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ANALYSIS

Causal relationship between energy consumption and GDP growth revisited: A dynamic panel data approach☆

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A R T I C L E I N F O

Article history:
Received 30 September 2007
Received in revised form
8 November 2007
Accepted 9 November 2007
Available online 20 February 2008

Keywords:
Panel VAR
GMM
Environmental Kuznets Curve
Energy consumption
Economic growth

JEL classification:
Q_{43}

A B S T R A C T

This paper uses the panel data of energy consumption and GDP for 82 countries from 1972 to 2002. Based on the income levels defined by the World Bank, the data are divided into four categories: low income group, lower middle income group, upper middle income group, and high income group. We employ the GMM-SYS approach for the estimation of the panel VAR model in each of the four groups. Afterwards, the causal relationship between energy consumption and economic growth is tested and ascertained. We discover: (a) in the low income group, there exists no causal relationship between energy consumption and economic growth; (b) in the middle income groups (lower and upper middle income groups), economic growth leads energy consumption positively; (c) in the high income group countries, economic growth leads energy consumption negatively. After further in-depth analysis of energy related data, the results indicate that, in the high income group, there is a great environmental improvement as a result of more efficient energy use and reduction in the release of CO_2. However, in the upper middle income group countries, after the energy crisis, the energy efficiency declines and the release of CO_2 rises. Since there is no evidence indicating that energy consumption leads economic growth in any of the four income groups, a stronger energy conservation policy should be pursued in all countries.

1. Introduction

The crude oil price hit a historical high of $77.05 per barrel on August 2006. Practitioners and academics alike are again concerned about the economic impact of high oil prices. Similarly, could the economic growth resulting from the increase in oil consumption, at the same time, offset the negative externality inflicting on environments? This has been the focus of debate in the last two decades. If the benefit in economic growth outweighs the cost of environmental damage, it is worth increasing energy use to accelerate economic growth. On the other hand, if energy consumption

☆ The valuable comments from the editor and two referees are greatly appreciated. Any errors are our own.
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[1] Financial support from the National Science Council (NSC95-2415-H-194-002) is gratefully acknowledged.

0921-8009/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolecon.2007.11.006

does not increase or even adversely impacts economic growth, a conservation energy consumption policy is needed to avoid the adverse impacts on the economy.

The literature on the relationship between energy consumption and income dates back to the late 1970s. Kraft and Kraft (1978), in their pioneering work, used U.S. data from 1947–1974 to discover that GNP leads energy consumption. Using U.S. monthly data from 1973 to 1979, Akarca and Long (1979) showed instead that energy consumption leads employment (in the literature, some economists use employment or production to substitute for economic growth). More inconsistencies ensued. Akarca and Long (1980), Erol and Yu (1987a), Yu and Choi (1985), and Yu and Hwang (1984) found no relationship between the two. Erol and Yu (1987b, 1989), Yu and Jin (1992), and Yu et al. (1988) went one step further to test the neutrality hypothesis and found a neutrality relation (i.e., no causal relationship between the two).

The main reason for the discrepancy in results in the previous research comes from the use of different econometric methods. In most cases, the OLS model of log-linear was used to estimate parameters and to conduct statistical tests without taking into consideration the special features of time series data. As is well known, a spurious regression in the analysis could exist (Granger and Newbold, 1974) and as a result, the previous statistical results might well be misleading.

The statistical method in time series has made important advances in the past decade. As in many other economic fields, the relationship between energy consumption and economic growth was revisited and statistically tested again using newer time series analysis. Yu and Jin (1992) applied the Engle–Granger technique to 1974.01–1990.04 data and found no long-term cointegration relation and no causal relationship between the two. The neutrality relation is, therefore, established. Masih and Masih (1996, 1997) used the Johansen cointegration algorithm to test the existence of cointegration between real GDP and total energy consumption using data in the period of 1955–1990 for India, Pakistan, Indonesia, Malaysia, Singapore, the Philippines, Taiwan, and South Korea. Next, either the vector error-correction model (VEC) or the vector autoregressive model (VAR) was used to test the relative causal relationship. The test results indicate no cointegration relation exists in Malaysia, Singapore, and the Philippines and, therefore, the neutrality hypothesis was supported. The rest of the other five countries do have a cointegration relation between energy consumption and economic growth. In particular, the test results show that: in India, energy consumption leads economic growth as a causal relationship; in Indonesia, GNP leads energy consumption; and Pakistan, Taiwan, and South Korea show a bi-directional relationship.

Cheng and Lai (1997) employed Engle-Granger's cointegrating test for Taiwan during 1955–1993 to investigate the relationship between energy and GDP, and between energy consumption and employment. They used the FPE (Final Prediction Error) version of Hsiao (1981), rather than AIC or SBC, to determine the optimal lag in Granger's causality test. They discovered that GDP leads energy as a uni-directional causal relationship in Taiwan. Their test result is in contrast to that of Masih and Masih (1997) and Hwang and Gum (1992) (bi-directional relationship). Interestingly, Yang (2000) updated the data of Taiwan to 1997 (1954–1997) and used the same Engle and Granger (1987) cointegration method along with the FPE of Hsiao (1981) to discover a bi-directional relationship between energy consumption and economic growth.

Glasure and Lee (1997) applied the cointegrating technique and error-correction model to test the relationship between energy consumption and economic growth for South Korea and the Philippines. Based on the Granger cointegrating causality test, they discovered a bi-directional relationship in these two countries. Without considering the cointegration among variables, South Korea shows no Granger causal relationship, and the Philippines indicates a uni-directional causal relationship running from energy consumption to GDP.

In the bivariate model, Asafu-Adjaye (2000) added the price factor (using the consumer price index, i.e., CPI, to represent energy price) and applied Johansen's cointegration technique and the Granger causality test to investigate energy dependency and the relationship between energy consumption and economic growth in four countries in Asia: India, Indonesia, the Philippines, and Thailand. Both Thailand and the Philippines show a bi-directional relationship, while India and Indonesia show a uni-directional causality with energy consumption leading economic growth. Hondroyiannis et al. (2002) employed a trivariate model (energy consumption, real GDP, and price) and applied Johansen's cointegration technique and error-correction model to test the causality relationship in Greece during 1960–1996. They found no relationship among the three variables in the short run and some relationship in the long run. They concluded that the adoption of suitable structural policies aiming at improving economic efficiency can induce energy conservation without impeding economic growth.

Using cointegration and vector error-correction techniques, Soytas and Sari (2003) examined the causal relationship between GDP and energy consumption from 1950 to 1992 in the top 10 emerging countries (China excluded) and the G-7 countries. They discovered bi-directional causality in Argentina, uni-directional causality with energy consumption leading GDP in Turkey, France, West Germany and Japan, and the causality with GDP leading energy consumption in Italy and Korea.

Altinay and Karagol (2004) employed Hsiao's criterion to investigate the causal relationship between the GDP and energy consumption in Turkey during the period of 1950–2000. They concluded that there was no evidence of causality between the two and the data were trend stationary with a structural break.

Oh and Lee (2004a) used four variables (energy consumption, GDP, capital, and labor) from the supply side and three variables (energy consumption, GDP, and price) from the demand side in their multivariate Granger causality analysis to investigate the relationship between energy consumption and GDP in South Korea during the period of 1981:1–2004:4. They also employed the VEC model to distinguish between a long run and short run relationship among the variables and to identify the source of causation. In the short run, no causality was detected; however, GDP led energy consumption in the long run. Therefore, the government in South Korea can pursue conservation energy policy in the long run without compromising economic growth. Using the same techniques, with different periods during 1970–1999, Oh and Lee (2004b) indicated a short run uni-directional causality running from energy consumption to GDP and a long run bi-directional causal relationship.

