Energy Consumption and Economic Growth：Evidence from 5 Asian Countries

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This paper investigates the causal relationship between nuclear energy consumption, renewable energy and oil consumption, natural gas consumption, coal consumption and economic growth for 5 Asian countries: China, India, Japan, Pakistan and Korea. We observe that oil is the substitute energy for both coal and renewable energy; renewable energy is the substitute energy for coal. Moreover, no energy can act as a substitute for nuclear energy. There is bidirectional causality between renewable energy consumption and economic growth, oil consumption and economic growth, and coal consumption and economic growth. Keywords: energy consumption, substitute effect, economic growth, panel data

Ⅰ. Introduction

Over the past few decades, the relationship between energy consumption and economic growth has become one of the most popular topics in the literature of energy economics. A large number of empirical studies have devoted increasing interest to investigating the energy consumption and economic growth nexus in both developing and developed countries because this relationship has important energy policy implications. At first view, the link between energy consumption and economic growth is distinct. However, theoretical models and empirical results offer conflicting evidence on the energy consumption and economic growth nexus.

Since the seminal study of Kraft & Kraft (1978), who used U.S. data for the period 1947-1974 to find unidirectional causality from GNP growth to energy consumption, a large number of studies have contributed to establishing the causal relationship between energy consumption and economic growth over the past few decades. There are four major different hypotheses: (i) *the growth hypothesis* refers to the causality from energy consumption to economic growth, showing that energy consumption stimulates economic growth and implying that negative energy shocks and energy conservation policies may depress economic growth; (ii) *the conservation hypothesis* argues that economic growth is the dynamic that causes the consumption of energy resources, implying that energy conservation policies may have little adverse or no effect on economic growth;

(iii) *the feedback hypothesis* states that there is a mutual relationship between energy consumption and economic growth, which implies that reducing energy consumption may lead to pressure on economic activity and vice versa; and (iv) *the neutrality hypothesis* indicates an absence of causality between energy consumption and economic growth, allowing policy makers to develop energy policies that are not dependent on economic activity. Table 1 shows a summary of the empirical studies on the energy consumption and economic growth nexus.

As the literature review shows, there is a lack of unanimity regarding the nature of causality between energy consumption and economic growth. The lack of consensus on the direction of causality provides room to analyze the nature of the connection between energy consumption and economic growth. In addition, the energy consumption variables utilized by the existing literature generally represent total energy consumption or oil consumption. Only a few published research studies exist that examine the relationship between other types of energy and economic growth. Surprisingly, the mixed results also exist in this literature. Furthermore, the existing published literature only examines the relationship

Table 1 Summary of the Empirical Studies on the Energy Consumption-Economic Growth Nexus

Causality relationship	Study	Sample country
Growth	Masih & Masih (1996)	India
	Asafu-Adjaye (2000)	India, Indonesia
	Wolde-Rufael (2005)	Cameroon, Morocco, Nigeria
	Chiou-Wei et al. (2008)	Taiwan, Hong Kong, Malaysia, Indonesia
	Narayan & Smyth (2008)	G-7 countries
	Apergis & Payne (2009)	6 Central American countries
Conservation	Masih & Masih (1996)	Indonesia, Pakistan
	Wolde-Rufael (2005)	Algeria, Congo DR, Egypt, Ghana, Ivory Coast
	Lee & Chang (2007)	18 developing countries
	Mehrara (2007)	11 oil exporting countries
	Chiou-Wei et al. (2008)	Philippines, Singapore
Feedback	Asafu-Adjaye (2000)	Philippine, Thailand
	Wolde-Rufael (2005)	Gabon, Zambia
	Lee & Chang (2007)	22 developed countries
	Lee et al. (2008)	22 OECD countries
Neutrality	Masih & Masih (1996)	Malaysia, Philippines, Singapore
	Wolde-Rufael (2005)	Benin, Congo RP, Kenya, Senegal, South Africa, Sudan, Togo, Tunisia, Zimbabwe
	Chiou-Wei et al. (2008)	USA, Thailand, South Korea
	Lee & Chang (2008)	16 Asian countries

between one or two forms of energy and economic growth. One item worth noting is that because most studies have focused on the causal relationship between each type of energy and economic growth (i.e., oil consumption and economic growth, renewable energy and economic growth), to best of our knowledge, only a few studies report substitute relationships. Thus, this paper tries to fill this gap.

