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Energy consumption, economic growth and prices: A reassessment using panel VECM for developed and developing countries

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Abstract

This paper reinvestigates the energy consumption–GDP growth nexus in a panel error correction model using data on 20 net energy importers and exporters from 1971 to 2002. Among the energy exporters, there was bidirectional causality between economic growth and energy consumption in the developed countries in both the short and long run, while in the developing countries energy consumption stimulates growth only in the short run. The former result is also found for energy importers and the latter result exists only for the developed countries within this category. In addition, compared to the developing countries, the developed countries' elasticity response in terms of economic growth from an increase in energy consumption is larger although its income elasticity is lower and less than unitary. Lastly, the implications for energy policy calling for a more holistic approach are discussed.

Keywords: Energy consumption; Energy prices; Economic growth

1. Introduction

The recent unprecedented increases in crude petroleum prices due to the Iraq war and the 2005 hurricanes in the US have again raised questions about their detrimental effects on economic growth in oil-importing countries in particular. The price hikes have also brought the issue of energy conservation and efficiency back on the policy agenda, that is, whether the adoption of energy saving policies inhibits or stimulates economic growth. This matter has been debated at length in the energy economics literature and often rests on the direction of causality between energy consumption and economic growth.

For example, if it is found that unidirectional causality runs from energy consumption to economic growth, then conserving (or reducing) energy could reduce economic growth. On the other hand, if unidirectional causality runs from economic growth to energy consumption, then energy conservation measures may be implemented with little or no adverse impacts on economic growth. The finding of a lack of causality in either direction implies that increasing energy consumption does not have any effect on economic growth. Some studies (Yoo, 2006; Jumbe, 2004; Shiu and Lam, 2004) have used electricity consumption which although a narrow definition,[1] may be appropriate for certain economies which are heavily reliant on electricity for energy.

So far, the empirical findings on the causal relationship between energy consumption and economic growth have been mixed. The seminal paper on this topic was by Kraft and Kraft (1978) who used bivariate causality procedures and found evidence of causality running from GNP to energy consumption for the US. Since then there has been a proliferation of such studies using different techniques, time periods and different sample of countries as seen in Table 1.

In this study, we make a contribution to the debate on the relationship between energy consumption and economic growth in three ways. First, we employ recently developed panel methods to test for unit roots, cointegration and Granger causality. This method avoids problems

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[1] Energy is obtainable from many sources such as coal, crude petroleum, natural gas, hydropower, geothermal energy, and nuclear energy.

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Table 1
Overview of selected studies

Study	Estimation method	Period	Countries	Results
Kraft and Kraft (1978)	Bivariate Sims causality test	1947–1974	USA	Income→energy
Yu and Choi (1985)	Bivariate Granger test	1954–1976	South Korea	Income→energy
			Philippines	Energy→income
Erol and Yu, 1987	Bivariate Granger test		USA	Energy~income
Yu and Jin (1992)	Bivariate Engle & Granger test	1974–1989	USA	Energy~income
Stern (1993)	Multivariate VAR	1947–1990	USA	Energy→income
Masih and Masih (1996)	Trivariate VECM	1955–1990	Malaysia, Singapore, & Philippines	Energy~income
			India	Energy→income
			Indonesia	Income→energy
			Pakistan	Energy↔income
Glasure and Lee (1997)	Bivariate VECM	1961–1990	South Korea & Singapore	Energy↔income
Masih and Masih (1998)	Trivariate VECM	1955–1991	Sri Lanka & Thailand	Energy→income
Asafu-Adjaye (2000)	Trivariate VECM	1973–1995	India & Indonesia,	Energy→income
			Thailand & Philippines	Energy↔income
Hondroyiannis et al. (2002)	Trivariate VECM	1960–1996	Greece	Energy↔income
Soytas and Sari (2003)	Bivariate VECM	1950–1992	Argentina	Energy↔income
			South Korea	Income→energy
			Turkey	Energy→income
			Indonesia & Poland	Energy~income
			Canada, USA, & UK	Energy~income
Fatai et al. (2004)	Bivariate Toda and Yamamoto (1995)	1960–1999	Indonesia & India	Energy→income
			Thailand & Philippines	Energy↔income
Oh and Lee (2004)	Trivariate VECM	1970–1999	South Korea	Energy↔income
Wolde-Rufael (2004)	Bivariate Toda and Yamamoto (1995)	1952–1999	Shanghai	Energy→income
Lee (2005)	Trivariate Panel VECM	1975–2001	18 developing countries	Energy→income
Al-Iriani (2006)	Bivariate Panel VECM	1971–2002	Gulf Cooperation Countries	Income→energy

Notes: → means variable x Granger causes variable y; ↔ means bidirectional causality; ~means no causality in any direction. VAR means vector autoregression and VECM means vector error-correction model.

of low power associated with the traditional unit root and cointegration tests. Pooling increases the sample size considerably, allowing for higher degrees of freedom and hence more accurate and reliable statistical tests. It also reduces collinearity between regressors. Another advantage of using panel cointegration is that it allows for heterogeneity among the countries.