Paul and Bhattacharya (2004) applied the Johansen multivariate cointegration technique on four variables (energy consumption, GDP, capital, and labor) and found bi-directional causality between energy consumption and economic growth. Lee (2005) employed panel cointegration and panel error-correction models to investigate the causal relationship between GDP and energy consumption in 18 developing countries during the period of 1975 to 2001. There is evidence of a short run and long run uni-directional causal relationship running from energy to GDP. Consequently, energy conservation may harm economic growth in those developing countries. Lee (2006) used the Granger causality cointegration test suggested by Toda and Yamamoto (1995) to investigate the relationship between energy consumption and GDP for 11 industrialized countries from 1960 to 2001. He discovered that: (i) there is no causal relationship between the two for the UK, Germany, and Sweden; (ii) U.S. data indicate a bi-directional causal relationship; (iii) Canada, Belgium, Netherlands, and Switzerland show a uni-directional causal relationship running from energy consumption to GDP; and finally (iv), France, Italy, and Japan show the relationship with GDP leading energy consumption. However, Lee and Chang (2007) applied the panel data to 22 developed countries and 18 developing countries to investigate the causal relationship between energy consumption and GDP using the bivariate model under the panel VAR framework of Holtz-Eakin et al. (1998). They discovered a uni-directional causal relationship running from GDP growth to energy consumption in the developing countries. In the developed countries, however, a bi-directional (or feedback) causality exists between the two.

Based on the literature review in Table 1, the causal relationship using the same country data could be different due, in part, to differences in research periods or in research methodologies. The most probable reason for the discrepancy is the insufficient number of observations in the data. It is manifest from the literature that most data are in the 30 to 40 years span. For the unit root or Johansen cointegration test, the 30–40 data points are few and as such, low statistical testing power is expected. Thus, the inconsistency in results is not unexpected.

In order to compensate for the deficiency in an inadequate sample size, the panel data approach is needed to reevaluate the relationship between energy consumption and income. The Granger causality test is mostly used in the time series data to investigate the relationship between energy consumption and economic growth. However, the dynamic panel estimation (DPE) approach needs to be used to identify the causal relationship for the panel data. Holtz-Eakin et al. (1998) and Arellano and Bond (1991) first suggested using all of the available lags as instruments to estimate the equation in first difference from dynamic panel data (DPD). With the availability of macroeconomic panel data, more DPE are used to investigate the causal relationship among macroeconomic variables. Though the DPE approach has not been widely used to investigate the relationship between energy consumption and economic growth in the literature, it is beginning to be used in recent years in other research areas such as defense spending and military growth (Yildirim et al., 2005), public finance (Fiorito and Kollintzas, 2004; Feeny et al., 2005), finance (Alessie et al., 2004), and labor supply (Baltagi et al., 2005). Due to the econometric deficiency of inadequate sample size in time series data, and the greater availability of macropanel data, the literature is on the rise in the use of panel data in the macrorelated research. As was indicated

Table 1 – Summary of Literature review on the causal relationship between energy consumption and income

Authors	Countries	Results
Kraft and Kraft (1978)	US	y→ec
Akarca and Long (1979)	US	ec→employment
Akarca and Long (1980)	US	Neutral
Erol and Yu (1987a)	Japan	ec→y
Yu and Choi (1985)	S. Korea	y→ec
Yu and Hwang (1984)	Philippines	ec→y
Yu and Jin (1992)	US	Neutral
Masih and Masih (1996)	India	ec→y
	Pakistan	y↔ec
	Indonesia	y→ec
	Malaysia, Singapore, Philippines	Neutral
Masih and Masih (1997)	Taiwan	y↔ec
	S. Korea	y↔ec
Cheng and Lai (1997)	Taiwan	y→ec
Yang (2000)	Taiwan	y↔ec
Glasure and Lee (1997)	S. Korea	y↔ec
	Singapore	y↔ec(ec→y)
Asafu-Adjaye (2000)	India, Indonesia	ec→y
	Philippines, Thailand	y↔ec
Stern (2000)	US	ec→y
Hondroyiannis et al. (2002)	Greece	Neutral
Soytas and Sari (2003)	Argentina	y↔ec
	Italy, S. Korea	y→ec
	Turkey, France, Germany, Japan	ec→y
	Brazil, India, Indonesia, Mexico, Poland, South Africa, U.S., U.K., Canada	Neutral
Altinay and Karagol (2004)	Turkey	Neutral
Oh and Lee (2004b)	S. Korea	y↔ec(ec→y)
Paul and Bhattacharya (2004)	India	y↔ec
Jumbe (2004)	Malawi	y→ec
Lee (2006)	U.K., Germany	Neutral
	Sweden, U.S.	y↔ec
	Canada, Belgium, Netherlands, Switzerland.	ec→y
	France, Italy, Japan.	y→ec
Lee and Chang (2007)	Developing Countries (18)	y→ec
	Developed Countries (22)	y↔ec

Notes: → denotes leads, ↔ denotes bi-directional causality or feedback, ec = energy consumption, and y = per capita real GDP.

by Bond (2002), "Dynamic models are of interest in a wide range of economic applications, including Euler equations for household consumption, adjustment cost models for firm's factor demands, and empirical models of economic growth. Even when coefficients on lagged dependent variable are not of direct interest, allowing for dynamics in the underlying process may be crucial for recovering consistent estimator of other parameters (p.142)".

It is, therefore, necessary that the DPE approach be used to investigate the dynamic relation between energy consumption and economic growth. As such, this is one of our major contributions.

However, the use of panel data also creates another problem, in which different countries as a whole are treated as an entity, not as a separate unit. As a result, we cannot identify the difference in the dynamic relationship between energy consumption and income among countries. As the degree of economic development in each country is different, the relationship between energy consumption and economic growth will be different as well. For example, a developed country may use more resources to increase the efficiency of energy use and to better regulate environmental protection, while a developing country may put more resources in industrial production rather than energy efficiency and environmental protection. As a result, the relationship between energy consumption and economic growth should be different in two countries with different degrees of economic development (e.g., Lee, 2006). Another contribution of this paper is to partially resolve the "lump-together" problem in using panel data; we classify the panel data into four sub-panels based on the difference in income levels before further estimation.[2] Our results indicate that the dynamic relationship between income and energy consumption is indeed different in each income group.

If we use the panel data as a whole for 82 countries from 1972 to 2002, there is a bi-directional (feedback) relationship between energy consumption and economic growth. However, by grouping the data into four income groups based on the income levels defined by the World Bank (low income group, lower middle income group, upper middle income group, and high income group), we discover: (a) in the low income group, there exists no causal relationship between energy consumption and economic growth; (b) in the middle income groups (lower and upper middle income groups), economic growth leads energy consumption positively; (c) in the high income group countries, economic growth leads energy consumption negatively. This paper is organized as follows. Section 1 discusses the research motives and a review of related literature. Section 2 introduces data and econometric methods. Section 3 analyzes and discusses empirical results. Section 4 is the policy implications derived from this study. The final Section 5 gives concluding remarks.

