Analysis of the Trend of CO_2 Emissions in China, Korea, Japan, UAS, Canada, Australia using an Environmental Kuznets Curve Approach

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1. Introduction

After China opened its economy to the world in 1978, it has a rapid development and growth in the economic sphere. Especially, it is obvious that there is a great advanced in the industrial economic, which brings the high consumption of fossil energy and serious pollution problems. In order to develop and keep a high growth rate of GDP, it seems that, no matter China or other countries, it must spend its environment as external costs. The consumption of coal, that covers a half of the total fossil consumption, induces serious air pollution in China. For example, recently it is getting worse in air pollution which is affected by fine dust; however, it also has a deep relationship with CO_2 emissions, especially in Beijing and Shanghai. He *et al*. (2010) proposed that CO_2 emission in 2020 will be about 40% higher than prevailing in 2005 because of rapid growth of GDP. It implies that the CO_2 emission will increase because the heavy industry, energy-intensive business, will play an important role on the economic growth. In addition, the CO_2 pollution is not only problems for one country but also global problems.

This study focuses on the relationship between per-capita real GDP growth and CO_2 emissions. As known, there are many kinds of previous literatures regarding the Environmental Kuznets Curve (EKC) to explain the relationship between GDP growth and pollutions such as SO_2, CO_2 and NO_X. This study will also use the EKC theory to show if the curve (between the change of per-capita CO_2 emission and per-capita real GDP) has an inverted-U-shaped or different shaped by the influence of the final fossil energy (coal and gas) and non-fossil energy (renewable energy). This study chooses China and 5 OECD countries such as Korea, Japan, USA, Canada, and Australia. Korea and Japan are the nearest countries to China which are playing important roles on solving global CO_2 pollution issue in Asia relatively. USA, Canada and Australia have rich fossil energy resource and great size of land. USA, Canada and Australia also have high technology on producing non-fossil energy. There is an obvious phenomenon (Fig. 1) that China, Korea, and Japan show the increase trends of per-capita CO_2 emission, while USA, Canada, and Australia show a relative decrease trend. So, it is possible to get comparison results among 6 countries.

Most previous literatures used linear model or logarithm model to analysis the relationship between CO_2 emissions and GDP growth, and also summarized results about how endogenous factors (such as trade, pollution emission, etc.) influence the change of CO_2 emissions. However, they do not explain why they choose specific functional formula. Wooldridge (2010) denoted that there are advantages on using the logarithm model. Firstly, the logarithm can be used to overcome the heteroskedasticity problem; secondly, many variables violate the normal distribution condition in econometrics, however the logarithm can make these variable obey the normal distribution condition; thirdly, since the basic variables are all the macroeconomic data, the logarithm is able to make sure these variables are stable. However it is known that, the basic theory of EKC is using the non-linear model to analysis the relationship between CO_2 emissions and GDP growth; at the same time, there are still a lot of studies which just used the non-linear model of EKC. This study has two objectives. The first one is to test whether both a non-linear model and a logarithm model will have similar results or not. Additionally, it will be tested whether or not an inverted U-shaped or an inverted-N-shaped is proper to each countries. The second one is to use the vector auto regression (VAR) to test how the CO_2 emission is affected by the endogenous factors, which are coal consumption, gas consumption, and renewable energy consumption. For example, as known, the coal consumption has a positive effect on CO_2 emissions; while this study will estimates how much power does it take to affect CO_2 emissions. Meanwhile, the renewable resource will play an important role on reducing the CO_2 emissions in the further. It is necessary to know that, even though the EKC model also concludes the energy factors which affect the result of the relationship between CO_2 emissions and GDP growth, it is difficult to know how much affection each energy takes to increase or decrease the CO_2 emissions. The VAR model seems more useful to estimate this kind of affection where does not consider the GDP growth.

It is necessary to mention that coal, gas and renewable consumptions are the only influence factors to be considered. As known, the coal is still playing an important role on the heavy industry and its consumption almost charges the half of total final energy consumption in China; its chemical component is the direct reason to produce CO_2 which induces the global greenhouse effect. The gas consumption is the second factor to be chosen. Even though gas is the fossil energy, one of its characteristics is that it can induce relatively low level of CO_2 emissions. The last factor to be considered is renewable resource. As known, the using of non-fossil energy instead of fossil energy is an inevitable trend in the further.

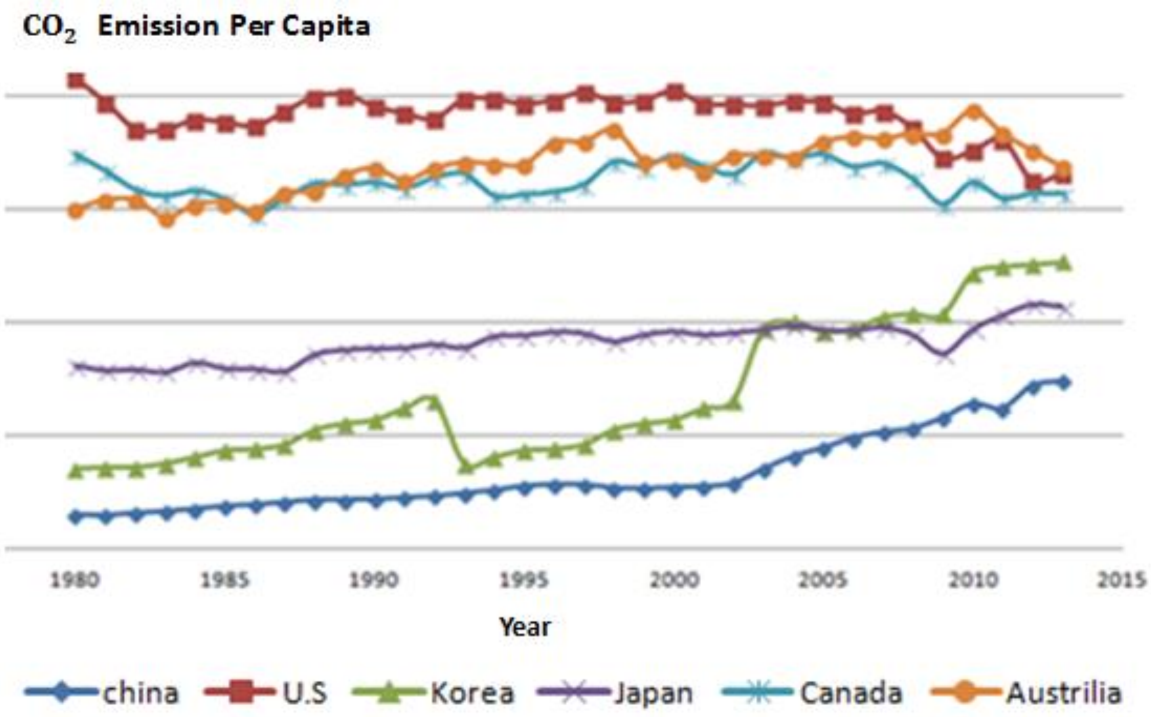


Fig1. Trend of CO_2 Emission per capita (unit: toe)

2. Literature Review

The Basic Theory of Environmental Kuznets Curve

The environmental Kuznets curve (EKC) shows the relationship between pollution emissions and GDP growth (or economic development) and the general EKC function is as following;

$$E_i = \alpha + \beta_1 Y_i + \beta_2 {Y_i}^2 + \beta_3 {Y_i}^3 + \beta_4 Q_i + \delta \tag{1}$$

Where, E means the per-capita emission; Y means the per-capita real GDP growth; **i** is the number of country. Q_i indicates a vector of variables such as coal, gas, and non-fossil energy consumption. δ denotes an error term. If β_1>0 (or β_1<0) and β_2=β_3=0, then there is a monotonically increasing (or decreasing) relationship between variable E and variable Y. If β_1>0, β_2>0 and β_3=0, then it matches with the basic theory of environment Kuznets curve (EKC) which means an inverted U shaped of EKC between GDP growth and pollution emissions (Orubu and Omotor, 2011). Finally, if β_1<0, β_2>0 and β_3<0, it comes up with an inverted-N-shaped relationship (Kijima et al., 2010).

