Does Energy Consumption Volatility Affect Real GDP Volatility? An Empirical Analysis for the UK

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10. April 2013

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August 24, 2013

Abstract

This paper empirically examines the relation between energy consumption volatility and unpredictable variations in real gross domestic product (GDP) in the UK. Estimating the Markov switching ARCH model we find a significant regime switching in the behavior of both energy consumption and GDP volatility. The results from the Markov regime-switching model show that the variability of energy consumption has a significant role to play in determining the behavior of GDP volatilities. Moreover, the results suggest that the impacts of unpredictable variations in energy consumption on GDP volatility are asymmetric, depending on the intensity of volatility. In particular, we find that while there is no significant contemporaneous relationship between energy consumption volatility and GDP volatility in the first (low-volatility) regime, GDP volatility is significantly positively related to the volatility of energy utilization in the second (high-volatility) regime.

JEL classification: C22; E32

Keywords: energy consumption volatility; GDP volatility; asymmetry; Markov switching ARCH models; Markov regime switching models

Paper has been accepted for forthcoming issue of

"International Journal of Energy Economics and Policy"

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1 Introduction

The role of energy in economic growth has long been a controversial topic in the literature. According to the traditional neo-classical growth models, energy inputs are intermediate, whereas, land, labor, and capital are considered as basic factors, suggesting the neutrality between energy consumption and output. However, the biophysical and ecological models suggest that energy plays an important role in income generation. Similarly, Beaudreau (2005), Stern (1997), and Stern and Cleveland (2003) criticize the traditional growth model for treating energy as a secondary factor and argue that production is not possible without energy use. Along same lines, Sari and Soytas (2007) empirically show that energy is a relatively more important input as compared to both capital and labor.

On empirical grounds, numerous studies in the energy economics literature have investigated the relationship between the use of energy/electricity and macroeconomic performance for developed and developing countries. Most of these studies have focused to explore the causal relationship between energy consumption and real GDP using cointegration and Granger causality tests. Their findings are inconclusive, however. For example, some studies, such as Hwang and Gum (1991), Glasure (2002), Soytas and Sari (2006), Erdal et al. (2008), Narayan and Prasad (2008), and Belloumi (2009), have found bidirectional Granger causality between energy consumption and real GDP. Some others, such as Nachane et al. (1988), Stern (1993), Wolde-Rufael (2004), Lee and Chang (2005), and Bowden and Payne (2009), have found a uni-directional Granger causality running from energy consumption to real GDP. By contrast, Kraft and Kraft (1978), Yu and Choi (1985), Soytas and Sari (2003), Erol and Yu (1987), Masih and Masih (1996), Lee (2006), and Zachariadis (2007) have documented evidence of the unidirectional Granger causality running from real GDP to energy consumption. On the other hand, several empirical studies including Murry and Gehuang (1996), Altinay and Karagol (2004), Chontanawat et al. (2006), Jobert and Karanfil(2007), Karanfil (2008), Halicioglu (2009), and Soytas and Sari (2009) have concluded that there exists no causal relation between energy consumption and GDP, conforming the neutrality of energy.

Perhaps the lack of well-accepted empirical consensus regarding the causal relationship between energy consumption and real economic activities in prior empirical studies may be attributed to the time dependent nature of the results of Granger causality tests. As in Lee (2006) and Fallahi (2011), the results of standard Granger causality and cointegration tests are very sensitive to the change in sample period and model specifications. One of the possible reasons behind this argument is that there are potential structural changes or breaks embedded in energy consumption series due to energy crisis, such as hikes in oil prices. Indeed, some studies have taken into consideration such structural breaks and provided strong evidence of the presence of non-linearity in the energy consumption-growth nexus. Examples of these studies are Chiou-Wei et al. (2008) and Narayan and Smyth (2008). Similarly, Mork (1989), Lee et al. (1995), Hamilton (1996), and Davis and Haltiwanger (2001) have also pointed out that the relationship between energy prices and real economic activity is nonlinear.