2. Model specification, econometric method, and data

In reference to the often-used explanatory variables in the literature (Oh and Lee, 2004a,b), we specify $\mathrm{lec}_{i,t}$ (log of energy consumption), $\mathrm{ly}_{i,t}$ (log of per capita real GDP), and other controlling variables as $\mathrm{liy}_{i,t}$(log of the share of capital formation to GDP to represent capital stock),[3] $\mathrm{lf}_{i,t}$(log of population to represent labor force), and $\mathrm{lp}_{i,t}$(log of GDP deflator). This is a 5-variable VAR model, where the subscripts are *i*th country and *t*th period. By taking into consideration the individual effect, the 5-variable panel VAR model can be shown as:

$$y_{i,t} = \sum_{j=1}^{p} \alpha_j y_{i,t-j} + \beta'(L)x_{i,t} + \eta_i + v_{i,t}. \tag{1}$$

η_i represents unobserved country-specific and time-invariant effect with $E(\eta_i)=\eta$ and $\mathrm{Var}(\eta_i)=\sigma_\eta^2$. The $v_{i,t}$ are assumed to be independently distributed across countries with zero mean, but arbitrary forms of heteroskedasticity across units and times are possible. $y_{i,t}$ is $\mathrm{lec}_{i,t}$ or $\mathrm{ly}_{i,t}$; $x_{i,t}$ are predetermined variables as $\mathrm{liy}_{i,t-j}$, $\mathrm{lp}_{i,t-j}$, $\mathrm{lf}_{i,t-j}$, $\mathrm{ly}_{i,t-j}$ or $\mathrm{lec}_{i,t-j}$, where $j=1,\ldots,p$. Since η_i is assumed to follow a stochastic process of an individual effect, $E(y_{i,t-l}\ \eta_i)\neq 0$ and $E(x_{i,t}\ \eta_i)\neq 0$. $\beta(L)$ is a polynomial lag operator. To avoid the bias from the OLS estimate as a consequence of the country specific effect, we take the first difference of Eq. (1) suggested in the literature as

$$\Delta y_{i,t} = \sum_{j=1}^{p-1} \alpha_j^{*} \Delta y_{i,t-j} + \beta^{*\prime}(L)\Delta x_{i,t} + \Delta v_{i,t}, \tag{2}$$

where Δ is the first-difference operator. Eq. (2) may take care of the OLS estimation problem due to a correlation between individual effect and explanatory variables, but it also gives rise to another problem: the correlation between the lagged dependent and error term, that is, $E(\Delta y_{i,t-l}\ \Delta v_{i,t})\neq 0$. Thus, the estimation of Eq. (2) by OLS will render a biased and inconsistent result. Arellano and Bond (1991) employed lagged dependent variables ($y_{i,t-s}$ for $s\geq 2$) in level as instrument in the GMM (Generalized Method of Moment) to overcome the problem of $E(\Delta y_{i,t-l}\ \Delta v_{i,t})\neq 0$. Then, the corresponding optimal instrument matrix Z_i with predetermined regressors x_{it} correlated with the individual effect is given by

$$Z_i = \begin{pmatrix} y_{i1} & x_{i1} & x_{i2} & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & \cdots & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & y_{i1} & y_{i2} & x_{i1} & x_{i2} & x_{i3} & \cdots & 0 & \cdots & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & & \vdots & & \vdots & \vdots & & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & y_{i1} & \cdots & y_{i(T-2)} & x_{i1} & \cdots & x_{i(T-1)} \end{pmatrix}, \tag{3}$$

[2] If we pool every country's data together as a whole, the statistical testing power of estimation is greatly enhanced, but the heterogeneity among countries is neglected. On the other hand, if each country's data is separately estimated, there could be small sample bias in estimation due to inadequate data points. Owing to the difference in the degree of economic development, the relationship between energy consumption and economic growth may well be different. We classify the data into four categories according to different income levels. As a result, we solve the problem of inadequate data points in each country and partially solve the problem of not tackling the homogeneity when combining all 82 countries.

[3] Since the share of capital formation to GDP is a flow variable and capital stock is a stock variable, the use of the share of capital formation to GDP to represent capital stock may seem inappropriate. In reality, capital stock is difficult to estimate, and a proxy variable is needed. Most related literature uses the share of capital formation to GDP to represent capital stock (see Ram, 1986). We thank greatly one of the referees for pointing out this problem.

where rows correspond to the first-difference equation (Eq. (2)) for periods $t=3, 4,\ldots, T$ for individual i, which exploit the moment conditions

$$E[Z_i' \Delta\upsilon_i] = 0 \quad \text{for } i = 1, 2\ldots, N, \tag{4}$$

where $\Delta\upsilon_i=(\Delta\upsilon_{i3}, \Delta\upsilon_{i4},\ldots, \Delta\upsilon_{iT})'$. In general, the asymptotically efficient GMM estimation based on this set of moment conditions minimizes the criterion.

$$J_N = \left(\frac{1}{N}\sum_{i=1}^{N} \Delta\upsilon_i' Z_i\right) W_N \left(\frac{1}{N}\sum_{i=1}^{N} Z_i' \Delta\upsilon_i\right). \tag{5}$$

Using the weight matrix

$$W_N = \left[\frac{1}{N}\sum_{i=1}^{N} \left(Z_i' \widehat{\Delta\upsilon_i} \quad \widehat{\Delta\upsilon_i}' Z_i\right)\right]^{-1},$$

where the $\widehat{\Delta\upsilon_i}$ are consistent estimates of the first-differenced residuals obtained from a preliminary consistent estimator. Hence, this is known as a two-step GMM estimator. Under the assumption of homoskedasticity υ_{it}, the particular structure of the first-differenced model implies that an asymptotically equivalent GMM estimator can be obtained in one-step, using instead the weight matrix

$$W_{1N} = \left[\frac{1}{N}\sum_{i=1}^{N} (Z_i' H Z_i)\right]^{-1},$$

where H is a $(T-2)$ square matrix with 2's on the main diagonal, −1's on the first off-diagonals and zeros elsewhere. Notice that W_{1N} does not depend on any estimated parameters.[4]

As to the use of the one-step or two-step estimator, Bond (2002) mentioned that "In fact, a lot of applied work using these GMM estimators has focused on results for the one-step estimator rather than the two-step estimator. This is partly because simulation studies have suggested very modest efficiency gains from using the two-step version, even in the presence of considerable heteroskedasticity (see Arellano and Bond, 1991; Blundell and Bond, 1998; Blundell et al., 2000), but more importantly because the dependence of the two-step matrix on estimated parameters makes the usual asymptotic distribution approximations less reliable for the two-step estimator (p.147)". For this reason, in our estimation, the robust one-step estimator is employed.[5]

Ever since Nelson and Plosser (1982) pointed out the unit root problem in aggregate time series data, the procedure of a unit root test has become one of the necessary procedures in econometric estimation. Bound, Jaeger and Baker (1995) stated that "When the individual series have near unit root properties, the instruments available for the equations in first-difference are likely to be weak. Instrument variable estimator can be subject to serious finite sample biases where the instruments used are weak".

To solve the problem of estimating the first-difference equation, the use of an instrument variable in level form is non-stationary and, therefore, is a weak instrument. Blundell and Bond (1998) suggested the use of the system GMM (GMM-SYS) model by Arellano and Bover (1995). In other words, lagged difference instead of the level form is used as possible instruments to solve the statistical problem of unit root or near unit root. Their simulation results indicate that when the coefficient on the lagged dependent variable is close to 1, the efficiency of using the GMM-SYS estimator is greatly improved.[6] The estimation of the GMM-SYS is to stack another instrument variable of the first difference to the original level instrument variable matrix (Eq. (3)) as follows:

$$Z_i^+ = \begin{pmatrix} Z_i & 0 & 0 & \cdots & 0 \\ 0 & \Delta y_{i2} & 0 & \cdots & 0 \\ 0 & 0 & \Delta y_{i3} & \cdots & 0 \\ \cdot & \cdot & \cdot & & \cdot \\ 0 & 0 & 0 & \cdots & \Delta y_{i(T-1)} \end{pmatrix}, \tag{6}$$

where Z_i is defined as in Eq. (3). The computation of the one-step or two-step GMM-SYS is as earlier shown. The only difference is the substitution of Z_i^+ for Z_i in the instrument variable matrix.

