New Evidence on Electricity Consumption and Economic Growth Nexus from the Four Asian Economies

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Abstract

Using data from 1972 to 2008 of four East Asian Economies, Japan, Taiwan, South Korea and China, we find electricity consumption positively Granger-causes carbon dioxide emission for all four countries. In addition, electricity consumption is found to positively Granger-cause economic growth while carbon dioxide emission is found to negatively Granger-cause electricity consumption in Taiwan. It implies that fossil fuel consumption ought to be reduced in order to generate clean electricity. Otherwise it leads to higher carbon emissions and hence lower electricity consumptions, which in turn translates into slower economic growth in Taiwan. In Korea it is found that electricity consumption positively Granger-causes carbon dioxide emission while carbon dioxide emission negatively Granger-causes economic growth. As with Taiwan, Korea ought to reduce fossil fuel consumption to lessen carbon emission or else economic growth will suffer. China's economic growth emanates mainly from capital stock increase. Neither capital stock nor electricity consumption can lead to economic growth for Japan. In both Japan and China, we cannot find carbon emission Granger-causes or impacts economic growth directly or indirectly. Since electricity consumption can Granger-cause carbon emission in both countries, we suggest that fossil fuel consumption ought to be reduced in generating electricity in order to lessen greenhouse gases to betters protect their environments.

Keywords: electricity consumption, carbon dioxide, economic growth, Pooled Mean group.

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I. Introduction

Needless to say, energy input plays an important role in economic development. During the 1972-2008 period, mean economic growth was 3.14% while the growth rate for final energy consumption averaged around 3.72%. The correlation between the two variables reaches 85.2%. Electricity consumption is regarded as a key indicator for economic development. According to International Energy Agency (IEA) in 2002, about one quarter of the world population, 1.6 billion people, do not have access to electricity. Without implementing a better policy, an estimate 1.3 billion people will not be consumers of electricity, especially in rural area of developing counties by 2030. Not only can electricity consumption improve quality of living and poverty, it is instrumental to industrialization and technological advances. For example, computer usage and network facility require availability and support of electricity. In addition, the share of electricity consumption of total final energy consumption has been on the rise: from 8.87% in 1971, to 15% in 1999 and to 17.15% in 2008. [1] The growth rate of electricity consumption in the 1972-2008 period averaged 3.73%, a rate slightly higher than that of final energy consumption. Besides, the correlation coefficient between electricity consumption and annual economic growth is as high as 94.01% reflecting a close tie between them. Despite such a correlation, policy implementation seems to be more appropriate if it is based on causal relationship instead.

The four East Asian nations -Japan, China, Taiwan and Korea- play important roles in the world economic development. Japan the world's second largest economy until 2010 when she was surpassed by fast-rising China. After the Asia financial crisis of 1997, economy of South Korea took a quantum leap and her electronic products and automobile have gradually encroached into the Japanese markets. Taiwan, one of the Four Asian Dragons had her economy built on labor-intensive industries in early 1970s. The rapid economic growth was since not as strong in the presence of rising wage. However, Taiwan's economy remains resilient with robust high tech industries. What role does electricity consumption plays in the 4 economies is the major theme of this paper.

Notwithstanding the close correlation between electricity consumption and economic growth, the source where electricity is generated may better explain economic growth. For instance, fossil fuels (coal and oil) are largely used to generate electricity along with greenhouse gases. Between 1972 and 2008, China's coal-generated electricity accounted for 68.75% of total electricity consumption, the highest in the 4 economies compared to 38.3% of world average, followed by Taiwan (30.58%), Korea (21.79%) and Japan (16.21%). As for oil-generated electricity, the shares were much greater than the world averge (13.27%) except for China (10.85%). These shares (32.52% for Japan, 32.71% for Taiwan and 38.58% for Korea) together with coal-generated electricity shares speak volumes about larger shares of fossil fuel-generated electricity by the 4 countries (except for Japan) when compared to the world average. The major problem with fossil fuel-generated electricity lies in the emission of carbon dioxide, a significant negative externality, which offsets economic growth to some extent. Thus, an analysis on electricity consumption-economic growth relationship without taking carbon dioxide emission into consideration will most likely lead to biased results. Given the large shares of fossil fuel-generated electricity, hence high CO_2 emission, this paper attemps to study the dynamic relationships among economic growth, electricity consumption, capital stock and CO_2 emission assuming that the 4 economies share the same long-run equilibrium framework. Such an analysis that incorporates CO_2 emission, economic growth and electricity consumption has thus far evaded the literature. The organization of the paper is as follows: Section II presents the literature review. Section III discusses research model and data source. Section IV reports empirical results. Section V concludes the paper with policy implication.

