

# Economic Growth, Trade and Environment

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## **Abstract**

The Environmental Kuznets Curve (EKC) posits that there is an inverted-U relationship between pollutants emissions and economic growth. A number of papers have studied empirically the EKC for carbon dioxide and sulfur dioxide emissions. In this paper, we use large dataset to test the existence of EKC. Different specifications are tested using panel data and pool data to estimate the turning points. The empirical results support the EKC hypothesis, though some turning points are much higher than the current income per capita. Moreover, in order to explore the interaction between trade and income or other characteristics that may influence pollutants emissions of a country, trade liberalization is added into the EKC model to see its impact on the EKC relation. The estimated impact of trade is significant but relatively small. The turning points decreased when trade was applied to the model. The implication of the relationship between globalization, economic development and environmental future is outlined.

## **I. Introduction**

The interrelation between economic development and climate change represent some of the most challenging problems for both policy makers and people around the world. Increased emphasis is being put on environmental protection because of the rising sea levels, desertification, diminishing urban air quality, acid rain, dirty water, global warming and a host of other environmental issues. Without regulation, the impact of rapid economic development has the potential to harm the environment severely.

The debate surrounding the inverted U-shape relationship between pollution and economic development, referred to as the Environmental Kuznets Curve (EKC), has been analyzed for years. The EKC indicates that at the early stage of development, the rapid modernization and industrialization of a country may lead to increasing pollution. When the country has developed to a certain level (turning point), the gradually improved environmental regulation and the introduction of less pollution-intensive techniques may reduce the pollution to some extent.

On the empirical front, a number of researchers have tested the existence of the EKC from the early 1990s (Shafik and Bandyopadhyay 1992; Panayotou 1993; Grossman and Krueger 1991, 1995, Seldon and Song 1994). They have studied various air and water pollutants with cross-country or local focus. Evidence is found to support the existence of EKC. However, the results regarding carbon dioxide and sulfur dioxide emissions vary due to diverse datasets and techniques utilized. Recent empirical results such as Mazzanti et al.(2008), Vollebergh et al. (2009), Martinez-Zarzoso et al. (2011) have provided more evidence to support the EKC hypothesis. If the inverted U-shape relation exists, there will be a turning point of the GDP level which means that the pollution starts to decrease as the income increases after this point. Researchers studying different regions or pollutants have obtained diverse turning points that have a large range.

In these pollutants, carbon dioxide and sulfur dioxide emissions have been studied to test the EKC for times. Carbon dioxide has been studied a lot due to its great contribution to global warming (carbon dioxide accounted for 76.7% of total greenhouse gas emissions in 2004 according to IPCC<sup>1</sup> (2011)). Similarly, sulfur dioxide, which is usually generated by burning coal and petroleum, is also one of the major pollutants from various industrial processes. The turning points calculated for carbon dioxide are usually far above from the current income per capita level. It is always explained that carbon dioxide has impact on global but not local scale. The incentive of free-riding in the emissions is larger than other pollutants. Comparatively, sulfur dioxide is more of a local pollutant. Despite the significant characteristics of pollutants, the results will also vary among different choices in regions, functional form, other variables of influence and methodology (Spangenberg, 2001; Harbaugh et al., 2002). Although EKC cannot be easily regarded as a theoretical basis for policy implication in terms of the non-predictable nature, if it is supported by the data, it can also imply that GDP could be the reason to dampen or improve the environmental quality. Thus it is also necessary to study the environmental Kuznets curve.

The majority of evidence supporting EKC is found in the group of OECD countries. Researchers prefer the developed countries due to the data availability as well as more

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<sup>1</sup> IPCC (Intergovernmental Panel of Climate Exchange)

homogeneous characteristics within the countries themselves. But it will be necessary to take more developing countries into account due to the fact of rapid globalization—the pollution may be transmittable by increased trade (Suri and Chapman 1998, Cole 2003). Therefore, trade is a vital role that influences both the economic development as well as the environmental quality. Grossman and Krueger (1991) have established the fundamental decomposition model of trade's effect on environment, in which, the effect of trade has been broken down into scale, composition and technique effects. Some research has indicated that composition effect lead to the EKC relationship. In general, regarding the relationship between income and pollutants emissions, the interaction may be stimulated or dampened by trade.

A detailed literature review will be divided into two parts. The first will focus on the EKC of carbon dioxide and sulfur emissions. We review around twenty-five empirical papers studying the inverted U-shape relationship between these two pollutants and income level. The econometric techniques, dataset used as well as turning points in the papers will be listed in Table I. The second part will review the influence of trade on environment. The scale, composition and technique effects have been introduced. The major points regarding the relationship between trade liberalization and environment have been reviewed. In general, the trade will influence the environmental quality but it will be difficult to identify the effect convincingly.

There are two main issues that are the focus of this paper. The first one is to assess the robustness of the EKC model with carbon dioxide and sulfur dioxide emissions. There are 98 countries (24 developed countries and 74 developing countries) with 40-year period in the dataset used in the regression section. The time and country will influence the GDP per capita thus time effect and country effect is used in this paper. In the literatures, fixed/random effect has been used (See Seldon and Song 1994, Stern and Common 2001, Kaufmann et al., 1998). In fixed effect, time or country are assumed to be correlated with other variables while the random effect will regard time and country as stochastic variables. Panel data and pool data have been used in this paper to analyze the existence of EKC. Time effect and country effect will be set as dummy variables in the EKC. For panel data, the coefficients of time effect will be estimated while country effect

is fixed or random effect. Then the trend of time effect will be analyzed by the value of the time coefficients furthermore. For pool data, the variables have been classified according to its diverse characteristics. And time effect will also be fixed or random in this dataset. The Hausmen test will be used to identify which effect is favoured. Two kinds of dataset have been used to see their difference.

The second aim of the paper is to see how trade will impact the EKC relation. Antweiler et al. (2001) first developed the empirical model discussing the impact of trade on sulfur emissions. But it assumes the existence of the single relationship between pollution emissions and openness (Cole, 2003). Then Cole (2003) suggests that country's characteristics will determine its specification in different industries, which will influence the relation between trade liberalization and environment. In this paper, we follow the claim of Cole (2003). Trade is added to the EKC model that will interact with other variables such as country effect. But this paper explores more possibilities in dataset.

This paper is organized as follows. In the following section, literature review is conducted and the background research of EKC and the relationship between trade and environment will be briefly summarized. The Part III introduces the data and methodology in this paper. Then the Part IV analyzes the empirical results and presents further discussion. The Part V discusses the potential implication of the results and concludes.

## **II. Literature Review**

### **1. The Environmental Kuznets Curve (EKC)**

A number of authors have studied the existence and implication of EKC models regarding different countries and different categories of environmental indicators. They have used various dataset and techniques to examine whether the income per capita as well as other variables, can contribute to the EKC relationship. In this section, we summarize the recent research result in Table I which mainly focuses on the sulfur and carbon dioxide emissions. In general, sulfur emissions are more apt at generating the

EKC model significantly. EKC evidences also exist for carbon dioxide emissions but more probably in the restricted set of OECD countries (Cole, 2005, Galeotti et al., 2006).

The empirical studies of EKC started from Grossman and Krueger (1991). This paper aims to identify the role of North American Free Trade Agreement and studies the relation between air quality and economic growth with a cross-sectional data. The results suggest that sulfur dioxide and smoke's concentration increase with GDP per capita when a country has low level of income, but decrease with GDP per capita when countries have a higher level of income. Furthermore, with panel data, Grossman and Krueger (1991) have studied more environmental indicators to examine the relation of environmental degradation and income per capita and find no evidence that environmental quality will fall following economic growth. There are also inverted U-shaped relations and the corresponding turning points are also estimated for GDP per capita which is around \$8000). Another early representative empirical paper (Seldon and Song, 1994) also investigated the EKC model with a cross-country panel data and found inverted U-shape relation existed for the four pollutants (sulfur dioxide, suspended particulates, oxides of nitrogen, carbon monoxide) as well.

Initially, research focused more on developed economies—probably primarily due to the data availability as well as more homogeneous characters within developed countries. De Bruyn et al., (1998) suggested the positive effect of economic growth on the growth of emissions with data of four developed countries. Cole et al., (1997) examined the EKC model using cross-country panel data sets in OECD countries from 1970-1992. The result indicates that EKC exists only for local air pollutants. This paper and Stern (1998) both discovered that the emissions per capita will become a monotonic function of income or predict a higher turning point level with larger standard errors when a more heterogeneous sample is used.