Since the coefficient of lagged dependent variable from yearly macrodata is close to 1, the robust one-step GMM-SYS of Blundell and Bond (1998) is used to estimate the relation in Eq. (3) and test the Granger causality between energy consumption and economic growth.

The kilograms (kg) of oil equivalent per capita are used to represent energy consumption. The data are obtained from the Energy Balance CD published by the International Energy Agency (IEA). The real GDP in terms of U.S. dollars based on the 2000 price index is used to represent income data. In addition, other control variables such as liy(gross capital formation as % of GDP), lf(population), and lp(GDP deflator) are all collected from the World Development Indicators (WDI) of the World Bank database. The data span 32 years from 1971 to 2002, including 82 countries from the poorest country (Congo) based on GNI of 2000 to the richest country (Luxembourg). Among these 82 countries, 19 countries are classified by the World Bank as low income countries, 22 countries are lower middle income group, 15 countries are upper middle income group, and 26 countries are high income countries.[7]

3. Analysis and discussion of results

Before Eq. (3) can be estimated, an optimal lag period p needs to be determined. There is a certain standard procedure such as AIC or SBC to determine the optimal lag period under the VAR model in time series data. However, the panel VAR model does not have a similar procedure to identify the

[4] This portion of the discussion on the GMM methodology is mainly based on Bond (2002).

[5] For the applied work using the one-step GMM estimator, see the related literature by Arai et al. (2004), Yao (2006) and Falk (2006) etc.

[6] In addition to deal with the weak instrument problem, the GMM-SYS can also handle the problems related to measurement error and time-invariant country specific effect (see Felbermayr, 2005).

[7] Appendix Table 1 displays the names of 82 countries, income groups classified from the GNI in 2000 by the World Bank.

optimal lag. So far, two approaches in the literature are available to select the optimal lag. First, the likelihood ratio test is used to select the optimal lag (Holtz-Eakin et al., 1998). Second, the *mj* statistics suggested by Arellano and Bond (1991) (where *j* is the order of autocorrelation) is employed to identify the most appropriate optimal lag. That is, under different lag periods, the selection is based on the existence of no serial correlation in the panel VAR residuals.[8] The *mj* statistic is a standardized residual autocovariance, which are asymptotically $N(0,1)$ under the null of no autocorrelation. If the disturbance υ_i is not serially correlated, there should be evidence of significant and negative first order ($j=1$) serial correlation in the difference form (i.e.$\hat{\nu}_{i,t} - \hat{\nu}_{i,t-1}$), and no evidence of second order ($j=2$) serial correlation in the differenced residuals (Doornik et al., 2006). The advantage of using *mj* statistic for an optimal lag is that the panel VAR model will also be free of misspecification from serial correlation with the optimal lag. Table 2 displays the estimated results in four different income groups from the panel VAR model using one-step GMM-SYS.[9]

The m1 and m2 of Table 2 display the first order and second order serial uncorrelated test results from the panel VAR residuals. The selection of the three lag periods is needed for the 82 countries as a whole (fifth column) and the high income group (fourth column) in order to rid the serial correlation of panel VAR residuals. For the lower middle income group (second column), the use of VAR(1) is sufficient to satisfy the assumption. Yet, the low income and the upper middle income group countries (first and third columns) require a lag of 2 periods for the economic growth equation and a delay of 1 period for the energy consumption equation in order to satisfy the assumption. Further, in all models, the Sargan statistics indicate that we cannot reject the null hypothesis, H_o: over-identifying restrictions are valid. It is apparent that the instrument variables used in the GMM-SYS estimation in our model are appropriate.

Looking at the estimated results of the panel data from 82 countries as a whole (fifth column), the test results of Granger causality indicate that we reject the null hypothesis of $\Delta lec_{i,t-j} \nrightarrow$ (does not Granger cause) $\Delta ly_{i,t}$ at the 5% significance level and also reject $\Delta y_{i,t-j} \nrightarrow \Delta lec_{i,t}$ at the 1% significance level. That is, the estimated dynamic panel data (DPD) from the GMM-SYS show that there is a feedback relationship between energy consumption and economic growth. Further analysis reveals a positive feedback relationship. In other words, an increase in energy consumption may bring about economic growth and an increase in economic growth may also bring about further increase in energy consumption. As is expected, most other explanatory variables under this 82-country category do not have significant explanatory power. The only exception is that there is a negative causal relationship between capital stock variable and economic growth.[10]

The advantage of using the panel data approach is the increase in data points and hence the power of statistical estimation. The disadvantage is that all 82 countries, as a whole, are treated as a unit, and we neglect the difference among countries. In past research using time series data for individual countries, only a few researchers discovered a bi-directional causal relationship. Most of these bi-directional relationships occurred in developing countries (Pakistan, as indicated by Masih and Masih, 1996; Taiwan and South Korea, by Masih and Masih, 1997; the Philippines and Thailand, by Asafu-Adjaye, 2000; Argentina, by Soytas and Sari, 2003; and India, by Paul and Bhattacharya, 2004). The U.S. is the only industrialized nation exhibiting the bi-directional relationship (Lee, 2006). As indicated in the introduction, the deficiency of the time series approach is the small sample size for statistical analysis, and the estimated results are not as reliable.

To investigate the difference among country blocks with sufficient sample size, groups of countries are classified based on their income characteristics (as a proxy for economic development). The panel data approach is then used to test the causal relationship between energy consumption and economic growth under different characteristics of countries in groups. The national income (representing the living standard in a country) is often used in the literature as a way to classify panel data into different groups. For example, De Gregorio and Guidotti (1995) classify data into three groups based on different income levels to investigate the correlation between banking development and economic growth. In addition, based on Fig. 1, the relationship between the energy consumption growth (average) and the economic growth (average) under different income groups from 1972 to 2002 is clearly different. There seems to be a strong positive relationship in the low income and middle income groups, but no such relationship appears in the high income group. Given the correlation coefficients between energy consumption growth and economic growth from the low to high income groups are calculated to be 0.7524, 0.6791, 0.5401, and 0.1050 respectively, the relationship between the two tends to decrease as income increases. If the data are not classified into four income groups, the correlation coefficient will be 0.5072, and the weak relationship between the two in the high income group cannot have been detected. Finally, an Environmental Kuznet Curve (EKC) indicates that there is an inverted U relation between the level of pollution and the level of income. Since the source of pollution is from energy consumption, it is reasonable to investigate energy consumption based on income levels.

According to the World Bank definition of GNI (Gross National Income) in 2000, these 82 countries are classified as low income (19 countries), lower middle (22 countries), upper

[8] In general, an optimum lag period is determined by rendering the panel VAR residual free of serial correlation. Therefore, the optimal lag is selected until no serial correlation in residual is obtained (Arellano, 2003, p.123).

[9] All of our estimations in this paper employ the DPD package under Ox. (see Doornik et al., 2006 for the use of the package). We thank the free package of DPD under Ox provided by the web-site, www.doornik.com/download.htm.

[10] Since we use the “first-difference” approach to solve the existence of an individual effect (η_i) problem in the model, the capital stock variable represents a change in capital stock. Also, the VAR model does not take into consideration the change in capital stock in the period (t). As a result, there may not be a positive relationship between economic growth and the change in the capital stock of a lagged period.