Another gap in the literature is that the purpose of most of prior studies has been to explore the causal relationship between energy consumption and GDP series, ignoring totally how unpredictable variations in energy utilization cause GDP volatility. Therefore, empirical evidence on the effects of energy consumption variability on the volatility of GDP is rather limited. However, knowing the link between energy consumption volatility and GDP volatility is of great significance to policy-makers. In fact, Owyang et al. (2008) find that reductions in aggregate macroeconomic volatility in the United States are largest in states with high average energy consumption, relatively high initial levels of volatility, and high concentrations in durable goods industries. In this regard, one may consider that understanding the fluctuations in energy consumption is a prerequisite for understanding how output growth varies over time. It is also worth exploring whether the effects of energy consumption volatility on GDP volatility are different across low- and high-volatility regimes.

Moving from the existing studies in the energy economics literature, in this paper, we therefore explore whether unexpected variations in energy consumption lead to higher volatility in real GDP in the United Kingdom accounting for regime shifts in the data. Specifically, we study whether the volatility of energy consumption has any significant influence on the volatility of real GDP. And if so, then whether this impact changes across low- and high-volatility regimes.

Our estimation procedure involves two steps. First, allowing for state and time dependence, we estimate Markov switching ARCH (hereafter MS-ARCH) models to obtain the conditional variance which is used as proxies for unpredictable variations in real GDP and total energy consumption. Standard ARCH/GARCH models show how the conditional variance changes over time taking the economic structure as given. Therefore, to take into account structural changes that may exist in the data, we estimate the volatility of each related variable using the MS-ARCH model. We take into consideration this because it is well accepted in the empirical literature that while volatility is likely to rise during periods of falling growth, it tends to fall during episodes of increasing growth.

However, standard ARCH class models are unable to capture such kinds of asymmetries in the volatility behavior. The MS-ARCH approach allowing time variation in the parameters of the conditional mean and conditional variance enables the researchers to take into account such asymmetric patterns. Second, we use the Markov regime switching (hereafter MRS) model to estimate the impact of energy consumption volatility on the volatility of real GDP. We contribute to the existing literature on energy-growth nexus by providing evidence that the variability of energy consumption is statistically significant for determining the behavior of real GDP volatility.

The rest of this paper is preceded as follows. Section 2 presents the empirical model and discusses the econometric framework. Section 3 presents our empirical results followed by concluding remarks in Section 4.

2 Empirical Model

We start our examination by estimating the MS-ARCH(1) model for output and energy consumption series. The specification of the model is based on the methodology, which is proposed by Gray (1996). More specifically, the conditional mean in the model is expressed as follows:

$$X_t = \mu_{it} + \varepsilon_t,\ \varepsilon_t \ |\Omega_{t-1} \sim N(0, h_{it}),\ \text{i} = 1{,}2 \ \text{ regimes} \tag{1}$$

where $X_t' = [y_t, ec_t]$. Here y_t is output (real GDP) and ec_t is energy consumption.

Regimes are assumed to follow a first order Markov chain on $(0,1)$ with following transition probabilities:

$$\begin{aligned}
\Pr &= [S_t = 1 | S_{t-1} = 1] = P \\
\Pr &= [S_t = 0 | S_{t-1} = 1] = 1 - P \\
\Pr &= [S_t = 0 | S_{t-1} = 0] = Q \\
\Pr &= [S_t = 1 | S_{t-1} = 0] = 1 - Q.
\end{aligned} \tag{2}$$

We use the MS-ARCH(1) model to estimate the conditional volatility of energy consumption and output series. Specifically, the specification of the Markov Switching ARCH(1) is defined as follows:

$$h_{it} = \alpha_{0i} + \alpha_{1i}\varepsilon_{t-1}^2 \tag{3}$$

As in Gray (1996), the likelihood function is constructed in terms of regime probability which is defined as $p_{it} = P(S_t = i|\Omega_{t-1})$. Here, the regime probability is the ex-ante probability of being in a specific regime at time period t and is the function of information set revealed at time $t-1$. Therefore, the conditional distribution can be written as follows:

$$f_{it} = f(X_t | S_t = i, \Omega_{t-1}) = \frac{1}{\sqrt{2\Pi h_{it}}} \exp\left\{ -\frac{(X_t - \mu_{it})^2}{2h_{it}} \right\} \tag{4}$$

where h_{it} and μ_{it} are the conditional variance and conditional mean in regime i at the time period t and Ω_{t-1} is the information set available at time $t-1$.