Along with more extensive datasets and new techniques arising, recent papers have revealed more evidence of EKC. For example, Aldy (2005) added the heating degree day (HDD) and cooling degree day (CDD)<sup>2</sup> as variables and proved evidence for EKC in the

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<sup>2</sup> HDD/CDD refers to the energy need to heat/cool a home.

United States. Martinez-Zarzoso and Bengochea-Morancho (2004) test the slope heterogeneity of the income coefficient and find the N-shaped relation between income per capita and carbon dioxide emissions. Moreover, more papers have begun to focus on the provincial or sectoral impact on the EKC model and the evidence proves that diverse factors may lead to inconsistent results. Some papers also suggest that analysis at the macro level can be a promising approach for the further EKC study (Mazzanti, 2008).

Some previous papers also cannot prove the existence of EKC evidence. For instance, by using the US state level data, Carson and McCubbin (1997) find that seven major air pollutants decrease with regard to the income per capita. Liu (2005) finds no EKC evidence in 24 OECD countries with simultaneous model. Azomahou et al. (2006) finds that the relationship between CO<sub>2</sub> and GDP per capita is upward sloping by using nonparametric approach.

In the Table I listed below, I also summarize the turning points obtained in the literatures. For carbon dioxide, many literatures cannot obtain the turning point. Most of the panel datasets they are using conclude both OECD and non-OECD countries (See Azomahou et al., 2006; Caviglia-Harris et al., 2007; De Bruyn et al., 1998; Liu, 2005; Vollebergh et al., 2005; Roy, van and Kooten, 2004, etc.). Turning points estimated for OECD countries range greatly from \$1,577 to \$114,663 which determined by different methodologies, pollutants and time periods. Regarding the sulfur emission, the span of the peak value is also large but the distribution is relatively smoother than carbon dioxide. The value ranges from \$2805 to \$101,166 but most data are around \$20,000. Specifically, if the paper focuses on the state level or only one country, with specification on diverse sectors or states, EKC evidence may well exist (Aldy 2004; He and Richard 2010; Marzzanti et al., 2004)

| Authors                                   | Emissions                          | Time Period  | Countries   | Turning Point   | Estimation technique  | Specifications  |
|---|------------------------------------|--|---|---|---|---|
| Azomahou et al. (2006)                    | CO <sub>2</sub>                    | 1960-1996  | 100 countries   | No EKC evidence   | Nonparametric approach  | The relationship between CO <sub>2</sub> and Gdp per capita is upward sloping             |
| Aldy (2005)                               | CO <sub>2</sub>                    | 1960-1999  | 48 states in USA  | \$15844 for pre-trade EKC<br>\$18231 for post-trade EKC       | A quadratic function; a cubic (for income per capita) spline function | Added CDD, HDD as variables   |
| Caviglia-Harris, Chambers and Kahn (2007) | CO <sub>2</sub>                    | 1961-2000 5-year period                                    | 146 countries   | No EKC evidence   | OLS, 2SLS<br>Quadratic function                                       | Only limited support for relationship among components of the EF and economic development |
| Cole, Rayner and Bates (1997)             | SO <sub>x</sub><br>CO <sub>2</sub> | SO <sub>x</sub> : 1970-1992<br>CO <sub>2</sub> : 1960-1991 | SO <sub>x</sub> : 7 OECD countries<br>CO <sub>2</sub> : 7 regions | --  | Quadratic function  | EKC only exists for local air pollutants  |
| Cole (2003)                               | SO <sub>2</sub>                    |  |   |   |   |   |
| Cole (2005)                               | SO <sub>x</sub><br>CO <sub>2</sub> | 1975-1990 5-year period                                    | 110 countries/<br>OECD countries                                  | SO <sub>2</sub> \$15986<br>CO <sub>2</sub> for OECD: \$114663 | Random coefficient model  | Random coefficient allowing for greater cross-country heterogeneity                       |
| De Bruyn, Van den Bergh, Opschoor(1998)   | CO <sub>2</sub><br>SO <sub>x</sub> | 1960-1995 5-year period                                    | Netherlands, UK, USA and west Germany                             | No EKC evidence   | Growth model  | As economic growth grows, emissions grows   |

| Authors                          | Emissions       | Time Period  | Countries                                       | Turning Point                          | Estimation technique                                     | Specifications  |
|----------------------------------|-----------------|--------------|---|--|--|---|
| Galeotti, Lanza and Pauli (2006) | CO <sub>2</sub> | 1960-2002    | 24 OECD countries                               | 3<br>—                                 | Tests of system fractional integration and cointegration | More EKC's appear relative to traditional integration/cointegration test  |
| Halkos (2003)                    | SO <sub>2</sub> | 1960-1990    | 73 countries                                    | \$2805-\$6230                          | GMM and random coefficients                              | No EKC evidence with only random coefficients   |
| He and Richard (2010)            | CO <sub>2</sub> | 1948 to 2004 | Canada  | \$22615                                | Cubic Parametric Models                                  | Using semiparametric and flexible nonlinear parametric modeling methods, little evidence of EKC found                     |
| Kaufmann et al.(1998)            | SO <sub>2</sub> | 1974-1989    | 13 developed countries; 10 developing countries | \$12340-12693                          | Cross-section Fixed effect; random effect                | Add the intensity of economic activity into variable(GDP/area)  |
| List and Gallet (1999)           | SO <sub>2</sub> | 1929-1994    | 48 States in USA                                | \$20138 (quadratic)<br>\$22553 (cubic) | Quadratic model and cubic model                          | The studies with restrict cross-sections to undergo identical experience may be statistically biased                      |
| Liu (2005)                       | CO <sub>2</sub> | 1975-1990    | 24 OECD countries                               | No EKC evidence                        | Simultaneous model                                       | The relationship between CO <sub>2</sub> and income per capita is negative, when energy consumption is added to the model |

<sup>3</sup> In this paper, the turning point is calculated for each country individually. So they are not listed here.

| Authors  | Emissions                          | Time Period | Countries                                      | Turning Point                                    | Estimation technique                                       | Specifications  |
|--|------------------------------------|-------------|--|--|--|---|
| Martinez-Zarzoso and Maruotti (2011)           | CO <sub>2</sub>                    | 1975-2003   | 88 developing countries                        | --   | LSDVC, fixed-effects instrumental variable and GMM methods | Three groups of countries' urbanization will have different impact on CO <sub>2</sub> emissions |
| Martinez-Zarzoso and Bengochea-Morancho (2004) | CO <sub>2</sub>                    | 1975-1998   | 22 OECD countries (in Kyoto Protocol)          | Cubic:\$1577-\$32209<br>Quadratic:\$4914-\$18364 | Slope heterogeneity  | Evidence for N-shaped EKC   |
| Mazzanti et al.(2008)                          | SO <sub>2</sub><br>CO <sub>2</sub> | 1990-2001   | 29 production branches in Italy                | -  | Cubic function   | The impact of different industry will differ  |
| Roy and Kooten (2004)                          | CO <sub>2</sub>                    | 1990        | States in U.S.                                 | -  | Semi-parametric model                                      | The statistical results suggests semi-parametric model rather than quadratic form.              |
| Stern and Common(2001)                         | SO <sub>2</sub>                    | 1960-1990   | 23 developed countries/50 developing countries | Fixed effect \$101166<br>Random effect \$54199   | Fixed effect/Random effect                                 | For all country: a monotonic function<br>Developed country: inverted U shape                    |
| Vollebergh et al. (2009)                       | SO <sub>2</sub><br>CO <sub>2</sub> | 1960-2000   | 24 OECD countries                              | --   | Panel data   | Clear U-shaped curve for SO <sub>2</sub> but only slightly so for CO <sub>2</sub>               |

Table 1. Recent EKC Studies on Carbon Dioxide and Sulfur<sup>4</sup> Emissions

<sup>4</sup> For the paper which contains more air pollutants rather than CO<sub>2</sub>, SO<sub>x</sub>, other pollutants will not be shown in this table.

## 2. Trade and Environment

The relationship between trade and environment has also been a major focus for researchers in both the academic and policy sectors in recent years. Trade liberalization may influence the environment in different ways. Grossman and Krueger (1991) have established the fundamental decomposition model of trade's effect on environment, in which, the effect of trade has been decomposed into scale, composition and technique effects.

Scale effects capture the fact that trade may serve to extend the level of economic activity and so place more pressure on the environment. If the technology and environmental regulation stays the same, increased trade will lead to increasing deterioration of the environment. However, the extended economic activity may be also likely to bring some beneficial environmental effect in terms of the improving technique and regulation so it is hard to define the pure scale effect (Kirkpatrick et al., 2007).

