The relationship between energy consumption, energy prices and economic growth: Time series evidence from Asian developing countries

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This paper estimates the causal relationships between energy consumption and income for India, Indonesia, the Philippines and Thailand, using cointegration and error-correction modelling techniques. The results indicate that, in the short-run, unidirectional Granger causality runs from energy to income for India and Indonesia, while bidirectional Granger causality runs from energy to income for Thailand and the Philippines. In the case of Thailand and the Philippines, energy, income and prices are mutually causal. The study results do not support the view that energy and income are neutral with respect to each other, with the exception of Indonesia where neutrality is observed in the short-run.

Keywords: Energy consumption; Economic growth; Granger causality

In the past two decades numerous studies have examined the causal relationships between energy consumption and economic growth, with either income or employment used as a proxy for the latter. To date, the empirical findings have been mixed or conflicting. The seminal article on this topic was published in the late seventies by Kraft and Kraft [14] who found evidence in favour of causality running from GNP to energy consumption in the United States, using data for the period 1947 to 1974. Their findings were later supported by other researchers. For example, Akarca and Long [2] found unidirectional Granger causality running from energy consumption to employment with no feedback, using US monthly data for the period 1973 to 1978. They estimated the long-run elasticity of total employment with respect to energy consumption to be -0.1356.

However, these findings have been subjected to empirical challenge. Akarca and Long

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[1], Yu and Hwang [22], Yu and Choi [21], Erol and Yu [5] found no causal relationships between income (proxied by GNP) and energy consumption. On the causal relationship between energy consumption and employment, Erol and Yu [6], Yu et al. [23], Erol and Yu [7] and Yu and Jin [20] found evidence in favour of neutrality of energy consumption with respect to employment, referred to as the ‘neutrality hypothesis’.

One of the reasons for the disparate and often conflicting empirical findings on the relationship between energy consumption and economic growth lies in the variety of approaches and testing procedures employed in the analyses. Many of the earlier analyses employed simple log-linear models estimated by ordinary least squares (OLS) without any regard for the nature of the time series properties of the variables involved. However, as has recently been proven, most economic time series are non-stationary in levels form (see Granger and Newbold [10]. Thus, failure to account for such properties could result in misleading relationships among the variables.

Following advances in time series analysis in the last decade, recent tests of the energy consumption-economic growth relationship have employed bivariate causality procedures based on Granger [9] and Sim’s [18] tests. However, these tests may fail to detect additional channels of causality and can also lead to conflicting results. For example, recently, Glasure and Lee [8] tested for causality between energy consumption and GDP for South Korea and Singapore using the standard Granger test, as well as cointegration and error-correction modelling. They found bi-directional causality between income and energy for both countries, using cointegration and error-correction modelling. However, using the standard Granger causality tests, they found no causal relationships between GDP and energy for South Korea and unidirectional Granger causality from energy to GDP for Singapore.

The direction of causation between energy consumption and economic growth has significant policy implications. If, for example, there exists unidirectional Granger causality running from income to energy, it may be implied that energy conservation policies may be implemented with little adverse or no effects on economic growth. In the case of negative causality running from employment to energy (Akarca and Long [2]), total employment could rise if energy conservation policy were to be implemented. On the other hand, if unidirectional causality runs from energy consumption to income, reducing energy consumption could lead to a fall in income or employment. The finding of no causality in either direction, the so-called ›neutrality hypotheses: (Yu and Jin [20]), would imply that energy conservation policies do not affect economic growth.

This paper examines the energy-income relationship for four energy-dependent Asian developing countries: India, Indonesia, the Philippines and Thailand. These countries were chosen because they represent energy-dependent LDCs which are poised for take-off into a phase of industrialisation. We depart from previous studies by considering a trivariate model (energy, income and prices) rather than the usual bivariate approach. This approach offers the opportunity to investigate other channels in the causal links between energy consumption and economic growth.

The remainder of this paper is organised in the following fashion. Sections 2 presents a brief overview of the economic and energy use profiles of the countries in the sample. Sections 3 and 4 briefly describe the methodology employed and the data sources, respectively. The penultimate section presents and discusses the empirical results while the final section contains the conclusions.

Economic and Energy Use Profiles

The four countries are heavily populated and have a combined total of 1.3 billion people (Table 1). Of the four, India is the least wealthy on a per capita income basis of comparison, with a per capita GDP of US$380 (1996 dollars) which is the average for the South Asia region. The others have per capita incomes of over US$1,000 (see Table 1). All four countries recorded high annual growth rates in their manufacturing sectors in 1996, ranging from 10.5 percent for Indonesia to 5.6 percent for the Philippines. Of course, these impressive growth rates would have declined in 1997 and beyond in view of the Asian financial crisis. To maintain the high levels of economic output these countries make high demands on energy resources.