The regime probability p_{1t}, as defined by Gray (1996), is expressed as follows:

$$p_{1t} = P\left[\frac{f_{1t-1}p_{1t-1}}{f_{1t-1}p_{1t-1} + f_{2t-1}(1-p_{1t-1})} \right] + (1-Q)\left[\frac{f_{2t-1}(1-p_{1t-1})}{f_{1t-1}p_{1t-1} + f_{2t-1}(1-p_{1t-1})} \right] \tag{5}$$

where

$$\begin{aligned}
p_{1t} &= P(S_t = 1|\Omega_{t-1}), \\
f_{1t} &= f(X_t|S_t = 1), \\
f_{2t} &= f(X_t|S_t = 0).
\end{aligned}$$

Based on the defined regime probabilities, the log likelihood function is constructed as follows:

$$L = \sum_{t=1}^{T} \log\left[p_{1t} \frac{1}{\sqrt{2\Pi h_{it}}} \exp\left\{ -\frac{(X_t - \mu_{1t})^2}{2h_{1t}} \right\} + (1-p_{1t}) \frac{1}{\sqrt{2\Pi h_{2t}}} \exp\left\{ -\frac{(X_t - \mu_{2t})^2}{2h_{2t}} \right\} \right] \tag{6}$$

The above equation can be maximized using the following specifications for h_{it} and ε_t:

$$h_t = p_{1t}\left(\mu_{1t}^2 + h_{1t}\right) + \left(1 - p_{1t}\right)\left(\mu_{2t}^2 + h_{2t}\right) - \left[p_{1t}\mu_{1t} + \left(1 - p_{1t}\right)\mu_{2t}\right]^2,$$

$$\varepsilon_t = X_t - \left[p_{1t}\mu_{1t} + \left(1 - p_{1t}\right)\mu_{2t}\right]$$

We use the conditional variances of both series as the proxies for energy consumption volatility and real GDP volatility while we scrutinize the impact of the energy consumption volatility on output volatility. Specifically, we estimate the following model:

$$\sigma_t^y = \alpha_{0i} + \sum_{k=1}^{l}\delta_{ki}\sigma_{t-k}^y + \sum_{p=0}^{r}\beta_{pi}\sigma_{t-p}^{ec} + \xi_t, \tag{7}$$

$$\xi_t \mid \Phi_t \sim N\left(0, \sigma_{0i}^2\right)$$

where σ_t^y and σ_t^{ec} denote the volatility of real GDP and total energy consumption, respectively.

3 Data and Summary Statistics

3.1 Data

The main purpose of this paper is to examine the impact of the volatility of energy consumption on real GDP volatility for the United Kingdom. The data used in the paper consists of log real GDP and log total final energy consumption. The frequency of real GDP series is quarterly. However, the total final energy data is only available at annual frequency. Given the objective of the paper, we attempt to use Markov Switching ARCH model based on the methodology proposed by Gray (1996). As it is well established in the time series literature, ARCH/GARCH models tend to yield more efficient estimates in case of the data with high frequency, we interpolate annual total final energy consumption series to quarterly frequency by employing Denton's (see, Baum and Hristakeva (2011)) methodology.

The quarterly data for real GDP is obtained from the International Financial Statistics (IFS) database, while the annual series of total final energy consumption is attained from the International Energy Agency (IEA) database accessed through Economic and Social Data Service (ESDS) International. The sample period is from 1960:Q1 to 2009:Q4 (200 observations).

