Energy Consumption and Economic Growth Nexus Revisited in an EGARCH-M Model: Evidence from Five Asia Pacific Countries

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Abstract

The aim of this study is to empirically investigate the relationship between energy consumption (EC) and economic growth (EG) for five Asian Pacific countries over the 1971-2007 period. We use annual data and employ a bivariate EGARCH-M model (exponential GARCH in mean, see Nelson, 1991) in which, in addition to energy consumption and real GDP, we incorporate real oil price and real exchange rate. The empirical results we find that most the coefficients of impact of uncertainty on energy consumption and economic growth have a significant and negative effect, and there is a bidirectional Granger causality runing from energy consumption to economic growth for China and Taiwan, while a unidirectional Granger causality runing from energy consumption to economic growth for Singapore, and neutrality hypothesis stand as in the case of Philippines and Korea. The results provide practical policy implications for decision makers for five countries of macroeconomic planning.

JEL classifications: C22; Q43;

Keyword: **Energy consumption; Economic growth; EGARCH-**

1. Introduction

The causal relationship between energy consumption and economic growth has been noticed increasing attention in the recent energy economics literature ever afterwards, since that time the crude oil price had doubled or ever tripled during the two energy crises in the 1970s. In recent decade years, the prices of international crude oil dramatic fluctuated are generally seen as a major according to the Iraq war, 2005 hurricanes in the US and depreciation of US dollar. By 2008, crude oil price surged to nearly $144 per barrel as US commercial oil stocks fell, simmering tensions in the Middle-East and oil supply declines sharply, resulting in the high energy costs and an increase of production cost, which may have reduced the productive capacity and export competitiveness of Asia developing economies of industrialized countries. Accordingly, these Asia developing countries were noticed this questions again and took various measures to conserve energy that reduce their dependency on imported foreign oil, but there are also some concerns which have been raised regarding the adverse side-effects of adopting conservation policies on economic growth. It is important to know what is plausible policies may be adopted to achieve conservation goals in an economy without substantially impeding its growth. And the investigation of the energy consumption–economic growth causality nexus, the results not only provides insights with respect to the role of energy consumption in economic development, but also provides a basis for discussion of energy and environmental policies. For instance, if there exist a causality running from energy consumption to economic growth, then this denotes an energy-dependent economy such that energy is an impetus for economic growth, the energy conservation policies which reduce energy consumption may have an adverse impact on a country's growth prospects.

The seminal paper on this topic was Kraft and Kraft (1978), who employed U.S. data from 1947-1974 to find causality running from GNP to energy consumption. Several researchers started to doubt about the findings, as Kraft and Kraft (1978) had published the article. Because of their doubt, the issue has been widely investigated. Therefore, some researchers supported the findings; some researchers opposed to the finding. For example, the supporters who were like Akarca and Long (1979) used Granger causality to find unidirectional causality running from energy consumption to employment on U.S. monthly data for the period 1973-1978. Moreover, there also have some opponents who were like Erol and Yu (1987) and Yu and Hwang (1984), who found no causal relationships between GDP and energy consumption. Since that the relationship between energy consumption and economic growth has been the topic of considerable research in the energy economics literature until now. However, the unanimous investigate results of empirical literature had not yet been reached in the energy consumption-economic growth nexus. Because of the different data set, different countries' characteristics (The countries have a different phase of development and thus their dependency on energy consuming technology may also differ.) and different econometric methodologies used, there is no consensus on the investigate results

In addition to all of the above mention, based on this topic mixed or conflicting results, we approximately has been categorized it as four groups as follows. At first, some of article concentrated different variables that tested the economic growth and energy consumption causal nexus. Asafu-Adjaye (2000) employed Johansen's cointegration technique and the Granger causality test and added the price factor to examined the relationship between energy consumption, energy price and economic growth in Asian developing countries. In the short-run, there are bidirectional Granger causality runs from energy consumption to economic growth for Thailand and the Philippines, while unidirectional Granger causality runs from energy consumption to economic growth for India and Indonesia. The second point that was discussed unidirectional or bi-directional causal between economic growth and energy consumption. No matter what the direction of causation has been found between energy consumption and economic growth, and every government could make different manner in different result. To generalize findings from the related Energy literature, there are four views regarding the causal relationship between economic growth and energy consumption. The first view is called "conservation hypothesis", the concept that the economic growth Granger causes energy consumption, and it also means that economic growth as the driver for energy consumption, if the energy conservation policies be implemented with little adverse or no effects on economic growth. The view is supported by Kraft and Kraft (1978) and Al-Iriani (2006). The second view argues that energy consumption Granger causes economic growth, and then this denotes the energy conservation policies may negatively affect economic growth. It is called "growth hypothesis", Masih and Masih (1998)has supported. The first view and the second view were discussed unidirectional causal between economic growth and energy consumption. Academics continue using those finding to study more extensive investigation, including position and negative. Akarca and Long(1979) went one step further to find negative causality running from employment to energy. The third view argues that energy consumption and economic growth has bidirectional causality each other, the so called "feedback hypothesis". Some of article's findings identical with this view, Glasure and Lee (1997) found the bidirectional causality between economic growth and energy consumption in Singapore and Korea. Asafu Adjaye (2000) also obtained a result of the economic growth and energy consumption bidirectional causal nexus. The fourth view, "neutrality hypothesis" (Yu and Jin, 1992) implies that there is no causality between economic growth and energy consumption, and energy conservation policies do not affect economic growth. Li, Wang and Song (2009) used Granger causality to find the no similar causal relationship in developing and developed countries. This view has been supported by other studies such as, Akarca and Long (1980), Yu and Jin (1992), Altinay and Karagol (2004), among others.