Table 1 reports figures for per capita energy use and carbon dioxide emissions for the four countries in the sample. Energy use per capita is highest for Thailand in 1995 with 878 kg, followed by Indonesia with 442 kg per capita. India has the lowest per capita energy use with 260 kg. Carbon dioxide emissions per capita are also relatively high, ranging from 2.9 metric tons for Thailand to 0.9 metric tons for the Philippines. Most of the countries have to rely on imports for their energy needs, except Indonesia which is a net exporter of fuel. India is among the largest consumers of energy in the region. India's energy sources comprise mainly coal, and was estimated to be 244 million metric tons in 1991 (OECD [16]).

The above figures show that Asian LDCs account for a significant proportion of the world's energy consumption. Given the recent phenomenal growth in awareness of and concern for global warming, an examination of the energy-income relationship has implications for energy policy in these countries. It is important to add that most of the studies referred to above have dealt with advanced or newly industrialised countries (NICs) and it may be argued that the results are not applicable to countries at a different stage of development.

Methodology

The modelling strategy adopted in this study is based on the Engle-Granger testing procedure. The first step is to pre-test the variables for their order of integration. The augmented Dicky-Fuller (ADF) [Dickey and Fuller 3] and the Phillips-Perron (PP) [Phillips and Perron 16] tests of stationarity are used. A variable is stationary if it is integrated of order zero. If the time series are not stationary then the estimated coefficients are likely to be inconsistent (Engle and Granger [4], Granger and Newbold [10]). Furthermore, the assumption of the usual asymptotic econometric properties will not hold and the standard statistical tests will not be invalid[1]. On the other hand, if all the variables are stationary, standard estimation techniques such as ordinary least squares (OLS) may be used.

The second step in the process is to determine whether there is a cointegrating relationship among the variables of the model. This step involves the estimation of the long-run equilibrium relationship of the form:

$$y_t = \alpha_0 + \alpha_1 en_t + \alpha_2 p_t + e_t \qquad (1)$$

where y_t is the logarithm of income, en_t is the logarithm of energy consumption, p_t is the logarithm of energy prices and e_t is an error term. Two conditions must be met for two or more variables to be cointegrated. The first is that the individual series must have the same order of integration. The second is that linear combinations of the variables from an OLS regression of the levels of the non-stationary variables must be stationary[2].

If the dependent variable is found to be cointegrated with at least one of the independent variables, the next step in the testing procedure is to use the residuals from the equilibrium relationship (Equation 1) to estimate an error-correction model (ECM) of the form,

$$Dy_t = A_{21}(L)Dy_{t-1} + A_{22}(L)Den_{t-1} + A_{23}(L)Dp_{t-1} + \gamma_y ECT_{t-1} + u_{2t} \quad (2)$$

$$Den_t = A_{11}(L)Dy_{t-1} + A_{12}(L)Den_{t-1} + A_{13}(L)Dp_{t-1} + \gamma_{en} ECT_{t-1} + u_{1t} \quad (3)$$

$$Dp_t = A_{31}(L)Dy_{t-1} + A_{32}(L)Den_{t-1} + A_{32}(L)Dp_{t-1} + \gamma_p ECT_{t-1} + u_{3t} \quad (4)$$

where $A_{ij}(L)$ are polynomials in the lag operator L; D is a difference operator; ECT is the lagged error-correction term(s) derived from the long-run cointegrating relationship in (1); and the u_{it}=s are error correction terms assumed to be uncorrelated and random with mean zero. The coefficients, γ_i (i= en, y, p), of the ECTs represent the deviation of the dependent variables from the long-run equilibrium.

Through the error-correction mechanism, the ECM opens up an additional causality channel which is overlooked by the standard Granger [9] and Sims [18] testing procedures. In the Granger sense a variable X causes another variable Y if the current value of Y can better be predicted by using past values of X than by not doing so. The Granger causality testing procedure involves testing the significance of the A_{ij}=s conditional on the optimum lags[3]. Through the ECT, an error correction model offers an alternative test of causality (or weak exogeneity of the dependent variable). If, for example, γ_{en} is zero, then it can be implied that the change in en_t does not respond to deviation in long-run equilibrium in period t-1. Also, if γ_{en} is zero and all A_{11} and A_{13} are also zero, it can be implied that income and prices do not Granger-cause energy consumption. The nonsignificance of both the t and Wald F-statistics in the ECM will imply that the dependent variable is weakly exogenous[4].