II. Descriptive Statistics of the Four East Asian Economies

Descriptive statistics about economic growth, CO_2 emission and electricity consumption are segmented into two sub-periods: Period I (1972~1990) and Period II (1991~2008) in order to study potential differences before and after 1990 (see Table 1).

Insert Table 1 here

[1] Consumption of oil and other related products accounts for the largest share of total energy consumption: 47% in 1971 and 41.31% in 2008.

In terms of size of economy, Japan takes the lead of all 4 countries: it accounted for 15% of the world GDP on average in the entire sample period. China accounted for 1.18% in Period I and 3.89% in Period II while Korea's GDP shares were 0.87% in Period I and 1.65% in Period II on average. Taiwan, the smalles of the four had her GDP shares of 0.46% and 0.95% respectively. This is to say, the sizes of their economies are increasing on average signaling the importance of the region. In addition, economic growth rates of the 4 nations far exceed the world average (1.55%): China's growth rate tops the region (7.74%) followed by Taiwan (5.73%), Korea (5.01%) and Japan (2.23%). World average is about 1.55% in both Period I and Period II. Of the four economies, only China had higher growth rate in Period II than Period I (9.39% vs. 6.17%). The rest had lower growth rates in Period II than in Period I especially for Japan who had economic growth rate of only 1.09% (lower than world average) after the bubble burst in 1990s.

Electricity production of Japan accounted for 7.1% of the world total in 1990s, but decreased to 6.66% after the economic slowdown. Taiwan's shares were 0.5% in Period I and 1.11% in Period II. Korea's share leaped from 0.4% in Period I to 1.7% in Period II perhaps due to her greater economic growth. China, the late starter, accounted for only 3.71% of the world total but jumped to 10.01% (higher than Japan) in Period II.

Beyond that, we can also witness rapid growth rates in electricity consumption per capita in the 3 countries except for Japan (Table 1). Korea's growth rate of electricity per capita for the entire period was 9.73%, noticeably greater than the economic growth rate (5.61%). For Taiwan, the growth rate was 6.58% versus her economic growth rate of 5.73%. China's growth rate (7.9%) was almost the same as her economic growth rate (7.74%). For Japan, the growth rate was slightly greater than her economic growth rate (2.23%).

In terms of shares of coal-generated electricity, the world averages were 38.30%: 37.90% in Period I and 38.83% in Period II. Only in China, do we find the higher percentage (68.70%) than the world average. Note that shares of coal-generated electricity in Period II actually were greater than that of Period I for Japan, Taiwan and Korea: for Taiwan, the share was 46.21%, higher than the world average (38.83%); for Korea and Japan the shares rose rapidly to 32.68% and 21.58% respectively. World average of shares of oil-generated electricity in Period II went down from 17.94% to 8.08%, a 55.5% drop indicating a trend. The East Asian 4 economies were no exception: shares dropped for Japan from 46.85% to 16.61%; 48.40% to 15.27% for Taiwan; 60.99% to 13.69% for Korea; and 17.04% to 3.96% for China. With the exception of China, the other 3 economies relied more on oil-generated electricity in Period II than the world average (8.08%).

Industrial sector consumed about 46.2% of total electricity consumption, worldwide for the entire sample period: 50.29% in Period I and 42.1% in Period II. It indicates a declining trend worldwide. Some of the decline was picked up by increases in residential electricity consumption in Period II. Average share of world residential electricity consumption for the entire period was 26.46% with 24.96% in Period I and 27.91% in Period II. In the East Asian region, both shares of industrial and residential electricity consumptions in Japan were on par with the world average. Between 1972-2008, industrial usage of electricity accounted for 60% in Taiwan and Korea, and 72.4% in China. These large shares were very much in line with the world trend: as income increases industrial usage share drops while residential share increases.