The third point is based on different countries to test for causality between energy consumption and economic growth. Some studies employed the data of individual country to test the causal relationship, such as Erman Erbaykal (2008) employed Bound test approach to investigate disaggregate energy consumption and economic growth causal nexus in Turkey during 1970-2003. The result show that in the short run both oil and electricity consumption has positive and statistically significant effect on economic growth. Stela Cani (2010) applied a modified version of the Granger causality test proposed by Toda and Yamamoto (1995) to find the causal relationship between aggregated or disaggregated energy consumption and economic growth for Greece from 1960-2006. And some studies employed Multi-country data, Lee and Chang (2008) test for causality between energy consumption and economic growth employed Asian economies data include 16 Asian countries during the 1971-2002 period. The results show there was a positive long-run cointegrated relationship between real GDP and energy consumption when the heterogeneous country effect is taken into account. And in the long-run, there is unidirectional causality running from energy consumption to economic growth. The fourth point, investigate economic growth and energy consumption causal nexus through different econometric methods. Most of previous studies are considered that the data has special features of time series, so articles are used various time series analysis models to substitute the OLS model. Some of the related articles about energy consumption and economic growth in the last 20 years, there are many time series analysis models which are the Granger causality test (Granger, 1988) within a bivariate Vector Autoregression (VAR) model and the Error Correction Model (ECM) in the case of cointegration that have been extensively applied. Glasure and Lee (1997) examined the causality between energy consumption and GDP for South Korea and Singapore through the cointegration technique and error-correction model. The results of the standard Granger causality tests show no causal relationship between GDP and energy consumption for South Korea and causal relationship from energy consumption to GDP for Singapore. IIhan Ozturk and Ali Acaravci (2010) employed autoregressive distributed lag (AEDL) and a dynamic vector error correction (VEC) to find that there is no a unique long-term or equilibrium relationship between energy consumption variables and real GDP per capita in Albania, Bulgaria and Romania during 1980-2006. So far as time series models are concerned, VECM, cointegration and Granger test are well-applied in the topic of economic growth and energy consumption nexus (Yu and Jin. (1985), Hondtoyiannis et al. (2002), Lee (2005), and Al-Iriani(2006)), but there with little attention being paid to use the GARCH family model to investigate the causal relationship. The GARCH-family has been extensively applied in the financial and economic literature on account of financial and economy data which have the characteristics of uncertainty (volatility). In this study, we employ the many time series data (i.e. real GDP, exchange rate), moreover it has the common characteristic. Therefore, we attempt to investigate the causal relationship between economic growth and energy consumption by the GARCH technique. However, the measurement of uncertainty generated by the GARCH models is by a construction invariant to the direction of change in the variable under consideration (see Nelson, 1991), which is not capable of providing reliable assessments of the energy consumption-economic growth-uncertainty nexus. To estimate these relationships simultaneously in a single statistical model, we adopt a bivariate exponential GARCH in mean (i.e. EGARCH-M) model of economic growth and energy consumption. The feature of uncertainty (or volatility) often present in many time series including exchange rate, energy consumption and economic growth (in this study, we take the kg of oil equivalent per capita as energy consumption data). More specifically, exchange rate, oil price (energy consumption) and economic growth is sensitive to news pertaining to concerns, including war, natural disaster, anthropogenic factor, terrorism, and political instability in oil production of OPEC or Non-OPEC. These factors cause the uncertainty (volatility) phenomenon in exchange rate, oil price (energy consumption) and economic growth.

The purposes and contributions of this study are as follows. This study depart from previous studies by not only discussing economic growth and energy consumption causal nexus, but also considering the impact of uncertainty (or volatility) of economic growth, energy consumption and oil price, hence we revisits this debate using the bivariate EGARCH-M model to investigate the relationship among energy consumption, economic growth and real oil price. Furthermore, this paper examines the energy consumption-economic growth relationship for five Asian developing countries: China, Singapore, Taiwan, Korea and Philippines. These countries were chosen because they represent energy- exporting that the same pattern to countries have a highly phase of industrialization and a similar level of economic development, and goes on to investigate if these countries have different impacts from economic growth uncertainty on energy consumption

The rest of the paper is organized as follows. The next section discusses the Definitions of the variable and data description. The third section presents the methodology and data. The fourth section discusses the empirical results, and the fifth section offers the conclusion and implication.

