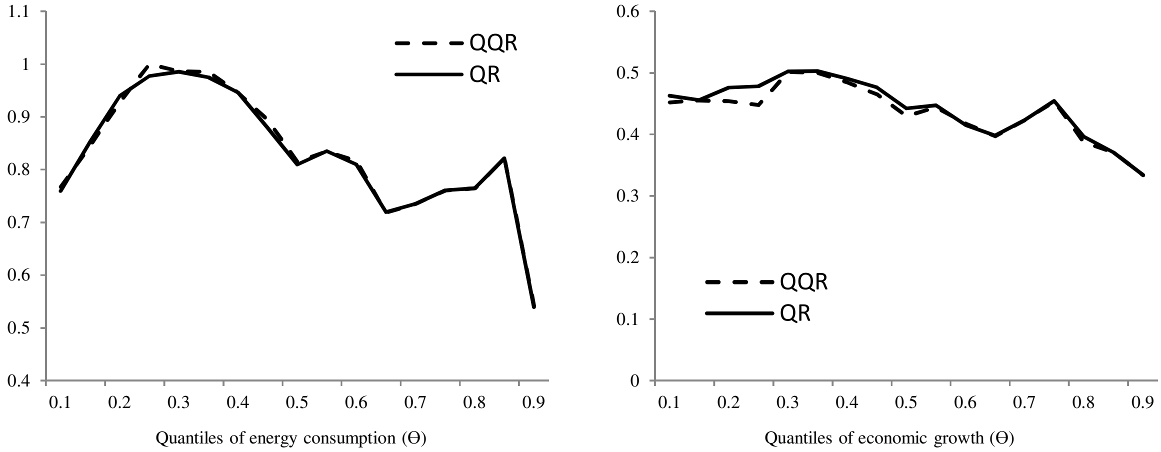


v). Japan

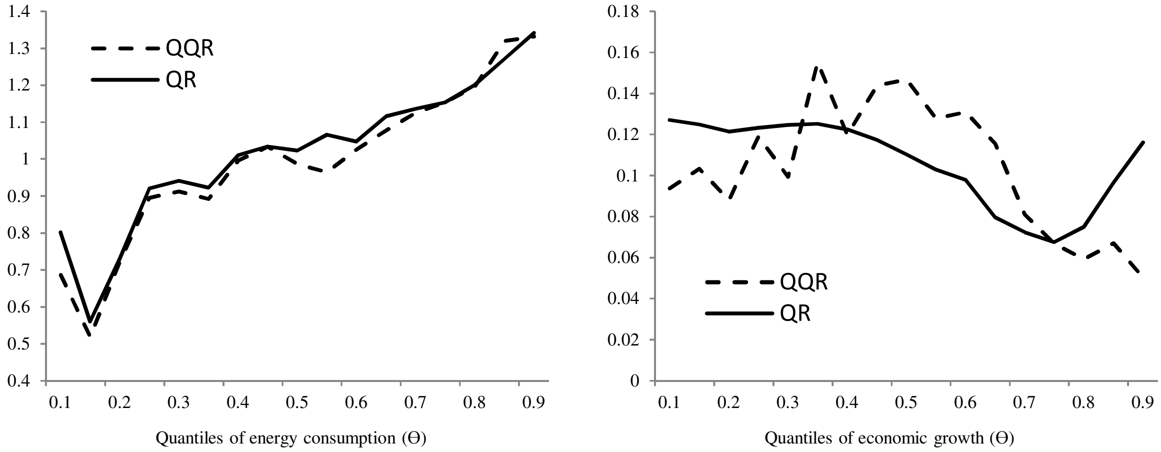




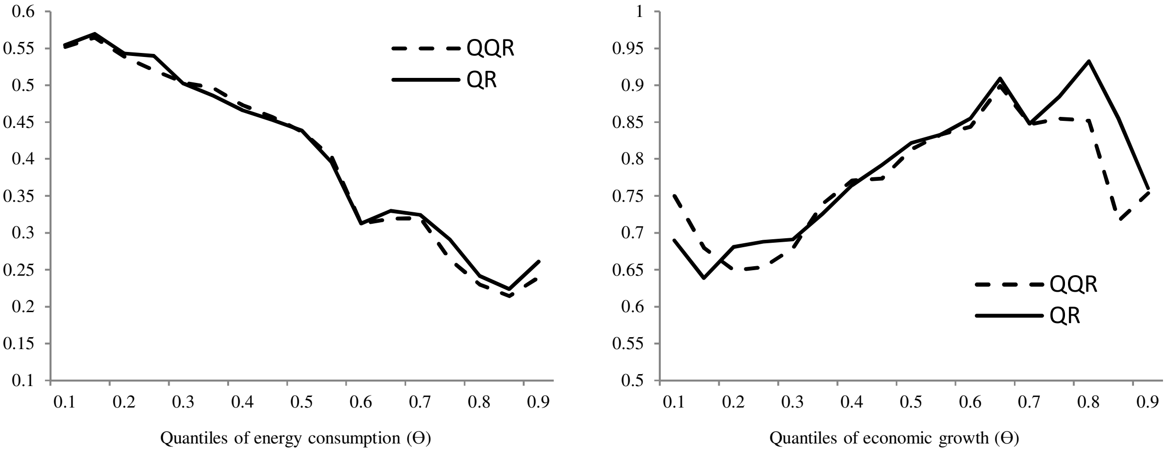
vi). Canada



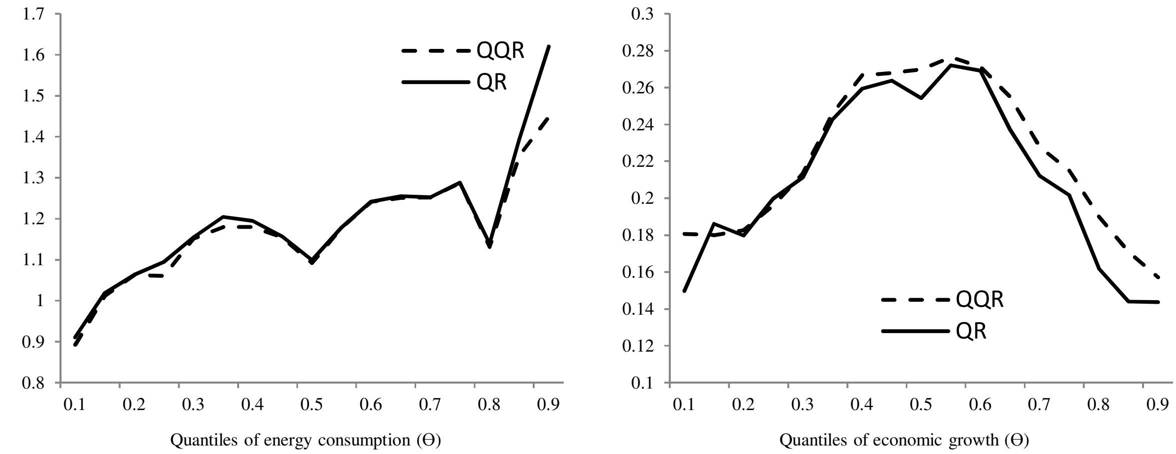
vii). Germany



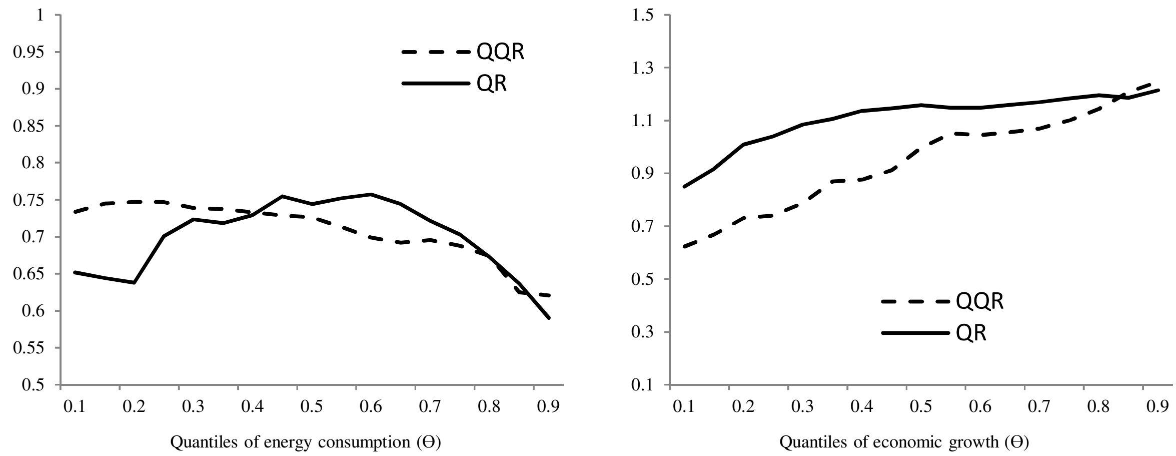
viii). Brazil



ix). France



x). South Korea



Note: The graphs display the estimates of the standard quantile regression parameters, denoted by QR (continuous black line), and the averaged QQ parameters, denoted by QQ (dashed black line), at different quantiles of energy consumption and economic growth rates for all countries examined.

When we consider the effect of economic growth on energy consumption, the graphs in Figure 5 reveal that the averaged QQ estimates of the slope coefficient are very similar to the quantile regression estimates for all countries (except China and South Korea), regardless of the quantile considered. In China and South Korea, the trend of the QQR lines is the same as the QR line, but the values are somewhat different. This graphical evidence provides a simple validation of the QQ methodology by showing that the main features of the quantile regression model can be recovered by summarizing the more detailed information contained in the QQ estimates. Therefore, Figure 5 largely confirms the results of the QQ analysis reported earlier. First, the effect of economic growth on energy consumption is consistently positive across quantiles for all countries. A negative effect of economic growth on energy consumption is only found for intermediate to upper quantiles of energy consumption in China (0.35-0.85) and at very low quantiles in India (0.15-0.25). This result again supports the results of Figure 4. Second, a notable