If the variables, y_t, en_t and p_t are cointegrated then it is expected that at least one or all of the ECTs should be significantly non zero. Granger causality of the dependent variables is tested as follows: (1) by a simple t-test of the γ_i=s; (2) by a joint Wald F-test of the significance of the sum of the lags of each of the explanatory variables in turn, and (3) by a joint Wald F-test of the following interactive terms: Equation 2 - (γ_y & A_{22}), (γ_y & A_{23}); Equation 3 - (γ_{en} & A_{11}), (γ_{en} & A_{13}); and Equation 3 - (γ_p & A_{31}), (γ_p & A_{32}).

Data Sources

Annual time series data were utilised in this study. The series for India and Indonesia cover the period 1973-95, while those for Thailand and the Philippines cover the period 1971-95. The data were obtained from *World Development Indicators (WDI) 1998*, published by the World Bank. The choice of the starting period was constrained by the availability of data on energy consumption. The precise definitions of the variables are as follows:

en - commercial energy use in kg of oil equivalent per capita.

y - real income, defined as GDP in constant 1987 prices in local currency units.

p - prices. Since energy prices were not available, this variable was proxied by the consumer price index (CPI), 1987=100.

Empirical Results and Discussion

Table 2 reports the results for both the ADF and PP test results it can be seen that, with exception of Indonesian prices, the null hypothesis of nonstationarity cannot be rejected at the 10 percent level for the levels of the variables. However, when first differences are taken, the null hypothesis of nonstationarity is rejected for most of the variables. We have mixed results for the differenced Thailand energy and income variables. The null hypothesis of nonstationarity cannot be rejected by the ADF test but is rejected by the PP test. It can therefore be concluded that in most cases, income, energy and prices are integrated of order one, that is, I(1), except Thailand energy and income which could be integrated of order two.

Given that most of the variables are integrated of the same order, the next step was to test for cointegration using Johansen=s multivariate maximum likelihood procedure[5]. The test results are reported in Table 3, where *r* represents the number of cointegrating vectors. It can be seen that, for India, the null hypothesis of no cointegration relationships is rejected against the alternative of one cointegrating relationship at the 1 percent level. In the case of Indonesia, the test results suggest the presence of two cointegrating relationships. Finally, the results for Thailand and the Philippines suggest that, in both cases, the null hypothesis of no cointegrating relationship can be rejected in favour of the alternative of a single cointegrating relationship[6]. The existence of cointegrating relationships among income, energy and prices suggests that there must be Granger causality in at least one direction. However, it does not indicate the direction of temporal causality between the variables. To determine the direction of causation, we must examine the ECM results.

In addition to providing an indication of the direction of causality, the ECM enables us to distinguish between Ashort-run@ and Along-run@ Granger causality. In Tables 4a and 4b, we provide joint Wald F- statistics of the lagged explanatory variables of the ECM. These tests give an indication of the significance of short-run causal effects. We also provide t-statistics for the coefficients of the ECTs which give an indication of long-run causal effects. Finally, we provide joint Wald F-statistics for the interactive terms (ie., the ECTs and the explanatory variables) which give an indication of which variables bear the burden of short-run adjustment to re-establish long-run equilibrium, given a shock to the system.

Turning first to the short-run results for India (Table 4a), it can be seen that the F- statistic for energy (in the income equation) is significant at the 5 percent level. However, none of the lagged explanatory variables in the other two equations (energy and price) are statistically significant. These result imply that, in the short-run, there is unidirectional Granger causality running from energy consumption to income, while price has a neutral effect on both energy and income. Looking at the t-statistics, it can be seen that the coefficient of ECT is significant in the income equation but is not significant in either the energy or price equation. This result can be interpreted as follows. Given a deviation of income from the long-run equilibrium relationship as defined by ECT = y_t - p_t - en_t, all three variables interact in a dynamic fashion to restore long-run equilibrium. However, the nonsignificance of the F-statistics for price indicates it is exogenous in the system, implying that energy consumption bears the burden of the short-term adjustment to long-term equilibrium. The Wald F-test results in the last three columns of Table 4a suggest that, in the long-run, both energy and price Granger-cause income.

The results for Indonesia are not much different from those of India. The standard Granger tests would have concluded that there are no causal relationships among y_t, en_t and p_t. However, the coefficient of ECT in the energy equation is significant at the 5 percent level. This implies that, as in the case of India, energy and prices interact interact in the short-term to restore long-run equilibrium after a change in income. None of the interaction terms are statistically significant, implying that the long-run energy and price effects are weak. The results for the other equations suggest that, in the long-run, income and prices have no effect on energy consumption. However, both energy consumption and income cause price changes.