2. Methodology

2.1 Definitions of the variable and data description.

Stronger economic framework, strong domestic demand and stimulus policy responses have helped Asian emerging market to cushion the impact of the financial crisis from 2007 and quickly return to economic recovery. Since drive of the global economic was transferred from the West of world to the east, Asian emerging market become significant status in the world. As we discussed above, in this study, we are interested in the relationship between energy consumption (EC) and economic growth (EG) for five Asian Pacific countries (China, Singapore, Korea, Philippines and Taiwan.) over the 1971-2007 period, which are the representative of Asian emerging market. The data used in this paper are real GDP, real exchange rates relative to the US dollar, real oil price and annual energy consumption, denoted as y, π, R, $OilP$ and EC respectively. EC is kg of oil equivalent per capita, exchange rate is national currency per U.S. dollar, was obtained from the World Bank's World Development Indicators (2010) and AREMOS (MOE, Taiwan, 2010).

2.2 Unit root tests and cointegration tests

Before proceeding to the relation between economic growth and energy consumption through the E-ARCH technique developed by, we test to see whether the level of the series is trend stationary or I(1) in the case of time series data(include real GDP growth, energy consumption and real exchange rate). To determine the data-generating properties of the series under investigation in order to ensure robust and reliable results is necessary. we conducted there different unit root/stationarity tests to determine whether or not the data are stationary, which are augmented Dicky-Fuller(ADF),and Phillips and Perron (1988, PP) test. While the ADF test corrects for higher order serial correlation by adding lagged difference terms to the right-hand side, the Phillips–Perron test makes a non-parametric correction to account for residual serial correlation without restricting the residuals to be white noise. All of the series data is natural logs. The results of the unit root tests are reported in Table 1 The appropriate lag selection based on a criterion such as Akakie Information Criterion (AIC) and Schwarz Bayesian Criterion (SIC). In table 4 can be seen that, the null hypothesis of a unit root cannot be rejected at the 10% significance level for the levels of the variables. However, after first difference are taken, the unit root null hypothesis is rejected for all variable. Therefore, we conclude that the series are integrated of order one. To examine the existence of cointegration relations for the nonstationary variables with I(1), we utilized Johansen (1988) and Johansen and Juselius (1990) to test for cointegration, which is employed to test the potential longrun equilibrium relationship(s) among variables. Both tests with and without time trend are performed. Table 2 reports the cointegration tests. It shows that the existence of a cointegration relationship are not evident in the case of two variables (*y,EC*) in all countries, and therefore we construct the VAR model with differenced variables substitute for the ECM model to analyze.

Table 2

Unit root test

Country	Variable	ADF				PP			
		No time effects		Time fixed effects		No time effects		Time fixed effects	
		Level	Δ	Level	Δ	Level	Δ	Level	Δ
Oil price		0.17	−3.42**	-1.16	−4.84***	-0.24	−4.26***	-2.18	−11.01***
China	*y*	2.54	−4.78***	0.18	−5.51***	2.62	−4.76***	0.29	−3.30***
	EC	0.52	−3.11***	-2.01	−3.28*	1.08	−3.11**	-0.81	−3.28*
	π	-0.41	−3.93***	-1.32	−3.86**	-0.60	−3.91***	-1.79	−3.83***
Philippines	*y*	-1.64	−3.97***	−3.49*	−3.97*	-1.47	−4.02***	-2.46	−4.03**
	EC	-1.48	−5.86***	-1.81	−5.82***	-1.48	−5.85***	-1.89	−5.82***
	π	-1.06	−3.95***	-2.06	−3.96***	-1.02	−3.95***	-1.67	−3.96**
Singapore	*y*	-1.66	−3.05**	-2.97	−3.25**	2.16	−3.02**	-2.22	−3.27**
	EC	-1.48	−5.86***	-1.81	−5.82***	-1.48	−5.85***	-1.89	−5.82**
	π	-1.74	−3.44***	-3.06	−3.43*	-1.69	−3.42**	-2.24	−3.41*
Korea	*y*	-2.59	−4.41***	-1.89	−5.05***	-2.59	−4.42***	-1.23	−4.97***
	EC	-2.24	−5.18***	0.24	−5.88***	-2.22	−5.24***	-0.25	−5.88***
	π	-2.12	−4.94***	-2.56	−4.96***	-2.12	−4.87***	-2.17	−4.82***
Taiwan	*y*	−5.18*	−3.26**	-0.63	−5.05***	−4.79*	−3.23**	-0.63	−5.06***
	EC	-2.22	−6.16**	-1.22	−7.01***	-4.05	−6.15***	-0.86	−7.63***
	π	-1.85	−4.02***	-1.93	−3.99**	-1.65	−4.04***	-1.63	−4.01**

Note: y, EC, and π denote real GDP growth, energy consumption, real exchange rate in logarithm, and Δ is the difference operator. All variable are in natural logarithms. ADF = augmented Dicky-Fuller; PP = Phillips and Perron (1988) unit root test with H_0: variable is I(1); * and ** represent 5% and 1%, respectively, significance levels.