The composition effect is caused by the change in trade policy. With trade liberalization, the production factors will be reallocated among sectors. Free trade will result in each country shifting resources into the sectors which make more use of the factors with comparative advantage. Sectors with comparative advantage will be more intensive in international trade or face less regulation, while the uncompetitive sectors will face the opposite effects. On the one hand, if the expanded sectors have high pollution intensities, the environment will be damaged more. On the other hand, if the expanded sectors have less dependence on resources or pollute less, the environment will be cleaner. Generally, in the early stage of development, the first circumstance may appear. As the country developed, it will enhance the production factors shift to less polluted sectors. Actually, the composition effect is used most often to explain the EKC.

The technique effect is caused by the change in the production technology which is derived by the increasing trade liberalization. The technique effect is determined by the difference between the economic benefit of old techniques and new techniques. If a new technique has better economic performance but less pollution, the environment will be

cleaner. If the new technique has higher performance as well as higher pollution, there will be increasing destruction on environment.

An important paper by Copeland and Taylor (1994) builds a static model of North-South trade and examines the linkages among income, pollution and trade. In this paper, the authors isolate the scale, composition and technique effects of international trade on pollution. In a country without trade, a policy-induced adjustment to cleaner production can mitigate the pollution generated by economic growth—the technique effect offsets the scale effect. When trade is added within the two economies, the composition effect increases as real incomes rises. The trade will make the factor prices different due to the different pollution taxes, so a movement will occur from autarky to free trade which increases the aggregate worldwide pollution. Meanwhile, different regulations between the developed country (North) and the developing country (South) will lead to the shift of pollution-intensive sectors to the low-income economies.

Antiweiler et al. (2001) developed a theoretical model which is used to empirically decompose trade's impact on pollution into scale, technique and composition effect with data on sulfur dioxide emission. The effects are consistently exhibited. Increasing and freer trade liberalization will have an impact on pollution concentration by changing the pollution intensity on the GDP growth. As the GDP increases, the sulfur dioxide concentration will increase, which indicates the positive scale effect. The sulfur pollution concentration will fall as the per capita income rises, which suggests the negative technique effect. Moreover, the negative composition effect exists when pollution decrease as the openness rise. Furthermore, Cole and Elliott (2003) provide evidence on the capital-labor endowments and environmental regulations effects of the trade-induced composition effect. Cross-country data of sulfur dioxide emission, carbon dioxide emission, etc. have been used in this paper. The results provide partial evidence of the conclusion of Antiweiler et al. (2001) as well as a broader view for further discussion.

There are also a number of studies which indicate that the composition effect leads to the EKC relation (see Grossman and Krueger 1995, Stern 1998). A study by Suri and Chapman (1988) provide notable evidence to study the relationship between trade and

EKC. In this paper, the authors suggest that the import ratio of GDP has a negative impact in energy use while the export ratio of GDP has a positive influence in energy use. The composition effect is a determinant of energy use which contributes a lot for the air pollution. So the composition effect has also become a possible determinant of pollutants emissions. Cole (2003) further explores the relation and suggests that the relation between trade and environment should not be a single one but trade will interact with other variables that explain a country's characteristics. Thus trade has been added into the EKC model. The empirical result indicates that the impact of trade on EKC varies by different pollutants, only sulfur dioxide showing evidence for both factor endowment and pollution have hypothesis. Other pollutants show small evidence that trade patterns matters in the EKC.

In an extension of the literature, endogeneity problems in policy have been taken into consideration. Endogenous policy means that the policy regime in place is itself responsive to economic factors such as the income level or environmental regulations. Policy cannot be taken as externally given. Initially, people assumed that poor countries have less environmental regulation. But then people found that pollution haven effects also exist in models with endogenous policy (Copeland et al. 1994, 2003). Copeland (2005) has reviewed several approaches to model the endogenous policy and concluded that models with endogenous policy have had a major impact both on theoretical and empirical literatures.

The debate surrounding the relationship between global trade and environment has continued for several years. Opponents suggest several reasons of how trade liberalization may harm the environment: (1) Environmental degradation will be derived by trade liberalization; (2) Countries will lower the environmental standard to attract foreign investment; (3) The World Trade Organization may choose trade benefit rather than environmental quality (Neumayer 2000). The opponents claim that environment is a normal good so that its protection will be required more when income per capita has increased. According to the pollution haven hypothesis, less-developed countries will attract more pollution-intensive sectors. For example, some papers find evidence of pollution haven effects (see Lucas et al. 1992, Birdsall et al. 1993, Mani et al. 1998).

Furthermore, free trade extends the exposure to markets. If the environment is not optimally managed—taking the market failure into consideration—the trade liberalization might harm the environment. Therefore, it is entirely possible that the inefficient allocation will become worse with more market failures. Meanwhile, rising international trade will stimulate the development of the transportation and energy sectors (Cole, 2006) which also play a critical role in greenhouse gas or other pollution emissions. The worldwide environment will become even worse if the pollution is transmittable.

Otherwise, the proponents of trade liberalization argue that the income growth could increase people's demand for environmental quality, which may enhance the technical progress in the industries. With the pooled provincial data on Chinese water pollution, Dean (2002) finds that freer trade aggravates environmental damage through trade but also mitigate it as the income growth rises. Using exogenous geographic determinants of trade as the instrumental variable, Frankel and Rose (2005) conclude that little evidence has been found that trade will cause environmental degradation. Managi et al. (2009) also find that trade will benefit the environment in OECD countries.

In summary, researchers have tested the relationship between trade and environment in theoretical and empirical ways. However, the relationship between trade liberalization and environment is determined by a combination of different complicated process that may also interact with others. It is difficult to define them thoroughly through data and econometric methods.

### **III. Data and methodology**

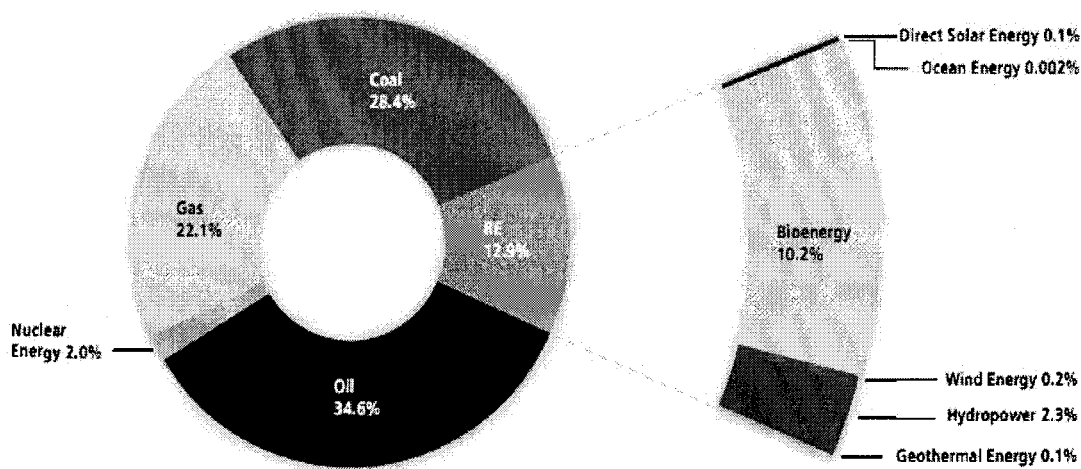
#### **1. Data**

Data for our study was drawn from a number of sources. The data for GDP per capita, population and openness are from Penn World Table 6.3. In this dataset, the GDP per capita are Purchasing Power Parity converted, derived from growth rates of consumption, government expenditure, investment, at 2005 constant prices. The openness values are measured by the total trade as a percentage of GDP, obtained from the summation of

exports and imports divided by GDP. The amount of population is used to calculate the sulfur/carbon dioxide emission per capita.

Sulfur dioxide and carbon dioxide are selected to measure air pollution. The main reason for studying these two pollutants is that the sulfur emission, which will cause acid rain, is a significant way to measure the industry pollution while carbon dioxide is regarded as the main contributor to the greenhouse effect. Another important reason is these two air pollutants are directly related to the energy industry—sulfur dioxide is mainly obtained from coal consumption while carbon dioxide measures consumption of resources such as oil and gas. The energy industry has played an essential role that contributes much to the GDP. According to Figure 1, we observe that coal, oil, gas have accounted for more than 80% of the energy supply. Thus these two air pollutants will be necessary to study.

