**Dynamic causal relationships among CO2 emissions, energy consumption, economic growth and FDI in the most populous Asian countries**

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**Running Title:** Dynamic causal relationships in the most populous Asian countries

**Abstract**

This paper investigates the dynamic causal relationships among environmental degradation, economic growth, foreign direct investment (FDI) and energy consumption in the 12 most populous countries in Asia. This panel sample shows evidence that supports the Environmental Kuznets Curve (EKC), and that CO2 emissions begin to decline when income level reaches to 8.9341 (in logarithms). Applying Granger causality test, we find the existence of both short and long-run causality relationships among these variables, and economic growth, FDI, energy consumption and CO2 emissions of 12 Asian most populous countries have relationships with Japanese income. On the other hand, our estimated results suggest that these countries have been exchanging the environmental degradation to implement economic activities. Furthermore, these results support the pollution haven hypothesis, which indicate the less stringent environmental regulations of the host countries have attracted FDI inflows. However, FDI inflows are found significantly that does not intensify the environment degradation within these 12 Asian countries as a panel sample.

***Keywords:*** *MPCA12, EKC curve, Cointegration, Granger Causality, Japanese income, FDI inflows, CO2 emissions.*

*JEL* codes: C33, O44, O53.

**1. Introduction**

Asia is currently considered as one of the most dynamic economic areas in the world, showing the highest economic growth. While the average growth rate of global real Gross Domestic Product (GDP) was 1.1% in period 2006-2009, 4.02% in 2010 and 2.74% in 2011 (United Nations, 2013), Asia, comprised mainly of developing countries, had an average GDP growth at 7.1%, 9.0% and 6.8% in same periods, respectively.

[[3]](#footnote-3) It also has the greatest potential for development, being the region with more than 60.3% of total world population as of 2011, which provides both a huge potential market and a large working population. The 12 most populous countries in Asia (*MPCA12*) make up more than 88.1% of the region’s population, and since the 1980s, this group accounts for almost 85.4% of Asian total GDP annually. In descending order, these are: China, India, Indonesia, Pakistan, Bangladesh, Japan, Philippines, Vietnam, Thailand, Iran, Myanmar and South Korea).[[4]](#footnote-4) Most of these countries have strong economic ties with each other, facilitated by their geographical proximity and free trade agreements. Many a times the existing literatures have found that economic fluctuations in these economies can have a great impact on the economies of other countries and regions globally. Contributions include Angresano (2004), Lee (2006b), Eichengreen (2006), Holscher *et al*. (2010) and Mackenzie *et al*. (2012). Thus, these countries may be seen as the very important part of Asian economy as a whole, and the economic characteristics of the whole Asia region also appeared in *MPCA12*, such as Japan for developed countries; South Korea for new industrialized economies; Indonesia for crude oil exporters; China and India for developing, changing economies with high economic growth; Malaysia and Thailand for upper low income countries; and Iran for countries under economic embargo and other domestic crises (nuclear and political).[[5]](#footnote-5) While getting the full data to investigate and estimate economic relationships of the Asia region as a whole is difficult, the *MPCA12* panel data sample can provide a good representation of patterns existing in Asia’s economy.

FDI flows to *MPCA12* has increased rapidly in the last three decades, from 8.3% of total FDI inflows to the Asia region in 1980, to 19.1% in 1990, 36.9% in 2000 and 40.8% in 2010, according to data from UNCTAD database, 2013. FDI contributes to these countries’ economic development (Bende-Nabende *et al*., 2000; Chakrabarti, 2002), which in turn affecting their energy demand and environmental degradation ([Minh Nguyen & Nurul Amin, 2002](#_ENREF_2), Jian and Rencheng, 2007). Energy consumption increased rapidly in *MPCA12*, where from 1.38 million kilotonnes (kt) oil equivalence in 1980, it went up to more than 4.75 million kt in 2010. This makes up more than 80% of Asia’s annual energy consumption. Likewise, CO2 emissions increased from 3.3 million kt carbon dioxide emissions to 13.79 million kt at the same period. The percentage of Asia’s total CO2 emissions that came from *MPCA12* gradually increased from 77% in 1980 to around 83% in 2010.[[6]](#footnote-6)

There are some existing literatures studying the relationships between CO2 emissions, energy consumption, economic growth and FDI. However, these studies focus only on one country, or separate the sample of developed from developing countries, or use a sample with only a few types of economies. We have not found any study examining the relationships of these variables using the panel sample of Asian countries, which usually have strong relationships and affect each other’s social and economic development. In this study, we investigate the causal nexuses of environmental degradation – energy consumption – economic growth – FDI inflows. This paper also estimates the trend of environmental pollutants with respect to the abovementioned variables based on a panel sample of *MPCA12* over 30 years, from 1980 until 2010. It is expected that working on a larger sample, which includes both developed and developing countries in Asia, will provide more accurate estimations. This will help us find causal relationships between said factors, which may provide valuable insights to these countries’ policy makers.

**2. Literature Review and Hypotheses**

Energy is one of the most important components of economic development. Kraft and Kraft (1978) found unidirectional causality from income to energy use in the United States. Succeeding studies such as those of Lee (2005) and Sari and Soytas (2007) found the causal nexus of energy consumption and economic growth, both in developed and developing countries. Lee’s study (2006a) on energy intensity and economic development in G-11 countries found bidirectional causality between the two, which means that energy consumption supports economic growth and economic growth also increase energy consumption. The same conclusion was made in a recent study by Pao and Tsai (2011) on BRIC (Brazil, Russia, India and China) countries. However, economic growth and energy consumption are usually accompanied by environmental degradation both in developed and developing countries, as proven by a large number of studies, such as that of Keppler and Mansanet-Bataller (2010) for European countries, Narayan and Narayan (2010) for 43 developing countries, and Pao and Tsai (2010) for BRIC countries.