Table 3
Cointegration tests

Country	Null hypothesis	Test statistic			
		Without a trend		With a trend	
		trace	Max	trace	Max
China					
Varibles (y,EC)	$r = 0$	12.35(15.49)	7.69(14.26)	12.79(25.87)	7.82(19.39)
	$r \leq 1$	4.66*(3.84)	4.66*(3.84)	4.97(12.52)	4.97(12.82)
Philippines					
Varibles (y,EC)	$r = 0$	5.36(15.49)	5.32(14.26)	15.20(25.87)	13.18(19.39)
	$r \leq 1$	0.43(3.84)	0.04(3.84)	2.02(12.52)	2.02(12.52)
Singapore					
Varibles (y,EC)	$r = 0$	8.88(15.49)	7.82(14.26)	17.82(25.87)	13.77(19.39)
	$r \leq 1$	1.06(3.84)	1.06(3.84)	4.04(12.52)	4.04(12.52)
Korea					
Varibles (y,EC)	$r = 0$	12.67(15.49)	7.49(14.26)	17.27(25.87)	11.85(19.39)
	$r \leq 1$	5.18 (3.84)	5.18 (3.84)	5.42(12.52)	5.42(12.52)
Taiwan					
Varibles (y,EC)	$r = 0$	13.05(15.49)	11.93(14.26)	21.44(25.87)	16.60(19.38)
	$r \leq 1$	2.13(3.84)	2.13(3.84)	6.84(12.87)	6.83(12.51)

Note: All variables are transformed to natural logs. r indicates the number of cointegrating relationship. The tests were conducted with a trend and without a trend. The optimal number of lags, determined by minimum AIC. Values in parentheses are critical values, taken from Johansen and Juselius (1990). * indicate significance at the 10% levels, respectively.

2.3 E-GARCH model

In order to accommodate the characteristic of serial correlation in residuals and to examine the information impact, there are various models within the GARCH-family has been developed and widely applied in different time series studies, especially in the typical characteristic of volatility data of finance studies. Because of there are several of properties with a standard GARCH model we use the EGARCH model substitute for common GARCH model. The GARCH model is necessary to ensure that all of the estimated coefficients are positive. Furthermore, the GARCH models assume that the underlying volatility is due to the number of error lags and not their sign. In other words, the underlying volatility is only determined by the number of lags, but not the sign of lags in the disturbance term. This hypothesis is limited and these models are not adequate to capture the leverage effect (see Black,1976). The Nelson (1991) EGARCH model relaxes the restrictions of the GARCH model and incorporates the asymmetric volatility effect in the volatility equation. Since the exponential generalized autoregressive conditional heteroscedasticity (EGARCH) model allows for leverage effects to detect the time-varying volatility process with asymmetric responses of the positive and negative shock between economic growth and energy consumption are neglected in previous studies, we utilize EGARCH model to measure the relationship between economic growth and energy consumption volatility and the negative impact of a news shock. Equations (1) and (2) characterized the EGARCH (p, q) model. Under this model the underlying volatility is expressed in logarithmic form, so as to always be positive. Hence, it is permissible for the coefficients to be negative. The model used in this study can be expressed as follows：

$$\Delta Y_t = \alpha_0 + \sum_{i=1}^{m} \alpha_i Y_{t-i} + \sum_{j=1}^{n} \beta_j EC_{j,t-n} + \gamma_1 \sigma_{\varepsilon t}^2 + \gamma_2 \sigma_{vt}^2 + \varepsilon_t \quad (1)$$

$$\Delta EC_t = \theta_0 + \sum_{i=1}^{m'} \phi_{i'} Y_{t-m'} + \sum_{j=1}^{n'} \theta_{j'} EC_{t-n'} + \tau_1 OilP_t + \psi_1 \pi_{t-1} + \delta_1 \sigma_{\varepsilon t}^2 + \delta_2 \sigma_{vt}^2 + v_t \quad (2)$$

$$\log \sigma_{\varepsilon t}^2 = \lambda_0 + \sum_{i=1}^{p} \omega_i \log \sigma_{\varepsilon, t-i}^2 + \sum_{j=1}^{q} \eta_q \left\{ |z_{y,t-j}| - E|z_{y,t-j}| + \lambda_1 z_{y,t-j} \right\} \quad (3)$$

$$\log \sigma_{vt}^2 = \varphi_0 + \sum_{i=1}^{p'} \varpi_i \log \sigma_{v,t-i}^2 + \sum_{j=1}^{q'} \xi_{q'} \left\{ |z_{ec,t-j}| - E|z_{ec,t-j}| + \varphi_1 z_{ec,t-j} \right\} \quad (4)$$