Figure 1 World Energy supply in 2008<sup>5</sup>



The dataset from Stern (2005)<sup>6</sup> is used to obtain annual sulfur emission, from 1850 to 2000, 2001, 2002 (OECD countries), or 2003 (China, Mexico, and USA). According to Stern and Common (2001), which used the same dataset, the new dataset includes “emission of sulfur from burning hard coal, brown coal, and petroleum, and sulfur

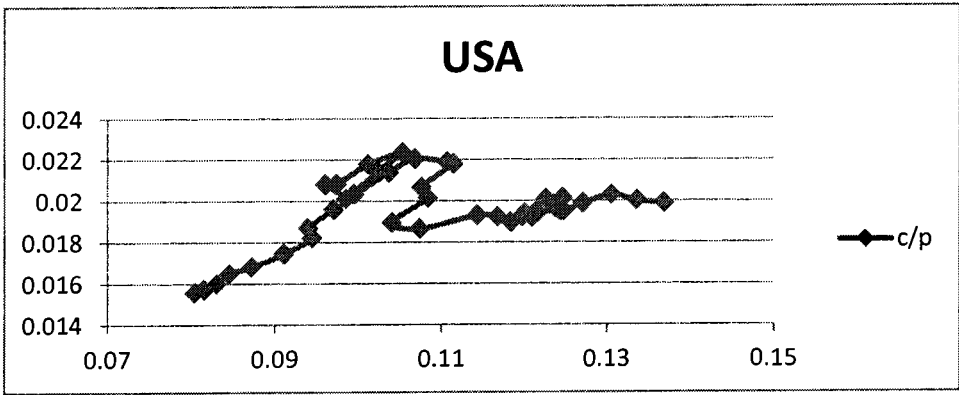
<sup>5</sup> Resource from IPCC 2010.

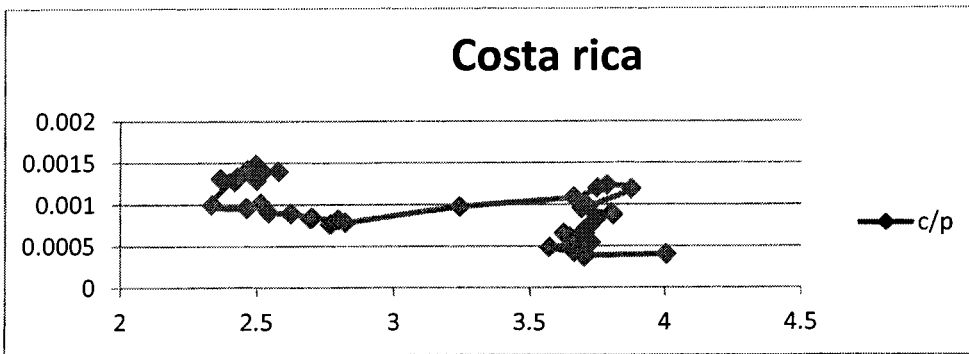
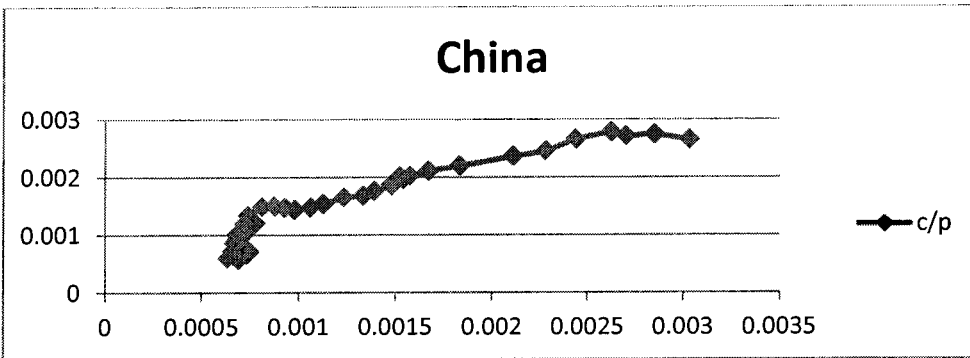
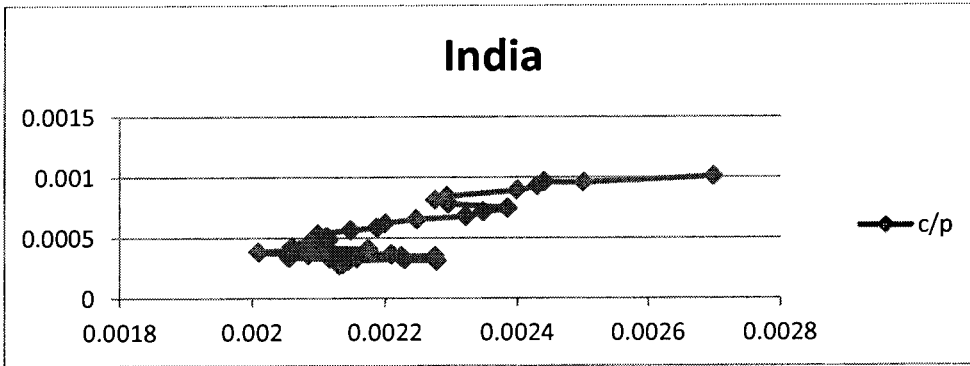
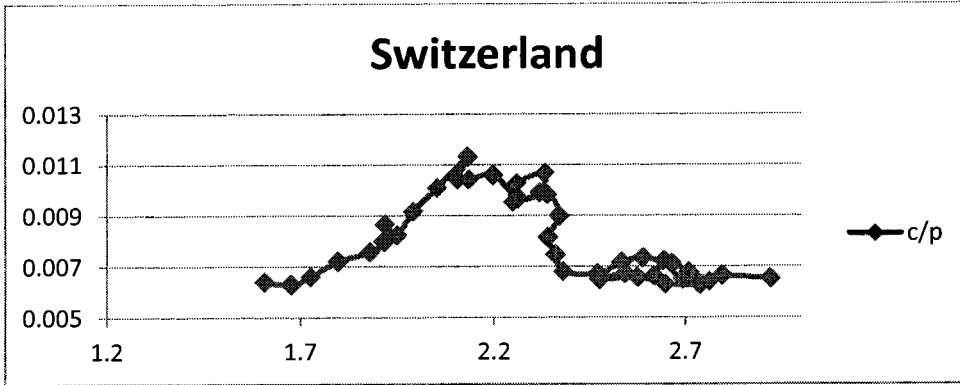
<sup>6</sup> Resource from: [www.sterndavidi.com/datasite.html](http://www.sterndavidi.com/datasite.html)

emissions from mining and smelting activities for most of the countries of the world”. The data as carbon dioxide emissions are obtained from World Resource Institute (2012). There are 24 developed countries and 74 developing countries in our sample---98 countries in total (Listed in Appendix I).

Figure 2 indicates the trend of carbon dioxide emissions per capita as the GDP per capita changes in some countries. The horizontal axis represents the GDP per capita while the vertical axis measures the value of carbon dioxide per capita. The time period is from 1960-2000. It is notable that for USA and Switzerland, developed countries with relatively fully environmental regulation, the carbon dioxide emissions per capita increases at the early stage of development. When GDP per capita has reached a turning point, the pollution will have a downward trend and then become relatively smooth, which indicate the inverted U-shape relation. Regarding developing countries, three examples are included here. India and China have been developing rapidly in recent years and the figures clearly illustrate the increasing trend of carbon dioxide emissions in line with the economic growth. Costa Rica is a developing country with focus on agriculture and tourism, so the whole country does not have systematical industrialization. In the figure, there is no obvious trend of carbon dioxide.

Figure 2. Single country’s relation between carbon dioxide emissions and income per capita





Initially we intended on using panel data which covered all the countries but some countries' data were not available due to political or other reasons. The main regions omitted are the Soviet Union and Eastern Europe. However, the sample used covers 82% of the population and 56% of the GDP of the world in 1999. The total dataset is divided into OECD and non-OECD groups to see whether there's any difference between the two. The descriptive statistics of all the countries are listed in the Table 2.