3.2 Summary Statistics

We begin our empirical investigation by presenting summary statistics of log real GDP, log total final energy consumption, real GDP volatility, and total final energy consumption volatility series in Table 1. The average of log real GDP is 2.273, which is approximately identical to the median value of log real GDP (2.254). This implies that the log real GDP series is nearly normally distributed. Likewise, the average and median values of log total final energy consumption are almost similar, implying that this series is also normally distributed. Comparing the standard deviation of both series, we observe that log real GDP is more volatile as compared to log total final energy consumption over the examined period. It is also interesting to note that the difference between the maximum and minimum values of log real GDP is clearly visible. By contrast, the log total final energy consumption series is narrowly ranged in between 4.429 and 4.579. Turning to the estimated volatility series we observe that the average real GDP volatility is 0.170, which is significantly less than its median value, indicating that the series is negatively skewed. The maximum value of real GDP volatility is 0.771, while the minimum value is 0.002, suggesting that there are considerable variations in the volatility of real GDP series.

The mean value of total final energy consumption volatility is 0.260, while the median value of the series is 0.310. The greater value of median than that of mean suggests that the underlying series is negatively skewed. The standard deviation of both the volatility series indicates that total final energy consumption volatility is more variable than the real GDP volatility. It should also be noted that the actual total final energy consumption is less volatile than the real GDP, whereas the volatility of energy consumption is more variable than the volatility of real GDP over the period under study. Overall, the preliminary descriptive analysis points out that our computed volatility series exhibit significant variability and are well populated. Hence, they are appropriate for use in any further empirical investigation.

4 Empirical Findings

Tables 2 and 3 present the results of the MS-ARCH model for real GDP and energy consumption, respectively. Based on the estimates, we have two different regimes. Specifically, in the first regime, the estimated parameters of mean and conditional variance are both low. Hence, we identify this regime as the low-volatility regime. By contrast, in the second regime, the estimated parameters are relatively higher. We therefore recognize this regime as the high-volatility regime. In particular, the ARCH persistence parameter (φ_{12}) in the high-volatility regime is about 2 times the corresponding

ARCH parameter (φ_{11}) in the low-volatility regime. This difference even appears more profound for the case of energy consumption series. More specifically, the ARCH persistence parameter (η_{12}) is around 4.5 times the corresponding parameter in the low-volatility regime (η_{11}). The presence of two different regimes is also confirmed by the estimates of transition probabilities. Specifically, the estimates of transition probabilities P and Q are statistically significant and they are close to one. This implies the existence of high persistence of both regimes for real GDP and energy consumption in the UK over the period under study.

Table 1: Descriptive Statistics

	LRGDP	LTEC	VGDP	VTEC
Average	2.273	4.526	0.170	0.260
Median	2.254	4.536	0.220	0.310
Maximum	2.528	4.579	0.779	1.010
Minimum	0.007	4.429	0.020	0.051
Standard	0.149	0.038	0.122	0.156
Observation	200	200	200	200

Note: LRGDP, LTEC, VGDP, and VTEC represent log real gross domestic product, log total energy consumption, gross domestic product volatility and total energy consumption volatility, respectively.

Table 2: Parameter Estimates and Related p-value for Markov Regime Switching ARCH Model for Real UK GDP

$$y_t \mid \Omega_{t-1} \sim \begin{cases} N\left(\psi_{01} + \sum_{j=1}^{p} \psi_{j1} y_{t-j}, h_{1t}\right) \text{w.p. } p_{1t}, \\ N\left(\psi_{02} + \sum_{j=1}^{p} \psi_{j2} y_{t-j}, h_{2t}\right) \text{w.p. } 1\text{-}p_{1t}, \end{cases}$$

$$h_{it} = \varphi_{0i} + \varphi_{1i}\varepsilon_{t-1}^{2}.$$

Parameters	Estimate	p-value
ψ_{01}	0.027	(0.000)
ψ_{02}	0.021	(0.000)
ψ_{11}	0.988	(0.000)
ψ_{12}	0.992	(0.000)
φ_{01}	0.228	(0.000)
φ_{11}	0.141	(0.122)
φ_{02}	0.013	(0.000)
φ_{12}	0.285	(0.000)
P	0.964	(0.000)
Q	0.944	(0.018)
Log likelihood	856.486	