$$Cov_t = \rho \sigma_{\varepsilon t} \sigma_{vt} \quad (5)$$

where *E* is mathematical expectation, $\sigma_{\varepsilon t}^2$ and σ_{vt}^2 are respective the conditional variances of the error of economic growth and energy consumption. z_t (e.g. $z_{yt} = \frac{\varepsilon_{i,t}}{\sigma_{\varepsilon,t}}$ and $z_{ect} = \frac{v_{i,t}}{\sigma_{v,t}}$) is standardized (i.i.d) residuals with zero mean and unit variance, which helps in interpreting the magnitude and the persistence of the shocks, if its coefficient λ_1 is positive, then the conditional variance, a proxy for economic growth uncertainty, will rise more in response to a positive shock than to a negative shock. In other words, while if λ_1 is negative, then the negative shock is greater than a positive one in its influence on the conditional variance.

Equation (1) and (2) shows the conditional mean equation of economic growth and energy consumption, where the real oil price one period lagged and real exchange rate, $OilP_t$ and π_{t-1} respectively, they are included as an exogenous variable to test the effect of real exchange rate and real oil price depicted in the energy consumption function. The two error terms, $\varepsilon_{i,t}$ and $v_{i,t}$, are assumed to be jointly conditionally normal with zero means. Equations (3) and (4) describe the conditional variance of real economic growth rate and of energy consumption in log-linear form, respectively, indicating that the implied value of $\sigma_{\varepsilon,t}^2$ (or $\sigma_{v,t}^2$) can never be negative regardless of the magnitude of ($\log \sigma_{\varepsilon,t}^2$ or $\log \sigma_{v,t}^2$). Finally, equation (5) is simply a constant conditional correlation model of the covariance between the two error terms ($\varepsilon_{i,t}$ and $v_{i,t}$). And the other coefficients here are the γ_1, which represent the effect of real GDP growth uncertainty on real GDP growth; γ_2, which represent the effect of energy consumption uncertainty real GDP growth; δ_1,which represent the effect of real GDP growth uncertainty on energy consumption; δ_2, which represent the effect of energy consumption uncertainty on energy consumption; $\sum_{i=1}^{p} \omega_i$ represent the magnitude of persistence of real GDP growth variance, the closer the magnitude approaches unity, the greater the persistence of shocks to volatility; $\sum_{i=1}^{p'} \varpi_i$ represent the magnitude of persistence of energy consumption variance.

2.4 Preliminary tests on residuals

We estimates serial correlation and autoregressive conditional heteroskedasticity (ARCH) for real output growth (y) and energy consumption (EC) series. In order to confirm appropriate of the parameters in the model, first, we perform the Ljung-Box(Ljung&Box, 1979)test for serial correlation.

Table 4

Preliminary tests on residuals

Variable	Q(4)	Q(8)	$Q^2(4)$	$Q^2(8)$	LM
China					
ΔY	3.131	5.952	32.606***	54.449***	32.620***
ΔEC	1.677	2.930	38.135***	40.042***	30.898***
Philippines					
ΔY	1.979	4.641	36.187***	89.742***	21.536***
ΔEC	5.204	11.989	41.804***	73.343***	25.084***
Singapore					
ΔY	4.143	5.581	22.093***	45.599***	11.338***
ΔEC	1.245	4.802	21.006***	55.986***	20.534***
Korea					
ΔY	0.785	2.891	32.491***	75.721***	31.146***
ΔEC	0.798	6.124	42.284***	74.761***	29.187***
Taiwan					
ΔY	4.046	10.671	23.306***	55.212***	21.039***
ΔEC	3.248	4.933	30.868***	61.452***	40.598***

Note: y and *EC* denote, respectively, real output, energy consumption, and Δ is the difference operator. Values in parentheses under these statistics are the p-values. Q(4) and Q(8) are the Ljung–Box statistics for the fourth and eighth-order serial correlation in the residuals. $Q^2(4)$ and $Q^2(0)$ are the Ljung–Box statistics but it corresponds to the serial correlation in the squared residuals. LM(4) are Lagrange Multiplier test statistics with four lags in the respective squared residual. Jarque–Bera is the test for normality of residuals

And then we examined autoregressive conditional heteroskdasticity (ARCH) through LM style ARCH tests, the results are reported in Table 5. The results are reported in Table5 that Ljung-Box Q tests for residual autocorrelation at 4, 8 and 12 lags, showing no evidence of any remaining pattern in the residuals. The Ljung-Box Q^2-statistics ($Q^2(4)$ and $Q^2(8)$) for the estimated squared residuals range from 21.006 to 89.742 and suggest the presence of strong ARCH effects (serial correlation of volatility).