Table 2 Descriptive statistics

|              | Carbon emission per capita <sup>7</sup> | Sulfur emission per capita | Income per capita | openness |
|--------------|---|----------------------------|-------------------|----------|
| Mean         | 0.005351                                | 0.015084                   | 3.945619          | 60.92575 |
| Median       | 0.001116                                | 0.005321                   | 0.432105          | 52.07431 |
| Maximum      | 0.310686                                | 0.194555                   | 137.1847          | 428.4395 |
| Minimum      | -2.45E-05                               | 4.52E-06                   | 0.000635          | 4.826035 |
| Std. Dev.    | 0.021874                                | 0.024118                   | 14.23404          | 42.32469 |
| Observations | 3920                                    | 3920                       | 3920              | 3920     |
| Countries    | 98                                      | 98                         | 98                | 98       |

## 2. Environmental Kuznets Curve Model

The environmental Kuznets curve implies that there is an inverted U-shape relationship between income per capita and the pollution. The hypothesis suggests that the income growth effect may vary as it increases. The general regression model has the following form:

$$E_{it}=f(Y_{it}, V_{it}, F_i, F_t, E_{it})$$

where,  $Y_{it}$ , refers as the income per capital of country  $i$  in period  $t$ ;  $E_{it}$  represents the pollution indicator in per capita in country  $i$ , period  $t$ ;  $V_{it}$  denotes other exogenous

<sup>7</sup> Carbon dioxide is measured by thousand metric tons per person. Sulfur emissions is measured by million metric tons per capita.

variables that may influence the pollution;  $F_i$  is the sectional effect and  $F_t$  is the time effect.  $E_{it}$  is the error term.

With a typical quadratic polynomial (quadratic in  $Y_{it}$ ), the basic EKC equation will be:

$$E_{it} = F_i + F_t + \beta_1 Y_{it} + \beta_2 [Y_{it}]^2 + V_{it} + \epsilon_{it}$$

In this model,  $\beta_1 > 0$  and  $\beta_2 < 0$  provide evidence for the inverted U-shape relationship—consistent with the EKC. The turning point of per capita GDP can be calculated by  $Y = -\beta_1 / 2\beta_2$ .

There is no consensus in specifying the EKC functional relationship—some authors insist using the quadratic polynomial while others estimate third or even fourth-order polynomials. The quadratic form will be used here following Grossman and Krueger (1995). Ordinary Least Square (OLS) will apply in this specification. A cubic spline function has also been applied because it is more flexible than power functions and can describe the EKC more precisely (Schmalensee et al., 1998). Third or fourth order polynomials will be more likely to estimate an N-shaped curve rather than a traditional inverted U-shaped relation between pollution emissions and income per capita. In other words, the cubic function basically assumes that the EKC is estimated twice differentially which implies the pollution tends to become infinite while the quadratic implies the pollution will converge to zero. Mazzanti et al. (2008) suggested that the scale effect of economic activity, which determined the N-shape relation, is non-linear which is hard to identify. The cubic polynomial has not been considered here because the main purpose of this paper is testing the EKC and extending the model with openness but not to further study the possible trend of pollution after a high income. Therefore, the quadratic form of EKC model using logarithm will be used in this paper. One main benefit of the logarithm is the relative elasticity can be calculated from the logarithm form.

In this paper, the environmental Kuznets curve is a quadratic in logarithms in which the emission per capita (or other measurements of pollution) is the dependent variable and the national product per capita is the independent variable. In this part, I have run

regressions using three different country subsets—the whole world, the OECD countries and the non-OECD countries to see whether the EKC model holds. The model is given by

$$\ln(S \text{ or } C/P)_{it} = \alpha_i + \mu_t + \beta_1 \ln(\text{GDP}/P)_{it} + \beta_2 [\ln(\text{GDP}/P)_{it}]^2 + \epsilon_{it} \quad (1)$$

Which S represents the sulfur emission in thousands of metric tons while C is the carbon dioxide emission which is measured in million metric tons;  $P_{it}$  is the population of country  $i$  during period  $t$ ; GDP/P is the GDP per capita which we obtained directly from Penn World Table, as described above; and  $\epsilon$  is the error term which represents the effect of the omitted variables.  $\alpha_i$  stands for the country-specific effects while  $\mu_t$  measures the year-specific effects. In general, the fixed effect regards the  $\alpha_i$  and  $\mu_t$  not as random observed quantities, but rather as having correlation with the coefficients in the model. But in a random effect equation, the  $\alpha_i$  and  $\mu_t$  are both random disturbances. It is apparent that GDP per capita has a correlation with time and specific country, so it will be more appropriate to apply for fixed effect here. In order to be more accurate to identify random or fixed effect, we could take the Hausman test which can be used to test the null of endogeneity of income per capita in EKC. Here, we can compare the instrumental variable estimates to ordinary least squares estimates to test the inconsistency in the estimate of random effects (Hausman, 1978).

The Hausman Test can specify whether the fixed effect estimator is significantly different from random effect estimator. In the regression, we need to set the period and country effect as random effect, which implies the null hypothesis that the effects are uncorrelated with the other regressors in the model. If the chi-square value obtained is larger than the relative chi-square value under the same degree of freedom, we can accept the null hypothesis which implies both effects can be used. If the chi-square value is higher, then the null hypothesis will be rejected and we should choose the fixed effect. The per capita income of the EKC turning point can be calculated followed the formula of quadratic polynomial by

$$T = \exp(-\beta_1/2\beta_2) \quad (2)$$

Moreover, regarding the estimated model's ability to predict future behavior, it is necessary to consider the time derivative of the pollution variable for a given country  $i$ . Taking time derivative on both sides of equation (1) we can get:

$$\frac{d \ln(S/P)_{it}}{dt} = \frac{d\mu_t}{dt} + [\beta_1 + 2\beta_2 \ln(GDP/P)] \frac{d(GDP/P)/dt}{GDP/P}$$

As shown above, the time derivative depends on  $\frac{d\mu_t}{dt}$  as well as  $[\beta_1 + 2\beta_2 \ln(GDP/P)] \frac{d(GDP/P)/dt}{GDP/P}$ . If we set the second part equals to zero, it can yield the turning point in equation (2). However,  $\frac{d\mu_t}{dt}$  also determines the time derivative. Thus, it is necessary to see the trend of  $\mu_t$ .

To capture the relationship between the openness and environment, in this paper, we will add openness, defined by exports plus imports divided by GDP, as a control variable in the EKC estimation. So the model will be extended to

$$\ln(S \text{ or } C/P)_{it} = \alpha_i + \mu_t + \beta_1 \ln(GDP/P)_{it} + \beta_2 [\ln(GDP/P)_{it}]^2 + \beta_3 \text{Openness}_{it} + \epsilon_{it} \quad (3)$$

If the coefficient of openness is positive (negative) here, it implies that increasing trade liberalization will increase (decrease) the pollution production or lowers (raises) the environmental productivity. Moreover, the openness represents the percentage of trade including imports and exports. So it will be a heterogeneous factor which reflects the possible change in policy or capital stock-related drivers (Mazzanti et al., 2008). If the openness is statistically significant, it is necessary to compare the turning point in the model without openness and with openness to see the trade's influence on the whole economy. In order to be consistent with the result of the Hausman test, for both pollutants, the extensive model (3) will be estimated with fixed effects for all three groups (world, OECD, non-OECD) and random effects only for OECD countries.

## IV. Empirical results and analysis

We test the EKC hypothesis for two air pollutants. First, the basic EKC is tested to see whether there is an inverted U-shape relationship between emissions and income per capita. Here, we have used panel data and pool data to make the results more comprehensive. Then, trade liberalization has been added to the model as a control factor.

### 1. EKC

The EKC hypothesis has been tested with the sulfur and carbon dioxide emissions. We have tested the EKC model in quadratic form to see the coefficients and then calculated the turning point. Dummy variables are used to measure the fixed period and cross-section fixed effect. I will present the empirical results and analyze the results of three subsets: OECD countries; non-OECD countries; all countries.

Two kinds of datasets are used to analyze the EKC: panel data and pool data. Panel data is a set of cross-sectional group which each country in it can be followed over time. The dataset is consistent with several observations in a time. Thus the trend of time effect can be estimated. A pooled cross-section is usually obtained by random sampling at different points in a time. An essential feature of pool data is that they include independent observations which are better for the estimates of random/fixed effect. Thus, according to the specifications of two dataset, I would like to measure the time effect in two ways: first, panel data with another time dummy variable which equals one in the year period and zero otherwise; second, pooled data with fixed/random time effects.

If the Environmental Kuznets Curve does exist, within the group of only OECD or non-OECD countries, the result may be biased because most of the independent variables (GDP per capita, the square of GDP per capita) will congregate only around the first increasing part of the EKC model (non-OECD countries group) or the falling part of the curve (OECD countries). It is normal that within the specific group, the regression cannot predict the EKC but an increasing monotonic function due to the narrow distribution of the data. But it is also meaningful to analyze the empirical result because, especially for

the developed countries, we can see its developing locus and analyze its turning point. This also can be a good forecast for other countries.