To the best of our knowledge, only Lee (2005) and Al-Iriani (2006) have used the panel causality tests but our study differs from theirs in more ways than one. While the latter study uses a bivariate model (and only reports long run results) for six countries in the Gulf Cooperation Council, the former uses a trivariate model with capital stock[2] for 18 developing countries. The trivariate model allows an additional channel of causality to be investigated. Thus similar to the Lee study, we consider a trivariate model but one that proxies energy prices. This is because price responses have been argued to have a crucial role in affecting income and energy consumption directly (Dunkerley, 1982; Hoa, 1993). Although data on energy prices would be ideal to use, given the multicountry nature in a panel estimation framework, it is not possible to obtain a comparable series on energy prices for all 20 countries over 1971–2002.[3] The information-intensive difficulty of this exercise is compounded by the fact that the use of energy sources (such as use of coal, oil, etc.) vary in these economies and different prices exist for residents and industries. Furthermore, industries that are energy-intensive may well be subsidised by the government and therefore face different prices. Hence the consumer price index is used instead as energy prices are expected to be sufficiently reflected in this index.

The second contribution of the study is in the check for robustness of the empirical outcome by a comparison of the panel causality results (both short and long run) with those from the separate estimation of a vector error correction model (VECM) for each country. In addition, the impact on elasticity with respect to changes in GDP growth and energy consumption are also discussed using both pooled and individual estimations.

The third contribution lies in the sample that considers a mix of countries comprising both net energy producers and consumers, as well as developing and developed countries. Most previous studies have either focussed on single countries or groups of countries of a similar level of economic development. Here, we examine countries at two different stages of development within the group of energy

[2]Although capital formation is a relevant variable, it reflects an investment decision for energy production which may not directly affect household energy consumption. The latter is determined more by prices.

[3]This is clearly too tedious a task even for the *World Development Indicators* to compile!

exporter and importers. This has important policy implications for energy use considering the differences in production, consumption and institutional structures.

The analysis of the sample mix adds to the existing debate by considering the following questions. First, what are the similarities and/or differences in the causality behaviour between the variables for net energy exporters and importers? Second, within this category, does the causality relationship depend on the level of economic development of the economy? Third, what implications does this have on elasticities of income and energy consumption as well as for energy policy? The paper proceeds as follows. Section 2 provides an overview of the panel VECM used in the study. Section 3 discusses the data. Section 4 presents and discusses the empirical results while Section 5 concludes.

2. Estimation method

Following established procedures, we conduct the test of the causal relationship between economic growth (GDP) and energy consumption in three stages. First, we test for the order of integration in the GDP, energy consumption and price series. Next, we employ panel cointegration tests to examine the long-run relationships among the variables. Finally, we use dynamic panel causality tests to evaluate the short run cointegration and the direction of causality among the variables. These results are then compared to the conventional VECM separately estimated for each country.

2.1. Panel unit root tests

Recent developments in the literature suggest that panel-based unit root tests have higher power than unit root tests based on individual time series. Newly developed panel unit root tests include Breitung (2000), Hadri (2000), Levin et al. (LLC) (2002), and Im et al. (IPS) (2003). Let us consider the following autoregressive model

$$y_{it} = \rho_i y_{it-1} + \delta_i X_{it} + \varepsilon_{it}, \tag{1}$$

where $i = 1, 2, \ldots, N$ represent countries observed over periods $t = 1, 2, \ldots, T$, X_{it} are exogenous variables in the model including any fixed effects or individual trend, ρ_i are the autoregressive coefficients, and ε_{it} is a stationary process. If $\rho_i < 1$, y_i is said to be weakly trend-stationary. On the other hand, if $\rho_i = 1$, then y_i contains a unit root. The LLC, Breitung, and Hadri tests assume that the ε_{it} are IID $(0, {\sigma_\varepsilon}^2)$ and $\rho_i = \rho$ for all i. This implies that the coefficient of y_{it-1} is homogeneous across all cross-section units of the panel and that individual processes are cross-sectionally independent. Pesaran and Smith (1995) stress the importance of parameter heterogeneity in dynamic panel data models and analyse the potentially severe biases that could arise from including it in an inappropriate manner.