4. Empirical results

In our empirical work, we estimate several bivariate EGARCH-M systems for energy consumption and economic growth. The model allows us to simultaneously estimate equations for the means of energy consumption and economic growth that include the conditional variance of both series as regressors, along with the time-varying residual covariance matrix. We use the Berndt, Hall, Hall, and Hausman(1974) numerical optimization algorithm (i.e. BHHH) to calculate the normal maximum likelihood to determine the optimal lag length out of four lags in the previous regressions. After calculate the regressions and lag length, we perform a Box–Jenkins (Box & Jenkins, 1976) approach to determine the exact lag structures of Equations (1)–(4) and consider up to 12 autoregressive lag terms in the execution of these tests in all country cases. The results of the final EGARCH-M model in five countries present in

Table 6.

Panel A and Panel B of Table 6 show that the lags coefficients of economic growth and energy consumption are significant at the 0.5 level (i.e In the case of China, the estimated coefficients on Δy_{t-1} and Δy_{t-2} are statistically significant at the 5% level,), implying the lags coefficients effect the dependent variables. In addition, we find the results of case in China that energy consumption ΔEC_{t-1}(0.05) has a positive and significant effect in mean equation of economic growth (ΔY_t), while that on ΔY_{t-1}(0.31) is significant in mean equation of energy consumption (ΔEC_t) as well, and therefore suggests a bi-directional relationship between economic growth and energy consumption in China. Consistent with China's result, there is a bi-directional relationship between energy consumption and economic growth in Taiwan according to the lagged energy consumption coefficient (ΔEC_{t-1}(-0.15)) in mean equation of economic growth and the lagged economic growth coefficient (Δy_{t-1}(-0.32)) in mean equation of energy consumption in Taiwan. Furthermore, the result is same from Yang, H.-Y. (2000). employing the Granger's technique to test the energy consumption-economic growth nexus in Taiwan over 1957-1997. In the case of Singapore, the lagged energy consumption coefficient (ΔEC_{t-1}) of the mean equation of economic growth is negative (-1.03) while that on Δy_{t-1}(0.36) in mean equation of energy consumption is not. The results suggests a unidirectional Granger causality running from energy consumption to economic growth, and it is same from Glasure's (1997) unidirectional relationship from energy consumption to economic growth in Singapore over the 1961-1990 period employed the cointegration, error-correction. Additionally, the estimated coefficients of the mean equation of economic growth and energy consumption are not significant in the case of Philippines and Korea, so we suggest the relationship between energy consumption and economic growth in Philippines and Korea are "neutrality hypothesis". Besides, the lagged coefficients of $OilP_{t-1}$ and ER_{t-1} in mean equation of energy consumption are significant at the 5% level in the case of China, Korea and Taiwan, while only the lagged coefficients of $OilP_{t-1}$ is significant in Philippines, and both coefficients are not significant at the 5% level in the case of Singapore.

Economic growth mean equation shows that the primary interest of the impact of uncertainty on energy consumption and economic growth be examine and denote through the sign and significance of the conditional variances (i.e σ^2_{Yt} and $\sigma^2_{\varepsilon t}$). In the mean economic growth equation (ΔY_t), the estimated coefficient on σ^2_{Yt} is negative (-1.23), which implies that increases in energy consumption lead to uncertainty and lower economic growth; moreover, in the mean equation of energy consumption (ΔEC_t), the calculated coefficient on $\sigma^2_{\varepsilon t}$ is negative (-0.21), which provides strong evidence that economic growth uncertainty lowers energy consumption in the case of China. The estimated coefficients on σ^2_{Yt} is negative (-1.61) in the mean economic of growth equation, which implies that increases in energy consumption lead to uncertainty and lower economic growth; Likewise, in the mean energy consumption equation, the calculated coefficient on $\sigma^2_{\varepsilon t}$ is negative (-1.04), which provides strong evidence that economic growth uncertainty lowers energy consumption in the case of Philippines. The estimated coefficient on $\sigma^2_{Yt}(-1.57)$ and $\sigma^2_{\varepsilon t}$ (-1.13) are negative at the 5% level respectively in the mean equation of economic growth and the mean equation of energy consumption, which imply that increases in energy consumption lead to uncertainty and lower economic growth, and economic growth uncertainty lowers energy consumption in Singapore. In the case of Korea, the estimated coefficient on σ^2_{Yt} is negative (-1.63) in the mean equation of economic growth, which implies that increases in energy consumption lead to uncertainty and lower economic growth; moreover, in the mean energy consumption equation, the calculated coefficient on $\sigma^2_{\varepsilon t}$ is negative (-0.95) the mean equation of energy consumption, which provides strong evidence that economic growth uncertainty lowers energy consumption in Korea. In the case of Taiwan, in the mean economic growth equation (Δy_t) and the mean energy consumption equation (ΔEC), the estimated coefficient on σ_{vt}^2 is negative (-0.93), which implies that increases in energy consumption lead to uncertainty and lower economic growth; moreover, the calculated coefficient on $\sigma_{\varepsilon t}^2$ is negative (-1.47), which provides strong evidence that economic growth uncertainty lowers energy consumption in Taiwan. From the conditional variance equation of economic growth ($log\ \sigma_{\varepsilon t}^2$) and energy consumption ($log\ \sigma_{vt}^2$), we see that the asymmetry effects are estimated the coefficient on $z_{y,t-1}$ in the $log\ \sigma_{\varepsilon t}^2$ equation is negative (-0.24) and statistically significant at the 5% level, suggesting negative economic growth impulses (information) have a greater impact on the conditional variance (or uncertainty) than those positive ones in the case of China. Likewise, the negative and significant coefficient on $z_{ec,t-1}$ (-1.88) in the $log\ \sigma_{vt}^2$ equation suggests that energy consumption uncertainty rises more in response to negative energy consumption impulses than positive ones. The results of other countries agree with China's result, either of the asymmetry effects of estimated coefficients in variance equation of economic growth (i.e z_{yt-1}, $z_{ec,t-1}$) negative impulses of variables are more than positive ones.

