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Energy consumption and GDP in developing countries: A cointegrated panel analysis

Chien-Chiang Lee*

Department of Applied Economics, National Chung Hsing University, Taichung 402, Taiwan

Abstract

In this paper we re-investigate the co-movement and the causality relationship between energy consumption and GDP in 18 developing countries, using data for the period 1975 to 2001. Recently developed tests for the panel unit root, heterogeneous panel cointegration, and panel-based error correction models are employed. The empirical results provide clear support of a long-run cointegration relationship after allowing for the heterogeneous country effect. The long-run relationship is estimated using a full-modified OLS. The evidence shows that long-run and short-run causalities run from energy consumption to GDP, but not vice versa. This result indicates that energy conservation may harm economic growth in developing countries regardless of being transitory or permanent.

JEL classification: Q43; C32

Keywords: Energy consumption; Income; Panel cointegration; Causality

1. Introduction

The relationship between energy consumption and income has been a popular issue of debate in economic development and the environment, yet a consensus has been lacking regarding the permanent as well as transitional relationship. To date, the causality may run

* Tel.: +886 4 22840352x308; fax: +886 4 22870203.
E-mail address: ccl@nchu.edu.tw.

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in either direction. For example, if there exists causality running from energy consumption to income, then this denotes an energy-dependent economy such that energy is an impetus for income, implying that a shortage of energy may negatively affect income (Masih and Masih, 1998). On the other hand, if there is a reverse chain of causality from income to energy, then this denotes a less energy-dependent economy such that energy conservation policies may be implemented with little adverse or no effects on income (Jumbe, 2004). Finally, the finding of no causality in either direction, the so-called 'neutrality hypothesis' (Yu and Choi, 1985), means that energy conservation policies do not affect income.

The original study by Kraft and Kraft (1978) finds evidence in favor of causality running from income to energy consumption in the United States, by using data for the period 1947–1974. This implies that energy conservation policies may be initiated without deteriorating the economic side effects. Empirical studies were later extended to cover many developing countries as well in order to facilitate the implementation of a proper energy policy. For example, instead of relying on the standard Granger causality test, Masih and Masih (1996), Glasure and Lee (1997), and Asafu-Adjaye (2000) present an entire review of recent studies covering this topic. The goal of these studies is to estimate the causal relationship between energy consumption and income for developing countries, using cointegration and error-correction techniques. The results have been mixed and conflicting.

Soytas and Sari (2003) similarly estimate the causal relationships for emerging markets for the period 1950–1992. Their result indicates bi-directional causality for Argentina, but the cointegration vector is rejected for Indonesia and Poland. Moreover, Oh and Lee (2004) calculate a Divisia energy aggregate and substitute it for a simple BTU energy aggregate for South Korea, which indicates the existence of a long-run bi-directional causal relationship between energy and GDP, and a short-run uni-directional causality running from energy to GDP. Table 1 summarizes the previous empirical findings of the causality tests between energy consumption and income for a number of developing economies.

As mentioned above, these causality results are based on an individual country and use time series data of about 20 to 30 years. However, there are different results for different countries, as well as for different time periods within the same country (see Table 1). For example, Masih and Masih (1996) and Asafu-Adjaye (2000) find opposite causality results in Indonesia. Soytas and Sari (2003) and Oh and Lee (2004) also provide different causality results for South Korea. Hence, the main contribution of our study is to pool together the data that differs across individual countries. Our paper differs from previous studies by applying the new heterogeneous panel cointegration technique to re-investigate the relationship between energy consumption and GDP across 18 developing countries.

This paper contributes the following. First, we use a cointegration test for a panel of countries which provides more powerful tests and allows us to increase the degrees of freedom compared to the cross-section approach. Next, we use the full-modified OLS (FMOLS hereafter) technique to estimate the cointegration vector for heterogeneous cointegrated panels, which correct the standard OLS for the bias induced by the endogeneity and serial correlation of the regressors. Finally, we specify and estimate an error correction model appropriate for heterogeneous panels, which distinguishes between long-run and short-run causality.