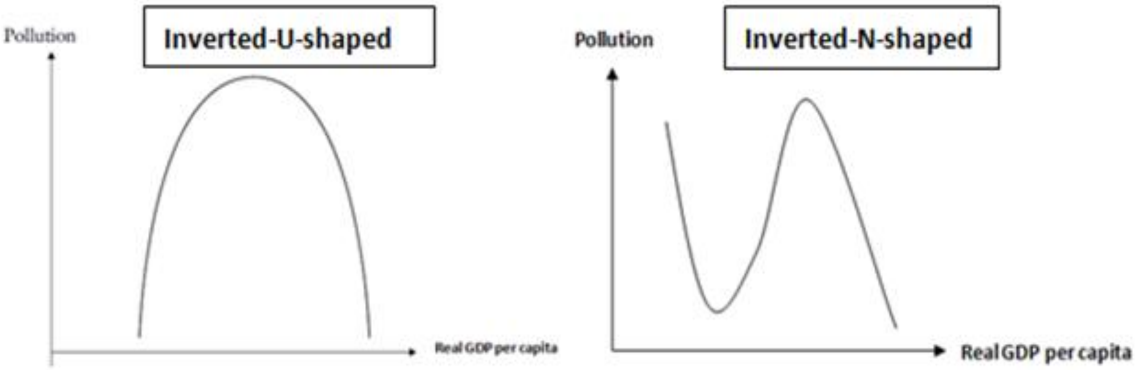


Fig 2 Quadratic and cubic functions for the estimation of the pollution and real GDP relationship

Besides equation (1), there is a popular equation formula of EKC. That is a logarithm function as following the equation (2).

$$\ln E = \gamma + \theta_1 \ln Y_i + \theta_2 \ln {Y_i}^2 + \theta_3 \ln {Y_i}^3 + \theta_4 \ln Q_i + \varepsilon \quad (2)$$

Where, variables E, Y and Q are same notation of the equation (1). If $\theta_1>0$ (or $\theta_1<0$) and $\theta_2=\theta_3=0$, then there is a monotonically increasing (or decreasing) relationship; if $\theta_1<0$, $\theta_2>0$ and $\theta_3=0$, then it can be denoted by an inverted-U-shaped relationship, the original EKC pattern; if $\theta_1>0$, $\theta_2<0$ and $\theta_3>0$, then it shows an N-shaped relationship.

Environmental Kuznets Curve and VAR model

Apergis and Payne (2009) used the basic and original equation of EKC which is:

$$C_{it} = \alpha_{it} + \beta_{it} E_{it} + \beta_{2i} Y_{it} + \beta_{3i} Y_{it}^2 + \varepsilon_{it}. \quad (3)$$

Where, C is the CO_2 emissions per capita; E is the energy consumption per capita; Y is the real output. Apergis and Payne (2009) extended CO_2 emissions, energy consumption, and output within a panel vector error correction model for six Central American countries over the period 1971-2004. It showed that energy consumption and real output exhibits the inverted U-shape pattern in long-run equilibrium.

Wang *et al*. (2011) used the basic formula of EKC to examine the causal relationships between carbon dioxide emissions, energy consumption and real economic output using a panel cointegration and a panel vector error correction modeling techniques based on the panel data for 28 provinces in China over the period 1995–2007.

$$C_{it} = \alpha_{it} + \beta_{1i} E_{it} + \beta_{2i} G_{it} + \beta_{3i} G_{it}^2 + \varepsilon_{it} \quad (4)$$

Where, C denotes the CO_2 emission per capita; E denotes the energy consumption per capita and G means the economic growth. It has also been found that energy consumption and economic growth are the long-run causes for CO_2 emissions. The CO_2 emissions and the economic growth are long-run causes for energy consumption. The results indicate that China's CO_2 emission will not decrease in a long period of time, and reducing CO_2 emission may handicap China's economic growth to some degree. Jalil and Mahmud (2009) also used this basic equation to get a similar result on the case of China.

Tao (2008) investigated the relationship between environmental pollution and economic growth in China using Chinese provincial data over 1985–2005. Waste gas, waste water and solid wastes are used as environmental indicators and GDP is used as the economic indicator. The formula of EKC of this study is as following:

$$\ln\left(\frac{S}{P}\right)_{it} = \alpha_i + \theta_t + \beta_1 \ln\left(\frac{GDP}{P}\right)_{it} + \beta_2\left[\ln\left(\frac{GDP}{P}\right)_{it}\right]^2 + \beta_3\left[\ln\left(\frac{GDP}{P}\right)_{it}\right]^3 + \mu_{it} \qquad (5)$$

Where, $\frac{S}{P}$ and $\frac{GDP}{P}$ mean per capita each pollution and per capita GDP respectively, denoting the population by P. This study applied a panel co-integration test in order to check whether or not there exists a long-run co-integrating relationship between the per capita emissions and the per capita GDP.

Orubu and Omotor (2011) investigated the relationship between per capita income and environmental degradation in Africa, using longitudinal data on suspended particulate matter and organic water pollutants. The specific objective was to estimate EKC for two indicators of environmental quality, and to establish whether the estimated relationships conform to the inverted U-shape hypothesis. The basic equation is:

$$\ln(ED)_t = \beta_1 + \beta_2 \ln(PCGDP)_t + \beta_3 \ln(PCGDP)^2 + e_t \qquad (6)$$

Where, variable ED and PCGDP denote a environmental pollution and a per capita GDP respectively. This study also did not tell the reason why it used the logarithm formula. While the results of the empirical investigation generally suggest the existence of EKC for a suspended particulate matter.

Baek *et al*. (2009) used a cointegration analysis to check a relationships among sulfur emissions (SO_2), income, and trade for the developed and the developing countries. They compiled annual time-series data on SO_2, income, and trade openness for 50 countries for the period 1960–2000. Baek *et al*. (2009) used the cointegrated vector auto regression (CVAR) model developed by Johansen in order to examine a dynamic interrelationship between trade, income and SO_2 emission. The Johansen method (Johansen, 1988; Johansen and Juselius, 1992) uses a statistical model involving up to k lags as following;

$$y_t = \mu + A_1 y_{t-1} + \cdots + A_k y_{t-k} + \mu_t \qquad (7)$$

Its results suggest that trade and income growth tend to increase environmental quality in developed countries, whereas they have detrimental effects on environmental quality in most developing countries.

Cui and Wang (2010) also mentioned that there are relationships of mutual influence, mutual constraints among energy system, economic system, and environmental system. VAR model has always been used for forecasting the relevant time-series and the random perturbation of variables that affect the dynamics of one system. Therefore, they established a VAR model of China's Energy-Economy-Environment based on the data of China's energy consumption, GDP and SO_2 from1995 to 2006, and then forecast the years from 1995 to 2015. The results confirm that the relationship among Energy-Economy-Environment based on VAR Model is reliable.

3. Estimation of EKC of China and other Countries

Logarithm model and Non-linear Model of EKC

First of all, this study used a logarithm formula to test a relationship between the per-capita CO_2 emissions and a per-capita real GDP in the whole data and the different data of each countries. The functional form applied to estimate is showed as:

$$\ln(\mathrm{CO2}_i) = \gamma + \theta_1 \ln(\mathrm{GDP_i})^1 + \theta_2 \ln(\mathrm{GDP_i})^2 + \cdots + \theta_\alpha \ln(\mathrm{GDP_i})^\alpha + \theta_{\alpha+1} \ln(\mathrm{Coal_i}) + \theta_{\alpha+2} \ln(\mathrm{Gas_i}) + \theta_{\alpha+3} \ln(\mathrm{Renewable_i}) \quad (8)$$

As known, the basic theory of EKC denotes that 'α=3' denotes N-shaped of EKC, and 'α=2' means U-shaped of EKC. This study analyzed all the datasets of these 6 countries together. Meanwhile, when testing the data of all countries, there are several problems such as a cross-sectional correlation (correlation with different country in same year) and a heteroskedasticity with different country in same year. To handle those problems, we used the Random-effect Generalized Least Squares model.