Generally speaking, with the exception of Japan, the 3 East Asian economies are characterized with high growth rates along with rapidly increasing electricity consumption. Unfortunately, fossil fuels are often used to produce electricity and as such produce high volumes of CO_2. CO_2 emission per capita averaged 4 tons worldwide of which Japan's average consumption was 8.38 tons, Taiwan 6.31 tons, Korea 5.74 tons and China 2.14 tons. The world average tonnage remained relatively stable before and after 1990. Of the 4 countries, CO_2 emissions per capita were greater in period II than in period I. Japan's CO_2 emission accounted for 5% of world total while China's share was 11.33% followed by Korea (1.14%) and Taiwan (0.6%) in the 1972-2008 period. A glance at Table 1 indicates that shares of total CO_2 emission in Taiwan, Korea and Chian were much higher (nearly twice) in Period II than in Period I.

II. Literature Review

Payne (2010) provided detailed literature review (37 articles) starting from Murray and Nan (1996). These papers focused on the relationship between electricity consumption and economic growth. This paper will dwell upon the literature from 2010 and on. In addition, the literature on CO_2 emission, one of the variables used in our model, is also included. Ozturk and Acaravci (2011) employed the bound test of Autoregressive Distributed Lag (ARDL) model to test cointegration and a bivariate vector error-correction (VEC) model was used to test electricity consumption-economic growth relationship for 11 countries in the Middle East and North Africa (MENA) between 1971~2006. The result indicated there existed no significant relationship.

Apergis and Payne (2011a) applied a panel data model to 16 emerging market economies from 1990 to 2007. By classifying electricity consumption into renewable and non-renewable components and by including capital stock and labor into the 4-variable model, they found the following empirical results: In the short run, economic growth leads renewable electricity consumption. In the long run, feedback relationships exist between economic growth and non-renewable electricity consumption in both short run and long run.

In another large panel model of 88 countries over the 1990~2006 period, Apergis and Payne (2011b) classifies income level into 4 panels (high, middle high, middle low, and low incomes) and employed a panel cointegration technique to discover cointegration relations among electricity consumption, real gross fixed capital formation, GDP and labor. The causality test of the VEC model indicates (i) feedback relationships existed between electricity consumption and economic growth for high income and middle-high income panels, (ii) electricity consumption in the short run led economic growth for the middle-low panel; there existed a feedback relationship between them in the long run, (iii) for low income panel, it was found that electricity consumption led economic growth.

Acaravci and Ozturk (2010) applied panel data of 15 transition countries over the 1990-2006 period to a bivariate model in order to explore the relationship between electricity consumption per capita and economic growth. Using the Pedroni panel cointegration test, they found no long run equilibrium relationship between them and hence the efficacy of a policy regarding electricity consumption and economic growth may be suspect. Yoo and Kwak (2010) investigated the electricity consumption-economic growth nexus for the 7 countries in South America. The time series analysis (1975-2006) suggested (i) the electricity consumption led economic growth in Argentina, Brazil, Chile, Columbia and Ecuador, (ii) a feedback relationship prevailed in Venezuela and (iii) no Granger causality existed between them in Peru.

Ciarreta and Zarraga (2010) applied a dynamic panel data model to 12 European countries over 1970-2007 in order to analyze both long term and short run equilibrium among electricity consumption, economic growth and energy price. Their findings suggested the existence of long term equilibrium relationships among the 3 variables. In the short run, it was found that electricity consumption led GDP and both energy price and GDP formed a feedback loop.

Shahbaz et al. (2011) identified long term equilibrium relationships among electricity consumption, economic growth and employment in Portugal over the 1971-2009 period. Using the ARDL bound test, the results supported the existence of feedback relationships among the variables. As the second stage estimation, the VEC model indicated the existence of 3-variable feedback relationships. Furthermore, it was found that economic growth of Portugal led electricity consumption in the short run.

Using Taiwan quarterly data from 1982 to 2008 and classifying electricity consumptions into total (TEC), industrial sector (ISC) and residential sector (RSC) components, Yang et al. (2012) were able to perform the Granger causality analysis with the results that there existed feedback relationships among TEC, ISC and GDP based on the linear Granger causality model. No causality was found between RSC and GDP. By using the Hiemstra-Jones non linear causality model (1994), they identified (i) feedback relationships between TEC and GDP and (ii) GDP led RSC, an unilateral causal relation.