Thus we adopt the IPS test which allows for a heterogeneous coefficient of y_{it-1}. This is a more reasonable proposition because heterogeneity could arise from different economic conditions and levels of development in each country. IPS propose averaging the augmented Dickey–Fuller (ADF) tests, that is, $\varepsilon_{it} = \sum_{j=1}^{p_i} \varphi_{ij}\varepsilon_{it-j} + u_{it}$ while allowing for different orders of serial correlation. Substituting this expression into Eq. (1), we get

$$y_{it} = \rho_i y_{it-1} + \sum_{j=1}^{p_i} \varphi_{ij}\varepsilon_{it-j} + X_{it}\delta_i + \varepsilon_{it}, \tag{2}$$

where ρ_i is the number of lags in the ADF regression. The null hypothesis is that each series in the panel contains a unit root, i.e. H_0: $\rho_i = 1$ for all i. The alternative hypothesis is that at least one of the individual series in the panel is stationary, i.e. H_1: $\rho_i < 1$ for at least one i. IPS define a t-bar statistic as the average of the individual ADF statistic

$$\bar{t} = \frac{1}{N}\sum_{i=1}^{N} t_{\rho_i}, \tag{3}$$

where t_{ρ_i} is the individual t-statistic for testing H_0: $\rho_i = 1$ for all i in Eq. (2). The t-bar statistic has been shown to be normally distributed under H_0 and the critical values for given values of N and T are provided in Im et al. (2003).

2.2. Panel cointegration

If it is established from the unit root tests that the variables are integrated of order one, then the next step is to apply cointegration analysis to determine whether a long-run relationship exists among them. This is done by applying the Johansen and Juselius (1992) maximum likelihood approach to identify the number of cointegrating relationships between the three variables of interest. The empirical model for this test is based on the following equation:

$$gdp_{it} = \alpha_i + \delta t + \beta en_{it} + \gamma p_{it} + \varepsilon_{it}, \tag{4}$$

where gdp, en, and p are the natural logarithms of GDP, energy consumption, and prices, respectively; and α and δ are country and time fixed effects, respectively. With a dynamic panel containing a large cross-section dimension, Johansen's procedure is likely to be infeasible and therefore panel cointegration methods are more appropriate.

In this study, we use Pedroni's (1999, 2000) method as it allows for heterogeneity across individual members of the panel. He considers seven different test statistics, four (the panel statistics in Table 6) of which are based on pooling the residuals of the regression along the within-dimension of the panel, and the other three (the group statistics in Table 6) are based on pooling the residuals of the regression along the between-dimension of the panel. In both cases, the basic approach is first to estimate the hypothesised cointegrating relationship separately for each panel member and then to pool the resulting residuals for conducting the panel tests. See Pedroni (1999) for the details on these tests and the relevant critical values.

2.3. Testing for causality

The procedures described above are only able to indicate whether or not the variables are cointegrated and a long-run relationship exists between them. To identify the direction of causality, we estimate a panel-based VECM and use it to conduct Granger causality tests on the energy consumption–GDP relationship. We do this using Engle and Granger's (1987) procedure. In the first step, we estimate the long-run model specified in Eq. (4) in order to obtain the estimated residuals. Next, we estimate a Granger causality model with a dynamic error correction term based on Holtz-Eakin et al. (1988). The empirical model is represented by the following 3-equation VECM.

$$\Delta gdp_{it} = \theta_{1j} + \sum_{k=1}^{m} \theta_{11ik} \Delta gdp_{it-k} + \sum_{k=1}^{m} \theta_{12ik} \Delta en_{it-k} + \sum_{k=1}^{m} \theta_{13ik} \Delta p_{it-k} + \lambda_{1i} \varepsilon_{it-1} + u_{1it}, \tag{5a}$$

$$\sum en_{it} = \theta_{2j} + \sum_{k=1}^{m} \theta_{21ik} \Delta en_{it-k} + \sum_{k=1}^{m} \theta_{22ik} \Delta gdp_{it-k} + \sum_{k=1}^{m} \theta_{23ik} \Delta p_{it-k} + \lambda_{2i} \varepsilon_{it-1} + u_{2it}, \tag{5b}$$

$$\Delta p_{it} = \theta_{3j} + \sum_{k=1}^{m} \theta_{31ik} \Delta en_{it-k} + \sum_{k=1}^{m} \theta_{32ik} \Delta gdp_{it-k} + \sum_{k=1}^{m} \theta_{33ik} \Delta p_{it-k} + \lambda_{3i} \varepsilon_{it-1} + u_{3it}, \tag{5c}$$