The selection between random effect and fixed effect of country effect has been discussed above. Meanwhile, as shown in the model, time effects have also been added to the model. Obviously, GDP per capita is also strictly related to the period. The results will be shown in Table 3 and 4 separately. In all empirical results, estimates that are significant at 1% level are denoted by two asterisks (\*\*), while those are significant at the 5% level have just one (\*) next to them.

Table 3 Panel data with time dummy variable

### Carbon dioxide

| Group                    | OECD                           |               | Non-OECD                         |               | All                                |               |
|--------------------------|--------------------------------|---------------|----------------------------------|---------------|------------------------------------|---------------|
|                          | Fixed Effect                   | Random effect | Fixed Effect                     | Random effect | Fixed Effect                       | Random effect |
| In(GDP/P)                | 5.384**                        | 5.327**       | 0.457**                          | 0.457**       | 2.722**                            | 2.733**       |
| [In(GDP/P)] <sup>2</sup> | -0.260**                       | -0.255**      | -0.025**                         | -0.021**      | -0.128**                           | -0.126**      |
| Constant                 | -32.732                        | -32.633       | -7.625                           | -7.665        | -20.896                            | -21.114       |
| R <sup>2</sup>           | 0.393                          | 0.405         | 0.168                            | 0.174         | 0.598                              | 0.608         |
| EKC                      | Yes                            | Yes           | Yes                              | Yes           | YES                                | YES           |
| Turning point(\$)        | 31130                          | 34183         | 10647                            | 52184         | 41332                              | 50336         |
| Hausman test             | Chi-sqaure 0.63<br>p-value:1.0 |               | Chi-square 18.68<br>p-value:0.99 |               | Chi-sqaure 113.08<br>p-value:0.000 |               |

### Sulfur dioxide

| Group                    | OECD                            |               | Non-OECD                        |               | All                                |               |
|--------------------------|---------------------------------|---------------|---------------------------------|---------------|------------------------------------|---------------|
|                          | Fixed Effect                    | Random effect | Fixed Effect                    | Random effect | Fixed Effect                       | Random effect |
| In(GDP/P)                | 14.862**                        | 14.821**      | 0.562**                         | 0.462**       | 6.351**                            | 6.119**       |
| [In(GDP/P)] <sup>2</sup> | -0.771**                        | -0.767**      | -0.0258*                        | -0.020*       | -0.338**                           | -0.322**      |
| Constant                 | -75.056                         | -74.924       | -5.431                          | -5.535        | -34.32                             | -33.502       |
| R <sup>2</sup>           | 0.346                           | 0.347         | 0.09                            | 0.09          | 0.331                              | 0.344         |
| EKC                      | Yes                             | Yes           | Yes                             | Yes           | YES                                | YES           |
| Turning point            | 15382                           | 15541         | 84377                           | 116693        | 11924                              | 13263         |
| Hausman test             | Chi-sqaure 29.70<br>p-value:1.0 |               | Chi-sqaure 29.64<br>p-value:0.9 |               | Chi-sqaure 29.70<br>p-value:0.9049 |               |

Hausman test is conducted to confirm that whether the random effect is valid because if there's any correlation between  $\alpha_i$  and  $\mu_t$ , the model cannot be estimated consistently (Hsiao, 1986). From the table above, regarding the carbon dioxide, we can observe that OECD group and non-OECD group both have homogeneous character—the random effect is estimated consistently here. For the all countries group, random effect is not statistically significant for the carbon dioxide so the empirical result will be biased. If there are no other statistical problems, the fixed effect model can be estimated consistently, but the estimated coefficients are conditional on the specific time and country effects which based on the sample chosen. This indicates that the coefficient obtained from the EKC model may not explain the future behavior of developing countries (Stern and Common 2001). In existing research, random effects have also been used before (See Selden and Song 1994, Grossman and Krueger 1993 and 1995, Stern and Common 2001). In this paper, both effects will be used for three groups and the coefficients and turning points will be analyzed.

In Table 3, for the OECD countries, there are EKC evidence that the group has an inverted U-shape for both fixed effect and random effect. For both effects, the estimators are consistent. The R-square values of carbon dioxide are 0.39 (fixed effect), 0.40 (random effect) and 0.346 (fixed effect), (0.347) random effect for sulfur dioxide emissions. The P-values of their regressions are all smaller than the level of significance indicating the coefficients are statistically significant. The turning points for carbon dioxide are \$31,130 (fixed effect) and \$34,183 (random effect). Comparatively, the peak points of sulfur emission are smaller, which are \$15,382 for fixed effect and \$15,541 for random effect.

There is also EKC evidence for non-OECD countries for both air pollutants. But the value of R-square is much smaller than the value for OECD group. Moreover, the p-value of GDP per capita, square of GDP per capita is only significant at 5% level. It indicates that comparing to OECD countries, here are more factors that may influence the environmental pollution except the income per capita. The EKC evidence is not as strong

as in OECD groups. Moreover, the difference of turning point between fixed effect and random effect is relatively large. The turning point of non-OECD group is only \$10,647 for carbon dioxide, much lower than the turning point for OECD group. The turning is likely to happen due to the instability at the early stage of development which may not be consistent as time goes by.

For all the countries, the estimators are statistically significant and the EKC has an inverted U-shape for both pollutants. For carbon dioxide, the random effect cannot be used here. The turning point for fixed effect is \$41,332. The turning point of sulfur emissions is lower, \$11,924 for fixed effect, \$13,263 for random effect. The concentration of sulfur dioxide tends to decrease as per capita GDP rises from \$11,924-\$13,263.

According to this empirical result, the income per capita level is still far from the turning point of carbon dioxide emissions for all the countries. Thus in recent years, economic development will have a negative impact on carbon dioxide emissions. Comparatively, the turning point of sulfur emissions is close to the current income level except for the non-OECD group. In conclusion, this panel data can derive the EKC, and both cross-sectional effects can be used here. Time effects are measured by the dummy variables. The coefficients measure the logarithmic difference in the specific year. In order to see the ability of future prediction in the model, we set time as a dummy variable and get coefficients for each year in order to analyze its trend. According to Figure 3, we can find the decreasing trend for both OECD and world countries group, but there is an increasing trend for non-OECD countries especially at the early years. It implies that as time goes by, the OECD or whole world will tend to discharge less sulfur dioxide. But the non-OECD group is at the early stage of development, so pollution has a rising tendency. The short-term time effect will be influenced by sudden financial shock or policy change such as the LRTAP (Long Range Transportation of Air Pollution) protocol (1979) or Koyto Protocol (1997).