Table 2 – The estimated results from the dynamic panel GMM-SYS (four different groups per 2000 GNI)

Independent	Dependent									
	Low income (1)		Lower middle (2)		Upper middle (3)		High income (4)		World (5)	
	$\Delta ly_{i,t}$	$\Delta lec_{i,t}$	$\Delta ly_{i,t}$	$\Delta lec_{i,t}$	$\Delta ly_{i,t}$	$\Delta lec_{i,t}$	$\Delta ly_{i,t}$	$\Delta lec_{i,t}$	$\Delta ly_{i,t}$	$\Delta lec_{i,t}$
$\Delta lec_{i,t-1}$	0.0091	0.9589*	−0.0033	0.8932*	0.0280	0.8929*	0.0103	0.7593*	0.0372***	0.8863*
	(0.17)	(73.0)	(−0.10)	(60.6)	(0.69)	(41.8)	(0.48)	(11.4)	(1.90)	(12.4)
$\Delta lec_{i,t-2}$	−0.0078				−0.0360		−0.0291	−0.1376	−0.0567	−0.0187
	(−0.16)				(−0.98)		(−1.11)	(0.11)	(−1.50)	(−0.18)
$\Delta lec_{i,t-3}$							0.0076	0.0198	−0.0150	0.0076
							(0.27)	(0.38)	(−0.37)	(0.86)
$\Delta ly_{i,t-1}$	1.1220*	0.0020	0.9531*	0.0358*	1.3884*	0.0852*	1.4185*	0.4378*	1.3484*	0.1790*
	(14.1)	(0.23)	(24.5)	(2.53)	(21.8)	(6.34)	(23.5)	(4.07)	(27.0)	(3.63)
$\Delta ly_{i,t-2}$	−0.1560**				−0.4195*		−0.5550*	−0.4832**	−0.3255*	−0.1138***
	(−1.97)				(−7.19)		(−6.14)	(−2.23)	(−4.14)	(−1.83)
$\Delta ly_{i,t-3}$							0.1372	0.0739	−0.0150	0.0071
							(1.36)	(0.48)	(−0.37)	(0.17)
$\Delta liy_{i,t-1}$	0.1879*	0.1139*	0.0862*	0.1703*	−0.2625*	0.1208	−0.4294*	−0.2558	−0.1804***	−0.0626
	(3.26)	(3.26)	(2.53)	(4.46)	(−4.66)	(1.10)	(−5.57)	(−1.45)	(−1.85)	(−0.79)_
$\Delta liy_{i,t-2}$	−0.0600				0.1809		0.3212*	0.2729	0.1513***	0.1057
	(−0.94)				(3.47)		(2.51)	(1.40)	(1.78)	(1.15)
$\Delta liy_{i,t-3}$							−0.1057	−0.1203	−0.0350	−0.0168
							(−1.07)	(−0.77)	(−0.72)	(−0.27)
$\Delta lp_{i,t-1}$	−0.0134**	0.0002	0.0004	0.0005	0.0108	0.0025**	−0.0559	−0.0965*	0.0006	−0.0075
	(−2.21)	(0.48)	(0.51)	(0.90)	(1.50)	(2.04)	(−1.30)	(−3.04)	(0.10)	(−0.87)
$\Delta lp_{i,t-2}$	0.0133**				−0.0099		0.0925	0.2154*	−0.0007	0.0130
	(2.19)				(−1.44)		(1.25)	(3.85)	(−0.06)	(0.87)
$\Delta lp_{i,t-3}$							−0.0374	−0.1095*	0.0009	−0.0031
							(−1.17)	(−4.57)	(0.14)	(−0.43)
$\Delta lf_{i,t-1}$	−0.3278	0.0054*	0.0030	0.0045	−0.0174	−0.0108	0.3572	−0.7027***	0.0500	−0.0116
	(−0.66)	(1.76)	(0.33)	(0.90)	(−0.09)	(1.10)	(1.24)	(−1.89)	(0.19)	(0.03)
$\Delta lf_{i,t-2}$	0.3356				0.0151		−0.4874	1.3807*	−0.2485	−0.6618
	(0.67)				(0.08)		(−1.03)	(2.68)	(−0.56)	(−0.69)
$\Delta lf_{i,t-3}$							0.1219	−0.6779*	0.1979	0.6512
							(0.53)	(−2.60)	(0.74)	(1.16)
N	19	19	22	22	15	15	26	26	82	82
NT	551	551	660	660	435	435	754	754	2296	2296
Sargan test *p*-value	0.79	0.16	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
m1	−3.48*	−2.85*	−2.59*	−4.05*	−3.35*	−1.82***	−4.04*	−3.32*	−6.03*	−5.19*
m2	−1.39	−1.25	−0.52	−0.97	−0.25	0.86	−0.37	−0.75	−1.19	1.50
$\Delta lec_{i,t-j} \nrightarrow \Delta ly_{i,t}$	0.03		0.01		3.06		4.63		8.26**	
	[0.99]		[0.92]		[0.22]		[0.20]		[0.04]	
$\Delta ly_{t,t-j} \nrightarrow \Delta lec_{t,-i}$		0.05		6.42*		40.25*		22.10*		69.71*
		[0.82]		[0.01]		[0.00]		[0.00]		[0.00]

Note: N = no of countries; NT = no of observations; Sargan statistics are used to test H_o: over-identifying restriction are valid; number inside ( ) are *t* statistics; number inside [ ] are *p*-values; Δ = first difference; ly, lec, liy, lp and lf represent log of per capital income, log of energy consumption, log of capital formation to output ratio, log of price level and log of labor force (population), respectively. m1and m2 denote the statistics of serial uncorrelated residuals of the first and second order in the testing of the panel model; ↛ represents "does not Granger cause"; *, **, and *** represent respectively 1%, 5% and 10% significance levels.

middle (15 countries), and high income (26 countries) groups.[11] The data span from 1971 to 2002 and year 2000 is used as a base year for both classification for income groups and per capita real GDP computation. The detailed grouping of countries under different GNI levels is shown in Appendix Table 1.[12] The estimated results from the GMM-SYS of panel data in four income groups are shown in Table 2.

For the low income group countries (column 1 in Table 2), the Granger causality test indicates that an increase in energy consumption does not lead economic growth and an increase in economic growth also does not bring about increase in energy consumption. The energy policy in this income group

[11] Following the World Bank definition for classification based on GNI in 2000, countries are classified as low income if GNI is lower than $826, as lower middle income countries if $826≤GNI≤$3255, as upper middle income countries if $3256≤GNI≤$10,065, and as high income countries if GNI is greater than $10,065.

[12] The standard for grouping based on GNI may have changed over the years, but very few countries have moved from one group to the other.