Meanwhile, this study also focus on the analysis of original formula. In fact, compared to the logarithm value, the original data has a better explanatory power to denote how the growth of real GDP affects the CO_2 emission and what affection of the endogenous factors are positive or negative for CO_2 emissions. In addition, since the results of non-linear formula in this study are not so much clear, we establishes the non-linear equation where the estimation on per-capita real GDP is not just square and cubic. It is estimated by η in equation (9) which means that, if η=0, then the per-capita CO_2 emission and the per-capita real GDP have no relationship at all; however, if η=1, 2 or 3, then the relationship between CO_2 emission and the per-capita real GDP matches the basic theory of Kuznets Curve; if η>3, it means the theory of Kuznets Curve in the situation of this study is not founding and the non-linear formula can reject the hypothesis theoretically.

$$\mathrm{CO_2}_\mathrm{i} = \alpha + \beta_1 \mathrm{GDP_i}^1 + \beta_2 \mathrm{GDP_i}^2 + \cdots + \beta_\eta \mathrm{GDP_i}^\eta + \beta_{\eta+1} \mathrm{Coal_i} + \beta_{\eta+2} \mathrm{Gas_i} + \beta_{\eta+3} \mathrm{Renewable_i} + \delta \quad (9)$$

Description of Data

It is necessary to introduce the basic information of the data in order to understand the meaning of different factor and some basic characteristics such as mean, median, maximum and minimum of all the data of China and other 5 OECD countries (USA, Korea, Japan, Canada, and Australia). This study compiles annual time-series data on carbon emission (CO_2), real GDP (measured by PPP) and final energy consumption (coal, gas and renewable) for China and 5 countries for the period 1980–2013 year. All the data is calculated into per capita. Table 1 summaries the value of mean, median, maximum and minimum. Meanwhile, CO_2per means the CO_2 emission per capita which is measured by "tonne"; GDP means per-capita real GDP ($) which is measured by parity power price (PPP); coal means coal per capita, gas means gas per capita and renewable means renewable per capita, which are all measured by "toe". It is easy to know that the usage of non-fossil energy is still very low, especially the usage of renewable in China and Korea are very low. It also confirms the serious situation where the fossil energy is still the main energy resource being used into the second industry.

Table 1. Description of data by country from 1980 to 2013
(Unit: $1,000 USD, toe)

Country	Variable	Mean	Median	Max	Min
ALL	GDP	21.027	20.253	53.001	0.302
	CO2	11.941	13.67	20.78	1.46
	Coal	2.687	1.976	7.507	0.684
	Gas	1.532	1.226	4.134	0.001
	Renewable	0.03	0.011	0.148	0.001
CHINA	GDP	3.389	2.11	11.867	0.302
	CO2	3.3	2.69	7.4	1.46
	Coal	1.439	1.132	3.165	0.684
	Gas	0.041	0.02	0.156	0.016
	Renewable	0.003	0.002	0.011	0.001
USA	GDP	32.075	30.8	53.001	12.576
	CO2	19.178	19.565	20.78	16.3
	Coal	3.502	3.615	3.842	2.693
	Gas	2.87	2.861	3.229	2.503
	Renewable	0.017	0.016	0.023	0.012
KOREA	GDP	14.963	13.296	33.791	2.308
	CO2	6.811	5.61	12.7	3.53
	Coal	1.527	1.291	2.814	0.807
	Gas	0.501	0.405	1.482	0.001
	Renewable	0.001	0.001	0.002	0.001
JAPAN	GDP	23.089	23.949	36.654	8.539
	CO2	9.129	9.42	10.8	7.82
	Coal	1.214	1.127	1.644	0.831
	Gas	3.458	3.625	4.134	2.689
	Renewable	0.01	0.01	0.012	0.008
CANADA	GDP	24.915	23.093	39.544	11.115
	CO2	16.274	16.175	17.46	14.78

	Coal	1.941	1.992	2.263	1.288
	Gas	3.458	3.625	4.134	2.689
	Renewable	0.138	0.139	0.148	0.126
AUSTRALIA	GDP	26.136	24.524	45.138	10.36
	CO2	16.954	17.06	19.4	14.64
	Coal	6.444	6.271	7.534	3.988
	Gas	1.545	1.464	2.283	0.831
	Renewable	0.011	0.011	0.015	0.009
Note that "CO2" variable means CO2 emission per capital (tone), "GDP" means GDP per capital measured by PPP ($). "Coal", "Gas", "Renewable" denote the coal consumption per capita (toe), the gas consumption per capita (toe), and the renewable consumption per capita (toe), respectively.					

Results of EKC estimation

Table 2 denotes that the empirical results of equation (8). It is obvious that the biggest power of GDP is just 3 (that is, α=3) and the sign of ln(GDP), $\ln(GDP)^2$ and $\ln(GDP)^3$ are negative(-), positive(+) and negative(-), respectively. This results indicates that the emission of CO_2 will decrease with the increase of GDP, and then it will increase with the increase of GDP, at last it still decrease with the GDP growth after arriving the second turning point.

After analyzing the whole data, this study also uses the logarithm formula to analysis different data of each country, independently. In the table 2, it shows that all the results of these countries match with the basic theory of Kuznets Curve except the result of U.S. The results of China, Japan, Canada and Australia have the similar inverted-N-shaped with the result of the whole data. Meanwhile the result of Korea shows that the coefficients θ_1=-2.665012<0, $\theta_2 = 0.151324$>0 and θ_3=0, which means Korea has a normal-U-shaped in this situation. With the affection of coal consumption, gas consumption and renewable consumption, the CO_2 emission will decrease with the growth of real GDP, and then it will increase again. While, the result of USA denotes that the coefficient θ_1=-0.068937<0, and both $\theta_2 = \theta_3 = 0$. It can be understood as the growth of real GDP still has a negative effect on the CO_2 emission. So it is very easy to know that the logarithm formula cannot reject the first stage hypothesis. It means even though the endogenous factors are final fossil and non-fossil energy consumption, the results of each coefficient are able to construct a U-shaped or N-shaped, Kuznets theory.

Table 2. The Empirical Results of Logarithm Model

Factor / Countries	Log(GDP)	$Log(GDP)^2$	$Log(GDP)^3$	Log(Coal)	Log(Gas)	Log(Renewable)	R^2
ALL (Random effect)	-7.0559^{***} (0.759)	0.89^{***} (0.0896)	-0.0349^{***} (0.0034)	0.3647^{***} (0.0121)	-0.0127^{***} (0.0041)	0.1374^{***} (0.0055)	0.942
ALL	-0.9707^{***}	0.1376^{***}	-0.0058^{***}	0.5093^{***}	0.0119^{***}	0.1851^{***}	0.984

(Fixed effect)	(0.9968)	(0.1221)	(0.0048)	(0.0514)	(0.0049)	(0.0479)	
CHINA	-2.9615** (1.1114)	0.3575** (0.153)	-0.0136* (0.0074)	1.1652*** (0.0975)	-0.3165*** (0.1094)	0.1111** (0.0919)	0.997
USA	-0.0689*** (0.0082)	-	-	0.5088*** (0.0415)	0.3559*** (0.0625)	-0.0471 (0.0297)	0.906
KOREA	-2.665* (1.5564)	0.1513* (0.0836)	-	0.6067** (0.2441)	0.0139 (0.0625)	0.1211 (0.1396)	0.889
JAPAN	-60.1031* (30.6326)	6.1159* (3.1187)	-0.2074* (0.1057)	0.0402 (0.1148)	0.2088* (0.1135)	0.0871 (0.094)	0.860
CANADA	-113.588** (47.0981)	11.2272** (4.7339)	-0.3695** (0.1583)	0.1724*** (0.0622)	0.1722 (0.1621)	-0.3302** (0.1569)	0.709
AUSTRALIA	-38.411*** (3.58E-05)	3.9398*** (3.60E-06)	-0.1339*** (1.20E-07)	0.035*** (8.32E-08)	-0.0255*** (6.62E-08)	0.0862*** (3.45E-09)	0.082
Note: ***, ** and * denote rejection of the null hypothesis of weak exogeneity at the 1%, 5% and 10% levels, respectively.							

Table 3 carried out the Hausman test estimated the null hypothesis of this model existing random effect is correct or not. If $H_0 = 0$, it can reject the null hypothesis and vice versa . It showed that the P-value is 0.0000 which is smaller than 0.01 in 99% confidence interval, so this null hypothesis can be rejected. It confirmed that there existed a fixed effect on all the data of different country. Therefore, after adjusting the test equation, this study got a relative accurate analysis of the total countries' data.