Table 2 indicates that the conditional mean parameters of real GDP are statistically significantly different from zero in both regimes. Regarding the conditional variance parameters, we observe that while the estimated coefficient of the ARCH term is highly statistically significant in the high-volatility regime, it is statistically significant only at margin (12%) in the low-volatility regime. In line with Gray (1996), the high-volatility regime is found to be more sensitive to recent shocks as φ_{12} is substantially greater than φ_{11}. Looking at the estimates presented in Table 3 we find that the conditional mean parameters of energy consumption are positive and statistically significant. The parameters of conditional variance are also positive and appear statistically significant in both regimes. Once again, the high-volatility regime is likely to be more sensitive to recent shocks as compared to the low-volatility regime as η_{12} is considerably greater than η_{11}. Definitely, a single regime ARCH model cannot capture such sort of asymmetries across different regimes.

Figures 1 and 2 plot the conditional variance of real GDP and total energy consumption based on the models presented in Tables 2 and 3, respectively. The conditional variance series shown in the figures are the aggregated weighted variances of the two conditional variance series from the low- and high-volatility regimes based on the regime probabilities. It is clear from the plots that the conditional variance of the series is substantially higher in the high-volatility regime, as shown in the shaded region, than in the low-volatility regime. More importantly, it is obvious from the figures that the periods of high-energy consumption volatility overlap with the periods of high output volatility. In particular, when there are fluctuations in the energy consumption between 1960s and mid-1980s, the output growth is also highly volatile. Moreover, both energy consumption and output growth are found to be highly volatile between 2008-2009. Hamilton (2009) argues that this period should be added to the list of recessions to which oil prices have made a substantial contribution in the United States. However, it is obvious that the run-up of oil prices in this period appears to lead high volatility of energy consumption and thereby high volatility of output growth in the UK as well. These findings provide preliminary evidence on the impact of energy consumption volatility on the volatility of real GDP.

Table 3: Parameter Estimates and Related p-value for Markov Regime Switching ARCH Model for UK Energy Consumption

$$ec_t|\Omega_{t-1} \sim \begin{cases} N\left(\phi_{01} + \sum_{j=1}^{p}\phi_{j1}ec_{t-j}, h_{1t}\right) \text{w.p. } p_{1t}, \\ N\left(\phi_{02} + \sum_{j=1}^{p}\phi_{j2}ec_{t-j}, h_{2t}\right) \text{w.p. } 1\text{-}p_{1t}, \end{cases}$$

$$h_{it} = \eta_{0i} + \eta_{1i}\varepsilon_{t-1}^{2}.$$

Parameters	**Estimate**	**p-value**
ϕ_{01}	0.202	(0.000)
ϕ_{02}	0.286	(0.000)
ϕ_{11}	0.955	(0.000)
ϕ_{12}	0.937	(0.000)
η_{01}	0.327	(0.000)
η_{11}	0.121	(0.047)
η_{02}	0.451	(0.000)
η_{12}	0.545	(0.008)
P	0.990	(0.000)
Q	0.976	(0.000)
Log likelihood	791.056	