The contribution and objectives of this paper are as follows. First, we investigate the causal relationship among all of the energy components (nuclear energy consumption, renewable energy and oil consumption, natural gas consumption, coal consumption) and economic growth separately for 5 Asian countries : India, Japan, Pakistan and Korea for the period 1980-2010 and China for 1993-2010. These countries were selected because they are the only five countries owning nuclear power plants, and one goal of this paper is to address all types of energy resources.

The second contribution of this paper is to examine the substitute relationship between each pair of energy resources. As energy-importing countries, all of these countries are facing energy security problems; increasing oil demand means rapidly increasing dependency on fossil fuels. For policy makers, finding energy alternatives to fossil fuels is becoming an important issue.

Third, the methods used in this paper allow us to examine both causality and substitute relationships. Because of the delay of nuclear power development, the time-series data of each country is insufficient, which will affect the estimated results, thereby leading to biased results. Therefore, it is appropriate to adopt panel data to investigate the relationship between each type of energy and economic growth. First, we use panel unit-root tests for stationarity and more co-integration tests to check robustness to confirm the order of each variable and the long-run relationships between variables. Then, if co-integration is detected, the panel causality method is executed. As a result of this process, both causality and substitute relationships can be observed.

A better understanding of the causal relationship between each type of energy resource and the substitute relationship between each pair of energy resources can lead to accurate policy formulation. However, most studies on the causal relationship between energy consumption and economic growth have focused on advanced economies and other industrialized economies. Few studies have been reported that examine Asian countries.

The message of this paper is all the more useful because, to the best of our knowledge, this is the first empirical study that explores the causalities between nuclear energy consumption, renewable energy and oil consumption, natural gas consumption, coal consumption and economic growth in Asian countries. In addition, by investigating all types of energy sources used today, it is feasible to understand the substitute effect between each pair of energy resources and to estimate which form of energy will take an important position in the future.

The rest of the paper is organized as follows: Section 2 introduces the methodology; Section 3 defines the variables, data sources, and provides the empirical results. Some concluding remarks are provided in the final section.

Ⅱ. Methodology

1. Panel unit tests

We use the panel unit tests from Levin et al. (2002), Im et al. (2003), Breitung (2001), and Fisher (1932) and PP tests (Choi, 2001 and Maddla & Wu, 1999) to check whether the panel data are stationary. The Levin's ADF test for panel data should be modified as follows:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \sum_{j=1}^{P_i} \rho_{ij} \Delta y_{i,t-1} + \varepsilon_{it}$$

$$\varepsilon_{it} \sim \mathrm{i.i.d}N(0, \sigma_i^2), \qquad (2.1)$$

where y_{it} presents series data for country i; and P_i is the number of lags in the ADF regression.

Based on Levin's method, Im et al. (2003) released the assumption in equation (2.1). Im et al. (2003) assumed that β_i can vary for different countries. Furthermore, Bretung (2001) suggested an alternative test without bias adjustments to improve the panel unit test.

The paper also adopt modified Fisher's ADF test and the PP test to determine the robustness of the result. The modified Fisher's ADF test and PP test are represented by Maddla & Wu (1999) and Choi (2001).

2. Panel co-integration tests

The Pedroni (2004) heterogenous panel co-integration test in this paper is shown as follows:

$$\ln Y_{it} = \alpha_i + \beta_i \ln X_{nuclear,it} + \gamma_i \ln X_{renewable,it} + \delta_i \ln X_{oil,it} + \eta_i \ln X_{naturalgas,it} + \theta_i \ln X_{coal,it} + \varepsilon_{it}, \qquad (2.2)$$

where, Y_{it} is the GDP for country i; $X_{nuclear,it}$ is the nuclear consumption for country i; $X_{oil,it}$ is the oil consumption for country i; $X_{naturalgas,it}$ is the natural gas consumption for country i; $X_{coal,it}$ is the coal consumption for country i; and represents the specific fixed effect. We applied three types of panel co-integration test methods: Kao's (1999), Pedroni's (2004) and Maddala & Wu's (1999) panel co-integration tests.