Table 3. Correlated Random Effects - Hausman Test

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	504.122955	6	0.0000

Meanwhile, table 4 shows the results of equation (9) using all countries (η=3), USA (η=1) and Canada (η=3) are according with the basic concept of Kuznets Curve. USA and Canada seem to have similar trend with the logarithm results on the relationship between CO_2 emission and GDP growth, while the result of all countries is opposite with the logistical results which shows a normal-N-shaped. Meanwhile, these three results are all denoting that the CO_2 emission will increase with the increasing of coal consumption; it will decrease with the increasing of renewable consumption significantly. However, there is a normal relationship between CO_2 emission and gas consumption insignificantly. Thus, the Kuznets theory is not established in other 4 countries. The **η** of Korea and Australia are all equal to 5, the **η** of Japan is 4 and the **η** of China is 7 which is so much far away with the basic theory of Kuznets Curve.

Since this study is mainly focusing on the result of China[1], it will use the data of China as an example to proof

[1] These variety kinds of analysis on other countries will also be made and be showed in the appendix part. All of these four countries (China, Korea, Japan and Australia) can reject the null hypothesis $H_0 = 0$ by Wald test and $H_1 = 0$ by

some countries' model can reject the theory of Kuznets Curve in this situation. The coefficient β_4 is 1.89E-13, β_5 is -2.25E-17, β_6 is 1.35e-21 and β_7 is -3.22E-26, all of them are so much small to be conjectured if they are founded in this analysis. So it has to uses the likelihood ratio to test if variables (GDP^4, GDP^5, GDP^6, GDP^7) are thought as redundant variables to be omitted, will the model be founded or not? If the null hypothesis H_1=0, this null hypothesis can be rejected and vice versa. In the table 5, it denotes that the null hypothesis is rejected by the P-value of likelihood ratio what is 0.0005 in the 99% confidence interval. These 4 variables[2] should not be omitted. The likelihood test reject their own null hypothesis which means the non-linear formula design on the data of China is reasonable; and it also can reject the hypothesis of first stage, which can be said that not all the non-linear formula results are similar with logarithm formula. In the non-linear model, it always has some special cases where the Kuznets theory cannot be adopted into when considering the endogenous variables to be the data of final fossil and non-fossil energy consumption.

Table 4. The Empirical Results of Non-linear Model Estimation

Country \ Factor	GDP	GDP^2	GDP^3	GDP^4	GDP^5	Coal	Gas	Renewable	R^2
ALL	0.0005***	-2.04E-08	2.15E-13***	-	-	1.0428***	4.2614***	-31.6958***	0.971
(Random)	(4.46E-05)	(2.11E-09)	(2.87E-14)			(0.0473)	(0.1401)	(2.8836)	
ALL	0.0002***	-9.80E-09***	9.10E-14***	-	-	1.4359**	2.0132***	-93.664***	0.986
(Fixed)	(4.84E-05)	(1.94E-09)	(2.61E-14)			(0.1594)	(0.3486)	(20.955)	
CHINA	-0.0022***	1.97E-06***	-8.45E-10***	1.89E-13***	-2.25E-17***	2.8957***	-36.0201**	394.559***	0.998
	(0.0007)	(6.20E-07)	(2.56E-10)	(5.38E-14)	(6.05E-18)	(0.3322)	(16.3041)	(108.6313)	
	GDP^6	1.35E-21***	GDP^7	-3.22E-26***					
		(3.48E-22)		(8.03E-27)					
USA	-4.14-05***	-	-	-	-	2.4972***	2.4665***	-69.5866*	0.896
	(5.33E-06)					(0.2364)	(0.4232)	(34.4197)	
KOREA	0.0032***	-5.23E-07***	3.39E-11***	-9.42E-16***	9.45E-21***	-0.9572	5.1556	1629.86*	0.952
	(0.001)	(1.61E-07)	(1.03E-11)	(3.03E-16)	(3.35E-21)	(1.2874)	(4.7897)	(839.5343)	
JAPAN	0.0006***	-3.49E-08***	6.75E-13***	-4.61E-18**	-	1.0269***	4.3077***	-32.7515***	0.972
	(0.0006)	(7.22E-09)	(1.54E-13)	(2.19E-18)		(0.0475)	(0.1406)	(2.9025)	
CANADA	-0.001***	3.69E-08***	-4.28E-13***	-	-	1.3795*	1.6591**	-51.9866***	0.661
	(0.0003)	(1.21E-08)	(1.54E-13)			(0.6809)	(0.6978)	(18.6489)	
AUSTRALIA	-0.1201***	1.05E-06***	-4.26E-11***	8.14E-16***	-5.92E-21***	0.5086	0.4459	76.0072	0.917
	(0.0026)	(2.13E-07)	(8.21E-12)	(1.51E-16)	(1.07E-21)	(0.442)	(1.6625)	(122.101)	

Note: ***, ** and * denote rejection of the null hypothesis of weak exogeneity at the 1%, 5% and 10% levels, respectively.

likelihood test.

.[2] If 5 variables (GDP^3, GDP^4, GDP^5, GDP^6, GDP^7) are omitted, the estimated null hypothesis also can be rejected by the P-value of likelihood ratio be 0.0003 in the 99% confidence interval.

	Value	df	Probability
F-statistic	4.272411	(6, 23)	0.0049
Likelihood ratio	25.46050	6	0.0003

Table 5. Results of Likelihood Test for Redundant Variables

	Value	df	Probability
F-statistic	4.544366	(4, 23)	0.0075
Likelihood ratio	19.80149	4	0.0005

Box-Cox Transformation

When comparing the result of logarithm analysis and non-linear analysis, it is difficult to give a conclusion about which one is better to be used in the EKC. Therefore, it has to use the Box-Cox Transformation to test which model is better to be used or both them can be used. Box-Cox Transformation is a very good method to decide to choose a logarithm model or a non-linear model when establishing a model. There are three steps to do in the Box-Cox Transformation.

a) Calculating the geometric mean of the dependence variable P;

$$\widehat{P} = (P_1 P_2 \ldots P_n)^{1/n} = \exp(\frac{1}{n}\sum \ln P_i) \tag{10}$$

b) Getting the new order of the dependence variable P^*, which is form the dependence variable divided by the geometric mean;

$$P^* = P/\widehat{P} \tag{11}$$

c) Instead of P, using the P^* enter in to the logarithm model and non-linear model, then comparing the difference of their residual sum of squares (RSS) to estimate which model is better. Zarembka (1968) noted the testing statistic is

$$\frac{1}{2} n * \ln(\frac{RSS2}{RSS1}) \tag{12}$$

Where RSS2 is the bigger residual sum of squares and RSS1 is the smaller residual sum of squares, n is the sample size. Meanwhile the degrees of freedom are n-1-k, where k is the number of independent variable. If the result of testing statistic is smaller than the critical value, it has no difference to choose logarithm model or non-linear model at all; if the result is greater than the critical value, it is better to choose the model which has a small residual sum of squares.

Following these three steps, this study also gets the result of testing statistic in table 6. It is easy to see that the results of testing statistic of China and U.S are 37.865 and 38.239 which are smaller than the critical value $X^2_{0.05}(29) = 42.5569$ (n-1-k=29). The theory of the Box-Cox Transformation denotes when the value of the test statistic ($\frac{1}{2}\text{n} * \ln(\frac{\text{RSS2}}{\text{RSS1}})$) is bigger than the critical value, the formula which has a small value of RSS should be chosen, relatively. So for the case of China and U.S, there is no difference to choose logarithm model or non-linear model. While, in order to make sure the analysis result being more appropriate, the logarithm model is better to be used. On the other hand, the results of other countries are all greater than the critical value. So they have to use logarithm model to get a better EKC estimation result because their RSS1, which belongs to logarithm model, are smaller than RSS2.