Table 1
The comparison of empirical results from causality tests for developing countries

Authors	Empirical method	Period	Subject	Causal relationship
Yu and Choi (1985)	Standard Granger test	1954–1976	South Korea	Income→Energy
			Philippines	Energy→income
Morimoto and Hope (2004)		1960–1998	Sri Lanka	Energy↔income
Fatai et al. (2004)	Toda and Yamamoto (1995)	1960–1999	India and Indonesia	Energy→income
			Thailand and the Philippines	Energy↔income
Masih and Masih (1996)	Error-correction model	1955–1990	Malaysia, Singapore, and the Philippines	Non-cointegrated
			India	Energy→income
			Indonesia	Income→Energy
			Pakistan	Energy↔income
Glasure and Lee (1997)		1961–1990	South Korea and Singapore	Energy↔income
Masih and Masih (1998)		1955–1991	Sri Lanka and Thailand	Energy→income
Yang (2000)		1954–1997	Taiwan	Energy↔income
Asafu-Adjaye (2000)		1973–1995	India and Indonesia	Energy→income
			Thailand and the Philippines	Energy↔income
			Turkey	Energy→income
Soytas and Sari (2003)		1950–1992	Argentina	Energy↔income
			South Korea	Income→Energy
			Turkey	Energy→income
			Indonesia and Poland	Non-cointegrated
Oh and Lee (2004)		1970–1999	South Korea	Energy↔income
Paul and Bhattacharya (2004)		1950–1996	India	Energy↔income
Jumbe (2004)		1970–1999	Malawi	Income→Energy

Notes: Energy→Income denotes causality runs from energy consumption to income. Income→Energy denotes causality runs from income to energy consumption. Energy↔Income denotes bi-directional causality between income and energy consumption.

In many developing countries the estimation of causality cannot be achieved, because of a short data span, which lowers the power of the unit root and cointegration tests. Many countries, for instance, have only annual available data with a maximum span of 20 to 30 years.[1] In this paper we take a different direction to overcome the short span of data and the distortions of a small sample. Since the power of an individual unit root test can be distorted when the span of data is short (Pierse and Shell, 1995), we use a panel unit root test. The power of the traditional cointegration test (Johansen, 1988) is that multivariate systems with small sample sizes can be severely distorted. To this end, we need to combine information from time series and cross-section data once again, and thus we use a panel unit root test and heterogeneous panel cointegration tests.

[1] Of course, there are other research studies that use a longer time span, but they usually ignore the potential problem of a structural break.

The cointegration analysis of panel data consists of four steps: First, we test for a panel unit root. Three statistics proposed by Levine and Lin (1993, henceforth LL), Im et al. (1997, henceforth IPS), and Hadri (2000) are employed. Second, we test for cointegration data employing the heterogeneous panel cointegration test developed by Pedroni (1999) which allows different individual effects' cross-sectional interdependency. Third, the long-run relationship is estimated using the FMOLS technique for heterogeneous cointegrated panels (Pedroni, 2000). Finally, once the panel cointegration is implemented, we establish a panel error correction model to examine for short-run and long-run causalities between energy consumption and GDP.

The purpose of this paper is to empirically re-examine the long-run co-movement and the causal relationship between energy consumption and GDP in a multivariate model with energy consumption (EC hereafter), real GDP (GDP hereafter), and real capital stock (K hereafter).[2] We combine cross-sectional and time series data to examine the relationship between energy consumption and GDP, using updated data for 18 developing countries for the years 1975–2001. Previous studies having used time series data may yield unreliable and inconsistent results due to the short time spans of typical data sets. By contrast, we use panel unit root tests, heterogeneous panel cointegration tests, and a panel-based error correction model to conclude that there is fairly strong evidence in favor of the hypothesis that long-run and short-run uni-directional causalities run from energy consumption to GDP, but not vice versa.

The paper is organized as follows: In Section 2 we provide a brief discussion of the panel unit root test and the panel cointegration procedure. Empirical results are provided in Section 3. Finally, Section 4 concludes and policy implications.

2. Methodology

2.1. The panel unit roots test

Investigations into the unit root in panel data have recently attracted a lot of attention. Abuaf and Jorion (1990) point out that the power of unit root tests may be increased by exploiting cross-sectional information. LL (1993)[3] proposes a panel-based ADF test that restricts parameters γ_i by keeping them identical across cross-sectional regions as follows:

$$\Delta y_{it} = \alpha_i + \gamma_i y_{it-1} + \sum_{j=1}^{k} \alpha_j \Delta y_{it-j} + e_{it}, \tag{1}$$

where $t=1,\ldots, T$ time periods and $i=1,\ldots N$ members of the panel. LL tests the null hypothesis of $\gamma_i=\gamma=0$ for all i, against the alternate of $\gamma_1=\gamma_2\ldots=\gamma<0$ for all i, with the test based on statistics $t_\gamma=\hat{\gamma}/\mathrm{s.e.}(\hat{\gamma})$. One drawback is that γ is restricted by being kept identical across regions under both the null and alternative hypotheses.