3. Panel causality test

To investigate the causal relationship between various energy sources and GDP, the paper takes a panel causality test using two stage procedure methods (Engle & Granger, 1987). The first stage is to calculate the residuals ε_{it} from (2.2) and then to set up the Granger causality test equation as follows:

$$\begin{aligned}\Delta \ln X_{\mathrm{nuclear},it} = {} & \omega_{1i} + \lambda_1 \varepsilon_{i,t-1} + \\ & \textstyle\sum_{k=1}^{m} \omega_{11k} \Delta \ln X_{\mathrm{renewable},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{12k} \Delta \ln X_{\mathrm{oil},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{13k} \Delta \ln X_{\mathrm{naturalgas},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{14k} \Delta \ln X_{\mathrm{coal},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{15k} \Delta \ln Y_{i,t-k} + \mu_{1i,t}, \end{aligned} \tag{2.3}$$

$$\begin{aligned}\Delta \ln X_{\mathrm{renewable},it} = {} & \omega_{2i} + \lambda_2 \varepsilon_{i,t-1} + \\ & \textstyle\sum_{k=1}^{m} \omega_{21k} \Delta \ln X_{\mathrm{nuclear},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{22k} \Delta \ln X_{\mathrm{oil},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{23k} \Delta \ln X_{\mathrm{naturalgas},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{24k} \Delta \ln X_{\mathrm{coal},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{25k} \Delta \ln Y_{i,t-k} + \mu_{2i,t}, \end{aligned} \tag{2.4}$$

$$\begin{aligned}\Delta \ln X_{\mathrm{oil},it} = {} & \omega_{3i} + \lambda_3 \varepsilon_{i,t-1} + \\ & \textstyle\sum_{k=1}^{m} \omega_{31k} \Delta \ln X_{\mathrm{nuclear},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{32k} \Delta \ln X_{\mathrm{renewable},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{33k} \Delta \ln X_{\mathrm{naturalgas},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{34k} \Delta \ln X_{\mathrm{coal},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{35k} \Delta \ln Y_{i,t-k} + \mu_{3i,t}, \end{aligned} \tag{2.5}$$

$$\begin{aligned}\Delta \ln X_{\mathrm{naturalgas},i,t} = {} & \omega_{4i} + \lambda_4 \varepsilon_{i,t-1} + \\ & \textstyle\sum_{k=1}^{m} \omega_{41k} \Delta \ln X_{\mathrm{nuclear},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{42k} \Delta \ln X_{\mathrm{renewable},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{43k} \Delta \ln X_{\mathrm{oil},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{44k} \Delta \ln X_{\mathrm{coal},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{45k} \Delta \ln Y_{i,t-k} + \mu_{4i,t}, \end{aligned} \tag{2.6}$$

$$\begin{aligned}\Delta \ln X_{\mathrm{coal},i,t-k} = {} & \omega_{5i} + \lambda_5 \varepsilon_{i,t-1} + \\ & \textstyle\sum_{k=1}^{m} \omega_{51k} \Delta \ln X_{\mathrm{nuclear},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{52k} \Delta \ln X_{\mathrm{renewable},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{53k} \Delta \ln X_{\mathrm{oil},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{54k} \Delta \ln X_{\mathrm{naturalgas},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{55k} \Delta \ln Y_{i,t-k} + \mu_{5i,t}, \end{aligned} \tag{2.7}$$

$$\begin{aligned}\Delta \ln X_{i,t-k} = {} & \omega_{6i} + \lambda_6 \varepsilon_{i,t-1} + \\ & \textstyle\sum_{k=1}^{m} \omega_{61k} \Delta \ln X_{\mathrm{nuclear},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{62k} \Delta \ln X_{\mathrm{renewable},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{63k} \Delta \ln X_{\mathrm{oil},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{64k} \Delta \ln X_{\mathrm{naturalgas},i,t-k} + \\ & \textstyle\sum_{k=1}^{m} \omega_{65k} \Delta \ln X_{\mathrm{coal},i,t-k} + \mu_{6i,t}, \end{aligned} \tag{2.8}$$

where Δ means first differences; $\omega_{.,i}$ represents the fixed effect for country i; and k (k=1, 2 ... m) denotes the optimal lag length determined by the Schwarz Information Criterion. The paper adopts the dynamic panel generalized method of moments (GMM) to estimate equations (2.3) - (2.8). To solve the problems of simultaneity and heteroscedasticity, the paper also introduces an instrumental variable that relates to lagged dependent variables but not error terms.

Ⅲ. Data and empirical results

This study examines the causal relationship between all types of energy consumption and economic growth in the 5 Asian countries and explores the effect of substitution between various energy types. These countries have all used nuclear energy for more than 17 years. As the development of nuclear power plants was delayed, the sample period for China differs from that for the other countries. For China, the sample period is from 1993 to 2010.