One of the popular approaches used in studying the relationship between environmental degradation and economic development is Environmental Kuznets Curve (EKC). EKC theory suggests that environmental pollutant increases in the early stages of economic growth, but the trend reverses beyond some level of income per capita (which varies for different indicators) (Stern, 2004). This implies that the environmental impact indicator is an inverted U-shaped function of other economic variables. The development of EKC since its first application, when Grossman and Krueger (1991) used EKC to measure the potential environmental impacts of NAFTA, as well as critiques to the theory, were summarized in the literature of Stern (2004). Chen *et al*. (2007) and Managi and Jena (2008) continued to employ EKC in the cases of China and India. Coondoo and Dinda (2008) and Akbostanci *et al*. (2009) tested EKC, focusing on time series dynamics of income and CO2 emissions. Pao and Tsai (2011) also tested EKC hypothesis for BRIC countries.

This study tests the EKC hypothesis on the panel sample of *MPCA12*. In the same framework, we also conduct a similar test specifically for the the case of Japan, which is included in *MPCA12*, to see whether EKC curve appears in Japan and whether there have differences of Japan’s EKC curve (if appeared) from the sample. The parallel testing between Japan and our samples is due to Japan being one of the world’s most developed countries. It has high income and is the leader of technological development, which can help its economy develop stably and quickly reduce CO2 emissions. Thus, if EKC hypothesis is applicable in Japan’s case, its EKC curve may reverse earlier than the sample EKC curve.

In order to test the EKC hypothesis for *MPCA12* as well as examine the difference of Japanese EKC curve (if existed) from the sample EKC curve, we assume that:

***Hypothesis 1:*** Within the *MPCA12*, CO2 emissions increase in the early stages of economic development and its trend reverses when the income per capital passes certain point. Concurrently, Japan’s EKC reverses earlier than that of *MPCA12*.

Furthermore, many studies have discovered a strong link between capital investments and economic growth, and FDI emerged as an important contributor for economic development. Likewise, FDI may have relationships with energy intensity as well as environmental pollutants. Recent studies commonly applied time series dynamic with Granger causality test to assess the relationships among FDI, economic growth, energy consumption and environmental pollutants. Li and Liu (2005) expressed a strong complementary connection between FDI and economic growth in both developed and developing countries. Chakraborty and Nunnenkamp (2008) found the feedback effects between FDI and India’s economic output both in the short-run and long-run. Other studies also suggest the causal relationships between these two indicators, such as those of Zang (2001), Kim and Seo (2003) or Pao and Tsai (2011). Investigating the relationships between FDI with energy consumption and CO2 emissions, Mielnik and Goldemberg (2002) examined a sample of 20 developing countries and found that energy intensity declines as FDI increases. Sadorsky (2010) found that net FDI has a statistically significant impact on the energy demand after studying a sample of 22 emerging countries. Pao and Tsai (2011) validated the EKC hypothesis and suggested the short-run bidirectional causal relationships between energy consumption – FDI and CO2 emissions – FDI, and bidirectional long-run causality between FDI and emissions in BRIC countries. Chandran and Tang (2013) suggested the long-run relationship between FDI and CO2 emission in five ASEAN countries.

As with existing literature, this study examines the relationship among FDI, economic growth, energy consumption and CO2 emissions in the *MPCA12*. In the same framework, we also examine whether these factors of Japan have causal nexuses with the sample’s variables. We assume that:

***Hypothesis 2:*** FDI, economic growth, CO2 emissions and energy consumption not only have causal relationships with each other within the *MPCA12* panel sample but also have causal relationships with these of Japan.

**3. Methodology and Empirical Results**

**3.1 Data and variable forms**

*3.1.1 Data*

The data used in this report includes annual GDP per capita, annual FDI inflows and stocks per capita, measured by US Dollars at current prices and current exchange rates. These data was obtained from UNCTAD statistics database.[[7]](#footnote-7) *IN* represents GDP per capital and *FDI* represents FDI inflows and stocks per capital. Data on energy consumption and CO2 emissions were obtained from the World Bank Indicator database.[[8]](#footnote-8) The unit used for energy consumption and CO2 emission is kt oil equivalence, and for CO2 emissions is kt CO2 emissions. All four indicators are observed annually in *MPCA12* sample from 1980 until 2010, which contributes to a balanced panel data (12x31) with 372 observations.

*2.1.2 Variable forms*

The standard EKC regression model has natural logarithmic form in all variables (dependent and independent), and also has logarithmic quadratic form in some independent variables. The natural logarithmic form permits us to estimate the constant elasticity from each estimated coefficient, which expresses constant relative change between a regressor and dependent variable. Moreover, an assumption of every econometric framework is that the variables should have normal distribution. However, all the variables in this sample’s data have positively skewed distribution, with a long tail to the right (Fig. 1 shows the extremely skewed distribution of *CO2*). Thus, normalization of the data is necessary, and natural logarithmic transformation will regularize data from extremely skewed distribution to become less asymmetric (Fig. 2 expresses the histogram of *lnCO2*). This also reduces the possible distortions of the dynamic properties of the variables. The four new variables in natural logarithmic form are *lnIN* for *IN*, *lnFDI* for *FDI*, *lnCO­2* for CO2 emissionsand *lnEN* for energy consumption. By taking logarithms, we also estimate the pollutants, energy consumption and income elasticities for dependent variables.



**Fig. 1. Histogram of CO2 emission**



**Fig. 2. Histogram of lnCO2**

Table 1 indicates the skewness of those four series before and after logarithmic transformation. The results indicate that all new variables are better than their previous forms. Thus, the possible distortion of dynamic properties is reduced.