heterogeneity across countries and across quantiles within each country in terms of the link between energy consumption and real GDP growth is also observed. The largest effects of economic growth on energy consumption in China, the USA, Canada and Brazil are found at the lowest quantiles of their respective distributions of energy consumption. This result indicates that energy is not an important input in these countries, as energy demand decreases with increased economic growth in these countries. However, in China, energy demand increases at high quantiles of economic growth. In turn, the largest effects of economic growth on energy consumption in Russia, India. Japan, Germany, France are found at the intermediate to upper quantiles of their respective distributions of energy consumption. This finding suggests that demand for energy consumption is high in these countries when economic growth is also high, which indicates that energy is an important input for economic growth in these countries because economic growth increases the demand for energy. In South Korea, the effect of economic growth on energy demand is lowest at the extreme (very low and very high) quantiles. The highest effect of economic growth on energy demand is found at the middle quantiles of energy consumption. This result clearly supports the EKC hypothesis, i.e., energy demand increases with increases in economic growth; however, when economic growth reaches a threshold level, energy demand starts to decline.

A similar interpretation holds when we consider the effect of energy consumption on economic growth. The graphs indicate that the averaged QQ estimates of the slope coefficients are almost similar to the quantile regression estimates for all countries, except for Germany and South Korea, where the trend of the QQR lines is same as the QR line but the values are different. These results again validate the QQ methodology. This graphical analysis endorses our previous findings that the effect of energy consumption on economic growth is positive across quantiles of all countries. A negative effect is found only for low quantiles (0.05-0.10) of economic growth in China. Further, the results are heterogeneous across countries and quantiles within each country. In terms of the magnitude of the coefficients, the largest effect of energy consumption on economic growth is found in Russia, Brazil and South Korea. A relatively high effect is found in the USA, India, Japan, and Canada, while a low effect is found in China, Germany, and France. The effect of energy consumption on economic growth decreases at high quantiles of economic growth in

Russia, India, Canada, Brazil and France. This result indicates that after a certain level of economic development, energy demand decreases in these countries.

7. Conclusion and Policy Implications

This paper empirically examines the energy-growth inter-linkages for the top ten energy-consuming countries using quarterly data for the period from 1960-2015. The Quantile-on-Quantile (QQ) approach, recently developed by Sim and Zhou (2015), is used for the analysis because it allows one to estimate how different quantiles of economic growth affect different quantiles of energy consumption, thereby providing a more precise description of the overall dependence structure between energy consumption and economic growth compared to conventional techniques such as OLS or quantile regression.