Nuclear energy consumption and renewable energy consumption are expressed in terms of kilowatt hours (KWh). Oil consumption is measured by thousand barrels daily. Natural gas consumption is measured by billion cubic meters. Coal consumption is measured in million tonnes oil equivalent. GDP and PPP (constant 2005 international $) are used as a proxy for economic growth. The nominal GDP series in the local currency units are transformed into real GDP in constant 2005 US dollars. The natural logarithms for all variables are employed to reduce heterogeneity. The variables used in the models are LNC, LRC, LOC, LNG, LCC and LRY, representing the natural logarithms of nuclear energy consumption, renewable energy consumption, oil consumption, natural gas consumption, coal consumption, and real GDP, respectively. The data on the six variables were obtained from the World Bank (2010) and BP (2011).

1. Panel unit-root test results

In the panel data analysis, the panel unit root test must be taken first to identify the stationary properties of the relevant variables. To provide an analysis of sensitivity and robustness, this paper chose five panel unit root tests, namely Levin et al. (2002), Breitung (2001), ADF - Fisher Chi-square, and PP - Fisher Chi-square. The results of these tests are reported in Table 2. It can be inferred from Table 2 that the unit root hypothesis cannot be rejected when the variables are taken in levels expect for LNC, LOC, and LNG. However, after first-order differencing, it is found that almost all of the variables become stationary. In particular, all of the variables are stationary under the latter three methods. Therefore, we may conclude that each variable is integrated of order one.

Table 2 Panel Unit-Root Test Results

Method	LNC	LRC	LOC	LNG	LCC	LRY
Levin, Lin & Chu t*						
Level	-0.838	1.509	0.945	3.254	0.975	-0.615
	(0.201)	(0.934)	(0.828)	(0.999)	(0.835)	(0.269)
First difference	4.306	-2.61***	-3.079***	8.378	-2.941***	-5.082***
	(1.000)	(0.0045)	(0.0010)	(1.0000)	(0.0016)	(0.0000)
Breitung t-stat						
level	1.683	0.315	1.125	3.667	-1.438*	0.540
	(0.954)	(0.623)	(0.870)	(0.999)	(0.075)	(0.706)
First difference	-3.364***	-2.850***	-1.578*	-0.295	-2.897***	-3.676***
	(0.0004)	(0.0022)	(0.057)	(0.384)	(0.0019)	(0.0001)
ADF - Fisher chi-square						
level	14.535	5.692	8.103	5.280	7.660	12.595
	(0.150)	(0.840)	(0.619)	(0.872)	(0.662)	(0.247)
First difference	42.085***	40.557***	27.830***	39.934***	33.264***	37.373***
	(0.000)	(0.000)	(0.0019)	(0.000)	(0.0002)	(0.000)
PP - Fisher chi-square						
level	34.354***	9.17565	25.589***	49.232***	8.93441	4.29655
	(0.0002)	(0.516)	(0.0043)	(0.000)	(0.538)	(0.933)
First difference	149.328***	76.160***	48.364***	352.06***	52.397***	76.415***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

NOTES: All panel unit root tests were performed with a restricted intercept and trend for all variables.
*, **, *** represent significance at 10%, 5%, and 1%, respectively. In addition, P-values are in brackets.

2. Panel cointegration test results

From Table 2, it can be seen that all of the variables are integrated of order one, which meets the requirements of the cointegration test. In this paper, three types of panel cointegration tests were adopted, i.e., Pedroni (2004), Kao (1999) and Johansen Fisher Panel Cointegration Tests.

The Pedroni cointegration tests are composed of the panel cointegration tests, which include four statistics and the group cointegration tests that include three statistics. The variables are cointegrated if the statistics reject the null hypothesis of no cointegration. As shown in Table 3, the results of the Pedroni (2004) panel cointegration test indicate that there are two panel statistics that reject the null hypothesis of no cointegration while two statistics admit that there is no cointegration between the variables, i.e., the panel rho-statistics. In the group cointegration tests, two group statistics reject the null hypothesis and one admits it. Because most of the statistics can be rejected at the 1% significance level, it can be concluded that the existence of a cointegration relationship is accepted.