In the case of Thailand, it can be seen from the income equation that energy Granger-causes income in both the short- and long-runs. However, the energy equation results indicate that income also Granger-causes energy and therefore there is bidirectional Granger causality. The results for the price equation suggest that prices also Granger-cause energy consumption. For the Philippines, we again observe Granger causality running from energy and prices to income in both the short- and long-runs, with reverse causality running from energy to income.

Our results are consistent with the findings of Masih and Masih [15], Hwang and Gum [11] and Glasure and Lee [8] who found evidence of bidirectional causality between income and energy for South Korea and Taiwan. However, they refute the ›neutrality hypothesis= advanced in respect of the United States for the energy-income relationship (Erol and Yu [7], Yu and Jin [20]) in three out of four cases. It is only in the case of Indonesia and India where neutrality between energy and income is observed in the short-run. However, this can be expected in the case of Indonesia since it is a net energy exporter and therefore can be shielded from energy shocks.

The ECMs displayed reasonable goodness-of-fit based on the R^2 and F statistics (not reported here) and passed most of diagnostic tests including the Godfrey LM test for serial correlation, the Engle test for first order autoregressive heteroscedasticity (ARCH(1)), the Bera-Jacque test for normality and the Ramsey (RESET) test for model misspecification.

Conclusions

The purpose of this study was to test for Granger causality between energy consumption and income for four Asian developing countries, including price as a third variable. Maximum likelihood procedures were used to analyse the time series properties of the variables and error-correction models were estimated and used to test for the direction of Granger causality. From the test results, we conclude that unidirectional Granger causality runs from energy to income for India and Indonesia, while bidirectional Granger causality runs from energy to income for Thailand and the Philippines. In the long-run, there is unidirectional Granger causality running from energy and prices to income for India and Indonesia. However, in the case of Thailand and the Philippines, energy, income and prices are mutually causal. Price effects are relatively less significant in the causal chain. In general, the study results do not support the view that energy and income are neutral with respect to each other, with the exception of Indonesia and India where neutrality is observed in the short-run.

The study finding of bidirectional Granger causality or feedback between energy concumption and income has a number of implications for policy analysts and forecasters. A high level of economic growth leads to high energy demand and vice versa. In order not to adversely affect economic growth, energy conservation policies which aim at curtailing energy use must rather find ways of reducing consumer demand. Such a policy could be achieved through an appropriate mix of energy taxes and subsidies. At the same time, efforts must be made to encourage industry to adopt technology which minimises pollution.

The finding of bidirectional causality in two out of the four countries calls for caution in the use of single equation regressions of income on energy for conducting econometric forecasts. Our results suggest that in some cases energy consumption, income and price are endogenous and therefore single equation forecasts of one or the other could be misleading. In particular, any analysis which does not incorporate the error-correction terms is likely to give unreliable results. The study=s findings are consistent with the expectation that energy-dependent economies are relatively more vulnerable to energy shocks. Indonesia is the only net energy exporter in the sample and therefore we find short-run neutrality between energy and income. Thus, in the case of Indonesia, there is more scope for more drastic energy conservation measures without severe impacts on economic growth.

Notes

1. The use of non-stationary variables could result in spurious regression, characterised by high R^2 and t-statistics which have no economic meaning (eg, see Engle and Granger [4]).

2. Another way of stating this is that two variables, y_t and z_t are said to be cointegrated of order one, ie. CI(1,1) if they are individually I(1), but some linear combination (eg., $w_t = z_t + ay_t$) of the two is I(0). With three or more variables, various subsets may be cointegrated. Eg., a group of I(2) variables may be CI(2,1) or CI(2,2).

3. The lag lengths were assigned on the basis of minimising Akaike's AIC criterion.

4. Weak exoegeneity is a precondition for super-exogeneity. The latter issue is not pursued in this study.

5. The Johansen approach has been shown to be superior to Engle and Granger's residual-based approach. Among other things, the Johansen approach is capable of detecting multiple cointegrating relationships.

6. A similar pattern of results were obatined using trace tests.

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Table 1. Per capita energy use and carbon dioxide emissions (1995)

Indicator	**India**	**Indonesia**	**Thailand**	**Philippines**
Population mid-1996 (millions)	945.1	197.1	60.0	71.0
GNP per capita 1996 (US$)	380	1080	2960	1160
Manufacturing (average growth rate % p.a.)	8.1	10.5	7.7	5.6
Energy use per capita (kg)	260	442	878	307
CO_2 emissions per capita (m tons)	1.0	1.5	2.9	0.9

Source: [19].