**Table 1. The skewness statistics of variables**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | IN | lnIN | FDI | lnFDI | Energy | LnEN | CO2 | lnCO2 |
| Skewness | 2.9894 | 0.7257 | 2.6845 | -0.9555 | 3.2537 | 0.3508 | 3.8580 | -0.0145 |
| *Note:* The skewness closer to zero indicates that the variable is closer to normal distribution. | | | | | | | | |

**3.2 Models**

*3.2.1 Model forms*

EKC theory implies that the environmental impact is an inverted U-shaped function of income (*IN*) and logarithm of the indicator is modeled as a quadratic function of the logarithm of *IN*. Based on the EKC hypothesis, a linear logarithm quadratic model is formed to express the relationships between CO2 emissions, energy consumption, economic growth and FDI as follows:

*lnCO2i,t = β0 + β1lnENi,t +β2lnINi,t + β3ln+ β4lnFDIi,t* +*vi,t* (1)

or *lnCO­2i,t* =*β0 + βkXi,t + vi,t* (2)

where *i = 1,…, N* denotes the country, *t = 1, …, T* denotes the time period, *Xi,t* is the vector of explanatory variables and *vi,t* is the error term, which is assumed to be serial uncorrelated.

Based on the EKC theory, we expect the signs of *lnEnit*, *lnINit* to be positive, since CO2 emissions increase when energy consumption increases and income increases. We also expect that has a negative sign. For the purpose of testing our hypotheses, we estimate the relationship between the aforementioned variables using the panel data, and then we also examine the differences of Japan’s economy from the sample. There may be differences between the EKC of developed and developing countries, for example, Japan’s CO2 emissions may start its decline at a lower income level than of other countries. To examine these possible differences between Japan and the sample, and whether causality relationships exist between the characteristics of Japan’s economy and our sample series, interaction terms of Japan (hereinafter *JPN*) with all the original explanatory variables are taken into account. The model becomes:

*lnCO2it = β0 + βkXi,t + γjJPNt\*Xi,t + vi,t* (3)

The interaction terms between *JPN* and vector *Xi,t* include *JPN\*lnCO2*, *JPN\*lnEN*, *JPN\*lnIN*, *JPN\*lnIN*2 and *JPN\*lnFDI*, which are denoted as *JCO2*, *JEN*, *JIN*, *JIN2* and *JFDI*, respectively.

*2.2.2 Panel unit root test*

The economic variables used in this study are cross-sectional units which are observed over time. Thus, these variables may have stochastic trends and therefore non-stationary, resulting to estimates that are likely to be spurious in nature (Engle and Granger, 1987). To avoid this spurious regression problem, the unit root testsare employed in order to examine whether variables are stationary or non-stationary (have unit root).

This study uses five recent types of panel unit root test. These are: Levin *et al*. (2002) (LLC), Breitung, Im, Pesaran and Shin (IPS), and two Fisher-types tests. In these tests, LLC is a generalization of the ADF individual country unit root tests to a common panel unit root test. The null hypothesis is that each individual time series contains unit root against the alternative that each time series is stationary. IPS test has the same null hypothesis with LLC but the alternative allows for some of the individual series to have unit roots. Both LLC and IPS tests require N (number of cross-sectional units) such that N/T 0 (T is number of time periods), i.e. N should be small enough relative to T, which indicates LLC and IPS have size distortions if N gets large relative to T. Breitung (2000) found that the LLC and IPS test suffer from a dramatic loss of power if individual specific trends are included. The Breitung unit root test equation includes individual fixed effects and individual trends as regressors, with the same null and alternative hypotheses with LLC test. Fisher-type tests proposed by Maddala and Wu (1999) and Choi (2001) combine the p-values from unit root tests for each cross-section unit to test for unit roots in the panel data, where the alternative hypothesis would allow some groups to have unit root while others may not. While IPS is an asymptotic test, which depends on *N*, Fisher-type is an exact test which depends on *T*  (Maddala and Wu, 1999). In Fisher-type tests, Fisher augmented Dickey-Fuller (Fisher ADF) test can use different lag lengths in the individual ADF regressions and can be applied to any other unit root tests, and Fisher Phillips-Perron (Fisher PP) test removes the autocorrelation using an adjustment to the standard errors. The null and alternative hypotheses of these tests are summarized in Table 2.

**Table 2. The null and alternative hypotheses of unit root tests**

|  |  |  |
| --- | --- | --- |
| **Test** | **Null hypothesis** | **Alternative hypothesis** |
| LLC (no trends) | Panel contains a unit root | Panel is stationary |
| Breitung (include trends) | Panel contains a unit root | Panel is stationary |
| IPS (no trends) | Panel contains a unit root | Some of the individual series have unit roots |
| Fisher-type (no trends) | Each sample contains unit root | Some groups to have unit root |

The unit root test equations of LLC, IPS and Fisher-types tests only contain an intercept, while the equation of Breitung test includes the individual fixed-effect intercepts and time trends by augmenting a time specific constant. A series is considered as stationary after all unit root tests reject the null hypothesis expressed in Table 2. Table 3 shows the result of unit root tests at level, first difference and second difference. The row “level” in each series expresses that *lnEN*, *lnIN* and *lnIN2* are nonstationary after all kinds of tests. Only LLC test suggests *lnCO2* is stationary (at 5% levels of significance) while the others suggest *lnCO2* is nonstationary. Besides, we cannot reject the null hypothesis that *lnFDI* contains unit root after IPS and Fisher ADF tests. Inside the interactions between country dummy Japan with sample variables, all five tests indicate *JCO2* and *JEN* are non-stationary. Only LLC test suggests *JIN* and *JIN2* are stationary, while Beitung tests suggest *JFDI* is nonstationary. The unit root tests results express data is not informative enough to conclude each series is stationary at level.