As the global warming problem becomes more pronounced, CO_2 and other greenhouse gases play an ever more important role in modeling the energy consumption - GDP nexus. For example, Coondoo and Dinda (2002) applied Environment Kuznet Curve (EKC) concept along with the Granger causality model to 88 countries over the 1960-1990 period to investigate the income-carbon dioxide relationship. By partitioning the 88 countries into different development-based panels, they found that (i) CO_2 emission Granger–caused income for developed economies like North American and European countries, (ii) income Granger-caused CO_2 emission for Central American, South

American and Oceania countries, and (iii) feedback relationships existed for the Asian and African countries. Applying the same data set but using the panel unit root and panel cointegration tests, Coondoand and Dinda (2006) found cointegration relations between income and CO_2 emission. Based on the result of panel ECM, they also discovered feedback relationships between income and CO_2 emission for countries in Africa, Central America, West and East Europe and the world. Soytas et al., (2007) included CO_2 emission into the energy consumption- economic growth model and analyzed both the CO_2 emission-income and income- energy consumption relationships in addition to the energy consumption - CO_2 emission relationships. Using US data of 1960-2004, they could not find the causality from income to CO_2 emission, but rather, there existed a Granger-causality from energy consumption to CO_2 emission.

Despite the proliferation of the literature, majority of it focused on the electricity consumption-economic growth nexus. Some paper did include other explanatory variables such as capital stock, labor (employment) and applied multivariate models to individual countries or regions based on cointegration-error correction models. Some papers applied dynamic panel data to a region or multi-countries. Nonetheless, we think the previous literature is amiss in following aspects.

At first glance, electricity seems to be a clean energy. However one must be vigilant about the sources where electricity is produced. There is no doubt that fossil fuels play important role and as such CO_2 emission is the negative externality that cannot be ignored. Failing to take this into consideration may well lead to biased results. Second, unit root and cointegration tests using time series data (annual) lack power especially for non- OECD countries since only 37 observations (1972-2008) are available from the IEA. Granted some employed panel data models, they largely failed to consider the heterogeneity aspects of country-specific factors: sources of energy from which electricity is derived, sectors that use electricity, energy dependence and efficiency in energy consumption. Lumping them into a panel cannot truly reveal the difference among countries. Ever if some papers partitioned countries into different panels such as economic development stages or other sub-panels, country-specific differences cannot be disclosed.

To overcome the shortcomings, this paper attempts to constrain long term co-movements while allows for short-run relationship via the Pooled Mean Group (PMG) panel approach by Pesaran et al. (1999). That is, the PMG model enables us to study the electricity consumption-economic growth relationship for the 4 East Asian nations over the 1972-2008 period country by country. In order to take into consideration the sources from which electricity is derived, namely fossil fuel, we include CO_2 emission into the model. That is, we have a four-variable PMG model: electricity consumption, economic growth, CO_2 emission and capital stock. First, we estimate a common long term equilibrium relationship using the PMG approach before estimating the error correction model for each country. Second the Granger causality is tested for each country regarding these variables.

III. Empirical Models and Data Source

Note that the four countries in the East Asia are of similar economic development stage and use relatively more fossil fuels to generate electricity. Our four-variable model--income, electricity consumption, CO_2 emission and capital stock-- assumes these countries share same long-term equilibrium relationship. However, each country is different in size of economy and other factors and as such it has its own short-term interactions. This makes the PMG model (Pesaran et al., 1999) appropriate for the estimation purpose. Let ky_{it} be real per capita GDP for country i at time t; $kelec_{it}$ be per capita electricity consumption for country i at time t; $kco2_{it}$ be per capita CO_2 emission for country i at time t; and K_{it} be fixed capital formation for country i at time t. Using ky_{it} as dependent variable and applying ARDL model, we have

(1)
$$\begin{aligned}\Delta ky_{it} &= -\phi_{1i}(ky_{it-1} - \theta_0 - \theta_1 kelec_{it-1} - \theta_2 kco2_{it-1} - \theta_3 K_{it-1}) \\ &+ \sum_{j=1}^{p1}\delta_{11j}\Delta ky_{it-j} + \sum_{j=0}^{p2}\delta_{12j}\Delta kelec_{it-j} + \sum_{j=0}^{p3}\delta_{13j}\Delta kco2_{it-j} + \sum_{j=0}^{p4}\delta_{14j}\Delta K_{it-j} + \varepsilon_{1it}\end{aligned}$$
.

By the same token, $\Delta kelec_{it}$, $\Delta kco2_{it}$ and ΔK_{it} can be used as dependent variable to construct the ARDL models. Since a common equilibrium relationships is assumed as shown in equations (1), the vector cointegration coefficients are the same in both parentheses after the normalization process. However, the adjustment coefficients (ϕ_{1i}) and short-run dynamic coefficients ($\delta_{11j}, \delta_{12j}, \delta_{13j}, \delta_{14j}$) are free to vary.