where Δ denotes first differences and k is the optimal lag length determined by the Schwarz Bayesian Criterion. Using the specification in Eq. (5) allows us to test for both short-run and long-run causality. For example, in the short-run energy consumption does not Granger-cause economic growth if and only if all the coefficients of θ_{12ik} are equal to zero in Eq. 5(a). In the reverse case, economic growth does not Granger-cause energy consumption if and only if all the coefficients of θ_{22ik} are equal to zero in Eq. 5(b). Short-run causality tests between the other variables can also be undertaken in a similar fashion. The presence (or absence) of long-run causality can be established by examining the significance using a t-test on the coefficient, λ, of the error correction term, ε_{it-1} in Eqs. (5a)–(5c). Finally, we conduct a joint test of ε_{it-1} and the respective interactive terms to check for strong causality.

3. Data

Annual data covering the period 1971–2002 are used for this study. The length of the period is dictated by the availability of data on energy consumption. Twenty countries are selected for the sample (see Table 2), comprising equal numbers of net energy exporting and importing countries. Within each of this group, there are seven developing and three developed countries. All the series are obtained from the *2005 World Development Indicators*. Data on real per capita GDP (constant 2000 US$) are used as a proxy for economic growth and energy consumption is represented by energy use in kg of oil equivalent per capita. The consumer price index of base year 2000 is used to proxy energy prices.

Table 2
List of selected countries

Net energy exporters	
Developed	Developing
Australia	Argentina
Norway	Indonesia
UK	Kuwait
	Malaysia
	Nigeria
	Saudi Arabia
	Venezuela
Net energy importers	
Developed	Developing
Japan	Ghana
Sweden	India
USA	Senegal
	South Africa
	South Korea
	Singapore
	Thailand

Table 3
Average annual growth rates over 1971–2002 (percent)

Country	Energy consumption	GDP growth	Inflation rate
Argentina	0.32	−0.04	4.02
Australia	1.17	1.82	3.00
Ghana	0.69	−0.28	4.92
India	1.49	2.79	3.21
Indonesia	3.12	4.15	3.94
UK	0.09	2.14	2.94
Japan	1.57	2.43	2.08
South Korea	7.13	5.95	3.18
Kuwait	3.38	−2.62	2.13
Malaysia	4.76	4.12	2.38
Nigeria	0.28	−0.33	4.10
Norway	1.73	3.07	2.78
Saudi Arabia	6.11	0.27	2.21
Senegal	0.08	0.17	2.91
Singapore	5.33	5.07	2.06
South Africa	0.78	−0.02	3.59
Sweden	0.87	1.74	2.83
Thailand	4.27	4.59	2.76
USA	0.15	2.07	2.61
Venezuela	0.77	−0.99	4.44
Net energy exporters	2.56	0.99	3.31
Net energy importers	2.77	2.48	2.88

Table 3 presents average annual growth rates on the three data series for the sample countries during the period 1971–2002. South Korea had the highest growth in per

Table 4
Results of the IPS unit root tests for the full sample

Variable	Level		1st difference	
	Constant	Constant and trend	Constant	Constant and trend
en	−0.54(5)	−1.05(5)	−19.75(2)***	−18.33(4)***
gdp	1.02(4)	0.77(4)	−13.35(3)***	−11.87(3)***
p	−1.54(4)	−2.28(4)	−6.39(5)***	−8.30(3)***

Note: Numbers in parentheses are lag levels determined by the Schwarz Bayesian Criterion.
***Indicates significance at the 1% level.

Table 5
Results of Johansen's cointegration tests

Country	H_0	Trace statistics	Critical values	Country	H_0	Trace statistics	Critical values
Argentina	None	34.86*	29.80	Nigeria	None	24.24	29.80
	At most 1	15.49	15.49		At most 1	7.84	15.49
Australia	None	33.93*	29.80	Norway	None	39.01*	29.80
	At most 1	4.40	15.49		At most 1	16.70	15.49
Ghana	None	52.21*	29.80	Saudi Arabia	None	85.45*	29.80
	At most 1	14.21	15.49		At most 1	41.62	15.49
India	None	37.35*	29.80	Senegal	None	28.00	29.80
	At most 1	14.75	15.49		At most 1	12.13	15.49
Indonesia	None	37.81*	29.80	Singapore	None	45.91*	29.80
	At most 1	5.27	15.49		At most 1	14.51	15.49
UK	None	34.15*	29.80	South Africa	None	34.85*	29.80
	At most 1	7.98	15.49		At most 1	13.95	15.49
Japan	None	50.24*	29.80	Sweden	None	30.41*	29.80
	At most 1	15.75	15.49		At most 1	11.44	15.49
South Korea	None	28.24	29.80	Thailand	None	24.52	29.80
	At most 1	11.13	15.49		At most 1	11.20	15.49
Kuwait	None	31.61*	29.80	USA	None	36.92*	29.80
	At most 1	6.50	15.49		At most 1	17.69	15.49
Malaysia	None	49.17*	29.80	Venezuela	None	26.94	29.80
	At most 1	11.53	15.49		At most 1	10.90	15.49