**Table 3. Panel unit root tests results at level, 1st and 2nd differences**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | **Common** | | **Individual** | | |
|  |  | **LLC** | **Breitung** | **IPS** | **Fisher ADF** | **Fisher PP** |
| ***lnCO2*** | Level | -2.1745\*\* | -0.2314 | 2.6924 | 12.8877 | 13.1187 |
| 1st dif. | -11.4852\*\*\* | -5.8959\*\*\* | -12.4429\*\*\* | 176.402\*\*\* | 202.378\*\*\* |
| 2nddif | -3.5074\*\*\* | -6.7471\*\*\* | -15.1656\*\*\* | 223.551\*\*\* | 266.195\*\*\* |
| ***lnEN*** | Level | -0.9356 | 0.1222 | 4.9124 | 18.4654 | 21.7314 |
| 1st | -11.0144\*\*\* | -6.5849\*\*\* | -10.5759\*\*\* | 151.721\*\*\* | 199.460\*\*\* |
| 2nddif | -6.2403\*\*\* | -2.2596\*\* | -15.1707\*\*\* | 222.487\*\*\* | 298.397\*\*\* |
| ***lnIN*** | Level | 3.0377 | 3.2195 | 7.2426 | 5.1816 | 4.2730 |
| 1st | -8.5608\*\*\* | -6.0812\*\*\* | -8.1952\*\*\* | 114.879\*\*\* | 136.085\*\*\* |
| 2nddif | -9.5141\*\*\* | -4.4510\*\*\* | -14.6304\*\*\* | 214.718\*\*\* | 325.692\*\*\* |
| ***lnIN2*** | Level | 5.9438 | 3.7108 | 8.7713 | 3.6851 | 3.5661 |
| 1st | -7.8972\*\*\* | -5.3719\*\*\* | -7.6108\*\*\* | 106.478\*\*\* | 125.514\*\*\* |
| 2nddif | -8.4338\*\*\* | -4.7571\*\*\* | -13.7882\*\*\* | 202.509\*\*\* | 345.479\*\*\* |
| ***lnFDI*** | Level | -2.8122\*\*\* | -1.4207\* | -1.1934 | 32.2322 | 49.6468\*\*\* |
| 1st | -13.9336\*\*\* | -4.3039\*\*\* | -14.7278\*\*\* | 206.156\*\*\* | 338.014\*\*\* |
| 2nddif | 14.6380 | -3.7009\*\*\* | -11.4337\*\*\* | 169.579\*\*\* | 249.101\*\*\* |
| ***JC02*** | Level | -0.3918 | 0.2166 | 0.3767 | 0.8163 | 0.8006 |
| 1st | -4.4788\*\*\* | -0.6164 | -4.2274\*\*\* | 17.4006\*\*\* | 17.3842\*\*\* |
| 2nddif | -0.3025 | -1.3176\* | -4.9086\*\*\* | 20.8224\*\*\* | 18.5117\*\*\* |
| ***JEN*** | Level | -1.2783 | 1.3036 | -0.1644 | 1.6662 | 1.5576 |
| 1st | -3.3037\*\*\* | -0.8303 | -3.0815\*\*\* | 12.1184\*\*\* | 12.1184\*\*\* |
| 2nddif | 7.9189 | 2.6207 | -2.5726\*\*\* | 10.2191\*\*\* | 28.7408\*\*\* |
| ***JIN*** | Level | -1.5535\* | 0.4394 | -0.5846 | 2.6407 | 2.3756 |
| 1st | -3.3224\*\*\* | -2.8637\*\*\* | -2.4549\*\* | 9.3621\*\*\* | 9.2758\*\*\* |
| 2nddif | -3.0207\*\*\* | -1.9427\*\* | -3.2378\*\*\* | 13.0420\*\*\* | 30.6850\*\*\* |
| ***JIN2*** | Level | -1.5510\* | 0.3721 | -0.4835 | 2.3837 | 2.2541 |
| 1st | -3.1498\*\*\* | -2.8090\*\*\* | -2.4473\*\*\* | 9.3295\*\*\* | 8.9865\*\* |
| 2nddif | -2.8942\*\*\* | -3.1401\*\*\* | -3.4103\*\*\* | 13.8432\*\*\* | 34.7275\*\*\* |
| ***JFDI*** | Level | -2.4621\*\*\* | 0.2956 | -1.9217\*\* | 7.1667\*\* | 6.8945\*\* |
| 1st | -1.5339\* | 1.5283 | -3.3411\*\*\* | 13.5878\*\*\* | 36.0693\*\*\* |
| 2nddif | 2.7494 | -1.5736 | -3.8304\*\*\* | 16.1113\*\*\* | 18.4207\*\*\* |
| *Notes:* \*, \*\*, \*\*\* denote test statistic significance at the 10%, 5% and 1% level; Fisher ADF and Fisher PP tests use asymptotic Chi-squares distribution; All other tests assume asymptotic normality; The lag lengths are selected by Akaike Info Criterion (AIC). | | | | | | |

The same unit root tests are applied to the first difference of all series. The tests results in Table 3, rows “1st dif.” indicate that all variables (excluding the interactions of dummy) can be made stationary by taking the first difference, and are integrated of order one, denoted as I(1). Within the dummy interactions, *JCO2* is I(1) with LLC, IPS, Fisher ADF and Fisher FF (at 1% level of significance), but is not I(1) with Breitung tess. Breitung test continues to suggest that *JEN* is not I(1). On the other hand, the results from rows “1st dif.” of this table expresses *JIN* and *JIN2* are I(1), but one more time, Breitung test indicates *JFDI* is not I(1).[[9]](#footnote-9)

The panel unit root test results in rows “1stdif.”of Table 4 show that *lnCO2*, *lnEN*, *lnIN*, *lnIN2*, *lnFDI*, *JIN* and *JIN2* are I(1) after all tests but *JCO2*, *JEN* and *JFDI* are not I(1). Thus, panel unit root tests at second difference of all variables should be applied to investigate whether these variables are integrated of order two, I(2) or not. Rows “2nd dif.” in the same table express the unit root test results at the second difference of the series, all tests indicate that *lnCO2*, *lnEN*, *lnIN*, *lnIN2*, *lnFDI*, *JIN* and *JIN2* are I(2). However, LLC and/or Breitung tests continue suggesting that *JCO2*, *JEN* and *JFDI* are not I(2).