Table 6. The result of Box-Cox Transformation

Value \ Country	China	U.S	Korea	Japan	Canada	Australia
RSS (1)	0.01534	0.009378	**0.674861**	**0.03712**	**0.018565**	**0.03121**
RSS (2)	0.141289	0.088913	13.84575	1.313556	4.842116	3.46995
$\mathbf{\frac{1}{2}n * \ln(\frac{RSS1}{RSS2})}$	**37.86574**	**38.239**	**60.57735**	**58.08469**	**94.58509**	**80.08967**
the critical value	$X^2_{0.05}(29) = 42.5569$ (n-1-k=29)					

Compared to non-linear formula, logistic formula is more appropriate to estimate if relationship between CO_2 emission and GDP growth matches the Kuznets theory in this study. Even though the cases of China and U.S have no difference to choose logarithm model or non-linear model, the logarithm result can show an U-shaped or N-shaped model which matches with the basic theory of EKC. When using the Kuznets curve to estimate the relationship between CO_2 emission and GDP growth, it is necessary to test which model, logarithm formula or non-linear formula, should be chosen in the analysis process and explain a simple reason about it. Because for some cases, it has no problem to use either logarithm model or non-linear model to make a research; while for some other cases, an appropriate model will show a better result.

4. Vector Auto Regression (VAR) Analysis

Vector auto regression (VAR)[3] is used to capture the linear interdependencies among multiple time series. VAR models generalize the univariate *auto regression* (AR) models by allowing for more than one evolving variable. Although the estimated quantitative response coefficients will not in general be the same, all variables in a VAR are treated symmetrically in a structural sense; each variable has an equation explaining its evolution based on its own lags and the lags of the other model variables. VAR model describes the evolution of a set of *k* variables (called *endogenous variables*) over the same sample period (t = 1, 2, ..., T) as a linear function of only their past values. The variables are collected in a k × 1 vector $\mathbf{Z_t}$, which has as the **i th** element, $\mathbf{Z_{i,t}}$, the observation at time "t" of the i th variable. A ρ-th order VAR, denoted VAR (ρ), is

[3] The source of this concept is from Wikipedia, the free encyclopedia.

$$Z_{i,t} = C_i + A_{i,1} Z_{i,t-1} + A_{i,2} Z_{i,t-2} + \ldots + A_{i,p} Z_{i,t-p} + \mu_t \tag{13}$$

Where, the l-periods back observation Z_{t-l} is called the l-th lag of $\mathbf{Z_i}$; $\mathbf{C}$ is a k × 1 vector of constants; $\mathbf{A_i}$ is a time-invariant k × k matrix; $\boldsymbol{\mu}_t$ is a k × 1 vector of error terms. It takes CO_2 emission, GDP, the ratio of the primary coal consumption, the ratio of the gas consumption and the ratio of the primary renewable as endogenous variables into the VAR model. There is a 2nd order VAR in which the lag p is 2, denoted VAR (2), and the function will be shown as a matrix form:

$$\begin{bmatrix} \mathbf{CO_{2,t}} \\ \mathbf{GDP_t} \\ \mathbf{coal_t} \\ \mathbf{gas_t} \\ \mathbf{rrenewable_t} \end{bmatrix} = \begin{bmatrix} \mathbf{C_{C,1}} \\ \mathbf{C_{gd,1}} \\ \mathbf{C_{co,1}} \\ \mathbf{C_{g,1}} \\ \mathbf{C_{r,1}} \end{bmatrix} + \begin{bmatrix} \mathbf{A_{C,1}} \\ \mathbf{A_{gd,1}} \\ \mathbf{A_{C0,1}} \\ \mathbf{A_{g,1}} \\ \mathbf{A_{r,1}} \end{bmatrix} * \begin{bmatrix} \mathbf{CO_{2,t-1}} \\ \mathbf{GDP_{t-1}} \\ \mathbf{coalper_{t-1}} \\ \mathbf{gasper_{t-1}} \\ \mathbf{reper_{t-1}} \end{bmatrix} + \begin{bmatrix} \mathbf{A_{C,2}} \\ \mathbf{A_{gd,2}} \\ \mathbf{A_{C0,2}} \\ \mathbf{A_{g,2}} \\ \mathbf{A_{r,2}} \end{bmatrix} * \begin{bmatrix} \mathbf{CO_{2,t-2}} \\ \mathbf{GDP_{t-2}} \\ \mathbf{coalper_{t-2}} \\ \mathbf{gasper_{t-2}} \\ \mathbf{reper_{t-2}} \end{bmatrix} + \begin{bmatrix} \mu_{C,t} \\ \boldsymbol{\mu}_{gd,t} \\ \mu_{C0,t} \\ \mu_{g,t} \\ \mu_{r,t} \end{bmatrix} \tag{15}$$

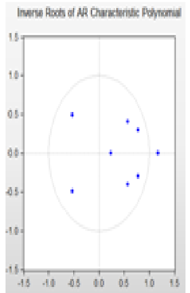
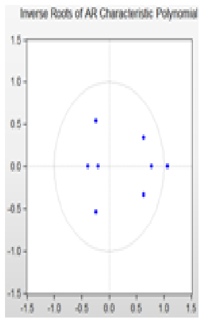
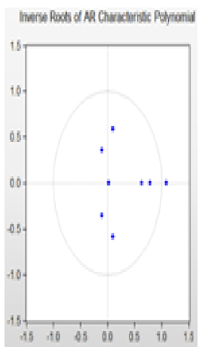
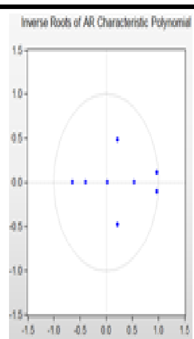
Results of VAR

In a VAR model, if the roots of AR are smaller than 1 and their points are nearly staying in the unit circle, it means that this VAR model is stable. The AR roots graph is used to test if the lag structure is stable and reasonable or not. In table 7, it just chooses three countries (Korea, Canada and Australia) to be used to compare with China in order to make compare the difference between the developing countries and the developed countries simply and intuitively. The graphs denote that these countries are relative stable because their roots are almost smaller than 1. Meanwhile, even though the countries, such as China, Korea, Canada, has one point being out of the unit circle, the other points all stay in the unit circle. What's more, Engle and Granger (1987) show that, even in the case that all the variables in a model are non-stationary, it is possible for a linear combination of integrated variables to be stationary. So it proofs that the design of this VAR model is reasonable relatively. It also denotes that the fossil and non-fossil energy consumption have sustainable equilibrium relations with CO_2 emission in long run. In short run, maybe the variable will deviate with the equilibrium value. However, it is just a transient phenomenon, it will return to the equilibrium value finally.

Table 7. The AR root of VAR model

Vector Auto Regression Estimation

the lag interval for endogenous ρ is 2. Standard Errors in () & t-statistics in []