Note: * indicates significance at the 5% level; Critical values are taken from MacKinnon et al. (1999).

capita energy consumption of 7.1 kg of oil equivalent followed by Saudi Arabia and Singapore. South Korea again had the highest annual GDP growth in the period under study followed by Singapore. In particular, the rapidly growing East Asian economies of South Korea, Singapore, Malaysia and Thailand, had the highest per capita energy consumption and GDP growth, as well as fairly low inflation rates. On the other hand, the less developing countries such as Nigeria, Ghana, Argentina and Senegal tended to have low energy consumption, low GDP growth and high inflation. Overall, net energy importers have relatively higher per capita energy consumption and GDP growth rates and lower inflation than net energy exporters.

4. Empirical results

The results of the IPS panel unit root tests for the full sample are presented in Table 4.[4] For all three variables, the null hypotheses of a unit root cannot be rejected at their levels. However, upon taking first differences, the null of unit roots is rejected at the 1% significance level. Therefore, it is concluded that all the series are nonstationary and integrated of order one.

Having established that energy consumption, GDP and prices are $I(1)$, we next proceed to test whether a long-run relationship exists between them. Here, we report both the results of Pedroni's heterogeneous panel test as well as Johansen's tests for the individual countries for comparison. The Johansen test results in Table 5 indicate that in 15 out of the 20 countries, the null hypothesis of no cointegration can be rejected at the 5% significance level. Within the group of energy exporters, Nigeria and Venezuela do not exhibit a long-run relationship and it is possible that the political environment, as well as the high level of corruption in these economies, has blurred the

[4]Similar results are obtained for the two separate samples of energy importers and exporters but these have not been reported to conserve space. For the same reason, the unit root tests for each individual country using ADF and the Perron (1989) tests are also not reported as they indicated that the variables were $I(1)$.

Table 6
Heterogeneous panel cointegration results

Test Statistics	Full sample	Energy importers	Energy exporters
Panel v	2.86*	3.21*	3.07*
Panel ρ	−0.95	−1.32**	−1.41**
Panel pp	−2.48*	−3.02*	−2.99*
Panel ADF	−2.32*	−2.98*	−2.85*
Group ρ	−0.44	−0.86**	−0.92**
Group pp	−3.01*	−3.55*	−3.74*
Group ADF	−3.58*	−3.86*	−3.91*

Note: *indicates significance at the 5% level; **indicates significance at the 10% level.

long-run economic behaviour. The absence of a long-run relationship among the energy importers is seen for the economies of South Korea, Senegal and Thailand. The results of the panel cointegration tests on the other hand are reported in Table 6. With the exception of the group ρ statistics for the full sample, all the other statistics reject the null hypothesis of no cointgeration for the two separate samples of energy importers and exporters.

4.1. Causality results

The causality results from the panel VECM based on generalised method of moments estimation are reported in Table 7. The optimal lag structure of one year is chosen using the Schwarz Bayesian Criterion and the 2-year lags of the dependent variables are used as instruments in the estimation.[5] The significance of the causality results are determined by the Wald *F*-test. It is evident that in the short run, there is a bidirectional relationship between energy consumption and GDP for the energy exporters as a group, but in the long run, there is a unidirectional causality from GDP to energy consumption. While a similar result is obtained for the energy importing developing countries, energy consumption and GDP are mutually causative for the energy importing developed countries.

In general, an increase in GDP would affect energy consumption in two ways. First, households can chose to spend the extra income earned on energy-intensive activities such as computers, better household appliances or transport. Second, economic growth would expand activities and energy is an important input in the production process more so for an industrialising economy. The need for energy input is especially relevant in energy exporting countries as they are energy-intensive users in the extraction and production of energy. Hence, energy consumption increases and this in turn can increase value added to GDP by way of output and exports. But the developing countries such as Kuwait, Saudi Arabia, Indonesia, Nigeria and Venezuela that are net energy exporters enjoy cheap energy domestically as prices are kept artificially low as a result of low government tariffs and high consumer subsidies. This has resulted in waste and inefficient energy use and hence energy consumption has not translated to GDP growth.