Equations (1) is known as restricted error correction model, which differs from traditional or unrestricted error correction model. The major difference lies in that the right side of equations (1) or (2) includes explanatory variables of current period, a concept inconsistent with the Granger causality which requires lagged variables in the right-hand–side of equations. To circumvent this possible endogeneity problem, the bound test is used to examine if a cointegration exists in a single-equation ARDL model. If a cointegration exists, a VEC model is formulated as the second stage to investigate the Granger causality. However, the issue of the cointegrating tests for the PMG model has not been definitively resolved. In this paper, we employ panel unit root test methods by Levin, Lin and Chu (2002) and Im, Pesaran and Shin (2003) to test if a relation in the parenthesis of (1) satisfies the cointegration (or I (0)). The estimated panel cointegration relation is included in the VEC model in order to perform the Granger causality test for each country as shown below.

(2) $$\Delta \mathbf{y_t} = \mathbf{A_0} + \mathbf{B}\mathbf{y_{t-1}} + \sum_{i=1}^{p-1} \mathbf{A_i}\Delta\mathbf{y_{t-i}} + \boldsymbol{\varepsilon}_\mathbf{t} \quad ,$$

$\mathbf{y_t}$= [$ky_{it}, kelec_{it}, kco2_{it}, K_{it}$] is a vector of 4x1, and $\mathbf{y_{t-1}}$ the error correction relation from equation (1)

(3) $$\mathbf{y_{t-1}} = ky_{it-1} - \theta_0 - \theta_1 kelec_{it-1} - \theta_2 kco2_{it-1} - \theta_3 K_{it-1} \, .$$

Let $\mathbf{A_0}$ is a matrix of intercept coefficients, **B** is the matrix of speed adjustment and $\mathbf{A_i}$ is a matrix of 4x4 given below

(4) $$\mathbf{A_i} = \begin{bmatrix} A_{11}(L) & A_{12}(L) & A_{13}(L) & A_{14}(L) \\ A_{21}(L) & A_{22}(L) & A_{23}(L) & A_{24}(L) \\ A_{31}(L) & A_{32}(L) & A_{33}(L) & A_{34}(L) \\ A_{41}(L) & A_{42}(L) & A_{43}(L) & A_{44}(L) \end{bmatrix} ,$$

where $\mathbf{A}_\mathrm{i}$(L) represents a lag polynomial of p-1 terms. The Granger causality in this framework is equivalent to test if coefficients of lagged terms are significantly different from zero. For instance, testing if electricity consumption Granger-causes economic growth is equivalent to testing $H_0 : A_{12}(L) = 0$.

Annual data from 1972 to 2008 are used in this study. ky_{it} is the real GDP per capita based on 2000 US dollars; $kelec_{it}$ denotes average electricity consumption (kwh) per capita; $kco2_{it}$ represents CO_2 emission (tons) per capita. Both ky_{it} and $kelec_{it}$ are obtained from Energy Statistics published by IEA; $kco2_{it}$ are taken from the website of IEA and ky_{it} are from International Financial Statistics (IFS) CD-ROM. Logarithmic transformation is perform on all variables before analyses.

IV. Empirical Results and Discussion

As the first step, we need to estimate the common long term equilibrium relationships for the 4 countries based on (4). The estimated result is shown in equation (4')

$$ky_{it-1} = -0.3151kelec_{it-1} + 0.3762kco2_{it-1} + 0.8575K_{it-1}$$

(4')

$$\quad (0.2038) \qquad (0.2233) \qquad (0.1164)$$

$$B = -0.0446 \qquad \log-L = 408.97$$

$$(0.0145)$$

Note that numbers in parentheses are standard error as shown in equation (4') in which real income per capita is used as dependent variable. Evident from equation (4'), there exist (i) a negative but insignificant long-term relationship between electricity consumption and income, (ii) a positive but insignificant long-term relationship between CO_2 emission and income, (ii) a positive and significant long-term relationship between income and capital stock. The result of (iii) confirms the conjecture that capital stock drives East Asia's economy. In addition, the estimated speed of adjustment coefficient B (-0.0446) being significantly negative signals the correct error correction path toward equilibrium. Although Pesaran et al. (1999) did not provide a panel cointegration technique for the PMG model, the negative and significant (t= -3.07) coefficient of the adjustment factor suggests equation (4') is consistent with the cointegration process. To reassure the existence of the cointegration process, we employ other panel unit root test. The results are shown in Table 2.