Figure 1: Markov Switching ARCH Conditional Variance of GDP–1960: QI-2009: QIV

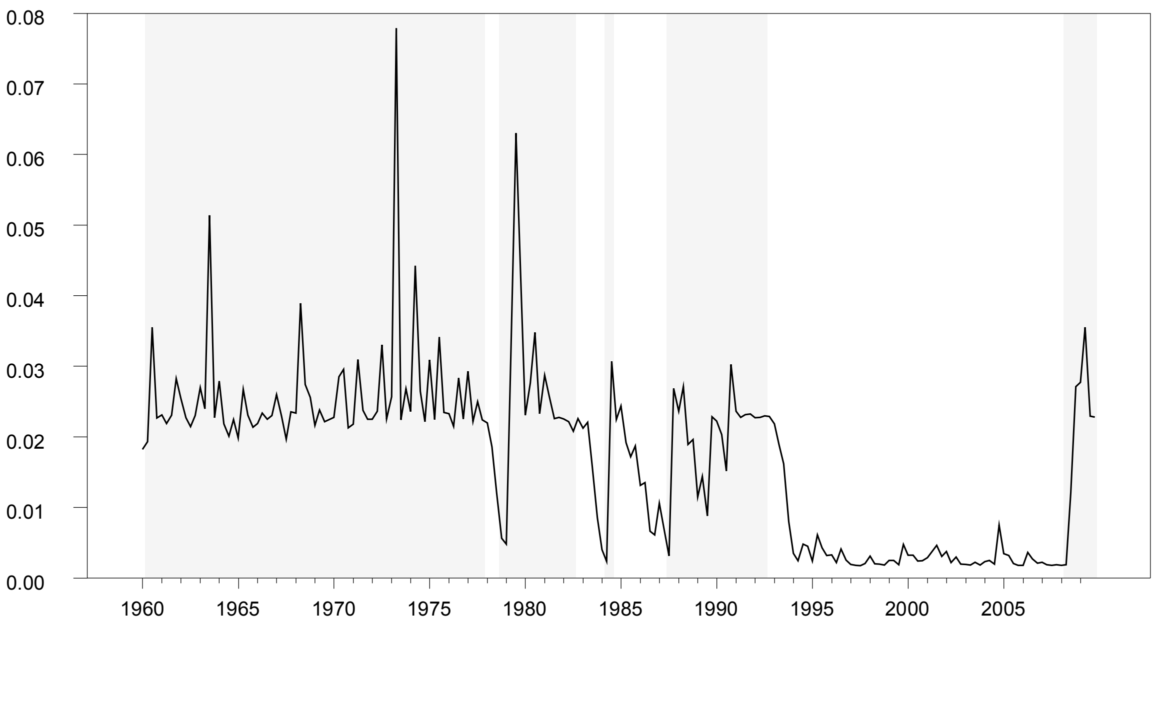
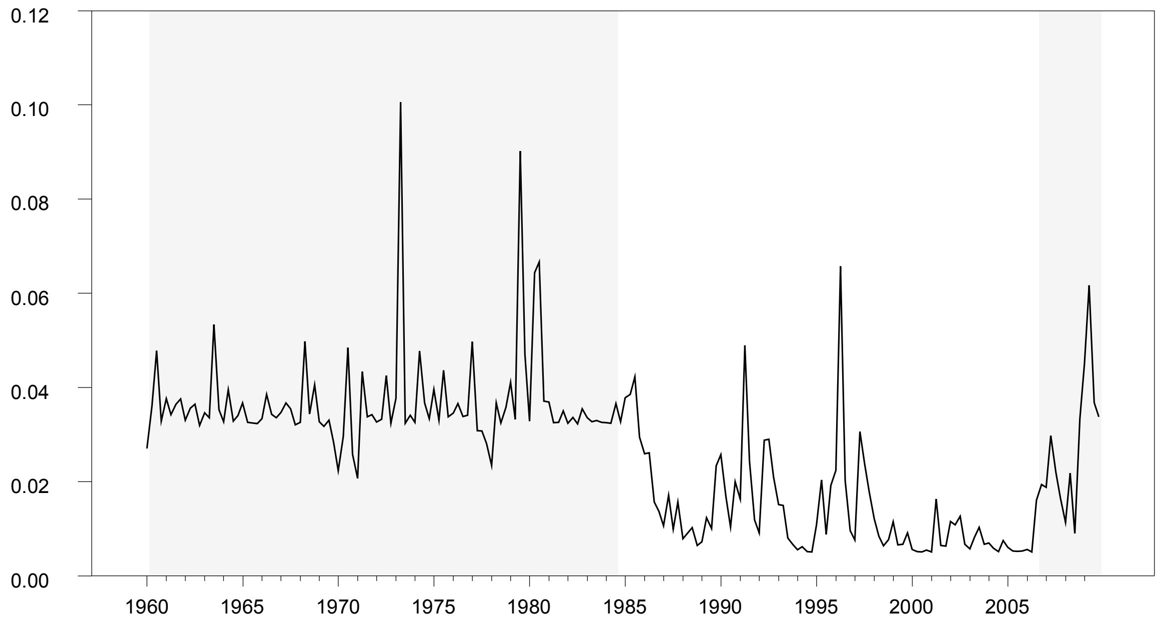