The energy exporting developed economies on the other hand do not enjoy low prices similar to their counterparts in developing economies. In addition, they have to comply with stringent environment regulations,[6] thereby using energy efficiently[7] such that any energy-intensive production translates to increase in GDP. Thus it appears that there may be a threshold in terms of development and responsible use of energy and compliance to environment that a country needs to achieve before energy exports can result in a bidirectional relationship between energy consumption and GDP.

For energy importers on the other hand, it is seen that energy consumption stimulates economic growth in both the short and long run, but the reverse holds in the short run only for developed countries. A look at the sample of developing economies may help explain this. First, in countries such as Singapore and Malaysia, energy conservation and efficient use is a high priority and is imposed by the government using high electricity prices. Thus an increase in GDP may not result in a significant expansion in energy consumption for households or producers. On the production side, high substitutability between energy and other inputs can mean that there may not necessarily be an increase in energy use when an economy expands but determining this is beyond the scope of this paper. Second, some countries such as Senegal, South Africa and Ghana are predominantly agricultural-based and an expansion in these activities due to economic growth may not significantly affect energy use in the short run. Third, poor energy supply infrastructure could hamper the use of energy for expanding activities in an economy. For instance, India is often singled out for its power shortages in Bangalore which adversely affects a major industry comprising call centres that service countries throughout the world. Another example is Thailand which according to the ASEAN Centre for Energy is in need of electricity supply investment to bridge its demand–supply gap.

With regards to the relationship between prices and energy consumption, as expected, energy consumption representing demand from a small number of countries will not have an effect on world energy prices and hence domestic prices will not be affected via this channel. However an increase in price adversely affects energy consumption in the energy importing economies only in the long run as energy is more often than not a necessity and hence is expected to be relatively price inelastic more so in

[5]Lags of more than two years were found to be insignificant.

[6]Out of a score of 7, Norway's stringency of environmental regulations is rated 6.3 while that of Australia and the UK is 5.8 and the developing countries Nigeria, Argentina, Kuwait, Venezuela and Indonesia average 3.35 according to *The Global Competitiveness Report 2005*.

[7]On average, the score for Norway, Australia and the UK is more than two times that of the developing countries in their prioritization of energy efficiency according to *The Global Competitiveness Report 2005*.

Table 7
Wald *F*-test statistics from panel VECM estimation

Null hypothesis	Full sample		Developed countries		Developing countries	
	Short-run causality test	Strong exogeneity test	Short-run causality test	Strong exogeneity test	Short-run causality test	Strong exogeneity test
Net energy exporters						
$\Delta en \rightarrow \Delta gdp$	8.34*	3.56	4.68*	4.23*	5.91*	3.24
$\Delta gdp \rightarrow \Delta en$	5.28*	4.56*	12.11*	8.08*	18.40*	16.81*
$\Delta p \rightarrow \Delta en$	0.30	0.72	1.98	1.46	2.19	2.67
$\Delta en \rightarrow \Delta p$	0.27	1.78	1.35	2.85	2.17	2.26
Net energy importers						
$\Delta en \rightarrow \Delta gdp$	17.15*	11.78*	25.47*	17.72*	17.34*	11.56*
$\Delta gdp \rightarrow \Delta en$	7.67*	2.11	6.62*	2.17	1.38	1.11*
$\Delta p \rightarrow \Delta en$	0.79	6.50*	1.63	10.95*	2.29	5.42*
$\Delta en \rightarrow \Delta p$	1.49	1.34	2.27	1.15	2.47	2.37

Notes: → means variable x does not Granger cause variable y.
*Indicates significance at the 1% level.
The relationship between p and gdp is not reported as this does not add to the discussion.

the short run. In the long run however, significant changes in investment and consumption patterns in energy use pertaining to price changes can take place. Although not reported, evidence shows that the difference among the energy importers is that the developed countries have a lower (elasticity) response in terms of a fall in energy consumption due to a price increase relative to the developing countries. This could be due to a difference in the composition of energy consumers (industrial and residential) in the two types of economies. For instance, the OECD (1992) reports that in the developed countries, residential and industrial consumers respectively account for 32% and 41% of total electricity consumption while the corresponding proportions are 24% and 51% in the developing countries. Hondroyiannis et al. (2002) show that the two groups of energy consumers have very different price elasticities. Thus, the results relating to price effects need to be interpreted with caution.