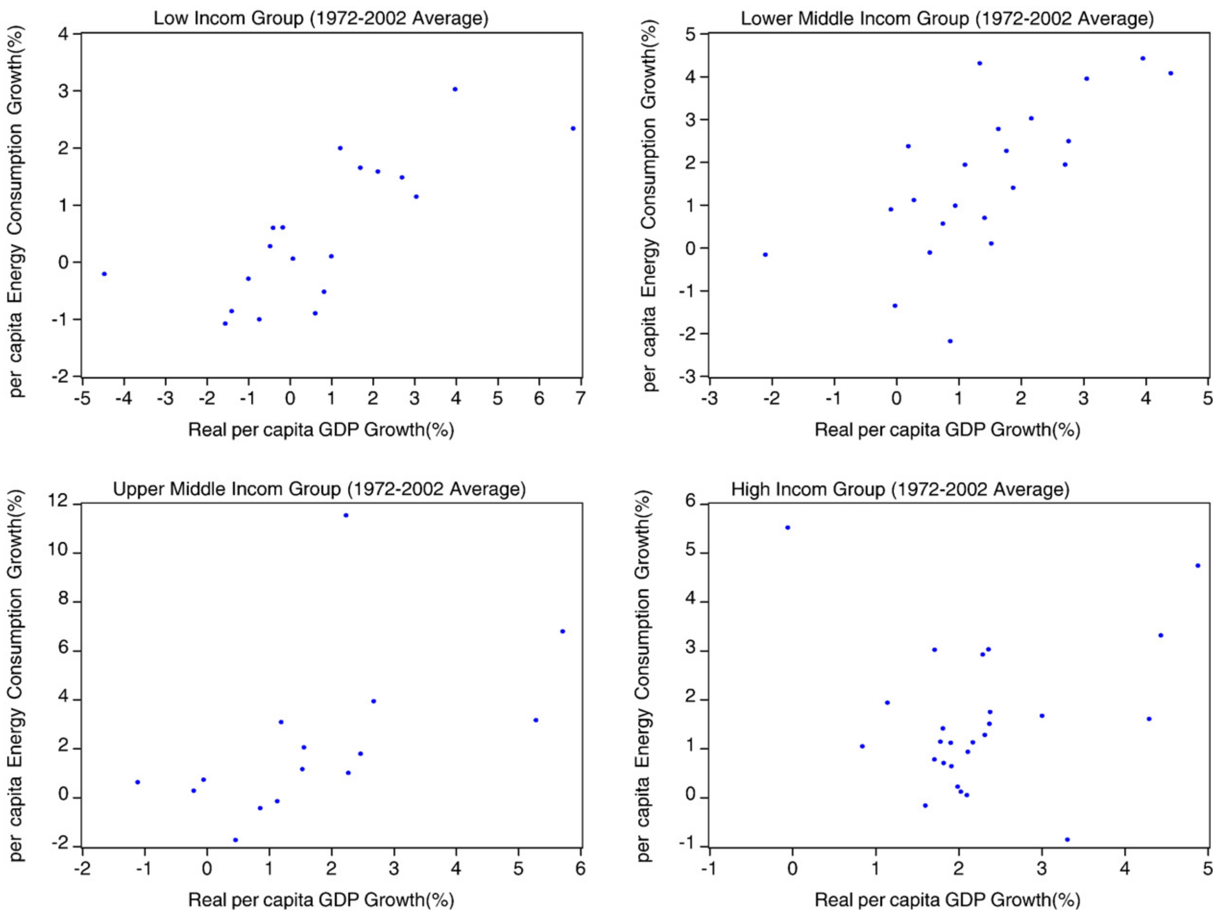

Fig. 1 – Per capita energy consumption growth vs. per capita GDP growth.

is difficult to determine because energy consumption may not bring about economic growth, according to our empirical evidence. For the lower middle income group countries (column 2 of Table 2), the energy consumption does not Granger cause economic growth, but an increase in economic growth may bring about increase in energy consumption at the 1% significance level. For the upper middle income group, we have a causal relationship similar to the lower middle income group. That is, an increase in economic growth will bring about an increase in energy consumption, but not vice versa. The only difference between those two groups is that it is statistically more significant for the upper middle income group than is the lower middle income group. For the middle income group countries (includes the lower middle income and upper middle income groups), it is appropriate to take a more aggressive energy conservation policy. Finally, for the high income group countries, the Granger causality test indicates that income change leads energy consumption change. The estimated results of the energy consumption equation further reveals that the overall effect of economic growth on energy consumption is negative (the coefficient for one-period lag is 0.4378 and for two-period is −0.4832). In other words, the economic growth may bring about a decrease in energy consumption. It seems to imply that the high income group countries have undertaken an energy conservation policy. After we group data into four categories on the basis of income levels in these 82 countries, we do not find the same causal relationship in each group as we found when 82 countries are pooled as a whole. In the 82-country data as a whole, energy consumption leads economic growth positively. It is apparent that the classification of countries into different income groups is conducive to a better and finer understanding of causal relationship between energy consumption and economic growth under different income levels.

As indicated previously, energy use may bring about both economic growth and the externality of environmental pollution. The question is whether energy consumption can result in greater benefits in economic growth relative to the cost of environmental pollution. This simple benefit–cost relation is implied in the causal relationship between energy consumption and income. When energy consumption can bring about economic growth, it suggests that the benefit of energy use to the economy is greater than the cost of environmental damage. Conversely, if economic growth leads energy consumption positively, it may suggest the cost of using energy is greater than the benefit it brings. After we classify these 82-country data into four different income groups, we do not find any group where energy consumption leads economic growth as a uni-directional causal relationship. Conversely, the economic growth leads energy consumption in the middle income groups (lower middle income group and upper middle income group). For those two middle

Table 3 – Mean and standard deviation of some energy related data characteristics in four different income groups

Group	ec/y	Δy	Δec	CO_2	ind/y	Δec/Δy
a. 1971–2002						
Low	0.3199	0.1478	0.2125	0.2991	25.4005	1.44
	(0.2036)	(5.1368)	(4.2003)	(0.2108)	(8.9467)	
Lower	0.1969	1.6745	1.5582	0.4816	32.7056	0.93
Middle	(0.0986)	(4.8444)	(5.6429)	(0.3514)	(8.4108)	
Upper	0.2200	1.9182	2.8025	0.6002	39.2199	1.46
Middle	(0.1206)	(5.2602)	(8.7131)	(0.4499)	(10.9005)	
High	0.2067	2.3463	1.4914	0.4834	33.1352	0.64
	(0.0733)	(2.6544)	(4.9375)	(0.2027)	(3.7049)	
b. 1971–1980						
Low	0.3294	0.5915	0.6701	0.2919	24.2093	1.13
	(0.2165)	(6.1130)	(3.7839)	(0.2335)	(9.1846)	
Lower	0.2086	2.9430	2.7936	0.4934	32.2813	0.95
Middle	(0.1662)	(5.9702)	(6.6326)	(0.4753)	(9.8380)	
Upper	0.1843	3.6108	4.5266	0.5850	42.7159	1.25
Middle	(0.0787)	(5.4993)	(9.6935)	(0.3800)	(14.6010)	
High	0.2328	2.8495	1.9795	0.6068	37.0352	0.69
	(0.0943)	(3.1386)	(6.1689)	(0.3204)	(3.8466)	
c. 1981–2002						
Low	0.3172	−0.0337	0.0252	0.3014	26.0839	−0.75
	(0.2060)	(4.6753)	(4.3497)	(0.2078)	(9.5750)	
Lower	0.1938	1.1556	1.0529	0.4780	32.8985	0.91
Middle	(0.0852)	(4.1978)	(5.1061)	(0.3242)	(7.9429)	
Upper	0.2297	1.2257	2.0972	0.6053	37.9504	1.71
Middle	(0.1381)	(5.0050)	(8.1903)	(0.4809)	(9.3390)	
High	0.1996	2.1405	1.2917	0.4483	31.5493	0.60
	(0.0698)	(2.4022)	(4.3247)	(0.1747)	(3.7918)	

Notes: ec/y = energy use per PPP GDP (kg of oil equivalent per constant 2000 PPP $); Δy = per capita real GDP growth (%); Δec = energy use (kg of oil equivalent per capita) growth (%); CO_2 = CO_2 emissions (kg per 2000 PPP $ of GDP); ind/y = % of value added in industry to GDP; numbers inside ( ) are standard deviations and numbers above ( ) are means; Δec/Δy represents the % increase in energy consumption resulting from a 1% increase in GDP.

groups, an increase in economic growth may enhance energy consumption and may bring about the externality of environmental damage without the benefit of economic growth from energy consumption. For the high income group countries, energy consumption does not bring about economic growth. However, as income increases, they begin to pay attention to the possible cost of environmental pollution and try to reduce energy consumption. For the low income countries, there is no evidence that energy consumption may bring about economic growth, or that an increase in income may bring about energy consumption. When energy consumption cannot bring about economic growth, the implication is that those countries should adopt a conservation policy to avoid damage to the environment and a waste of resources.