[2] We employ the same three variables in Stern's (1993, 2000) models.

[3] This was finally published as Levine et al. (2002).

For the above reason, IPS (1997) relax the assumption of the identical first-order autoregressive coefficients of the LL test and allow γ to vary across regions under the alternative hypothesis. IPS test the null hypothesis of $\gamma_i=0$ for all i, against the alternate of $\gamma_i<0$ for all i. The IPS test is based on the mean-group approach, which uses the average of the t_{γ_i} statistics to perform the following $\bar{Z}$ statistic:

$$\bar{Z} = \sqrt{N}(\bar{t} - E(\bar{t}))\Big/\sqrt{\mathrm{Var}(\bar{t})}, \tag{2}$$

where $\bar{t}=(1/N)\sum_{i=1}^{N} t_{\gamma_i}$, the terms $E(\bar{t})$ and $\mathrm{Var}(\bar{t})$ are, respectively, the mean and variance of each t_{γ_i} statistic, and they are generated by simulations and are tabulated in IPS (1997). The $\bar{Z}$ converges to a standard normal distribution. Based on Monte Carlo experiment results, IPS demonstrate that their test has more favorable finite sample properties than the LL test.

Hadri (2000) argues differently that the null should be reversed to be the stationary hypothesis in order to have a stronger power test. Hadri's (2000) Lagrange multiplier (LM) statistic can be written as

$$L\hat{M} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{\frac{1}{T^2}\sum_{t=1}^{T} S_{it}^2}{\hat{\sigma}_{\varepsilon}^2}\right), \quad S_{it} = \sum_{j=1}^{t} \hat{\varepsilon}_{ij}, \tag{3}$$

where $\hat{\sigma}_{\varepsilon}^2$ is the consistent Newey and West (1987) estimate of the long-run variance of disturbance terms.

2.2. The panel cointegration tests

Pedroni (1999) considers the following time series panel regression

$$y_{it} = \alpha_{it} + \delta_{it}t + X_i\beta_i + e_{it}, \tag{4}$$

where y_{it} and X_{it} are the observable variables with dimension of $(N*T)\times 1$ and $(N*T)\times m$, respectively. He develops asymptotic and finite-sample properties of testing statistics to examine the null hypothesis of non-cointegration in the panel. The tests allow for heterogeneity among individual members of the panel, including heterogeneity in both the long-run cointegrating vectors and in the dynamics, since there is no reason to believe that all parameters are the same across countries.

Two types of tests are suggested by Pedroni. The first type is based on the within-dimension approach, which includes four statistics. They are panel v-statistic, panel ρ-statistic, panel PP-statistic, and panel ADF-statistic. These statistics pool the autoregressive coefficients across different members for the unit root tests on the estimated residuals.

The second test by Pedroni is based on the between-dimension approach, which includes three statistics. They are group ρ-statistic, group PP-statistic, and group ADF-statistic. These statistics are based on estimators that simply average the individually estimated coefficients for each member. Following Pedroni (1999), the heterogeneous panel and heterogeneous group mean panel cointegration statistics are calculated as follows.

Panel v-statistic:

$$Z_v = \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{it-1}^2 \right)^{-1}$$

Panel ρ-statistic:

$$Z_\rho = \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{it-1}^2 \right)^{-1} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \left(\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i \right)$$

Panel PP-statistic:

$$Z_t = \left(\hat{\sigma}^2 \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{it-1}^2 \right)^{-1/2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \left(\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i \right)$$

Panel ADF-statistic:

$$Z_t{*} = \left(\hat{s}{*}^2 \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{it-1}^{*2} \right)^{-1/2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{it-1}^{*} \Delta \hat{e}_{it}^{*}$$

Group ρ-statistic:

$$\tilde{Z}_\rho = \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \hat{e}_{it-1}^2 \right)^{-1} \sum_{t=1}^{T} \left(\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i \right)$$

Group PP-statistic:

$$\tilde{Z}_t = \sum_{i=1}^{N} \left(\hat{\sigma}^2 \sum_{t=1}^{T} \hat{e}_{it-1}^2 \right)^{-1/2} \sum_{t=1}^{T} \left(\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i \right)$$