To summarize, based on all unit root tests’ results, *lnCO2*, *lnEN*, *lnIN*, *lnIN2*, *lnFDI*, *JIN* and *JIN2* are I(1). Finally, *JCO2*, *JEN* and *JFDI* are not I(1) after some tests, LLC or/and Breitung tests even express they are not I(2). Because a model can only be estimated if its variables are integrated of the same order, model consisting of Equation 3 should have only two interaction terms, *JIN* and *JIN2* in testing hypothesis. Because *JCO2*, *JEN* and *JFDI2* are not integrated with the same order with other variables, we cannot include them to the model. Thus, we cannot test one part of hypothesis 2, which implies that Japan’s CO2 emissions, energy consumption, economic growth and FDI inflows have causal relationships with these characteristics of *MPCA12*. The new hypotheses that replace to hypothesis 2 should be:

***Hypothesis 2a:*** FDI, economic growth, CO2 emissions and energy consumption not only have causal relationships with each other within the *MPCA12* panel sample but also have causal relationships with Japanese income.

Model consisting of Equation 3 becomes:

*lnCO2it = β0 + βkXi,t + γ1JINt + γ2JIN2t + vi,t* **(4)**

Now, assume a vector Zit which includes *lnCO2it* and all other variables in model consisting of Equation 4. From the panel unit root test results, all components of the vector *Zit* are I(1), or the first difference *Zi,t = (1-L)Zit* is integrated of order zero, where *L* is the lag operator of *Zi,t* and *(1 – L)* is the first difference.

*3.2.3 Panel cointegration test*

The panel cointegration estimation allows the appearance of heterogeneity problems among individuals within the panel both in long-run and in the dynamics (Kao and Chiang (2000). Granger (1981) and Granger and Weiss (1983) introduced a definition for co-integrating vector as follows:

The components of the vector *yt = (y1t, y2t,…, ynt)’* are said to be co-integrated of order d, b where b > 0, denoted *yt CI(d,b)*, if (i) all components of *yt* are *I(d)*; (ii) there exists a vector *α = (α1, α2,…,αn)* (α # 0) that the linear combination *zt = α1y1t + α2y2t +…*+ *αnynt* is integrated of order (d-b) or *zt = α’yt I(d-b)*. The vector *α* is called the *co-integrating vector.*

Despite the fact that all the variables in model consisting of Equation 4 are non-stationary, the first difference of each (i.e. *Zi,t = (1-L)*Z*i,t*) is stationary. Thus, the spurious regressions may be avoided if any existing linear combination of the series is integrated of order zero or one (which means that these variables are cointergrated of order smaller than one) (Engle and Granger, 1987). For clearing interpretation, if *y* and *x* are nonstationary I(1) variables, and the linear combination of them, such as *e* = *y* – β1–β2*x*, is stationary (or integrated of order zero, I(0)). In this case, *y* and *x* are said to be cointegrated. The cointegrating relationships imply long-run equilibrium relationships among these variables.

The first test that we used to examine the panel cointegration is Kao’s (Engle-Granger based) test. Kao’s (1999) test conveys residual-based tests for cointegration regression in panel data, which is suitable in testing the cointegration of all series that are integrated of order one, including dummy variables (one of the Kao’s test applications for the model with dummy variable is Kao *et al.,* 1999). Kao (1999) applied Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) tests, which are based on a simple ordinary least squares (OLS) regression of the residual, to test the null of no cointegration in panel data. The statistics were constructed to confirm that the limiting distribution of all tests converge to a standard normal distribution. Table 4 shows the Kao’s test results with the max lag of seven.

Kao’s test is residual-based, it cannot be used to test for more than one cointegrating equation (Carlsson *et al.*, 2007). On the other hand, we purpose to examine the difference between the EKC of Japan versus that of the *MPCA12*, and whether the Japan dummy variables affect the remaining variables. We treat Japan dummy variables as exogenous and propose Johansen’s (1991) cointegration test to examine whether *lnCO2*, *lnEN*, *lnIN*, *lnIN2*, and *lnFDI are* cointegrated in the context of vector autoregressive model. Although Johansen’s test critical values are not appropriate when the model includes dummy variables, even if all variables are integrated of the same order, but this test methodology performs well when error terms are not normally distributed (Gonzalo, 1994), and allows for some relationships to be cointegrated (Maddala and Wu, 1999). Johansen cointegration test employed trace and maximum eigenvalue tests to determine the number of cointegration relationships. Because the maximum eigenvalue test carries out separate tests on each eigenvalue, and has the sharper alternative hypothesis, its results should be used in choosing the number of cointegrated relationships. Table 4 reports the results of Johansen cointegration test with null and alternative hypotheses.

**Table 4. Results of the Johansen cointegration test**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Kao’s test*** | | | | | |
|  | *t*-statistic | | | | |
| ADF | -5.6101\*\*\* | | | | |
| ***Johansen cointegration test*** | | | | | |
| *Trace test* | | | *Maximum eigenvalue test* | | |
| Null Hypothesis | Alternative Hypothesis | Trace statistic | Null Hypothesis | Alternative Hypothesis | Max-Eigen  Statistic |
| r = 0 | r 1 | 67.9603\*\*\* | r = 0 | r = 1 | 88.0007\*\*\* |
| r 1 | r 2 | 79.9596\*\*\* | r = 1 | r = 2 | 39.8435\*\*\* |
| r 2 | r 3 | 40.1161\*\*\* | r = 2 | r =3 | 32.7887 \*\*\* |
| r 3 | r 4 | 7.3274 | r = 3 | r = 4 | 4.5734 |
| r 4 | r 5 | 2.7540 | r = 4 | r = 5 | 2.7540 |
| *Notes:* Trace and max-eigen statistics calculated at 5% level; \*\*\* denotes test statistic significance at the 1% level; Probabilities are computed using asymptotic Chi-square distribution, and r is the number of cointegration equations; The lag lengths are selected using AIC*.* | | | | | |

ADF test statistics reported in Table 4 indicate all variables (including Japan’s interaction terms) are cointegrated within our panel sample. The max-eigen statistics reported in the same table suggest that there are three cointegrating vectors at 1% and 5% levels of significance. The significance of both ADF and Max-eigen statistics imply the existence of long-run relationship between variables, and the spurious regression is avoided. The existence of cointegration among model consisting of Equation 4 variables suggests that the ordinary least square (OLS) estimation is super consistent in estimating the model parameters (Alves and Brueno, 2003).