Inert Table 2 here

By using the IPS (Im, Pesaran and Shin, 2003) and LLC (Levin, Lin & Chn, 2002) panel unit root teats, we can reject the null hypothesis, H_0: error correction terms obey the I(1) process, in favor of the I(0) process instead at 5% significance level. As the second stage, we include the estimated cointegration relation using PMG technique to equation (3) for each country. The VEC models can be used to examine the potential Granger causality for the 4 East Asian countries.

Insert Table 3 about here

An examination of Table 3 reveals that electricity consumption positively and significantly Granger-causes economic growth in Taiwan, the only country that can boost economic growth by electricity consumption in our sample. The other 3 countries cannot carry their economy via electricity consumption. It is to be pointed out that electricity consumption Granger-causes CO_2 emission in all 4 countries. It signals that electricity consumption begets CO_2 emission, the phenomenon agreeable to the descriptive statistics of Table 1. As shown in Section II, fossil-fuels-generated electricity is a commonplace in East Asia and as such its CO_2 emission far exceeds world average. In addition to that electricity consumption positively Granger-cause CO_2 emission, it is also found that capital stock negatively Granger-causes electricity consumption in Japan. Interesting enough, CO_2 emission in Taiwan negatively Granger-causes electricity consumption and electricity consumption positively Granger-cause economic growth. This is to say, there exist feedback relationships between electricity consumption and CO_2 emission; while more electricity consumption leads to higher CO_2 emission, higher CO_2 emission prompts Taiwan government to find ways to reduce electricity consumption. This will in term slowdown her economic growth. In the case of Korea, we find CO_2 emission negatively Granger-causes economic growth. In other words, more electricity consumption leads to high CO_2 emission, which in turn reduces economic growth (Table 3).

Electricity consumption, however, cannot Granger-cause economic growth in China. Instead, capital stock does (Table 3). Well known in the literature of economic development, capital accumulation plays a key role in economic growth as is confirmed in our analysis. Furthermore, increase in capital stock leads to electricity consumption in China.

Echoing the result by Narayan and Prasad (2008) we find no causality between electricity consumption and economic growth in Japan. It is to be noted that feedback relationships prevailed between electricity consumption and economic growth in Korea (Murry and Nan, 1996; Yoo, 2005; Narayan and Prasad, 2008). Besides, it was found that economic growth led electricity consumption in Korea (Chen et al., 2007) whereas we find no causality between them. In the case of Taiwan, we find electricity consumption leads (positively) economic growth, which agrees with the result by Lee and Chang (2005). However it is at odds with the results by Yang (2000): which suggests feedback relationships; by Chen et al. (2007), in which they found no relationship; and by Hu and Lin (2008) in which economic growth leads electricity consumption. In the case of China, majority of the research pointed to electricity consumption leads economic growth (Yuan et al., 2007; Yuan et al., 2008; and Shiu and Lam, 2004). As with the result by Chen et al. (2007), this paper cannot find any causal relationships between electricity consumption and economic growth in China. The difference may well lie in the sample size, and more importantly, addition of CO_2 emission to the model and assumption of sharing a common long run equilibrium condition for the 4 East Asian economies.

V. Conclusion and Policy Implications

Literature abounds regarding electricity consumption and economic growth but it ignores the role that CO_2 emission plays in the model. In this paper, we establish a four-variable panel VEC model that incorporates income, electricity consumption, CO_2 emission and capital stock for the 4 East Asian countries: Japan, Taiwan, Korea and China. The purpose is to analyze long run and short run interactions among economic growth, electricity consumption and CO_2 emission. As shown in Table 1, fossil fuels are chief sources to generate electricity in the 4 countries and thus CO_2 emission cannot be excluded from the model. Furthermore, by sharing a common long run equilibrium relationship due to perhaps geographic proximity and history, we are able to analyze short run interactions among variables.

Based on the PMG model by Pesaran et al. (1999), we can model the short term interactions for each country. Using the panel data from 1971 to 2008 for the 4 countries, we find the key variable that drives economy is capital stock in the long run. However, electricity consumption is found to Granger-cause positively CO_2 emission for all 4 countries in the short run. In particular, electricity consumption can Granger-cause both economic growth and CO_2 emission in Taiwan. In contrast, CO_2 emission can slowdown Taiwan's economy. The conundrum can be resolved if CO_2 emission is reduced in generating electricity. This can be done by adopting non-fossil fuel to generate electricity. In the case of Korea, it is found CO_2 emission negatively Granger-causes economic growth. At the same time, electricity consumption is expected to positively Granger-cause CO_2 emission. This is to say, increased electricity consumption leads to higher CO_2 emission, which in turn slowdowns economic growth in Korea. The policy implication is for Korea is to find ways to reduce CO_2 emission.