Figure 2: Markov Switching ARCH Conditional Variance of Total Energy Consumption–1960: QI-2009: QIV



Having obtained the proxies for volatilities in real GDP and energy consumption, we next study how the volatility of energy consumption relates to the volatility of real GDP. To examine this, we regress the conditional variance of real GDP on the conditional variance of energy consumption in a Markov regime-switching framework, as depicted in equation (7). The results are presented in Table 4.

Table 4: Parameter Estimates and Related p-value for Markov Regime Switching Model for GDP Volatility

$$\sigma_t^y = \alpha_{0i} + \sum_{k=1}^{l} \delta_{ki}\sigma_{t-k}^y + \sum_{p=0}^{r} \beta_{pi}\sigma_{t-p}^{ec} + \xi_t,$$

$$\xi_t | \Phi_t \sim N\left(0, \sigma_{0i}^2\right)$$

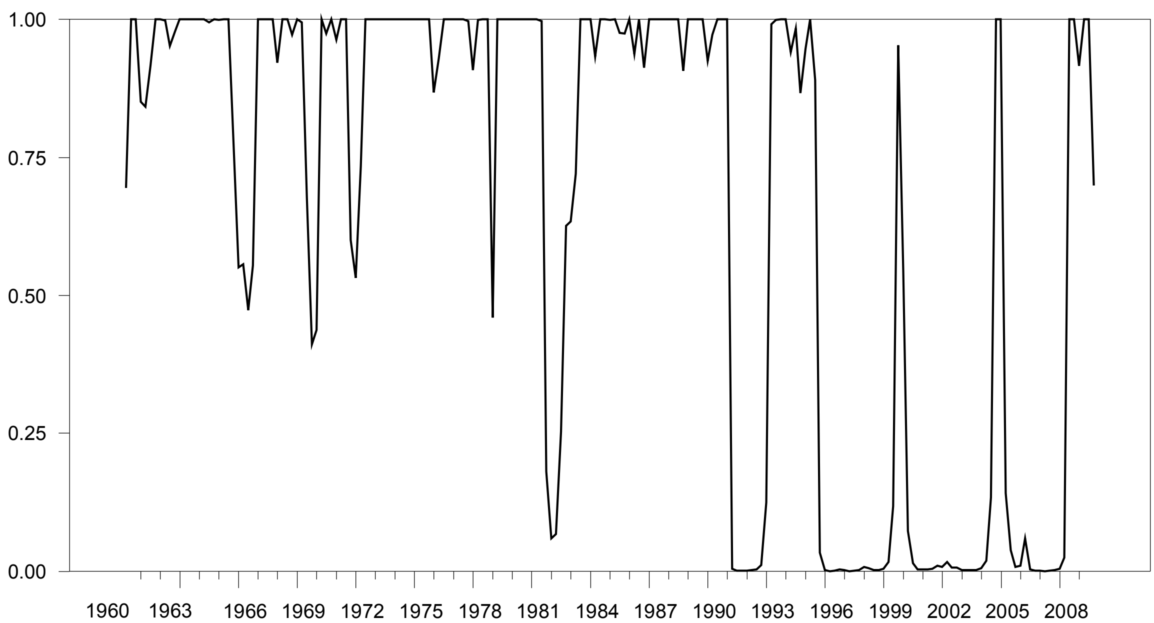
Parameters	Estimate	p-value
α_{01}	-0.009	(0.615)
δ_{11}	0.994	(0.000)
β_{01}	-0.013	(0.188)
β_{12}	0.033	(0.001)
β_{21}	-0.021	(0.045)
α_{02}	0.269	(0.044)
δ_{12}	0.449	(0.000)
β_{02}	0.618	(0.000)
β_{12}	-0.312	(0.000)
β_{22}	-0.795	(0.985)
σ_{01}	0.072	(0.000)
σ_{02}	0.587	(0.000)
P	0.862	(0.000)
Q	0.933	(0.029)
Log likelihood	2202.149	