Group ADF-statistic:

$$\tilde{Z}_t{*} = \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \hat{s}_i^2 \hat{e}_{it-1}^{*2} \right)^{-1/2} \sum_{t=1}^{T} \left(\hat{e}_{it-1}^{*} \Delta \hat{e}_{it}^{*} \right)$$

Here, $\hat{e}_{it}$ is the estimated residual from Eq. (4) and $\hat{L}_{11i}^2$ is the estimated long-run covariance matrix for $\Delta \hat{e}_{it}$. Similarly, $\hat{\sigma}_i^2$ and $\hat{s}_i^2$ ($\hat{s}_i^{*2}$) are, respectively, the long-run and contemporaneous variances for individual i. The other terms are properly defined in Pedroni (1999) with the appropriate lag length determined by the Newey–West method. All seven tests are distributed as being standard normal asymptotically. This requires a standardisation based on the moments of the underlying Brownian motion function. The panel v-statistic is a one-sided test where large positive values reject the null of no cointegration. The remaining statistics diverge to negative infinitely, which means that large negative values reject the null. The critical values are also tabulated by Pedroni (1999).

Table 2
List of selected developing countries

Developing region	Country groupings
East Asia	South Korea
	Singapore
East Europe and Central Asia	Hungary
Latin America	Argentina
	Chile
	Colombia
	Mexico
	Peru
	Venezuela
Southeast Asia	Indonesia
	Malaysia
	Philippines
	Thailand
South Asia	India
	Pakistan
	Sri Lanka
Sub-Saharan Africa	Ghana
	Kenya

In the presence of unit root variables, the effect of superconsistency may not dominate the endogeneity effect of the regressors if OLS is employed. Pedroni (2000) shows how FMOLS can be modified to make an inference in being cointegrated with the heterogeneous dynamic. In the FMOLS setting, non-parametric techniques are exploited to transform the residuals from the cointegration regression and can get rid of nuisance parameters.

3. Empirical investigation

Our study uses annual time series for the 18 developing countries listed in Table 2.[4] Annual data for real GDP (1995 = 100), energy use in kilotons of equivalent oil, and real gross capital formation (1995 = 100) are obtained from *World Development Indicators* (WDI, 2004).[5] The unit is expressed in US dollars. The empirical period depends on the availability of data, where the time period used is 1975–2001. All variables used are in natural logarithms.

Table 3 presents the panel unit root tests. At a 5% significance level, except for the LL statistic of the level model without time effects, other statistics significantly confirm that

[4] The countries used in the panel are selected as the same in Basu et al. (2003), but the topic is not the same. Basu et al. (2003) focus on the two-way linkage between FDI and growth for a panel of developing countries. Thus, this paper is not directly comparable, however it uses the energy consumption data for most developing countries, depending on the availability of data.

[5] Since capital stock data are not easy to collect and measure, gross capital formation is used as a proxy variable; see Sharma and Dhakal (1994) and Lee and Huang (2002).

Table 3
Panel unit root tests

Variables	LL		IPS		Hadri	
	No time effects	Time fixed effects	No time effects	Time fixed effects	No time effects	Time fixed effects
GDP	−3.85**	3.94	2.04	3.75	17.10**	6.20**
K	−2.83**	1.34	−0.46	1.42	14.27**	5.99**
EC	−2.57**	0.72	2.45	2.00	17.10**	6.21**
ΔGDP	−7.31**	−7.47**	−6.19**	−5.51**	0.82	3.33**
ΔK	−13.76**	−13.63**	−10.75**	−10.30**	0.24	2.81**
ΔEC	−5.18**	−5.61**	−5.58**	−4.81**	0.78	3.81**

Δ denotes first differences. All variables are in natural logarithms.
** Rejects the null of no cointegration at the 5% level.

three series have a panel unit root. Using these results, we proceed to test GDP, EC, and K for cointegration in order to determine if there is a long-run relationship to control for in the econometric specification.

We first implement the following equation:

$$GDP_{it} = \alpha_i + \delta_i t + \beta_i EC_{it} + c_i \mathrm{K}_{it} + \varepsilon_{it}, \tag{5}$$

where it allows for cointegrating vectors of differing magnitudes between countries, as well as country (α) and time (δ) fixed effects. Table 4 reports the panel cointegration estimation results. Except for the panel ρ and group ρ statistics, all other statistics significantly reject the null of no cointegration.[6] Thus, it can be seen that the GDP, EC, and K move together in the long run. That is, there is a long-run steady-state relationship between energy consumption and GDP for a cross-section of countries after allowing for a country-specific effect. The next step is an estimation of such a relationship.