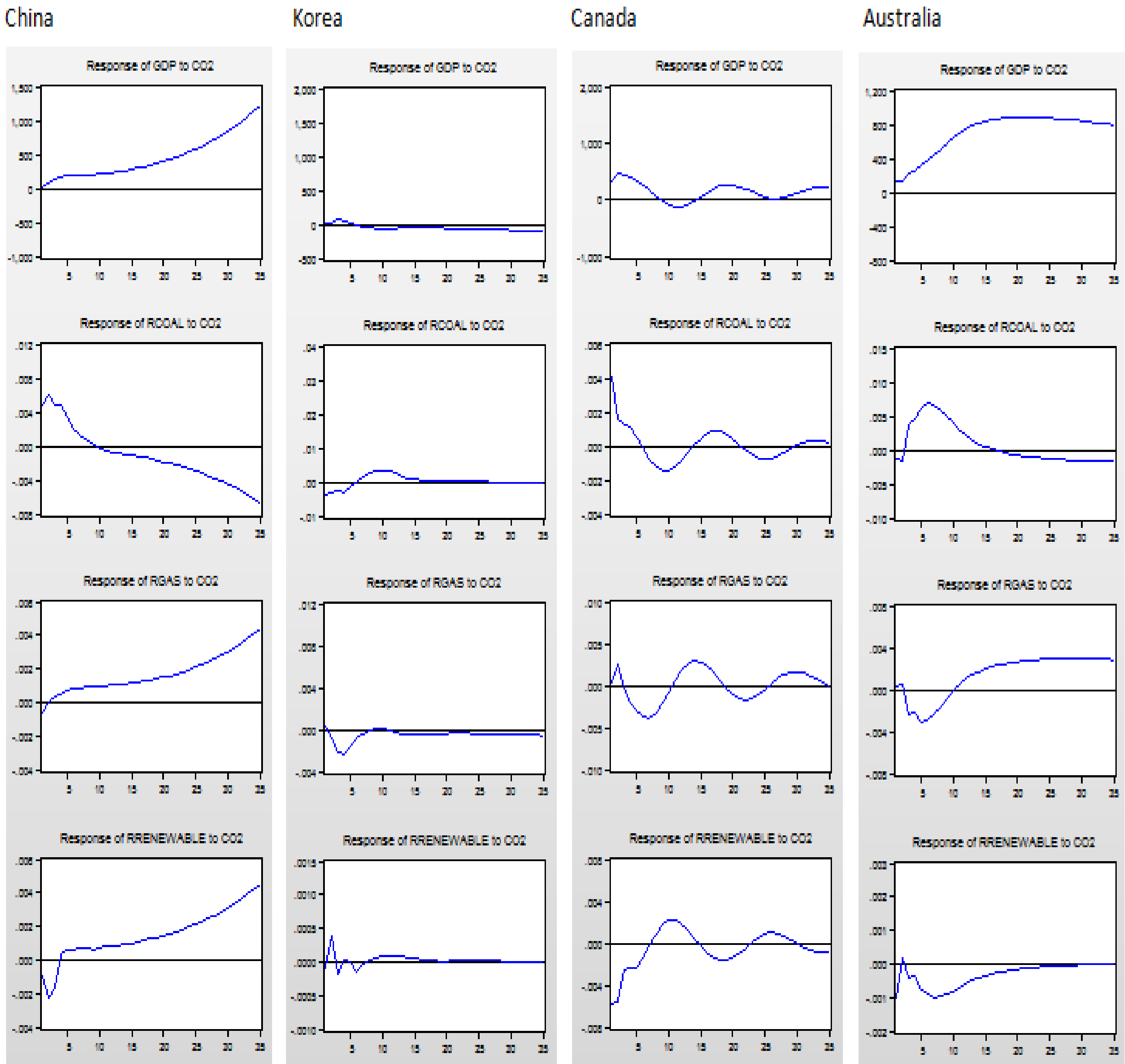
Country	Factor (lag ρ)	GDP	rcoal	rgas	rrenewable	AR roots graph
China	CO_2 (-1)	-0.016206	0.073506	0.010123	9.87E-05	
		(0.37844)	(0.13486)	(0.00487)	(0.00055)	
		[-0.04282]	[0.54506]	[2.07719]	[0.17781]	
	CO_2 (-2)	0.077312	0.07238	0.000856	-0.000777	
		(0.33886)	(0.12075)	(0.00436)	(0.0005)	
		[0.22815]	[0.5994]	[0.19619]	[-1.56395]	
	Adjusted R^2	0.993636	0.995548	0.998062	0.9939	
Korea	CO_2 (-1)	0.432325	-0.017956	-0.006644	3.68E-05	
		(0.19687)	(0.02378)	(0.01468)	(5.7E-05)	
		[2.19598]	[-0.755]	[-0.4527]	[0.6438]	
	CO_2 (-2)	-0.101025	0.008909	-0.009566	-5.40E-05	
		(0.17558)	(0.02121)	(0.01309)	(5.1E-05)	
		[-0.57537]	[0.41999]	[-0.73074]	[-1.0592]	
	Adjusted R^2	0.9535708	0.979393	0.984305	0.524848	
Canada	CO_2 (-1)	0.212232	-0.008091	-0.016797	-0.001543	
		(0.25609)	(0.05852)	(0.06872)	(0.00254)	
		[0.82874]	[-0.13826]	[-0.24443]	[-0.60754]	
	CO_2 (-2)	-0.017295	0.01566	-0.041429	-0.003013	
		(0.2042)	(0.04666)	(0.05479)	(0.00202)	
		[-0.0847]	[0.3356]	[-0.75607]	[-1.48839]	
	Adjusted R^2	0.633781	0.858812	0.921058	0.393166	
Australia	CO_2 (-1)	0.573795	-0.024658	0.01968	0.000676	
		(0.22511)	(0.10081)	(0.02508)	(0.00024)	
		[2.549]	[-0.24461]	[0.78481]	[2.86502]	
	CO_2 (-2)	0.206337	0.165482	-0.049327	-0.000478	
		(0.25652)	(0.11487)	(0.02858)	(0.00051)	
		[0.80438]	[1.44057]	[-1.72623]	[-1.78038]	
	Adjusted R^2	0.76275	0.868166	0.971825	0.647463	

Then, it carries on the VAR variance decomposition to estimate how much influence each energy takes to affect the trend of CO_2 emission. Fig. 3 shows the response of different primary energy consumption to CO_2 emission. The Horizontal axis means the period. In this part, the period is set as 35 (year) which is tending to conjecture how different energy consumption affects CO_2 emission in the next 35 years. It is easy to know if every country can do a positive active on reducing the consumption of coal and increase the gas and renewable consumption, there will have a great change on the emission of CO_2.

In the case of China, after coal consumption takes a peak point in the next 5 years, coal consumption will show a decreasing affection on CO_2 emission. From the 10^{th} period to the 35^{th} period, the coal consumption will reduce sustainably to affect the CO_2 emission. It means that because of the reduction of coal consumption, it will have a weak affection on the CO_2 emission in the further. The gas consumption at first will take a low property to affect CO_2 emission until 10^{th} period, then, the property will rise up rapidly. From 15^{th} period the rise of this property will tend to slow down and at last the ratio of primary gas consumption will reducing CO_2 emission significantly. Meanwhile, the response of the ratio of primary renewable consumption to CO_2 emission has a similar trend with the ratio of primary gas consumption. In the next 35 years, both of gas and renewable will play an important role on reducing the CO_2 emission.

The other three countries also show some other different trends in this graph. In the case of Korea, which is the nearest countries to China, it shows the coal consumption will take a low level to affect the CO2 emission and it has no so much difference in the further 35 years. It means that with the decreasing of coal consumption, its affection on CO2 emission will also become weaker. The renewable resource and the gas will play similar roles on the CO2 abatement. Then in the case of the least developed countries, the trend of coal to CO_2 emission is decreasing and float in Canada; the trends of the primary coal consumption and primary renewable consumption seem to be negative correlation when the coal consumption is decreasing, the renewable consumption is increasing, otherwise. This phenomenon can be understood very easily, because Canada is the only one country which uses the clear primary energy more than the fossil primary energy in these six countries, which can affect the change of response of coal to CO_2 by the clear primary energy easily. Australia seems to have similar trend with that of China, while the gas play a more important role than the renewable.

Fig. 3. Percent CO_2 Variance to different Energy Consumption



Note: Horizontal Axis is the further 35 years

5. Conclusion

All above the analysis of those results, it confirms that most countries show an N-shaped or U-shaped in the logarithm formula which matches with the theory of EKC. For the case of Korea and U.S, it has an increase relationship between CO_2 emission and GDP growth. However, in the non-linear formula, not all the data of every country can show a U-shaped or N-shaped relationship between CO_2 emission and GDP growth, such as China, U.S, Korea and Japan. The results of table 2 and table 4 confirm that by the different formulas, sometimes the result will be so much different. Actually, when just analyzing the results of the logarithm formula and non-linear formula, it is difficult to say which one is better because they all match with basic theory of EKC.

However, in the test of Box-Cox Transformation, all the cases of these countries show the test statistic $\frac{1}{2}\mathbf{n} * \mathbf{ln}(\frac{\mathbf{RSS1}}{\mathbf{RSS2}})$ is so much greater than the critical value which suggests the logarithm formula is better to be used to estimate the relationship between CO_2 emission and GDP growth in this study relatively. But it does not mean the non-linear model cannot be used in some other cases. As known, the basic theory of EKC is established by a non-linear model and the non-linear model is also very widely to be used in the other previous studies. Therefore, there is a suggestion that when writing a paper about EKC, a simple explanation on which formula (logarithm or non-linear formula) should be used is so much necessary. Because in some cases, maybe it has no problem to use either logarithm model or non-linear model to make a research; but in some other cases, only if the right formula is chosen, the result will be accurate.