Examining the estimates of mean of the volatility of GDP across both regimes we observe that while the estimate is statistically significantly different from zero in the second regime, it appears statistically insignificant in the first regime. Furthermore, comparing the magnitude of these estimates across both regimes we find that the mean value is positive with a magnitude of 0.269 in the second regime, whereas, the corresponding figure is approximately close to zero (-0.009) in the first regime. The greater mean value in the second regime implies that the second regime is likely to be appeared a high-volatility regime. Likewise, the estimates of standard deviation suggest that variations in GDP volatility are relatively higher in the second regime than in the first ones. When we examine the transition probabilities we observe that the high-volatility regime is relatively more persistent as compared to the low-volatility regime as the value of *Q* is significantly greater than the value of *P*.

Turning to the effects of energy consumption volatility on real GDP volatility we find that the impact of unpredictable variations in energy consumption on the volatility of real GDP is quite asymmetric across high- and low-volatility regimes. Specifically, we show that the volatility of real GDP is significantly and positively affected by energy consumption volatility in the high-volatility regime. However, we do not find any significant evidence of the impact of energy consumption volatility on real GDP volatility in the low-volatility regime. This implies that energy consumption volatility affects real GDP volatility only when the economy is in the high-volatility regime. These findings suggest that in periods of a relative stable economic growth, the unexpected shocks in energy utilizations do not significantly cause variations in real GDP. However, in periods when macroeconomic activities are relatively unstable, unpredicted shocks in energy consumption tend to further deepen the economic fluctuations.

Interestingly, one-period lagged energy consumption volatility is positively related to real GDP volatility in the low-volatility regime, whereas it is negatively correlated with real GDP volatility in the high-volatility regime. Similarly, the second lag of energy consumption volatility is significantly (and negatively) related to the volatility of real GDP only in the low-volatility regime. These results suggest that not only the current level of energy consumption volatility but also the past period volatility of energy consumption is asymmetrically related with the volatility of real GDP. Besides, when we examine the smoothed probabilities of high volatility regime obtained from the estimation of equation (7) which are plotted on Figure 3, we observe that high output growth volatility periods coincide with the periods in which the energy consumption is substantially volatile.

Figure 3: Smoothed Probabilities of State 2 (High Volatility Regime)–1960: QI-2009:IV



Our findings together with the existing empirical literature that relates the level of energy consumption with economic growth, suggest that not only the level of economic growth and energy consumption are interrelated (in cointegration sense) but also unpredictable dynamics in both series are significantly linked. Our results also point out that the relation between energy consumption volatility and real GDP volatility is asymmetric across low- and high-volatility regimes. Specifically, the impact of energy consumption volatility on output growth volatility is found to be more profound in periods of unstable economic growth than in periods when macroeconomic conditions are relatively stable.

5 Conclusions

Most of the existing empirical studies of energy-output nexus have focused on exploring the long-run causal relationship between real GDP and energy consumption. Departing from these studies, this paper contributes to the literature by examining the impact of energy consumption volatility on unpredictable variations in real GDP rather than the relation between the underlying series per se. We measure the volatility of both series by using the conditional variance of the series. To capture the non-linearities in the conditional variance, we use the Markov switching ARCH (MS-ARCH) procedure. We find a significant regime switching in the behavior of both energy consumption and GDP volatility.

Accounting for this regime shifts by applying the Markov regime-switching (MRS) model we find that the unpredicted shocks in energy consumption have significant and asymmetric effects on the volatility of real GDP across high- and low-volatility regimes. In particular, it is found that the volatility of energy consumption significantly increases the volatility of real GDP in periods when the state of macroeconomy is highly unstable. However, in periods when macroeconomic activities are relatively less volatile, our results reveal that the volatility of energy consumption does not have any significant impact on the volatility of real GDP. The results of the paper are of significance to policy-makers as they suggest that the unwanted fluctuations in real economic activities can be controlled by stabilization in energy consumption, particularly in episodes of high real GDP volatility.

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