However, in the cases of China, Singapore and Taiwan, the coefficient on the lagged residual variance for economic growth, $log\ \sigma_{\varepsilon t-1}^2$, is smaller than for energy consumption, $log\ \sigma_{vt-i}^2$, implying that the effects of growth impulses on economic growth uncertainty last less than the effects of tourism expansion shocks on tourism uncertainty. On the contrary, in the cases of Korea and Philippines, the coefficient on the lagged residual variance for energy consumption, $log\ \sigma_{vt-i}^2$, is smaller than for economic growth, $log\ \sigma_{\varepsilon t-1}^2$. Regarding the fitness of models for all sample countries, the diagnostic tests using the Ljung–Box Q-statistics are calculated for the standardized residuals and their corresponding squares. The result present in Table 6, none of these values is significant at conventional levels. Hence, we conclude that the standardized residuals and the squared residual are not serially correlated.

5.Conclusions

Different from previous studies, in this study, we employed the EGARCH-M model by considering the characteristic and impact of uncertainty substitutes for the traditional Granger causality tests to revisit the causal relationship between economic growth and energy consumption for five Asian Pacific countries (Singapore, Taiwan, Korea, the Philippines and China.) from 1971 to 2007. A more complete investigation of the study is needed, in addition to variables of economic growth and energy consumption, we augmented the variables of exchange rate and real oil price in the model. Our evidence shows results suggesting that most the coefficients of impact of uncertainty on energy consumption and economic growth have a negative and marginally effect, which provides evidence that economic growth uncertainty interact with energy consumption uncertainty in the reverse direction, and all the estimated coefficients of the asymmetry effect are significant at the 5% level besides in the case of Philippines and Singapore. In addition, the bidirectional Granger causality runs from energy consumption to economic growth for China and Taiwan, while unidirectional Granger causality runs from energy consumption to economic growth for Singapore, and there are "neutrality hypothesis" energy consumption-economic growth nexus in the case of Philippines and Korea.

The findings of this study have important policy implications and it shows that this issue still deserves further attention in future research. As a policy implication for future research on energy– growth relationship and causality, the authors may use new models or multi-variables to revisit. The results of uncertain impact and causality test can provide governments with useful information to examine and adjust their economic development policy, as well as help them to formulate economic growth and energy consumption strategies.

Table 5

Estimation results

Panel A. Conditional mean equation and variance equations for economic growth

	China	Singapore	Korea	Philippines	Taiwan
mean equations:					
Intercept	0.07*	1.39*	0.15	0.03*	1.20
	(2.05)	(2.23)	(0.03)	(1.92)	(1.48)
Y_{t-1}	0.09*	0.59*	1.46	0.35	0.36*
	(3.49)	(3.46)	(1.87)	(1.95)	(2.02)
Y_{t-2}	0.19*	-0.04	0.75*	0.05	0.05
	(1.08)	(-0.42)	(2.91)	(0.84)	(0.69)
Y_{t-3}	-0.21	0.06	0.03	0.12*	0.18*
	(-1.21)	(0.56)	(0.06)	(1.83)	(2.85)
Y_{t-4}	0.01	-0.35*	0.21*	0.04	0.02
	(0.06)	(-4.05)	(2.03)	(0.06)	(0.25)
EC_{t-1}	0.54*	-1.03*	-0.87	-0.41	-0.15*
	(1.39)	(-2.27)	(-1.54)	(-0.89)	(-3.36)
$\sigma^2_{\varepsilon t}$	-0.86	-0.42	-0.09	-1.05	-0.27
	(-0.47)	(-1.26)	(-0.12)	(-0.72)	(-0.96)
σ^2_{vt}	-1.23*	-1.57*	-1.63*	-1.61*	-0.93*
	(-3.95)	(-4.25)	(-2.48)	(-3.27)	(-2.29)
variance equations:					
Intercept	4.71*	-1.85*	-0.32	-1.75*	-2.14*
	(3.75)	(-5.41)	(-1.13)	(-2.63)	(-3.90)
$\log \sigma^2_{\varepsilon,t-1}$	0.93*	0.87*	0.29*	0.66*	0.42*
	(4.09)	(2.21)	(2.69)	(2.34)	(3.65)
$z_{y,t-j}$	-0.24*	-0.27*	-0.18*	-1.34*	-0.32*
	(-3.28)	(-3.34)	(-2.85)	(-2.08)	(-2.39)
covariance equations:					
Cov_t	0.072	0.017	0.041	0.02	0.011
	(0.58)	(0.02)	(0.19)	(0.95)	(0.65)
Standardized residual diagnostics:					
Q(4)	1.426(0.840)	1.408(0.846)	4.980(0.289)	2.297(0.681)	4.223(0.3777)
Q(8)	2.437(0.965)	4.891(0.769)	10.244(0.248)	12.52(0.127)	10.997(0.202)
$Q^2(4)$	0.581(0.896)	4.179(0.382)	0.682(0.953)	2.046(0.757)	1.827(0.767)
$Q^2(8)$	3.796(0.875)	7.552(0.478)	2.988(0.942)	5.010(0.854)	4.910(0.767)