4.2. Comparison of pooled and individual results

Here, the causality results from the panel VECM are compared against those obtained from the separate estimation of the VECM for each economy in Table 8. For some economies such as Singapore and Malaysia, bidirectional causality between energy consumption and GDP are observed in the long run unlike the generalised results from the panel estimations. Perhaps the fact that these economies are newly industrialising economies makes it inappropriate to categorise them as developing countries as was done in the panel analysis. These two economies together with the USA are heavily involved in information and communication industries that require electricity and as such economic growth can be expected to lead to increased energy consumption in the long run. A similar result is obtained using unpooled data for Ghana and South Africa. This reflects the effects of gold mining energy-intensive industry's expansion as a result of economic growth. On the other hand, the causality results from pooled and unpooled data on the developed countries are quite similar regardless of whether they are energy exporters or importers.

The coefficients from the VECM estimations also provide information on elasticities. Here, we only focus on the long-run cointegrating relationships as they show stable behaviour. For most countries, increase in energy consumption has a significant positive effect on GDP and vice versa. However, as these elasticity values vary depending on the choice of the variables in the model, they are best interpreted in terms of relative and not actual magnitudes. Let us first consider the responsiveness of GDP growth to a 1% increase in energy consumption. The energy exporting developed countries show an elasticity value greater than one for both the pooled and unpooled estimations. Saudi Arabia, a developing economy on the other hand, has a value less than one. A similar result is obtained for all the energy importers. But within the latter group, the developed economies of Sweden, Japan and the USA experience a greater increase in output growth than the developing economies for a 1% increase in energy use, possibly reflecting energy efficiency measures in place. These results are robust to panel and separate estimation of the VECM.

With income elasticity, the increase in energy consumption brought about by a 1% increase in GDP is close to unity for energy exporting developing countries except for Malaysia. Given that energy prices are heavily subsidised in these developing economies, energy is not perceived as a limiting source and there is a tendency to overuse it. However, the developed economies which export energy have an income elasticity that is less than unitary as efficiency in energy management (as discussed earlier) may

Table 8
Comparison of causality and elasticity results

Countries	Short-run	Long-run
Net energy exporters		
Argentina	$\Delta en \to \Delta gdp$	$\Delta gdp \to \Delta en$ (1.06)
	$\Delta gdp \to \Delta en$	
Australia	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (1.31)
	$\Delta gdp \to \Delta en$	$\Delta gdp \to \Delta en$ (0.51)
Indonesia	$\Delta en \to \Delta gdp$	$\Delta gdp \to \Delta en$ (0.91)
	$\Delta gdp \to \Delta en$	
Kuwait	$\Delta en \to \Delta gdp$	$\Delta gdp \to \Delta en$ (1.02)
	$\Delta gdp \to \Delta en$	
Malaysia	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.64)
	$\Delta gdp \to \Delta en$	$\Delta gdp \to \Delta en$ (0.74)
Nigeria	$\Delta en \to \Delta gdp$	n.a.
	$\Delta gdp \to \Delta en$	
Norway	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (1.03)
	$\Delta gdp \to \Delta en$	$\Delta gdp \to \Delta en$ (0.33)
Saudi Arabia	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.81)
	$\Delta gdp \to \Delta en$	$\Delta gdp \to \Delta en$ (0.98)
UK	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (1.23)
	$\Delta gdp \to \Delta en$	$\Delta gdp \to \Delta en$ (0.45)
Venezuela	$\Delta en \to \Delta gdp$	n.a.
	$\Delta gdp \to \Delta en$	
Panel (with time effects)		
All energy exporters	$\Delta en \to \Delta gdp$	$\Delta gdp \to \Delta en$ (0.66)
	$\Delta gdp \to \Delta en$	
Developed countries	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (1.17)
	$\Delta gdp \to \Delta en$	$\Delta gdp \to \Delta en$ (0.44)
Developing countries	$\Delta en \to \Delta gdp$	$\Delta gdp \to \Delta en$ (0.94)
	$\Delta gdp \to \Delta en$	
Net energy importers		
Ghana	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.71)
		$\Delta gdp \to \Delta en$ (0.54)
India	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.67)
Japan	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.91)
	$\Delta gdp \to \Delta en$	
South Korea	$\Delta en \to \Delta gdp$	n.a.
Senegal	$\Delta en \to \Delta gdp$	n.a.
Singapore		$\Delta en \to \Delta gdp$ (0.59)
		$\Delta gdp \to \Delta en$ (0.77)
South Africa	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.28)
		$\Delta gdp \to \Delta en$ (0.45)
Sweden	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.71)
	$\Delta gdp \to \Delta en$	
Thailand	$\Delta en \to \Delta gdp$	n.a.
USA	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.86)
	$\Delta gdp \to \Delta en$	$\Delta gdp \to \Delta en$ (0.64)
Panel (with time effects)		
All energy importers	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.65)
	$\Delta gdp \to \Delta en$	
Developed countries	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.82)
	$\Delta gdp \to \Delta en$	
Developing countries	$\Delta en \to \Delta gdp$	$\Delta en \to \Delta gdp$ (0.49)