The results of Kao's (1999) residual panel cointegration test are presented in Table 4, and they also reject the null of no cointegration at a 5% significance level. Finally, the results of the Johansen Fisher Panel Cointegration Test are reported in Table 5; it can be inferred from Table 5 that the presence of a cointegrated relationship among these six variables is significant. That is to say, there is a panel long-run equilibrium relationship between nuclear consumption,

Table 3 Pedroni Residual Cointegration Test

	Statistic	Prob.
Panel v-Statistic	-1.353	0.912
Panel rho-Statistic	2.144	0.984
Panel PP-Statistic	-6.840***	0.000
Panel ADF-Statistic	-3.991***	0.000
Group rho-Statistic	3.313	0.999
Group PP-Statistic	-10.339***	0.000
Group ADF-Statistic	-4.183***	0.000

Notes: The null hypothesis is that the variables are not cointegrated. Under the null tests, all of the statistics are distributed as normal (0, 1). *** indicates that the parameters are significant at the 1% level.

Table 4 Kao Residual Cointegration Test

ADF	t-Statistic	Prob.
	-2.008**	0.022

Note : ADF is the residual-based ADF statistic (Kao,1999). ** represents significance at a 5% level.

Table 5 Johansen Fisher Panel Cointegration Test

Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob.	Fisher Stat.* (from max-eigen test)	Prob.
None	192.7***	0.0000	102.6***	0.0000
At most 1	92.78***	0.0000	42.67***	0.0000
At most 2	61.51***	0.0000	31.62***	0.0001
At most 3	36.56***	0.0000	21.25***	0.0065
At most 4	23.47***	0.0028	17.55**	0.0249
At most 5	14.86*	0.0618	14.86*	0.0618

Notes: Asymptotic p-values are computed using a Chi-square distribution. *, **, *** indicate that the parameters are significant at the 10%, 5%, and 1% level, respectively. Fisher's test applies regardless of the dependent variable.

renewable energy consumption, oil consumption, natural gas consumption, coal consumption and GDP.

Table 6 reports the results of the short- and long-run Granger causality tests for each panel data set. Equation (2.3) shows that renewable energy consumption, oil consumption, natural gas consumption, coal consumption and economic growth are statistically insignificant on nuclear consumption. In terms of Equation (2.4), oil consumption has a negative and statistically significant influence on renewable energy, whereas economic growth has a positive and statistically significant impact. In the case of Equation (2.5), nuclear consumption has a negative and statistically significant impact on oil consumption while both natural gas and economic growth have a positive and statistically significant impact. Equation (2.6) reveals that nuclear energy consumption, renewable energy consumption, oil consumption,

Table 6 Panel Causality Test Results

Dependent variable	Source of causation (independent variable)						
	Short run						Long run
	△LNC	△LRC	△LOC	△LNG	△LCC	△LRY	△ECT
△LNC	-	-0.436 (0.664)	-0.399 (0.691)	1.054 (0.294)	0.733 (0.465)	0.879 (0.381)	-0.589 (0.557)
△LRC	1.003 (0.318)	-	-3.918*** (0.0002)	-1.113 (0.268)	-0.086 (0.932)	6.813*** (0.000)	0.974 (0.332)
△LOC	-2.648*** (0.0093)	-1.478 (0.143)	-	5.595*** (0.000)	-1.135 (0.259)	1.842* (0.068)	0.777 (0.439)
△LNG	1.084 (0.281)	-1.398 (0.165)	1.482 (0.141)	-	1.474 (0.143)	-0.0953 (0.924)	2.295** (0.0237)
△LCC	0.711 (0.479)	-1.914* (0.058)	-1.960* (0.0525)	-1.267 (0.207)	-	3.491*** (0.0007)	0.693 (0.490)
△LRY	1.385 (0.169)	1.819* (0.0717)	3.203*** (0.0018)	-0.084 (0.933)	3.703*** (0.0003)	-	-1.180 (0.240)

Notes: Figures denote F-statistic values. P-values are in parentheses. ECT indicates the estimated error-correction term. *, **, *** indicate that the parameters are significant at the 10%, 5%, and 1% level, respectively.

coal consumption and economic growth are statistically insignificant on natural gas consumption. In regards to Equation (2.7), both renewable energy consumption and oil consumption have a negative and statistically significant impact on coal consumption whereas economic growth has a statistically significant impact. Equation (2.8) shows that renewable energy consumption, oil consumption and coal consumption have a positive and statistically significant impact on economic growth in the short-run.

The empirical results are summarized as follows.