The second contribution this study does is that it conjectures the affection each energy resource takes on the CO_2 emission in a hypothesis situation. For all the VAR model result of these 6 countries, it implies that, although gas and renewable still do not show a significant effective action on reducing CO_2 emission in recent years, they will have a great positive effect on reducing the CO_2 emission in the further 35 years. In the hypothesis situation, all the energy resources construct can have some change in the next 35 years; especially, it shows that in China the gas and renewable resource can take a greater effect on reducing the CO_2 emission, only if Chinese government takes a positive and effective policy on changing the construct of fuel consumption, and the second industry also takes the advanced technology to improve the usage rate of fossil energy. At the same time it is necessary to study or bring in the advanced technology from developed countries which are good at protecting their environment. These can be used to enhance the increasing of non-fossil energy consumption which will play a very great role on reducing the CO_2 emission. What's more, in order to solve the more and more serious global pollution issue, it will be an inevitable trend in the further energy construct. This appearance can give some countries, which still do not take care of environmental issue so much, an incentive to change their idea of the using of the fossil and non-fossil energy consumption.

However, there is a limitation that this trend will only appear in a prefect hypothesis in which the usage of non-fossil energy will increase rapidly without thinking about the natural limitation on the non-fossil energy or some other unpredictable event. Meanwhile, it is a little difficult to estimate how much gas or renewable should increase to reach this kind of trend. However, because the global green effect becomes more and more serious, a relative explicit mass or property of different energy consumption is necessary to be estimated, which will also be an important issue to be studied in the further.

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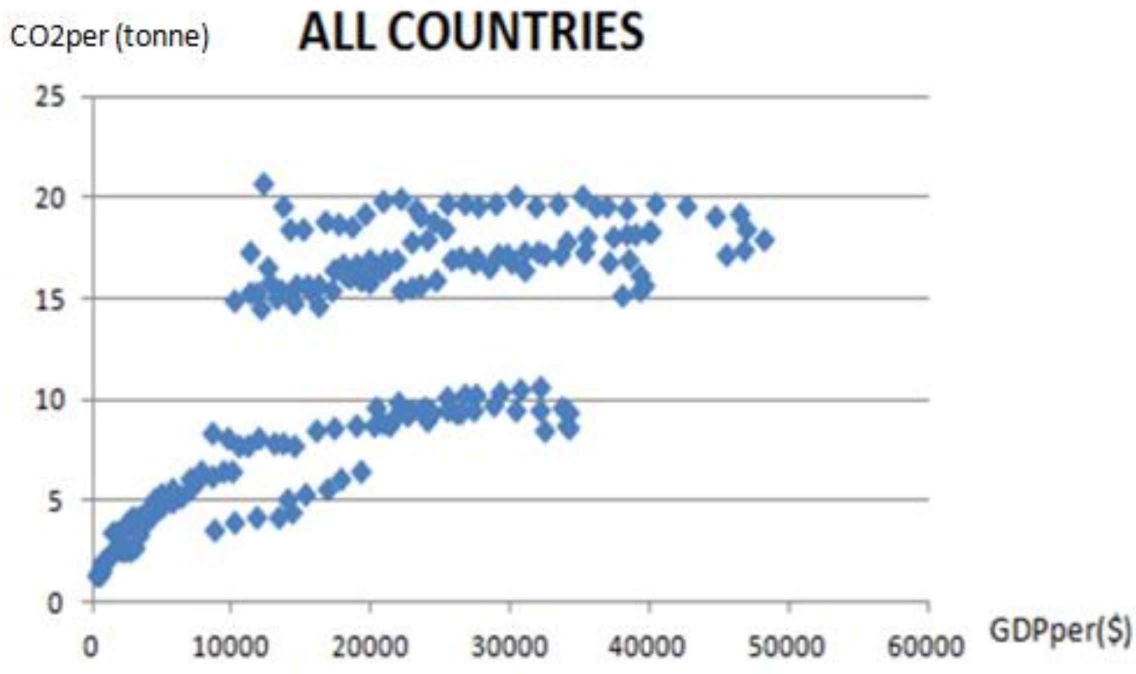
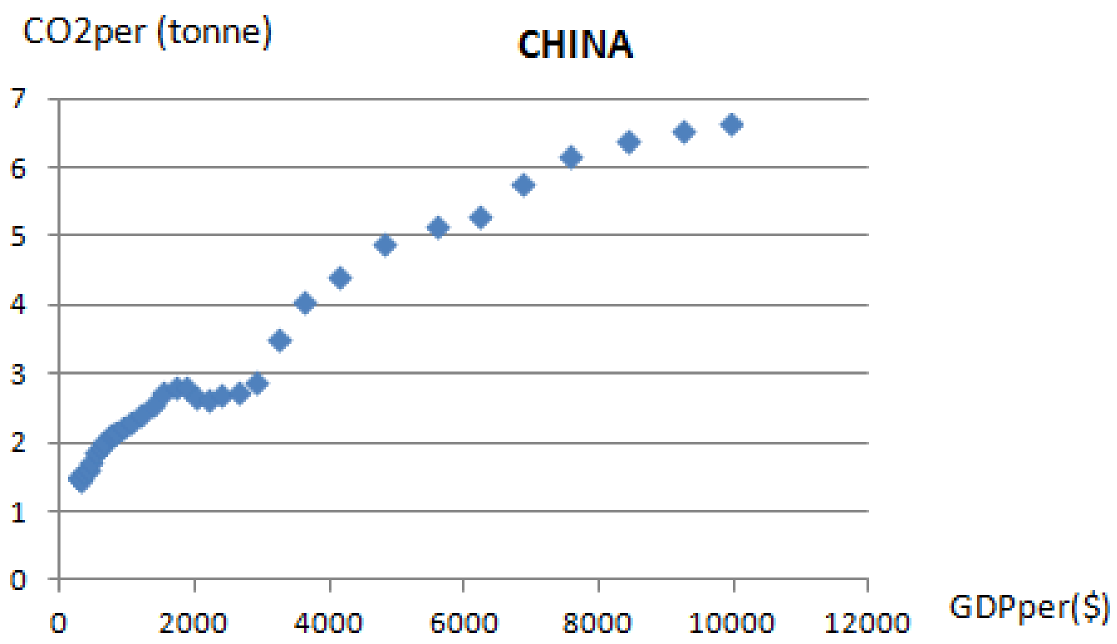
Appendix

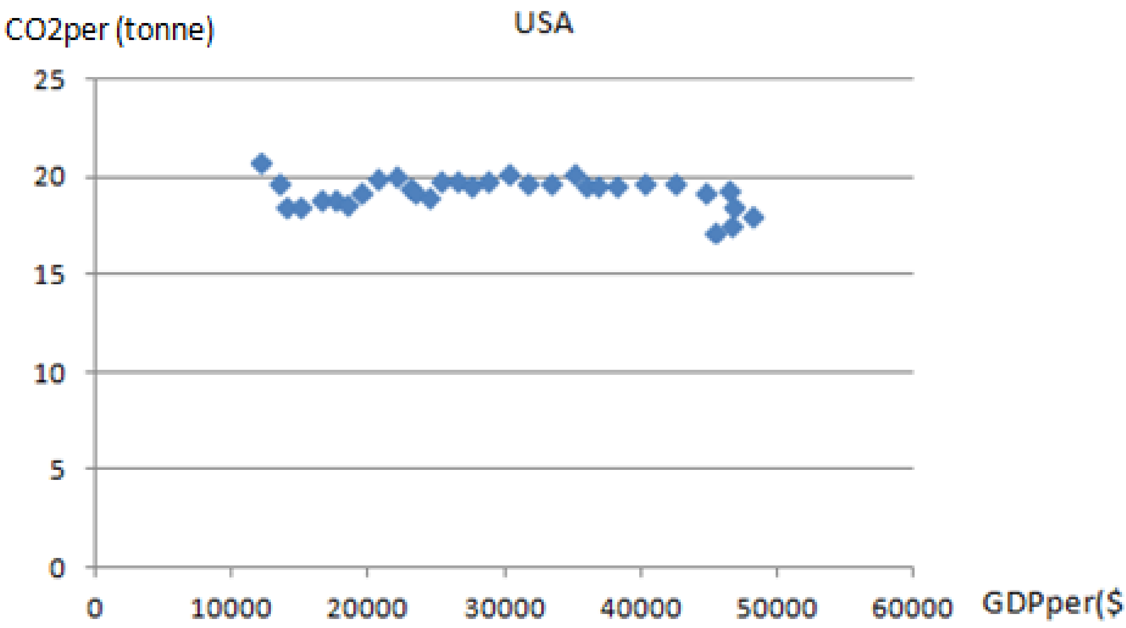
[Fig. A] Scatter Plot of GDP per capita and CO2 emissions for all 6 countries