For Japan, our results indicate (i) electricity consumption positively Granger-causes CO_2 emission, and (ii) capital stock negatively, Granger-causes electricity consumption. While it is not necessary for Japan to cut electricity consumption, it is recommended Japan uses more non-fossil fuel-generated electricity in order to control her CO_2 emission. Finally, capital stock in China is found to positively Granger-cause both economic growth and electricity consumption. As capital stock is the engine that drives Chinese economy, it inexorably lead to more electricity consumption, which gives rise to higher level of CO_2 emission. But as such China may not have to reduce electricity consumption now. As with Japan, it is recommended China develops more nonfossil fuel-generated electricity in order to control her CO_2 emission.

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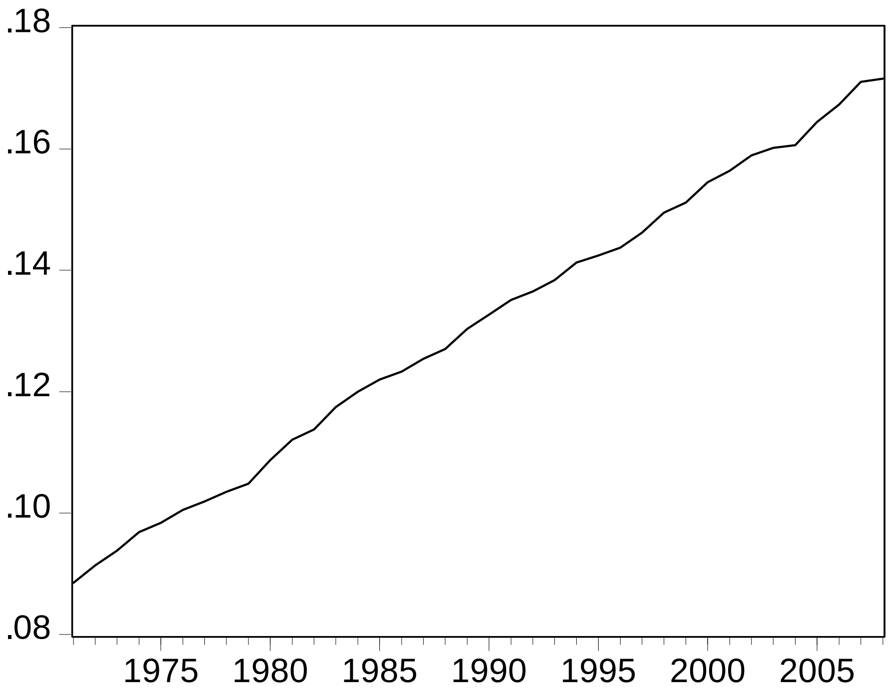
Figure 1

Electricity Consumption as % of Total Energy Consumption



Source: Energy Balance (International Energy Agency 2010 Edition).