Table 2. Results of unit root tests

Country/ Variable	Augmented Dickey-Fuller (ADF) Levels	Augmented Dickey-Fuller (ADF) First Differences	Phillips-Perron (PP) Levels	Phillips-Perron (PP) First Differences
India				
y_t	-1.26	-3.71	-2.51	-6.29
en_t	-1.92	-2.81	-1.39	-5.83
p_t	-0.35	-4.53	-0.07	-3.79
Indonesia				
y_t	-0.03	-3.65	-0.24	-4.74
en_t	-0.96	-3.77	-1.35	-3.73
p_t	-4.49	-3.11	-5.35	-2.64
Thailand				
y_t	-0.61	-2.27	-1.23	-2.87
en_t	-1.73	-2.55	-2.39	-2.80
p_t	-2.73	-3.15	-3.04	-2.61
Philippines				
y_t	-1.58	-3.15	-1.90	-2.32
en_t	-1.95	-3.35	-1.39	-5.78
p_t	-1.16	-4.33	-1.30	-3.97
Critical values:				
1%	-3.75		-3.73	
5%	-3.00		-2.99	
10%	-2.63		-2.63	

Note: The optimal lags for the ADF tests were selected based on optimising Akaike's Information Criteria (AIC), using a range of lags. Truncation lags for the PP test were determined using the highest significant lag from either the autocorrelation or partial autocorrelation function of the first differenced series.

Table 3. Results of Johansen's maximum likelihood tests for multiple cointegrating relationships (intercept, no trend)

Country/Null hypothesis	Characteristic roots	Test statistics[a]	5% Critical value	1% Critical value
India				
r = 0 r = 1	0.77	38.78^{***}	29.68	35.65
r = 1 r = 2	0.27	8.29	15.41	20.04
r = 2 r = 3	0.08	1.64	3.76	6.65
Indonesia				
r = 0 r = 1	0.80	54.83^{***}	29.68	35.65
r = 1 r = 2	0.62	21.29^{**}	15.41	20.04
r = 2 r = 3	0.02	0.37	3.76	6.65
Thailand				
r = 0 r = 1	0.75	41.78^{**}	29.68	35.65
r = 1 r = 2	0.33	9.53	15.41	20.04
r = 2 r = 3	0.01	0.18	3.76	6.65
Philippines				
r = 0 r = 1	0.61	34.00^{*}	29.68	35.65
r = 1 r = 2	0.30	12.61	15.41	20.04
r = 2 r = 3	0.17	3.31	3.76	6.65

a. The test statistic is the l_{max} *value.*

***, and ** indicate significance at the 1%,and 5% levels, respectively.

Table 4a. Temporal Granger-causality results for India and Indonesia

	Short - run effects			Source of causation:			
Country/ Dep var	Dy_t	Den_t	Dp_t	ECT[a] only	Den_t, ECT	Dp_t, ECT	Dy_t, ECT
India		Wald F-statistics		t-ratio		Wald F-statistics	
Dy_t	-	8.14**	1.01	-2.85**	4.09**	4.63**	-
Den_t	0.18	-	0.08	-1.01	-	0.77	0.83
Dp_t	0.39	0.07	-	-0.41	0.11	-	0.20
Indonesia							
Dy_t	-	0.81	1.68	-2.08**	2.19	2.40	-
Den_t	0.87	-	0.63	1.83	-	1.68	1.70
Dp_t	1.06	0.81	-	-2.83**	4.00**	-	4.67**

a. ECT - error correction term in the Error-Correction Model.
***, **, and * indicate significance at the 1%, 5%,and 10% levels, respectively.

Table 4b. Temporal Granger-causality results for Thailand and the Philippines

Country/ Dep var	Dy_t	Den_t	Dp_t	ECT[a] only	Den_t, ECT	Dp_t, ECT	Dy_t, ECT
	Short - run effects			Source of causation:			
Thailand	Wald F-statistics			t-ratio	Wald F-statistics		
Dy_t	-	11.3***	0.26	-0.54	9.98***	0.20	-
Den_t	9.66***	-	5.22*	-2.84***	-	6.55**	16.9***
Dp_t	0.40	9.02***	-	-3.48***	7.48***	-	6.60***
Philippines							
Dy_t	-	2.66*	21.6***	-1.16	-1.43	14.4***	-
Den_t	2.98*	-	0.00	-2.16*	-	2.38	6.14***
Dp_t	10.6***	0.21	-	-1.43	1.05	-	8.51***

a. ECT - error correction term in the Error-Correction Model.
***, **, and * indicate significance at the 1%, 5%,and 10% levels, respectively.