Figure 3 Time trends of three groups

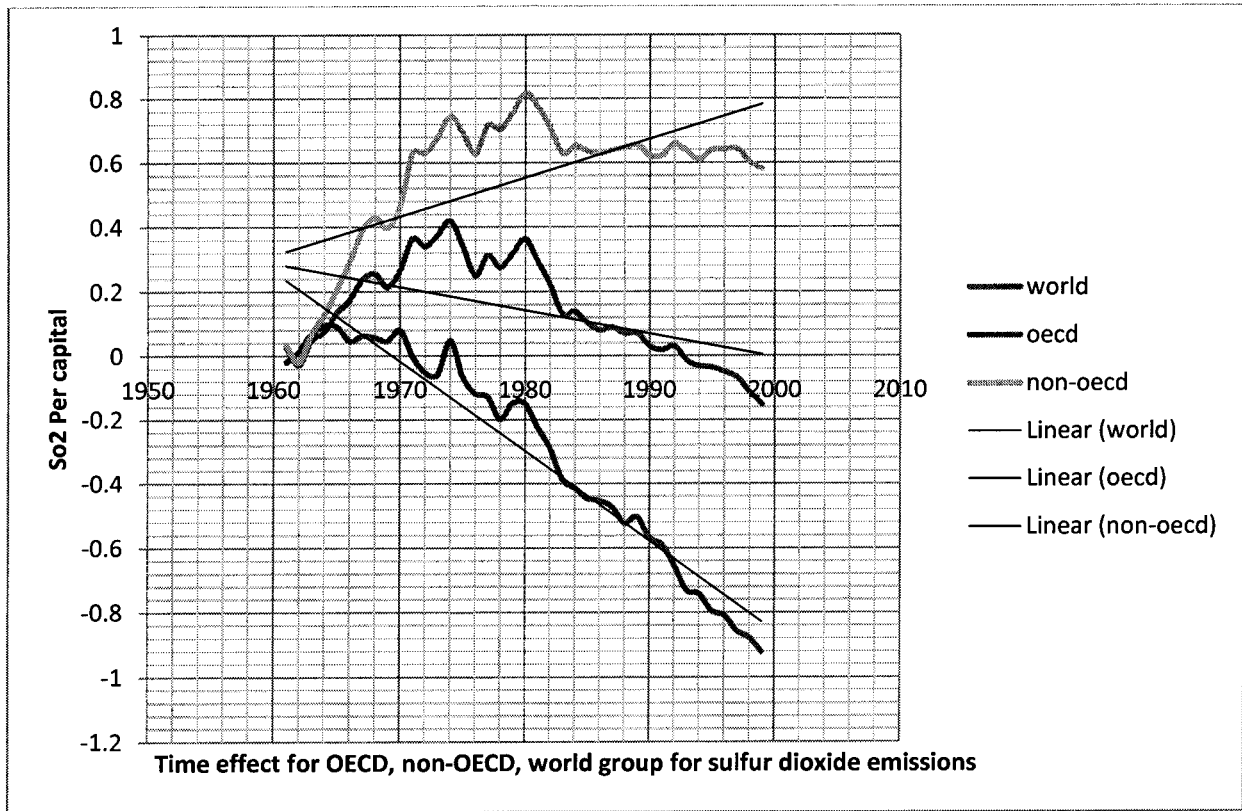


Table 4. Pooled data with fixed/random time effect

**Carbon Dioxide**

| Group                    | OECD                              |               | Non-OECD     |               | All          |               |
|--------------------------|-----------------------------------|---------------|--------------|---------------|--------------|---------------|
|                          | Fixed Effect                      | Random effect | Fixed Effect | Random effect | Fixed Effect | Random effect |
| In(GDP/P)                | 6.107**                           | 6.042**       | 1.626**      | N/A           | 4.124**      | n/a           |
| [In(GDP/P)] <sup>2</sup> | -0.304**                          | -0.273**      | -0.066*      |               | -0.224       |               |
| Constant                 | -26.112                           | -28.372       | -7.249       |               | -16.39       |               |
| R <sup>2</sup>           | 0.983                             | 0.632         | 0.975        |               | 0.981        |               |
| EKC                      | Yes                               | Yes           | Yes          |               | YES          |               |
| Turning point(\$)        | 23187                             | 63691         | 225941       |               | 10120        |               |
| Hausman test             | Chi-sqaure 44.53<br>p-value:0.000 |               |              |               |              |               |

## Sulfur dioxide

| Group                    | OECD                        |               | Non-OECD                          |               | All                               |               |
|--------------------------|-----------------------------|---------------|-----------------------------------|---------------|-----------------------------------|---------------|
|                          | Fixed Effect                | Random effect | Fixed Effect                      | Random effect | Fixed Effect                      | Random effect |
| In(GDP/P)                | 14.862**                    | 17.886**      | 2.617**                           | 3.019**       | 6.351**                           | 6.753**       |
| [In(GDP/P)] <sup>2</sup> | -0.771**                    | -0.974**      | -0.105**                          | -0.129**      | -0.338**                          | -0.364**      |
| Constant                 | -75.345                     | -85.472       | -19.650                           | -21.232       | -34.181                           | -35.701       |
| R <sup>2</sup>           | 0.983                       | 0.472         | 0.794                             | 0.152         | 0.829                             | 0.160         |
| EKC                      | Yes                         | Yes           | Yes                               | Yes           | YES                               | Yes           |
| Turning point(\$)        | 15382                       | 9679          | 274012                            | 120758        | 11923                             | 10679         |
| Hausman test             | Chi-sqaure 0<br>p-value:1.0 |               | Chi-sqaure 38.13<br>p-value:0.000 |               | Chi-sqaure 54.020<br>p-value:0.00 |               |

When fixed and random time effect is added to the model, the coefficients turn to be more consistent with the EKC hypothesis. The results are shown in Table 4. In the coefficient covariance method, taking the possible heteroscedasticity among factors into consideration, the cross-section weights have been applied here. The data of carbon dioxide emissions includes zero emissions in it so ln(c/p) group is missing some data (for eight developing countries<sup>8</sup>), thus the regression omits these countries. Two-way random effects are not allowed with unbalanced data. Therefore, random effect is not applied to the regression of carbon dioxide emission in non-OECD group and the all countries group. According to the Hausman test listed in Table 4, most of the group should only take fixed effect into application except for the OECD group with sulfur emissions.

For OECD countries, we find evidence is support of the EKC hypothesis. But with random effect for both country and period, the impact on the model varies in terms of different pollutants. For carbon dioxide, the turning point with both random effect is \$63,691, which is much larger than the value under fixed effect \$23,187. Due to the result of Hausman test, the random effect is not consistent with fixed effect. But for sulfur emissions, the peak value under random effect is smaller than the one with fixed effect.

<sup>8</sup> The eight countries are: Burkina Faso; Guinea-Bissau; Cape Verde; Burundi; Mali; Niger; Rwanda; Senegal.

Regarding the non-OECD countries, although there is evidence of the inverted U-shape relation, the turning points calculated are much higher than the present income per capita level for both carbon and sulfur dioxide emissions. The EKC for this group is actually monotonic. The R-square is much smaller in random effect rather than the fixed effect for sulfur dioxide emissions. The EKC also exists for the all countries group. The peak values for sulfur emissions are \$11,923 (fixed effect), \$10,679 (random effect), which are approximately equal to the value obtained from table ii. But the turning point of carbon dioxide emissions is far below the peak point with only country fixed/random effect.

However, when we study these three groups, we put the same coefficients restrictions in the regression, no matter studying the evidence of EKC or the impact of openness. In order to see whether the coefficient restriction here is legitimate, we can put an OECD dummy into the model and see whether it is significant. But in studying the panel data, fixed effect panel regression models involve subtracting group means from the regressors. Thus only time-varying dummies can be included in the model. Thus we will use random effect to test this cross-sectional dummy for the world group. The results are shown below (time dummies are also included)

Table 5. EKC model with cross-sectional dummy

| Emissions group          | CO2(world)                 |          | SO2 (world)                |          |
|--------------------------|----------------------------|----------|----------------------------|----------|
|                          | With cross-sectional dummy | Without  | With cross-sectional dummy | Without  |
| ln(GDP/P)                | 2.752**                    | 2.733**  | 6.162**                    | 6.119**  |
| [ln(GDP/P)] <sup>2</sup> | -0.129**                   | -0.126** | -0.327**                   | -0.322** |
| Cross-sectional dummy    | 1.747**                    | N/A      | 0.752**                    | N/A      |
| Constant                 | -21.524                    | -21.114  | -33.706                    | -33.502  |
| R <sup>2</sup>           | 0.609                      | 0.608    | 0.388                      | 0.344    |
| Turning point(\$)        | 43767                      | 50336    | 12242                      | 13263    |

From Table 5, we can observe that, the cross-sectional dummy is statistically significant. But it has few effects on the coefficients. It implies that although there is some difference

in coefficient restriction on different subsets, the results will be influenced only a little. Thus the model form can be applied to three subsets. The results are valid.

One interesting point to note is that the turning points obtained for all the countries are *smaller* than the other two groups (except carbon dioxide in panel data). This is contrary to the conjecture of Stern and Common (2001) that the turning point of an OECD group will be lower than those turning points of groups with more developing countries. The results here do not support this claim. It is consistent, here, with Cole (2003) who does not replicate Stern and Common's result as well and he concludes that it may be caused by smaller sample of developing countries. But in our group, we use a close replica of the Stern and Common (2001)'s dataset but more developing countries. The results are different especially in the turning points obtained. One possible reason here is the extensive period and dataset. Another possible reason here is the whole country group has a wide distribution of variables so that technically, it will be relatively precise to derive the quadratic polynomial and thus the turning points.

In general, the difference between carbon dioxide and sulfur dioxide emissions implies the distinct relationship between each respective pollutant and GDP per capita, which is possibly decided by the various correlations among factors. It also can imply that it is dangerous to predict other pollutants would have similar trends as GDP increases. Two datasets yields different results due to its diverse characteristics. Comparing to the panel data, the results of pooled data have higher R-square when the fixed effect is applied.

## **2. Openness**

The second objective of this study is to examine the impact of trade intensity on environmental quality. In this part, openness is added as a variable to the EKC model which is shown as model (3). Only the results of panel data will be used here due to its consistency with previous literatures (Cole 2003; Stern 2004; Seldon and Song 1994). Trade openness will have some influence on the base EKC model. The results are listed in Table 6. Only fixed effect is applied here.