One of the most important results that emerge from the short-run causality test presented in Table 5 is the substitute relationships between various energy resources. First, nuclear energy is a substitute energy for oil: a 1% increase in nuclear energy consumption contributes to a 2.648% decrease in oil consumption. Second, renewable energy is a substitute energy for coal: a 1% increase in renewable energy leads to a 1.914% decrease in coal consumption. Third, oil is a substitute energy for both coal and renewable energy, but coal and renewable energy cannot replace oil. It is also found that a 1% increase in oil consumption will lead to a 3.918% decrease in renewable energy consumption and a 1.96% decrease in coal consumption. Moreover, no energy can act as a substitute for nuclear energy.

Second, there is no direct causality between nuclear consumption and economic growth or between natural gas consumption and economic growth in the sample countries, which demonstrates the 'neutrality hypothesis' for nuclear energy consumption and natural gas consumption. This result suggests that natural gas and nuclear energy development will not be influenced by economic growth in the short run.

Third, there is bidirectional causality between renewable energy and economic growth. This result is consistent with Apergis & Payne (2011) for 80 countries and Apergis et al. (2010), but contrary to the no causality finding between renewable energy consumption and GDP for 27 European countries by Menegaki (2011). Additionally, we find that there is a bidirectional causality between oil consumption and economic growth in the short run; this is consistent with Al-mulali (2011) for the Middle East and North Africa (MENA) region but differs from the causality from economic growth to oil consumption found by Lee & Chiu (2011). Last, the results indicate that there is bidirectional causality between coal consumption and economic growth.

Finally, only the estimated coefficient of ECT in the natural gas equation is significant, revealing that natural gas could represent an essential adjustment factor as the system departs from the long run equilibrium.

Our empirical findings have major

policy implications as follows.

First, the substitute relationship between nuclear consumption and oil consumption indicates that the development of nuclear consumption may lead to lower demand for oil consumption in the short run. At the same time, the substitute relationship between nuclear consumption and coal consumption indicates that the development of renewable energy may reduce the degree of dependence on coal. To reduce the degree of dependence on oil and coal, the sample countries should develop nuclear energy and renewable energy to address their energy demands, especially taking into consideration the soaring price of imported energy and energy security. However, considering the insecurity of nuclear energy, we could estimate that rather than nuclear energy, renewable energy may become most governments' preferred energy resource.

Second, the results from the panel causality analysis imply that the nature of the causality between nuclear energy consumption and economic growth and between natural gas and economic growth in the short-run appears to be in favor of the neutrality hypothesis for these five Asian countries. The neutrality between nuclear energy and economic growth and between natural gas consumption and economic growth can be attributed to the fact that nuclear energy consumption as well as natural gas consumption may be a relatively small component of overall production. Hence, energy conservation polices in the nuclear and natural gas area would not retard economic growth.

Third, the bidirectional causality between renewable energy and economic growth, between oil consumption and economic growth and between coal consumption and economic growth lend support for the feedback hypothesis. The interdependence between these variables suggests that energy policies designed to increase the production and consumption of renewable energy, oil consumption and coal consumption will have a positive impact on economic growth. Moreover, the expansion of renewable energy will not only reduce the dependence on foreign energy sources for these countries, but it can minimize the risk associated with volatile oil and natural gas supplies and prices.

In sum, our results imply that although a decrease in nuclear energy consumption and natural gas consumption would not affect economic growth, reducing renewable energy consumption, oil consumption and coal consumption may retard economic growth. In addition, economic growth in these countries would stimulate the development of renewable energy, oil and coal in the short run.

Ⅳ. Conclusions

There is a growing literature that examines the causal relationship between energy consumption and economic growth. In this study, we employ a panel data analysis to investigate the causal relationships between nuclear energy consumption, renewable energy and oil consumption, natural gas consumption, coal consumption and economic growth for 5 Asian countries, and we examine the substitute relationship between each pair of variables to predict energy development in future.

The empirical results of this study provide a better understanding of the substitute effect for each pair of energy resources and each energy consumption-economic growth nexus, which allows for the formulation of energy policy implications. The results reveal that nuclear energy is a substitute energy for oil, renewable energy can serve as a substitute energy for coal, and oil can serve as a substitute energy for both renewable energy and coal. Moreover, evidence supporting both the neutrality hypothesis and the feedback hypothesis was found in this study.

Though an increase in oil and coal consumption will promote economic growth, taking into consideration the shortage of oil and coal supplies as well their GHG emissions, these five Asian countries should devote themselves to renewable energy development. We can predict that the development of renewable energy will grow rapidly in the coming years. Contrary to the rapid growth of nuclear energy, which then died out in Europe, the development of nuclear energy in Asia may be gradually reduced without a wave of nuclear construction.

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