The estimated equation of model consisting of Equation 4 by OLS is:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *=* | *– 4.9954* | *+ 1.1823lnEN* | *+ 0.8809lnIN* | *– 0.0493lnIN2* | **(5)** |
| S. E | (0.3131) | (0.0106) | (0.0915) | (0.0064) |  |
| *t*-statistic | -15.9547 | 111.2211 | 9.6302 | -7.7079 |  |
| *p*-value | 0.0000 | 0.0000 | 0.0000 | 0.0000 |  |
|  | *– 0.0301lnFDI* | *+ 0.0534JIN* | *– 0.0027JIN2* |  |  |
| S. E | (0.0068) | (0.0961) | (0.0096) |  |  |
| *t*-statistic | -4.4085 | -0.5557 | 0.2831 |  |  |
| *p*-value | 0.0000 | 0.5788 | 0.7772 |  |  |

The results from Equation 5 show that the estimated coefficients of *lnEnit*, *lnINit*, and have the expected signs at 1% level of significance, which support our EKC hypothesis 1, stating that when income is at 0.8809/(2\*0.0493) = 8.9341 (in logarithms), the EKC begins to reverse. Furthermore, the results indicate that CO2 emissions becomes income elastic when its absolute partial derivative on income is greater than unity, equals that income is smaller than -1.3292 (in logarithms, exclude Japan) or greater than 19.0761 (in logarithms), and significantly. Conversely, the variable CO2 emissions is inelastic if *lnIN* is smaller than 19.0761 (excluding Japan dummy interaction terms). As for energy use elasticity, the results express that CO2 emissions is elastic with energy consumption, where CO2 emissions will increase by 1.1823% when energy consumption increases by 1%. In Japan, the estimated results in Equation 5 show that *JIN* and *JIN2* are insignificant, although its coefficients’ magnitude is quite small. Thus, in testing EKC hypothesis, we cannot conclude the difference of Japan from *MPAC12*. We also cannot confirm the difference between Japan and the *MPAC12* with regard to CO2 emissions of income.

The estimated coefficients magnitude of *lnFDI* is quite small and negative (only –0.0260), but significant at 1% level. This result indicates that FDI is to be inelastic in reducing CO2 emissions in our *MPAC12* sample.

*3.2.4 Granger causality test*

The cointegration tests suggest the existence of at least one cointegrating relation (from Kao’s test results in Table 4), and of long-run equilibrium relationships between CO2 emissions, energy consumption, economic growth and FDI on the *MPCA12* sample. Granger causality test in the context of vector error-correction model (VECM) will help us know whether past value of one variable affects another variable in the current period. These test results also indicate the directions of causal relationships between variables in the model consisting of Equation 4. The Granger causality test in the context of VECM framework is as follows:

*Yi,t = α10 +α11(Yi,t-1 – Xi,t-1) + δ11Yi,t-p + δ12Xi,t-p + β1zi,t-p + ei,t* **(6)**

*Xi,t = α20 + α21(Yi,t-1 – Xi,t-1) + δ21Yi,t-p + δ22Xi,t-p + β2zi,t-p + vi,t*

where *i = 1,..., N* denotes the countries, *t = 1, …, T* denotes the time period, denotes change operator, *Yi,t* and *Xi,t* is a pair of endogenous variables, z is the vector of other variables where *β1* and *β2* are vectors of its parameters in each equation; *ei,t, vi,t­* are two error terms; and *(Yi,t-1 – Xi,t-1)* is the error correction term (ECT). *α11* and *α21* are the parameters that show the speed of adjustment to the long-run equilibrium, which might confirm the long-run relationship between variables.

Granger causality test will examine whether *Xi,t-p* (or *Yi,t-p*) affect *Yi,t* (or *Xi,t*) through the significance of *δ12* and *δ21*, which might express the short-run causality relationship. If both *δ12* and *δ21* are significant, we conclude the bi-directional causality between *Xi,t* and *Yi,t*. If only one between *δ12* and *δ21* is significant, we conclude the uni-directional relationship from *Xi,t* to *Yi,t* or from *Yi,t* to *Xi,t*. If both *δ12* and *δ21* are insignificant, then there is no short-run causality relationship between these two variables. If any component of *β1* and *β2* is significant, unidirectional relationships also exist from the corresponding component in vector *zi,t-p* to *Yi,t* or *Xi,t*. Long-run causality is determined by the error correction term, whereby if it is significant and negative, then it indicates evidence of long-run causality from the explanatory variable to the dependent variable. If both *α11* and *α21* are significant, we conclude the long-run bidirectional relationship between *Xi,t* and *Yi,t*. Finally, if only one between *α11* and *α21* is significant, we conclude long-run unidirectional relationship from *Xi,t* to *Yi,t*, or from *Yi,t* to *Xi,t*.

In this report, the pairs of (*Xit, Yi,t*) include (*lnCO2, lnEN*), (*lnCO2, lnIN* and *lnIN2*), (*lnCO2, lnFDI*), (*lnCO2, JIN* and *JIN2*) and other pairs that are combinations of each variable with one or two other variables such as *lnEN* with *lnIN* and *lnIN2* or with *lnFDI* and so forth.