Table 5 reports the results of the individual and panel FMOLS. The panel estimators with and without common time dummies are shown at the bottom of the table. The coefficients of EC and K are statistically significant at the 5% level, and the effect is positive as expected by the theory. The elasticity of energy consumption and capital stock with respect to GDP are significantly smaller than 1, but the growth effect of energy consumption is larger than capital stock. This implies energy is an important ingredient for economic development.

On a per country basis, energy consumption has a positive impact on GDP except for Hungary, where the statistical significance is marginal. The FMOLS estimates of the elasticity of energy consumption with respect to GDP range from 0.44 (Singapore) to 1.54 (Sri Lanka). Moreover, for three countries (Colombia, Sri Lanka, and Kenya), the energy consumption elasticity is significantly larger than 1. The coefficient of capital stock is

[6] Pedroni (1999) shows that the panel-ADF and group-ADF statistics have better small sample properties than the other statistics, and hence they are more reliable.

Table 4
Panel cointegration tests

	No time effects	Time fixed effects
Panel variance	2.02**	6.27***
Panel ρ	−0.84	0.39
Panel PP	−2.16**	−2.81***
Panel ADF	−1.89**	−3.54***
Group ρ	−0.35	1.12
Group PP	−2.89***	−1.79**
Group ADF	−3.13***	−3.36***

Statistics are asymptotically distributed as normal. The variance ratio test is right-sided, while the others are left-sided.

** Rejects the null of no cointegration at the 5% level.

*** Rejects the null of no cointegration at the 1% level.

positive and statistically significant in 14 cases out of 18; that is, an increase in capital stock tends to promote GDP.

Once the three variables are cointegrated, the next step is to implement the Granger causality test. We use a panel-based error correction model to account for the long-run relationship using the two-step procedure from Engle and Granger (1987). The first step is the estimation of the long-run model for Eq. (5) in order to obtain the estimated residuals,

Table 5
Full modified OLS estimates (dependent variable is GDP)

Country groupings	EC	K
South Korea	0.85 (11.39)**	0.02 (0.27)
Singapore	0.44 (4.18)**	0.57 (4.45)**
Hungary	0.50 (1.61)	0.27 (2.60)**
Argentina	0.84 (19.86)**	0.22 (8.03)**
Chile	0.83 (11.18)**	0.18 (4.67)**
Colombia	1.53 (18.55)**	−0.15 (−2.81)**
Mexico	0.81 (17.99)**	0.18 (4.54)**
Peru	0.96 (2.56)**	0.20 (2.23)**
Venezuela	0.58 (7.28)**	0.18 (3.17)**
Indonesia	0.91 (24.96)**	0.24 (10.80)**
Malaysia	0.80 (15.47)**	0.07 (1.52)
Philippines	0.60 (12.13)**	0.16 (2.96)**
Thailand	0.86 (9.55)**	0.18 (2.33)**
India	0.84 (8.88)**	0.38 (5.96)**
Pakistan	0.89 (17.76)**	0.23 (4.54)**
Sri Lanka	1.54 (6.79)**	0.11 (0.93)
Ghana	0.90 (27.33)**	0.15 (4.43)**
Kenya	1.45 (17.96)**	0.03 (0.37)
Panel (without time dummies)	0.90 (55.49)**	0.18 (14.38)**
Panel (with time dummies)	0.50 (31.32)**	0.22 (18.85)**

t-value in parenthesis.

** Indicate statistical significance at the 5% level.

Table 6
Panel causality tests

Dependent variable	Source of causation (independent variable)				
	Short run		Long run		
	ΔGDP	ΔEC	ε	ε/ΔGDP	ε/ΔEC
ΔGDP	–	$F_{36,270}=1.92$ [0.00]***	$F_{18,270}=2.75$ [0.00]***	–	$F_{54,270}=1.75$ [0.00]***
ΔEC	$F_{36,270}=0.91$ [0.61]	–	$F_{18,270}=1.18$ [0.28]	$F_{54,270}=1.01$ [0.46]	–

p-value in parenthesis.
*** Indicate statistical significance at the 1% level.