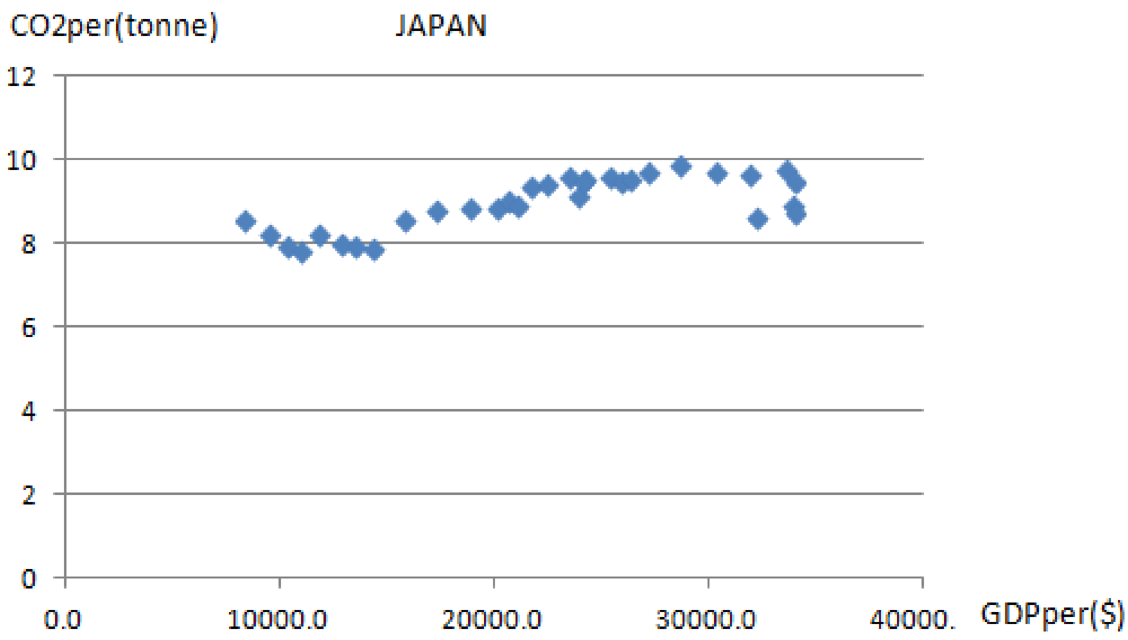
[Fig. B] Scatter Plot of GDP per capita and CO2 emissions for China



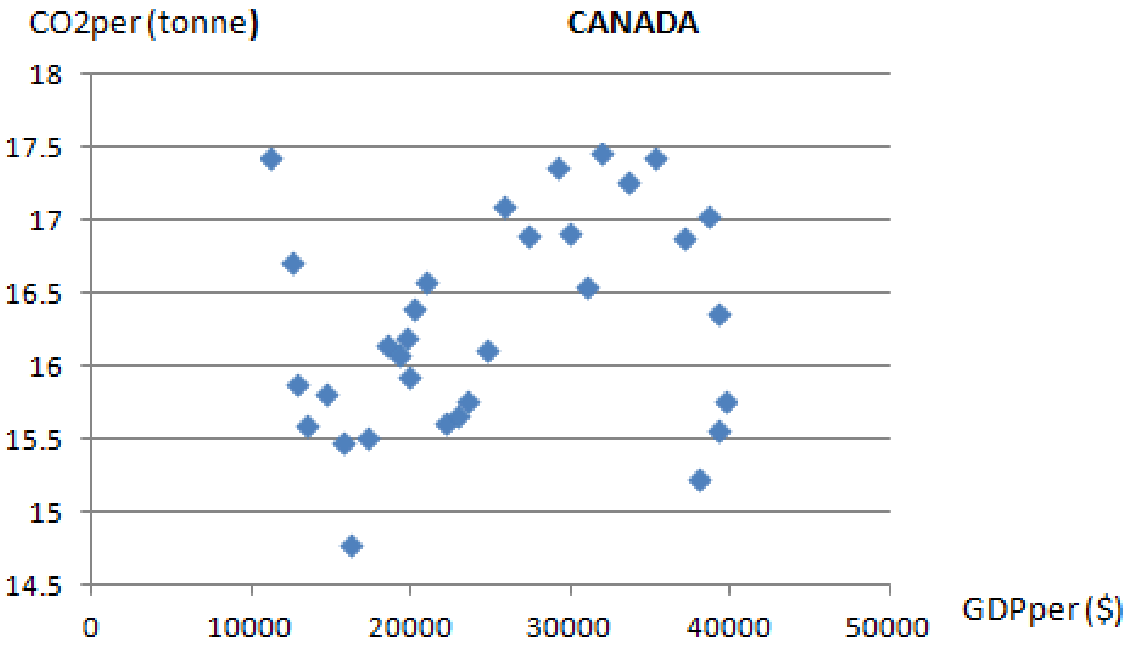
[Fig. C] Scatter Plot of GDP per capita and CO2 emissions for USA



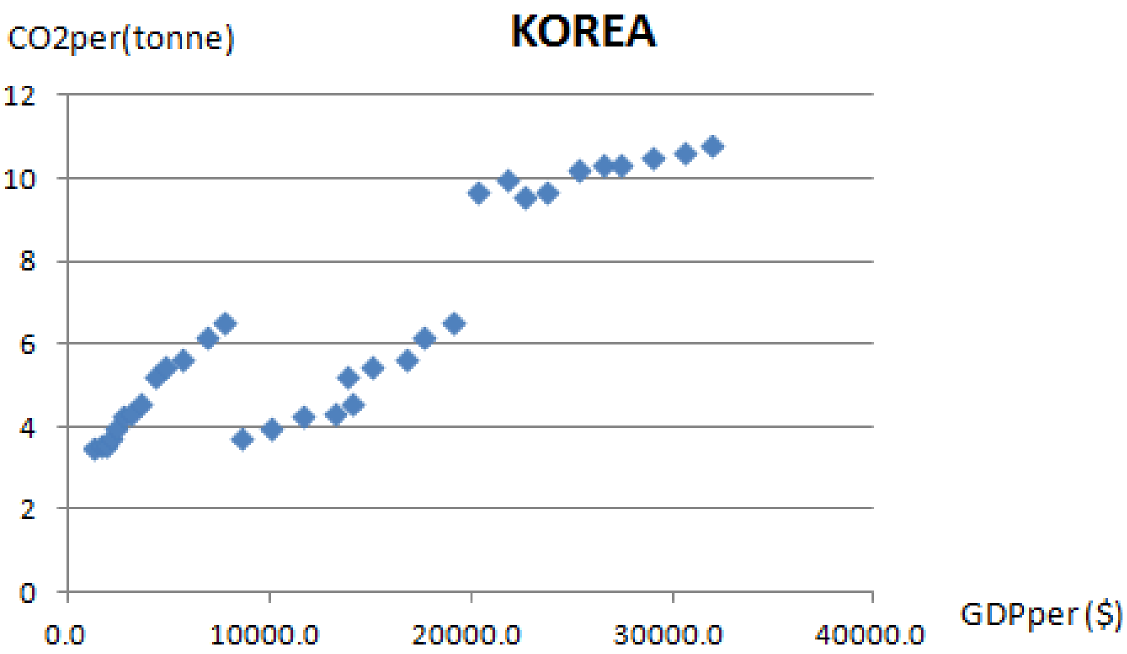
[Fig. D] Scatter Plot of GDP per capita and CO2 emissions for Japan



[Fig. E] Scatter Plot of GDP per capita and CO2 emissions for Canada



[Fig. F] Scatter Plot of GDP per capita and CO2 emissions for S. Korea



[Fig. G] Scatter Plot of GDP per capita and CO2 emissions for Australia