Table 5 presents Granger causality results with the null hypothesis of no causal relationship in each pair of variables. The results support hypothesis 2a, indicating the existence of short-run relationships between variables, where two bidirectional causality relationships exist between *MPCA12*’s CO2 and energy consumption, and between its income and FDI inflows. The unidirectional relationship is found from *MPCA12*’s income to CO2 emissions, and from its income to energy consumption. However, we do not find the short-run causality relationships between CO2 emissions and FDI, and between FDI and energy consumption within *MPCA12* sample. In testing the causality between Japanese income and *MPCA12*’s variables,we find only one bidirectional relationship between Japanese income and *MPCA12*’s FDI inflows, while we do not find any causal relationship between Japan income and *MPCA12*’s CO2 emissions, energy consumption and income.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 5. Results of short-run Granger causality test** | *D(JIN2)* | 0.0182 | 0.2309 | 0.2462 | 5.3473\*\* | - | *Notes:* \*, \*\* and \*\*\* denote test statistical significance at the 10%, 5% and 1% level; denotes causality direction from X Y |
| *D(JIN)* | 0.3480 | 0.2934 | 0.2539 | 7.0358\*\*\* | - |
| *D(lnFDI)* | 1.3606 | 0.1934 | 12.3663\*\*\* | - | 11.7717\*\*\* |
| *D(lnIN2)* | 1.1713 | 2.4523 | - | 2.3049 | 0.4786 |
| *D(lnIN)* | 0.6420 | 1.5361 | - | 12.2321\*\*\* | 0.5619 |
| *D(lnEN)* | 4.2810\*\* | - | 8.2438\*\*\* | 0.8533 | 1.0936 |
| *D(lnCO2)* | ˗ | 8.6356\*\*\* | 5.8396\* | 0.0130 | 0.0003 |
|  | *D(lnCO2)* | *D(lnEN)* | *D(lnIN) & D(lnIN2)* | *D(lnFDI)* | *D(JIN) & D(JIN2)* |

The significance of the estimated coefficients of ECTs from model consisting of Equation 6 indicates long-run causal relationship between variables. This result continues to support hypothesis 2a. Table 6 shows two bidirectional causality relationships in the *MPCA12* sample, which include energy consumption – income and income – FDI. CO2 emissions have unidirectional long-run relationships to energy use, income and FDI. *MPCA12*’s FDI has unidirectional relationship to energy consumption. Furthermore, we found that *MPCA12* has long-run causality relationships with Japan’s income. Unidirectional relationships are found as follows: from *MPCA12*’s CO2 emissions to Japan’s income, and from *MPCA12*’s FDI to Japan’s income. Bidirectional causality relationships are found in the following: Japan’s income with *MPCA12*’s energy consumption, and Japan’s income with *MPCA12*’s income.

**Table 6. Long-run panel causality test**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Causal direction** | **ECT t-stat** | **Causal direction** | **ECT t-stat** | **Conclusion Direction** |
| lnCO2 lnEN | -4.0042\*\*\* | lnEN lnCO2 | 0.4717 | CO2 energy use |
| lnCO2 lnIN | -20.7445\*\*\* | lnIN & lnIN2 lnCO2 | -1.2257 | CO2  Income |
| lnCO2 lnIN2 | -19.1462\*\*\* |
| lnCO2 lnFDI | -4.7120\*\*\* | lnFDI lnCO2 | -0.4266 | CO2 FDI |
| lnCO2 JIN | -2.2402\*\* | JIN & JIN2  lnCO2 | 0.8013 | CO2 Japanese income |
| lnCO2 JIN2 | -11.5598\*\*\* |
| lnEN lnINC | -21.4862\*\*\* | lnINC & lnINC2 lnEN | -4.5032\*\*\* | Energy use Income |
| lnEN lnINC2 | -18.3458\*\*\* |
| lnEN lnFDI | -0.6457 | lnFDI lnEN | -7.4977\*\*\* | FDI Energy use |
| lnEN JIN | -0.2389 | JIN &JIN2  lnEN | -2.7503\*\*\* | Energy use Japanese income |
| lnEN JIN2 | -11.5844\*\*\* |
| lnIN & lnIN2 lnFDI | -2.7343\*\*\* | lnFDIlnIN | -21.7924\*\*\* | Income FDI |
| lnFDI lnIN2 | -19.1462\*\*\* |
| lnIN&lnIN2 JIN | -1.5453 | JIN & JIN2  lnINC | -21.7901\*\*\* | Income Japanese income |
| lnIN&lnIN2 JIN2 | 11.0917\*\*\* | JIN & JIN2  lnINC2 | -18.3821\*\*\* |
| lnFDIJIN | -0.0162 | JIN & JIN2  lnFDI | -0.2833 | FDI Japanese income |
| lnFDIJIN2 | -11.5500\*\*\* |
| *Notes:* \*, \*\* and \*\*\* denote test statistical significance at the 10%, 5% and 1% level; denotes causality direction from X Y; denotes bidirectional relationship between X and Y. | | | | |

**4. Conclusions**

This study examines whether EKC hypothesis is confirmed in the case of the 12 most populous Asian countries (*MPCA12*), as well as whether the EKC of Japan, the most developed country within *MPCA12*, is different from the sample’s reference EKC. After applying unit root tests, we find that all series are integrated of order one and their linear combinations are stationary. This result permits us to use OLS as a super consistent estimator. From the consistent OLS estimated results, we find that when income per capita is at 8.9341 (in logarithms) or 7 586.306 US dollars, CO2 emissions begin to decline significantly. These results support the EKC concept, which suggest an inverted U-shape curve of environmental degradation with respect to income. However, we cannot find the difference between Japan’s EKC from the sample’s EKC due to the insignificance of interaction terms between dummy variable Japan and income series. On the other hand, the CO2 emissions variable is only elastic with income when income level is greater than 19.0761 (in logarithms), or when income per capita is greater than 192 million US dollars, which is not likely to happen in next many decades. Thus, we suggest that CO2 emissions are income-inelastic within our sample. In the case of energy consumption elasticity, we find that *MPCA12*’s CO2 emissions are elastic with energy consumption, where CO2 emissions increase 1.1823% if energy consumption increases by 1%. We also find that within *MPCA12*,pollutants decrease by 0.0301% when FDI inflows increase by 1%. We did not find a significant difference between Japan’s income and that of *MPCA12* that affects CO2 emissions, because the estimated coefficients of Japan dummy interaction terms are all insignificant.