Note: Y, EC, OilP and *ER* denote, respectively, energy consumption, economic growth, real oil price and real exchange rate in logarithm, and Δ is the difference operator. Values in parentheses are p-value. Q(4) and Q(8) are the Ljung–Box statistics for the fourth and eighth-order serial correlation in the standardized residuals. $Q^2(4)$ and $Q^2(8)$ are the Ljung–Box statistics for the fourth and eighth-order serial correlation in the standardized squared residuals. * represent 5% significance levels.

Table 5
Estimation results
Panel B. Conditional mean equation and variance equations for energy consumption

	China	Singapore	Korea	Philippines	Taiwan
mean equations:					
Intercept	0.15*	2.88	-0.07*	0.04	-0.03
	(2.05)	(0.26)	(-2.69)	(1.42)	(-0.78)
EC_{t-1}	0.44	-0.05	0.88*	1.32*	-0.01
	(0.08)	(-0.84)	(2.07)	(2.61)	(-0.02)
EC_{t-2}	0.05	-1.97	-0.11	0.07	0.12
	(0.09)	(-2.16)	(-0.91)	(0.29)	(0.87)
EC_{t-3}	-1.53*	0.56	-0.05	-0.618	0.398
	(-2.39)	(1.39)	(-0.46)	(-2.86)	(2.48)
EC_{t-4}	1.27*	0.43	0.19	-0.42*	0.19
	(1.82)	(0.85)	(1.75)	(-2.02)	(1.38)
Y_{t-1}	0.31*	-0.36	-0.23	-0.12	-0.328*
	(2.32)	(-0.71)	(-0.84)	(-0.46)	(-3.19)
$OilP_t$	-0.08*	0.01	-0.05*	-0.04*	-0.02*
	(-3.82)	(0.98)	(-2.06)	(-2.75)	(-1.52)
ER_{t-1}	0.29*	0.07	0.66*	0.38	0.05*
	(1.98)	(0.42)	(2.44)	(0.15)	(2.17)
σ^2_{et}	-0.21*	-1.13*	-0.95*	-1.04*	-1.47*
	(-2.92)	(-4.25)	(-1.67)	(-2.83)	(-3.74)
σ^2_{vt}	-0.07	-0.52	-0.05	-0.52	-0.16
	(-0.34)	(-1.78)	(-0.73)	(-0.29)	(-0.89)
variance equations:					
Intercept	-1.32*	-0.53	-1.50	-1.06	-2.25
	(-2.81)	(-0.18)	(-2.35)	(-2.37)	(-1.36)
$\log \sigma^2_{v,t-i}$	0.71*	0.07*	1.35*	0.93*	0.38*
	(5.42)	(2.64)	(2.31)	(3.09)	(1.96)
$z_{ec,t-2}$	-1.88*	-1.65*	-0.45*	-0.76*	-0.92*
	(-3.54)	(-2.23)	(-3.19)	(-2.41)	(-4.04)
Standardized residual diagnostics:					
Q(4)	6.269(0.180)	0.956(0.916)	3.319(0.506)	3.380(0.496)	11.388(0.237)
Q(8)	6.971(0.540)	3.791(0.812)	8.781(0.361)	8.434(0.392)	12.620(0.326)
$Q^2(4)$	1.455(0.835)	2.997(0.558)	5.098(0.310)	0.668(0.955)	3.256(0.517)
$Q^2(8)$	5.251(0.730)	4.851(0.664)	8.131(0.421)	2.449(0.964)	3.342(0.911)

Note: Y, EC, OilP and *ER* denote, respectively, energy consumption, economic growth, real oil price and real exchange rate in logarithm, and Δ is the difference operator. Values in parentheses are p-value. Q(4) and Q(8) are the Ljung–Box statistics for the fourth and eighth-order serial correlation in the standardized residuals. $Q^2(4)$ and $Q^2(8)$ are the Ljung–Box statistics for the fourth and eighth-order serial correlation in the standardized squared residuals. * represent 5% significance levels.

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