Notes: n.a. means not applicable and this is the case under long run when no cointegration is found among the variables as seen in Table 5.
Figures in parenthesis which are significant at the 5% level, represent elasticity of a 1% change in the variable on the right in response to a 1% increase in the variable on the left.

restrain energy consumption from increasing fully in response to an increase in GDP. Among the energy importers whose income elasticity is also less than one, the USA and Singapore experience relatively higher elasticities than the developing economies of Ghana and South Africa. It is postulated that the relatively large shares of an industrial sector and higher levels of urbanisation in the more developed countries require a larger response to energy consumption in an expanding economy.

4.3. Implications for energy policy

A key feature of energy policy has been the conservation of energy which is concerned with the more efficient use of energy and a reduction in the amount of energy wasted. Most studies on the causality between energy consumption and economic growth prescribe energy conservation policies strictly based on the empirical results without considering other economic or environmental factors such as energy supply infrastructure, energy efficiency considerations or institutional constraints. Energy policy cannot be formulated in isolation from a nation's social and other objectives such as balance of payments, security of supply and health of the national fuel industries. It is the wide-ranging nature of these objectives that makes energy policy complicated.

For instance, in the case of energy importers, energy consumption stimulates economic growth but this is not to say energy conservation will harm the economy if energy-saving technologies are used or production methods that combine energy efficiently with the other factors of production are implemented. For the energy exporting developing economies, while energy conservation may retard economic growth in the short run given that causality runs from energy consumption to GDP in this study, other measures can be used to curtail excessive energy demand as this will not adversely affect GDP growth in the long run. The abundance of cheap energy may be blamed for the low level of commitment to energy conservation. There needs to be information dissemination and best practice measures to overcome the lack of knowledge and technical skills that affect behaviour in relation to the purchase and use of energy consuming equipment. Important lessons can also be learnt from countries such as Norway which is the only country to have a carbon dioxide tax on oil extraction since 1999, or from Australia or the UK's investment in research and development efforts towards energy-saving or pollution-minimising technologies. This will enable energy consumption to enhance economic growth in the long run.

Another way of ensuring an effective energy policy for energy conservation and efficiency is to liberalise the energy market in order to allow prices to more realistically reflect market and cost conditions as well as for efficient energy operations in the areas of distribution and production as a result of competition. In this regard, there is some progress in the Asian economies. While Singapore privatised its energy sector in 2001, in Indonesia, control has slowly been removed from the state-run Pertamina which monopolised the oil and gas sector. Also, after a series of modest increases in petroleum prices over the past two years, a sharp rollback of subsidies was announced in September 2005 and this more than doubled the retail price of gasoline and diesel in Indonesia. Thus it remains to be seen how these structural reforms in the energy sector affect energy use and its subsequent impact on GDP growth especially now that Indonesia has reportedly become a net importer of oil in 2004. Malaysia is another economy which has considered reforms (but this is still at an early stage) to its power sector to make it more competitive and lower costs, and is expected to be net importer of oil by 2008.[8] Before 1994, three state-owned utilities dominated power generation and distribution in Malaysia but since the market has been opened to independent power producers.

In addition, in the area of energy supply infrastructure, there are also major plans underway to increase energy capacity with programs such as the ASEAN National Power Grid and power grid within the Gulf countries. This may help strengthen the causality from economic growth (due to autonomous expenditure in capacity generation) to energy consumption. This has implications for energy utilisation and hence energy conservation policy.

5. Conclusion

At the outset it must be noted that the purpose of this paper is not to resolve the conflicting evidence on the relationship between energy consumption and economic growth. Instead, the study provides some broad and useful generalisations about the relationship in both developed and developing economies within the group of net energy exporters and importers. The results on causality and the elasticity response of changes in energy consumption and economic growth on each other are compared and discussed using both pooled and unpooled estimation techniques in an attempt to reconcile country-specific analysis before the generalisations can be substantiated.

Lastly, the form in which energy policy takes effect is crucial. While it is difficult to be definitive about energy policy, it must be acknowledged that such a discussion needs a holistic setting to be more effective and not just based on the empirical evidence on causality between energy consumption and economic growth.

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[8]See ASEAN Energy Bulletin, May 2003, vol.7, no.1: 8–10.

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