To understand our contributions, it is necessary to compare our econometric models and empirical results with the most recent publication using DPD by Lee and Chang (2007). There are many differences between our analyses notwithstanding the fact that they also applied the DPD model to investigate the causal relationship between energy consumption and economic growth. First, we include more countries (82 countries vs. 40 countries). Our data are classified into four income group countries rather than two, as in their study. We also take into consideration the measurement error, weak instrument and time-invariant country specific effect from the GMM-SYS instead of the GMM model. Our VAR model includes other control variables, while Lee and Chang employ the bivariate model. We use EKC and related energy data to further investigate the causality results. Lee and Chang (2007) do not include such discussion. Our discovery of economic growth leading positively the energy consumption in the middle income group countries is the same as those of developing countries by Lee and Chang (2007). Lee and Chang indicated that, for those 18 developed countries, economic growth leads positively the energy consumption and energy consumption leads negatively the economic growth (a bi-directional feedback relation). Our results of economic growth leading energy consumption negatively for the developed countries (high income group countries) seems to be more consistent with the recent energy policy adopted in those developed countries.

Our estimated results can further be explained by the concept of EKC. EKC is an “inverted U” relationship between the level of economic development and the pollution level. In the low income countries, there are not many industrial activities to pollute the environment. As the economy improves, pollution gradually increases. Furthermore, as the industrial potential expands, it offers location advantages for high-pollution industries. Sooner or later, the pollution problem becomes a major concern which calls for remedial actions. Generally speaking, as the income increases beyond some threshold, there is a tendency towards producing low-pollution products. More resources are devoted to environmental protection. Therefore, we expect the causal relationship that economic growth leads energy consumption negatively. As a result, pollution falls as income grows. The pioneering work of Grossman and Krueger (1995) sets the path to investigate the existence of EKC in which they discovered the highest EKC point at $8000 per capita income (1985 price level). This corresponds to the income level of Mexico and Malaysia in 1994. Although the main purpose is not to investigate the EKC relation, our results, using the panel data analysis of four income groups, are quite consistent with those of the EKC prediction.[13] For the middle income group countries (lower middle income group and upper middle income group), we discovered that economic growth leads positively energy consumption. The implication is that, as income begins to increases, a negative externality (e.g., pollution) of energy consumption starts to increase. Once a country achieves high income group status, an increase in income may reduce the negative externality of energy consumption as is shown by the EKC relation. For the low income group countries in which basic industry and transportation systems are insufficient, and energy use is low, these countries are unable to generate much output (income). It is no wonder there exists no causal relationship between energy consumption and economic growth.

In order to analyze further the Granger causality in each income group, the pollution-related calculations need to be included in the statistical analysis. In each of these four income group countries, we collect additional information, such as average CO_2 emissions (pollution level) per $1 real GDP, the share of value added in industry to GDP (ind/y, the weight of industrial production), the share of energy used per $1 real GDP (ec/y, the efficiency of energy use), average per capita real GDP growth (Δy), and average growth of energy use (Δec).[14] These calculations are shown in Table 3.

As seen in the CO_2 column of Table 3a when all the data (1972–2002) are considered, the most serious pollution appears in the upper middle income group countries. The least pollution happens to be in the low income group countries, followed by the lower middle and high income group. These results indicate that there is indeed an EKC relation. By separating the data into during-energy crisis (1972–1980) and post energy crisis (1981–2002) periods, we found that the order of pollution levels in the four groups is slightly different. During the energy crisis, the most serious polluters of CO_2 are in the high income group, followed by the upper middle income group, the lower middle income group, and the low income group. After the energy crisis, the most serious polluters of CO_2 are in the upper middle income group, followed by the lower middle income group, and high and low income groups. Viewed from the prospect of pollution, the EKC relation in fact appears in the post energy crisis period. In other words, after the energy crisis, the high income group countries made great strides to reduce the pollution. Yet the upper middle income group and low income group countries increased rather than decreased their emission of CO_2. The lower middle income group countries tended to decrease slightly the pollution of CO_2 after the energy crisis.

The effort made by the high income group countries to reduce pollution and to increase the efficiency of energy use can be seen from the column of ec/y in Table 3. The variable for energy efficiency (ec/y) represents the required unit of energy use per $1 increase in GDP. It is difficult to see the trend of relative energy efficiency in four different income groups when the whole period (1972–2002 average) is used. The most efficient use of energy is in the lower middle income group countries followed by the high income group, the upper middle income group, and finally the low income group countries. If the data are delineated into energy crisis period and post energy crisis period, the ec/y ratio in the high income group decreases from 0.2328 of energy crisis to 0.1996 of post energy crisis (the most among those four groups). That is, the increase in the efficiency of energy use is the most for the high income group. For the lower middle income group and the low income group countries, there is a small increase in the efficiency of energy use. The upper middle income group is the only group with efficiency getting worse not better (from the energy crisis of 0.1843 to the post crisis of 0.2297). As was pointed out by Cleveland et al. (2000), in some industrialized nations, the decrease in the ec/y ratio comes from the change in energy mix. That is, "The change from coal to petroleum and petroleum to primary electricity is associated with a general decline in the ec/y ratio". As the high income group countries improve the weight of using pollution free electrical energy, the decrease in the release of CO_2 is expected.

For the high income group countries, the improvement in the release of CO_2 and ec/y ratio confirms the causal relationship that economic growth leads energy consumption negatively. This discovery further provides the evidence that the $\Delta ec/\Delta y$ ratio (the required % increase in energy consumption resulting from a 1% increase in economic growth) changes from the energy crisis of 0.7% to the post crisis of 0.6%. It is manifest that, as the income increases in the high income group, energy use tends to diminish (the efficiency of energy use increases) and the release of pollution (CO_2) also tends to decrease. It is not surprising then that economic growth leads energy consumption growth negatively in the high income group countries.

Similarly, in the upper middle income group, there is a unidirectional causality running from economic growth positively to energy consumption. The release of CO_2 pollution after the energy crisis tends to increase and the efficiency of energy use tends to decrease. A 1% increase in income requires more than 1% of energy consumption. The release of CO_2 in this income group is the highest among the four

[13] For the survey literature of EKC, see Dinda (2004). There is an abundant literature on empirical studies of EKC such as Torras and Boyce (1998), Agras and Chapman (1999), and Dinda et al. (2000).

[14] All the energy-related data are collected from the Energy Balance CD published by the International Energy Agency (IEA). Besides the computation of means for the period between 1972 and 2002, means for both during and after energy crisis are also calculated to facilitate comparisons of energy use in all four different income groups.

groups and the ec/y ratio is the second highest (second only to the low income group) due to both high ind/y (industrial production/GDP, among the highest) and Δec/Δy (energy increase rate is greater than 1) ratios. Upper middle income group countries have relatively low production cost and are eager to raise the income level. They take advantage of low labor costs to encourage construction of factories from foreign investments and production of goods and services. Since standards are lax regarding environmental protection and related environmental regulations, relatively more pollution generating energy sources (e.g., coal and petroleum) are used. As a result, greater release of CO_2 and inefficient use of energy are expected. The economic reality in this income group seems to be in agreement with the causality from our panel VAR results that economic growth leads energy consumption positively.

For the lower middle income group, we discover that, like the upper middle income group, economic growth leads energy consumption positively as a uni-directional causality. Table 3 shows that the release of CO_2 is slightly lower than the high income group in the entire period from 1972 to 2002. A 1% increase in income requires slightly less than 1% (about 0.93%) in energy consumption, which is less than that of the upper middle income group but higher than that of the high income group. The release of CO_2 in the lower middle income group is only behind the upper middle income group after the energy crisis. The ind/y ratio is also behind that of the upper middle income group after the energy crisis. Like the upper middle income group, the same argument may apply to the lower middle income group. That is, with low production cost, this group of countries encourages capital inflow (factories in particular) to produce goods and services. It is one of the reasons that they produce relatively larger amounts of pollution (relatively high among these four groups). Compared to the upper income group, this income group releases lower amounts of CO_2 and has a higher efficiency of energy use. Our empirical results demonstrate the causality that, like the upper middle income group, economic growth leads energy consumption positively.