Besides testing the EKC theory, this paper studies the dynamic relationship between CO2 emissions, energy consumption, FDI and economic growth in *MPCA12* panel sample from 1980 to 2010. We test not only the differences of Japan’s income from that of the sample that affects CO2 emissions but also whether this factor has a relationship with *MPCA12*’s CO2 emissions, energy consumption, income and FDI. By using the Granger causality test in the context of VCEM, we find that there are two short-run bidirectional relationships between CO2 emissions and energy consumption as well as between its income and FDI inflows within the *MPCA12* sample. Furthermore, we also find two long-run bidirectional relationships of the sample’s series, which are between income and energy consumption, and between income and FDI inflows. The long-run unidirectional causality relationships exist from CO2 emissions to energy use, income, FDI and from FDI to energy consumption. Both the short and long-run bidirectional relationships between income and FDI suggest that an increase income within *MPCA12* will attract more FDI, and FDI inflows in turn also helps increase income. Upon testing the causal relationship of Japan’s interaction terms with the sample variables, we find only one short-run bidirectional relationship between the sample’s FDI inflows and Japanese income. We also find two long-run bidirectional causality relationships between *MPCA12* and Japan, where Japan’s income has the relationship with *MPCA12*’s income and energy consumption. Meanwhile, two long-run unidirectional causality associations are found from *MPCA12* CO2 emissions to Japan’s income and from *MPCA12* FDI to Japan’s income.

For the *MPCA12* sample, our estimated results indicate the existence of causality relationships between environmental pollutants, energy consumption, economic growth, and FDI inflows. With regard to environmental protection and economic development, the existence of long-run causality among CO2 emissions – energy consumption – economic growth – FDI pose important challenges to the sample countries’ policy makers. The bidirectional causality between economic growth and energy use indicates that these variables are jointly determined and affect each other simultaneously. This bidirectional causality implies that the *MPCA12* in our panel sample have been developing its economy through increasing its energy consumption. Meanwhile, the unidirectional relationships from CO2 emissions to energy use and income within *MPCA12* seems to express that its environmental protection regulations are weak, allowing the entry of inefficient energy technologies causing energy wastage. This is a rational result because most countries in *MPCA12* are developing countries with very high population and low income such as China, India, Indonesia, Bangladesh, Philippines, and Vietnam among others. There have been many studied express the problem that these countries usually focus on increasing economic growth but do not take the necessary measures to protect the environment, such as Zang *et al.* (2013), Jafari *et al.*, (2012), Alam *et al.*, (2011) and Tisdell, (2002). These results should serve as a precaution to policy makers that focusing on economic development while being indifferent about the environment will accelerate their country’s environmental degradation. The countries involved in this study should implement more stringent laws that require the use of energy-efficient technologies, which can reduce CO2 emissions while driving economic growth.

Still from our estimated results, the long-run unidirectional causalities from FDI inflows to energy consumption and from CO2 emissions to FDI inflows within the panel sample imply the closed relationships of FDI – energy consumption – environmental reduction. Usually, energy consumption increases as FDI increase to cater to increased production in host countries. However, the one direction effect of CO2 emissions on FDI inflows supports the pollution haven hypothesis, which states that when the host countries are less able to afford the costs of implementing and monitoring environmental regulations, the country becomes a pollution haven.[[10]](#footnote-10) However, from OLS consistent estimated results, we find the significant role of FDI inflows in reducing CO2 emissions. Although the magnitude of the estimated coefficient FDI in Equation 5 is very small, expresses that pollutants only decrease by 0.0301% when FDI inflows increase by 1%, it implies that FDI still has positive effect on environmental improvement of *MPCA12* panel sample. This implication also appeared in some researches, such as Hübler (2009) for China or Letchumanan and Kodama (2000) for Thailand. Our evidence suggests that besides improving its energy efficiency and strengthening their economic growth, the, which includes almost developing countries, should try to attract more FDI, which can help their economies develop stably, increase the country’s income and curb environmental pollutants.

With the use of dummy variables, we find that Japan’s income has causal relationships with the *MPCA12*’s income, FDI, energy consumption and CO2 emissions. The long-run unidirectional relationship of CO2 emissions to Japan’s income and long-run bidirectional relationships between energy use and this series may imply that there are many Japanese firms operating in the *MPCA12* countries which sends money back to Japan, thereby increasing Japan’s income by, while contributing to these countries energy consumption as well as CO2 emissons. Similarly, the unidirectional relationship from the *MPCA12*’s FDI inflows to Japan’s income may be referred to the reason that Japan’s companies have been investing heavily to the most populous countries in Asia.

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2. Department of International Business and Center for Applied Economic Modeling, Chung Yuan Christian University, 200 Chung-Pei Road, Chung-Li, Taiwan 32023. [↑](#footnote-ref-2)
3. These numbers are calculated by the authors from United Nations Conference on Trade and Development (UNCTAD) Statistics, 2013. Growth rates are based on GDP in 2005 U.S. dollars. [↑](#footnote-ref-3)
4. 12 Asian most populous countries are ranked by total population of each country. We aggregate data from UNCTAD Statistics Database, 2013. We exclude Turkey out of the sample due to that Turkey is a member of Council of Europe (since 1949) and was an official candidate of European Union for full membership in 1999. See more on http://www.coe.int/en/web/portal/turkey [↑](#footnote-ref-4)
5. Embargo against Iran has begun since 1979 by the bans on the import of Iranian crude oil into the United States. Recent United Nations sanctions against Iran include resolutions 1737, 1747, 1803, 1929 and 2049. See more on http://www.un.org/sc/committees/1737/ [↑](#footnote-ref-5)
6. These numbers are calculated by the authors based on Word Bank Indicator database, 2013. This database is available online from ULR: http://data.worldbank.org/indicator [↑](#footnote-ref-6)
7. This database is available online from ULR: http://unctadstat.unctad.org/ReportFolders/reportFolders.aspx [↑](#footnote-ref-7)
8. This database is available online from ULR: http://data.worldbank.org/indicator [↑](#footnote-ref-8)
9. If we use the time period from 1980 until 2009 for *MPCA12* panel sample, all unit root tests (including Breitung test) suggest *JFDI* is I(1). [↑](#footnote-ref-9)
10. The pollution haven hypothesis is the idea that for given levels of environmental policy, polluting industries will relocate to countries with weaker environmental regulation. [↑](#footnote-ref-10)