Table 1

Descriptive Statistics of Four East Asian Countries

	JPN			TWN			KOR			CHN			World		
Sample period	1972-1990	1991-2008	1972-2008	1972-1990	1991-2008	1972-2008	1972-1990	1991-2008	1972-2008	1972-1990	1991-2008	1972-2008	1972-1990	1991-2008	1972-2008
Per capita economic growth	3.31%	1.09%	2.23%	7.01%	4.39%	5.73%	6.52%	4.65%	5.61%	6.17%	9.39%	7.74%	1.55%	1.54%	1.55%
GDP share as % of world total	15.55%	14.97%	15.29%	0.46%	0.95%	0.70%	0.80%	1.65%	1.22%	1.18%	3.89%	7.74%	n.a.	n.a.	n.a.
Population share as % of world total	2.61%	2.11%	2.36%	0.40%	0.36%	0.38%	0.85%	0.77%	0.81%	22.08%	20.76%	21.43%	n.a.	n.a.	n.a.
Electricity production share as % of world total	7.10%	6.66%	6.88%	0.50%	1.11%	0.80%	0.48%	1.70%	1.09%	3.71%	10.01%	6.80%	n.a.	n.a.	n.a.
Per capita electricity consumption (gwh/ person)	4832.05	7664.61	6247.7	2777.2	7538.78	4872.14	1054.20	5590.44	3281.51	294.45	1199.39	738.57	1702.80	2336.67	2022.46
Per capita electricity consumption growth	3.45%	1.25%	2.38%	8.06%	5.02%	6.58%	11.65%	7.70%	9.73%	6.68%	9.18%	7.90%	2.54%	1.68%	2.12%
% of electricity generated by coal	11.37%	21.58%	16.33%	16.50%	46.21%	31.07%	11.99%	32.68%	22.19%	61.31%	77.02%	68.70%	37.90%	38.83%	38.30%
% of electricity generated by oil	46.85%	16.61%	31.72%	48.40%	15.27%	31.75%	60.99%	13.69%	37.45%	17.04%	3.96%	10.93%	17.94%	8.08%	13.06%
% of electricity used by industrial sector	59.70%	38.40%	49.02%	63.86%	54.41%	59.17%	67.17%	54.89%	61.17%	77.41%	67.06%	72.37%	50.29%	42.10%	46.20%
% of electricity used by residential sector	22.73%	27.35%	25.09 %	20.68%	21.66%	21.17%	15.47%	15.80%	15.76 %	4.69%	13.95%	9.20%	24.96%	27.91%	26.46%
Per capita CO_2 emission (tons/person)	7.64	9.19	8.38	3.63	9.29	6.31	3.19	8.57	5.74	1.44	2.93	2.14	3.94	3.98	3.96
Per capita CO_2 growth rate	1.03%	0.29%	0.67%	5.65%	4.08%	4.89%	6.76%	3.87%	5.36%	3.93%	5.42%	4.66%	0.34%	0.56%	0.45%
CO_2 emission share as % of world total	5.05%	4.87%	4.97%	0.36%	0.84%	0.59%	0.68%	1.65%	1.14%	8.01%	15.02%	11.33%	n.a.	n.a.	n.a.

Note：JPN=Japan；TWN=Taiwan；KOR=Korea；CHN=China；n.a. = not available.

Table 2

Panel Unit Root Tests

Method	Statistics	p-value
Levin, Lin & Chu	-2.8105	0.003
Im, Pesaran and Shin	-2.0632	0.020

Table 3

Short-run Causality Test Results

	JPN(1)	TWN(1)	KOR(1)	CHN(1)
$\Delta kelec \nrightarrow \Delta ky$	0.8937 [0.34]	4.6823** [0.04]	0.0154 [0.90]	0.0101 [0.92]
$\Delta ky \nrightarrow \Delta kelec$	2.0477 [0.15]	1.0544 [0.30]	0.6001 [0.44]	2.1523 [0.14]
$\Delta kco2 \nrightarrow \Delta ky$	1.1633 [0.28]	0.9459 [0.33]	4.9624** [0.03]	0.4442 [0.51]
$\Delta ky \nrightarrow \Delta kco2$	0.4146 [0.52]	3.6143* [0.06]	0.0595 [0.81]	0.4558 [0.50]
$\Delta kco2 \nrightarrow \Delta kelec$	0.1596 [0.69]	3.9712** [0.05]	0.5863 [0.44]	2.5141 [0.11]
$\Delta kelec \nrightarrow \Delta kco2$	5.6976** [0.02]	9.1663*** [0.00]	4.0264** [0.04]	5.0207** [0.03]
$\Delta K \nrightarrow \Delta ky$	0.0223 [0.88]	0.0231 [0.88]	0.0025 [0.96]	6.2636*** [0.01]
$\Delta ky \nrightarrow \Delta K$	0.7637 [0.38]	0.0918 [0.76]	1.4637 [0.23]	0.9903 [0.32]
$\Delta K \nrightarrow \Delta kelec$	3.7788** [0.05]	0.0660 [0.80]	0.0246 [0.88]	5.5083** [0.02]
$\Delta kelec \nrightarrow \Delta K$	2.6850* [0.10]	1.3080 [0.25]	0.2065 [0.15]	0.1218 [0.73]

Notes：Numbers in ( ) are lagged periods of the VEC model; Numbers in [ ] are p values; *,**,*** denote 10%, 5% and 1% significance levels; $x \nrightarrow y$ implies x does not Granger-cause y; Δ = 1st difference; ky= per capita real GDP; kelec= per capita electricity consumption; kco2=per capita CO_2 emission; K= fixed capital formation.