Finally, for the low income group countries, a 1% increase in economic growth requires more than a 1% increase in energy use. The efficiency of energy use (ec/y) is the highest and the industrial production ratio (ind/y), and the release of CO_2 are the lowest among these four groups. As such, our empirical results indicate no causal relationship between economic growth and energy consumption.

4. Policy Implications

The investigation of the causal relationship between energy consumption and income has important policy implications. When energy consumption leads income positively, it suggests that the benefit of energy use is greater than the externality cost of energy use. Conversely, if an increase in income brings about an increase in energy consumption, the externality of energy use (e.g., pollution) will set back economic growth. Under this circumstance, a conservation policy is necessary. The importance of these policy implications is evident by the size of the literature. Some focused on an individual country while others concentrated on certain developing countries or developed countries. Because of insufficient observations in annual time series data, the power of statistical tests is suspect. On the other hand, when the panel data as a whole is used, the heterogeneity among countries will be neglected. In order to avoid the paucity of time series data and the "one size for all" homogeneity problem among countries, the data are grouped into four categories in those countries according to the World Bank definitions: low income group, lower middle income group, upper middle income group, and high income group. We employ the system GMM (GMM-SYS) model suggested by Blundell and Bond (1998) to estimate the correlation of the panel VAR taking into consideration the problem of correlation between the lagged dependent variable and residuals, and the near unit root of coefficients on lagged dependent variables. The result is interesting in terms of policy implication.

The policy implications derived from this study indicate that we need to take into consideration the degree of economic growth in each country when energy consumption policy is formulated. It is evident that global warming is mostly caused by the increase in CO_2 emission in the human consumption of fossil fuels. Our research also reveals that the countries with a greater weight of industrial production to GDP (the middle income group) tend to have a larger volume of CO_2 release. To those countries, a more conservative energy policy should be pursued. Cleaner energy sources should be used to replace fossil fuels. For the high income group countries, our empirical results indicate that energy consumption tends to decrease as GDP increases. Since global warming is becoming more serious, replacement of fossil fuels and more efficient energy use are needed to minimize the CO_2 emission. Those high income countries have greater resources and more advanced technology that enable them to do more to lessen global warming. Finally, in the low income countries, we find that energy consumption does not lead economic growth and hence substantial energy consumption is not likely to bring about significant economic growth. Instead, it will increase CO_2 emission. It is very important for those low income countries in implementing appropriate energy policy to promote economic growth. A one-size-for-all energy policy is not appropriate for it fails to implement correct policies for different income group countries.

5. Concluding remarks

We use the panel data of 82 countries from 1972 to 2002 and classify the data into income groups based on the World Bank definitions. In order to have uncorrelated residual series, we select the optimal lag in each income group from the panel VAR along with the GMM-SYS model. Using data for all countries as a whole, we discover that there is a bi-directional positive feedback relationship between economic growth and energy consumption. After the data are classified into four income groups, the causal relationship in each group is fairly different. For the low income group, there is no causal relationship between economic growth and energy consumption. For the middle income group countries (lower middle income group and upper middle income group), there is a uni-directional positive causal relationship running from economic growth to energy consumption. For the high income group countries, there is a negative uni-directional causal relationship running from economic growth to energy consumption. After we classify the data into four income groups, we do not find any uni-directional causal relationship running from energy consumption to economic growth, which we found when data are lumped into one group. It is apparent that the negative externality from the economic growth more than compensates the benefit from energy use. Therefore, a relatively stronger energy conservation policy should be pursued in all countries.

In order to further investigate the difference in causality in each income group between economic growth and energy consumption, more related data are used for an in-depth analysis. We found that the countries (the middle income groups) with a greater weight of industrial production to GDP (ind/GDP) tend to have a larger volume of CO_2 release. In addition, a 1% increase in economic growth requires closer to or greater than 1% of energy consumption. Those countries usually have the causality that economic growth leads energy consumption positively. As the income increases, the energy consumption will increase. Because of over-use in energy, there will be environmental pollution and the externality from resource use. After the energy crisis, the high income group countries tried to increase the efficiency of energy use and reduce industrial production share (ind/y), so as to reduce the release of CO_2. We discover that in the high income group, economic growth leads energy consumption negatively as a uni-directional causal relationship. Finally, in the low income group countries, the share of industrial production to GDP (ind/y) is low and the release of CO_2 is also low. Thus, there is no causal relationship between economic growth and energy consumption in the low income group countries. Our findings echo the concept of EKC in the literature. As income increases, pollution becomes a serious problem and as countries reach an even higher income level, the pollution begins to decline. Our findings indicate that, in the middle income group countries, economic growth leads energy consumption positively, which is disadvantageous to the environment. When the income is raised to the level of the high income group, economic growth leads energy consumption negatively as is shown in the high income group. It is manifest that, as the income is raised to the high income group level, those countries tend to reduce energy consumption in hopes to minimize the damage to the environment.

Appendix A

Table A1 – Sampled countries in ascending order based on 2000 GNI (82 countries)

Country name	GNI (2000 $)	Income group
Congo, Dem. Rep.	90	L
Nepal	230	L
Nigeria	260	L
Togo	320	L
Zambia	320	L
Ghana	330	L
Kenya	360	L
Bangladesh	390	L
Benin	390	L
Zimbabwe	440	L
India	450	L
Pakistan	480	L
Senegal	490	L
Haiti	500	L
Congo, Rep.	510	L
Cameroon	570	L
Indonesia	590	L
Cote d'Ivoire	690	L
Nicaragua	740	L
China	840	ML
Sri Lanka	850	ML
Honduras	860	ML
Syria	950	ML
Bolivia	1000	ML
Philippines	1030	ML
Morocco	1180	ML
Ecuador	1330	ML
Egypt, Arab Rep.	1490	ML
Paraguay	1510	ML
Algeria	1580	ML
Guatemala	1700	ML
Thailand	2010	ML
El Salvador	2020	ML
Colombia	2050	ML
Peru	2050	ML
Tunisia	2080	ML
Dominican Republic	2140	ML
Jamaica	2710	ML
Turkey	2980	ML
South Africa	3050	ML
Gabon	3120	ML
Malaysia	3390	MU
Brazil	3650	MU
Costa Rica	3820	MU
Panama	3870	MU
Venezuela	4100	MU
Hungary	4650	MU
Chile	4780	MU
Mexico	5110	MU
Trinidad and Tobago	5220	MU
Uruguay	6120	MU
Oman	6710	MU
Argentina	7490	MU
Saudi Arabia	8110	MU
Malta	9540	MU
Korea, Rep.	9790	MU
Portugal	10,930	H
Greece	11,290	H
New Zealand	13,700	H
Spain	14,790	H
Israel	17,060	H
Australia	20,090	H
Italy	20,160	H
Canada	21,820	H
Singapore	22,890	H
Ireland	23,030	H
France	23,990	H
Belgium	24,890	H
Finland	24,940	H
Germany	25,140	H
Netherlands	25,210	H
United Kingdom	25,410	H
Austria	25,700	H
Hong Kong, China	26,820	H
Sweden	28,650	H

Table A1 (*continued*)

Country name	GNI (2000 $)	Income group
Iceland	29,980	H
Denmark	31,460	H
United States	34,400	H
Japan	35,280	H
Norway	35,660	H
Switzerland	40,160	H
Luxembourg	43,550	H

Note: GNI = Gross National Income; L = Low Income (GNI<$826); ML = Lower Middle Income ($826≤GNI≤$3255); MU = Upper Middle Income ($3256≤GNI≤0,065); and H = High Income (GNI>0,065).

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