Our empirical results show that the relationship between economic growth and energy consumption is mainly positive for all countries, although there are wide differences across countries and across different quantiles of economic growth and energy consumption within each country. The heterogeneity among countries in the energy-growth nexus can be attributed to differences in the relative importance of energy as an input in economic growth of each country, the technical efficiency of each country, each country's production capacity constraints, and the possible negative externalities caused by energy consumption (carbon emissions) in some countries. In particular, a negative effect of economic growth on energy consumption is observed for some quantiles in China, India, Germany and France, probably because of the decreased importance of energy as an input at low levels of economic activity in these countries. Similarly, a negative effect of energy consumption on economic growth is found for some quantiles of China, Japan, Brazil and South Korea. Furthermore, the heterogeneous effect of economic growth (energy consumption) on energy consumption (economic growth) in different countries indicates that the energy-growth link depends on both the phase of the economic cycle, technical efficiency and the relative importance of energy as an input in economic growth. In this respect, for some countries, such as, Russia, India, Japan, Germany, France, the most pronounced linkage between energy consumption and economic growth is found only during periods of high economic growth.

The empirical evidence presented in this study has important implications for policy makers, who should take into account the specific phase of the economic cycle when designing energy conservation and environmental policies. Specifically, energy conservation policies might be beneficial in some countries during periods of economic downturn because energy conservation policies during economic booms will thwart these countries' economic growth. Thus, energy is an important input for economic development in these countries. The issue of global warming and environmental degradation can be mitigated by using less fossil fuels and more renewable energy resources. Further, increase in energy prices would encourage the more parsimonious and efficient use of energy, which would help to reduce the negative externalities of energy consumption. Consequently, increase in energy prices would also help the governments of the top ten energy-consuming countries to reduce the excessive use of energy in order to create higher economic growth and development, which is required to enhance the income-earning potential and living standards of their citizens. This would further result in lowering both the debt service burden and the huge import bills of the top ten energy-consuming countries in the world. Moreover, the efficient use of energy would also certainly help the top ten energy-consuming countries to reduce the overwhelming pressure of their debt service burden and huge import bills on their foreign exchange reserves.

On a final note, the results of this study also have country-wide policy implications. The negative/low effect of economic growth on energy consumption at lower quantiles for China, India, Germany and France reflects the fact that energy use at lower stages of production is a lower priority, and greater attention is paid to energy consumption when the pace of economic growth intensifies at higher levels of production. This phenomenon demonstrates that these countries use excessive energy as a potential resource to generate higher economic growth and prosperity. Although these countries benefit from the perspective of higher economic growth, it comes at the cost of environmental quality due to excessive energy consumption. From a policy standpoint, policy advisers in these countries should not only design their energy conservation policies in order to protect their environmental quality because such policies will only undermine the pace of economic growth. Policy makers tend to believe that slower economic growth will hinder developmental projects and will also not enhance the income-earning potential of their citizens. The only way out for these countries is to use energy more efficiently to produce higher economic growth. In doing so, it can be expected that the environmental consequences of excessive energy use will be better controlled in these countries.

Furthermore, the negative/low effect of economic growth on energy consumption in the United States, Canada, Brazil and South Korea at the highest quantiles of their economic growth indicates that energy demand decreases with the increase in economic growth as these countries have become energy efficient. From a policy perspective, this study suggests that the governments of these countries should maintain this momentum of efficient energy use in promoting higher economic growth and also for achieving greater environmental quality. On the other hand, a negative/low effect of energy consumption on economic growth is found for China, Japan, Brazil and South Korea at lower quantiles of energy consumption. This result implies that at low levels of energy consumption, economic growth is low. However, when energy consumption increases, economic growth also increases in these countries. Given the pronounced and higher correlation between energy consumption and economic growth in these countries, policy makers should consider energy as a potential resource in enhancing economic growth when designing growth policies. On a final note, this study leaves us a fertile research gap about the impacts of energy prices, geo-political uncertainty, imported energy, foreign growth and economic growth on energy consumption (energy intensity) in energy demand function. Though this unaddressed gap has been emphasized by the studies of Belke and Göcke (2005) and, Beckman and Czudaj (2013) and which is also beyond the scope of present study, but it can be empirically investigated within both multivariate time series models and panel framework. We can also consider global liquidity role following Belke and Dreger (2013) and Belke et al. (2014a) while investigating energy demand function as international oil prices and global liquidity may lead energy prices which ultimately affects energy demand. Last but not a least, exchange rate dynamics may effect spot and future energy demand under various exchange rate regimes suggested by Belke et al. (2014b).

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