ε_{it}. The second step is to estimate the Granger causality model with a dynamic error correction:

$$\Delta GDP_{it} = \theta_{1j} + \lambda_{1i}\varepsilon_{it-1} + \sum_k \theta_{11ik}\Delta \mathrm{GDP}_{it-k} + \sum_k \theta_{12ik}\Delta \mathrm{EC}_{it-k} + \sum_k \theta_{13ik}\Delta \mathrm{K}_{it-k} + u_{1it} \tag{6}$$

$$\Delta \mathrm{EC}_{it} = \theta_{2j} + \lambda_{2i}\varepsilon_{it-1} + \sum_k \theta_{21ik}\Delta \mathrm{GDP}_{it-k} + \sum_k \theta_{22ik}\Delta \mathrm{EC}_{it-k} + \sum_k \theta_{23ik}\Delta \mathrm{K}_{it-k} + u_{2it}, \tag{7}$$

where Δ denotes first differencing and k is the lag length and is chosen optimally for each country using a step-down procedure up to a maximum of two lags. The capital stock equations are omitted, because they are not relevant.

The sources of causation can be identified by testing for the significance of the coefficients of the dependent variables in Eqs. (6) and (7). First, the short-run effect can be considered transitory. For short-run causality, we can test H_0: $\theta_{12ik}=0$ for all i and k in Eq. (6) or H_0: $\theta_{21ik}=0$ for all i and k in Eq. (7). Next, the long-run causality can be tested by looking at the significance of the speed of adjustment λ, which is the coefficient of the error correction term, ε_{it-1}. The significance of λ indicates the long-run relationship of the cointegrated process, and so movements along this path can be considered permanent. For long-run causality, we can test H_0: $\lambda_{1i}=0$ for all i in Eq. (6) or H_0: $\lambda_{2i}=0$ for all i in Eq. (7). Finally, we can use the joint test to check for a strong causality test, where variables bear the burden of a short-run adjustment to re-establish a long-run equilibrium, following a shock to the system.[7]

Because all variables enter the model in stationary form, a standard F-test can be used to test the null hypothesis, which shows that none of the estimated country-specific parameters are significant.[8] Table 6 shows the result of a panel causality test between GDP and energy consumption. We find that the energy equations are not significant at the 1% level,

[7] See Asafu-Adjaye (2000) and Oh and Lee (2004).
[8] Canning and Pedroni (1999), Azali et al. (2001), and Basu et al. (2003) provide a detailed discussion.

implying a lack of short-run and long-run causalities. In addition, there are long-run and short-run causal relationships running from energy to GDP.

The uni-directional causality shows that energy conservation may harm economic growth in developing countries regardless of being transitory or permanent. The relationship also refutes the neutrality hypothesis advanced in respect of developing countries for the energy–income relationship. Our conclusion matches with Masih and Masih (1998) and Asafu-Adjaye (2000), but differs from Glasure and Lee (1997) and Soytas and Sari (2003).

4. Conclusions and policy implications

This paper employs data on 18 developing countries from 1975 to 2001 to re-examine the co-movement and causal relationship between GDP and energy consumption. The panel cointegration and the resulting panel-based error correction models are conducted to answer the question. The full-modified OLS deals with the problem of endogeneity. Our evidence shows results suggesting that there is a long-run steady-state relationship between energy consumption and GDP for a cross-section of countries after allowing for a country-specific effect.

Previous studies having used time series data may yield unreliable and inconsistent results due to the short time spans of typical datasets. By contrast, this paper applies the new heterogeneous panel cointegration technique to re-investigate the relationship between energy consumption and GDP across 18 developing countries. According to the short-run and the long-run dynamics of energy consumption and GDP, we refute the neutrality hypothesis advanced in respect of developing countries for the energy–income relationship. Energy consumption is found to Granger cause GDP, but not vice versa. The results of a uni-directional long-run causal relationship and a uni-directional short-run causal relationship running from energy to GDP show that energy consumption leads economic growth. This implies that energy consumption bears the burden of the short-run adjustments to re-establish the long-run equilibrium. In other words, high energy consumption tends to have high economic growth, but not the reverse. Thus, energy conservation may harm economic growth in developing countries regardless of it being transitory or permanent.

Our results support current as well as past changes in energy consumption that have a significant impact on a change in income in developing countries, however they match with the findings of Masih and Masih (1998) and Asafu-Adjaye (2000), but differ from Glasure and Lee (1997) and Soytas and Sari (2003). It is clear for developing countries in general that energy is an important ingredient for economic development. Production in industries demands a substantial amount of energy. This direction of causation expounds future energy use concerning environmental protection and economic development.

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