Table 6. EKC model using panel data with Openness

| Group                    | OECD            |                 | Non-OECD        |                 | All             |                 |
|--------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                          | CO <sub>2</sub> | SO <sub>2</sub> | CO <sub>2</sub> | SO <sub>2</sub> | CO <sub>2</sub> | SO <sub>2</sub> |
| ln(GDP/P)                | 5.923**         | 14.596**        | 0.421**         | 0.496**         | 2.706**         | 6.318**         |
| [ln(GDP/P)] <sup>2</sup> | -0.286**        | -0.758**        | -0.023**        | -0.0216*        | -0.129**        | -0.341**        |
| Openness                 | -0.0055**       | 0.002726        | -0.0029**       | 0.0053**        | 0.00143**       | 0.004**         |
| Constant                 | -35.198         | -73.835         | -7.82           | -5.796          | -20.805         | -34.117         |
| R <sup>2</sup>           | 0.158           | 0.814           | 0.178           | 0.09            | 0.592           | 0.307           |
| Turning point(\$)        | 31042           | 15207           | 9134            | 94995           | 36838           | 10613           |
| Old Turning point(\$)    | 31130           | 15382           | 10647           | 84377           | 41332           | 11924           |

When trade is added to the model, for carbon dioxide, the new model (3) has estimated a statistically significant inverted U-shaped relationship between carbon dioxide emissions per capita and income per capita. The coefficients are negative for the OECD group and the non-OECD group, but positive and significant for the all countries group. The explanation of negative coefficients may be that regarding the countries with similar characteristics, increasing trade openness has similar effect so may not lead to “pollution haven” effects. Pollution haven effects exist when the developed countries enhance production factors in less-polluted sectors while the less developed countries will have more pollution-intensive sectors. Only considering one homogenous group, the trade openness may not result in the increasing pollutions. It is also consistent with the lack of empirical evidence of pollution haven hypothesis. For the whole world, the positive coefficient indicates the fact that the rising trade will increase the pollution emissions. The reason may be the same as the EKC model that the estimation will be more accurate due to the wide distribution of variables. It will be prudent to discuss the existence of the pollution haven effects for the whole world because the measurement of pollution effect needs to take many factors into consideration, such as the change of pollution emissions in each country. The positive coefficients cannot predict that whether there is pollution shifting from developed countries to developing countries.

For sulfur emissions, the trade openness has a positive effect for three groups. It implies that as the trade openness increases, the sulfur emission will increase as well. The reason of the positive impact is consistent with both factor endowment and pollution haven effects. Nevertheless, for OECD group, the coefficient of openness is not statistically significant, contradicting to the results in Cole, 2003. It is reasonable that a country that developed to a certain level, the trade openness may not influence the pollutants emissions due to its well-established market and environmental restriction. For non-OECD group, the R-square is small while the coefficient of  $[\ln(\text{GDP}/P)]^2$  is only significant at 95% interval level. It means the evidence of the EKC relationship is not as significant here as in other groups.

The impact of trade liberalization on emissions varies by pollutant. Meanwhile, the openness variable seems to add little power to explain the emissions due to the small change in R-square, except for sulfur dioxide of OECD group (change greatly from 0.346 to 0.814). When we focus on the turning point, we can find that when openness is applied into the model, the turning point is lowered than before no matter in which group or for which pollutants. It implies that it may be different how trade behaves for a specific group, country or period, in the long run. But overall, it could enhance a more balanced endowment allocation. If there is pollution haven, as the model built by Grossman and Krueger (1991), there will be pollution transfer from north to the south. According to the hypothesis, when openness added to the model, the turning point obtained should be higher for developing countries while lower for developed countries. Thus the decrease for both OECD and non-OECD groups indicates that there is no pollution transfer from the rich countries to the poorer countries.

## **V. Discussion and Conclusion**

This paper reviewed the previous literatures regarding the EKC as well as the impact of trade liberalization on emissions. The results of the paper provide new evidence of the existence of base EKC. The hypothesis is that there is inverted U-shape relationship

between the emissions and income per capita. The major dataset using in this paper is the panel data with 98 countries in 40 years. Comparatively, pool data has been used with fixed/random time effect. Moreover, trade liberalization has been added to the EKC model, and the impact of openness on environmental pollution has been analyzed.

In this paper, the data on sulfur dioxide and carbon dioxide emissions have been used to test the EKC. The results of the paper strongly support the existence of the EKC. For OECD group, the EKC significantly exists. In non-OECD group, the statistical significance of EKC is relatively smaller while the high turning point implies the EKC into a monotonic curve. When openness is added to the model, it adds little to explain the EKC estimates. The turning points with openness have not changed significantly. The sulfur dioxide emissions have negative impact on environmental productivity while the influence of carbon dioxide differs from sub-groups. Moreover, the change of turning points cannot reflect the fact that there will be pollution transmission from the rich countries to poor countries.

The paper also investigates the relationship between trade and environment. The results indicate that the openness has relatively small but existed impact on the EKC. Moreover, the decreasing turning points in all three group suggests that the EKC relation is not determined mainly by the pollution transmission from the rich countries to pool countries, but rather the change on trade patterns by the environmental policy or factor endowments (Cole, 2003).

If the reality follows the hypothesis that the pollution is caused by the increasing income effect until a certain point, the policy implication of environmental regulation is that the best way to increase the environmental efficiency is to make each country's income per capita reach the turning point. Thus, there are still some problems remained.

Firstly, the turning points obtained from the regression in this paper are mostly higher than the current GDP level. As the income per capita increases, it is entirely possible that the turning points will change due to non-structural environmental or economic factors. Thus the turning point here may be not predictive for the further environmental regulation.

Secondly, the turning point is a mean value of the world so that there will be more countries lower than the mean value rather than above it due to the wealth allocation proportion (Cole, 2003). Thus it will be prudent to assume that the global emissions will decrease after the turning point. For the same reason, the decreasing turning points which resulted by the trade liberalization may cannot obtain less global emissions in the future. Thus the existence of pollution haven hypothesis and more details of the variables need to be further discussed.

Thirdly, the composition effect of trade liberalization indicates that there will be some countries that have comparative advantage in pollution-intensive industries. Therefore these countries should have more severe pollution as the trade increases. It will contradict the inverted U-shaped relationship between income per capita and pollution. In the EKC, the turning point of all the countries may not fit the reality. Nevertheless, another explanation of EKC is “when world incomes rise, the countries will remain at the same relative position on the curve, locked into a global structure of unequal pollution distribution.”(Thompson and Strohm, 1996) But it will also be hard to identify which expression here is more accurate in reflecting the comparative advantage as well as the income effect.

Fourthly, for policy makers, the robustness of EKC in this paper indicates that the more developing economics can be possibly to help reduce the emissions but it is still a long way to go. Moreover, trade liberalization should be enhanced by using tax system or trade agreement, etc. considering the fact that it does provide some positive impact on the relation between income per capita and environmental quality.

In conclusion, the main contribution of the paper is not just the extensive dataset with more countries and periods, but some new thoughts to the difference between pollutants, datasets as well as the impact of trade. This paper provides evidence that is supportive for the robustness of EKC. The income per capita relates to the scale and technique effects which will influence pollutions. The trade interacts with income and other characteristics of the country that reduce the turning point in small scale by stimulating the new environmental regulation and changing factors allocations, which related to the

composition effect. However, the decreasing turning point cannot necessarily predict that the global emissions will fall as the income increases. Empirical analysis of the EKC still poses a lot of challenges technically (Perman and Stern 1999) or empirically. How to identify accurately the further trend of environment and the exact effect of trade will be important issues that need further exploration.

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## Appendix I Country list

### OECD Countries (24)

Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Ireland, Israel, Italy, Japan, Luxembourg, New Zealand, Netherlands, Norway, Portugal, Romania, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States

### Non-OECD Countries (74)

Algeria, Argentina, Barbados, Benin, Bolivia, Brazil, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Congo Dem Rep., Congo Republic of, Costa Rica, Cote d'Ivoire, Cyprus, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Fiji, Gabon, Ghana, Guatemala, Guinea, Guinea-Bissau, Haiti, Honduras, India, Indonesia, Iran, Jamaica, Jordan, Kenya, Korea, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mauritius, Mexico, Mozambique, Nepal, Nicaragua, Niger, Nigeria, Panama, Papua, New Guinea, Paraguay, Peru, Philippines, Rwanda, Senegal, Singapore, South Africa, Sri Lanka, Syria, Taiwan, Tanzania, Thailand, Togo, Trinidad & Tobago, Uganda, Uruguay, Venezuela, Zambia, Zimbabwe