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Jie He

UNIVERSITÉ DE SHERBROOKE

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Jie He
Départment Economique and GREDI, Faculté d'Administration, Université de Sherbrooke, 2500 boulevard de l'Université, Sherbrooke, QC J1K 2R1, Canada
Tel: 819-821-8000 ext 62360, Fax: 819-821-7934, Email: **Jie.He@Usherbrooke.ca**

Abstract

This paper surveys the existing Environmental Kuznets Curve studies and discusses to what extent they may be valid and applicable for developing countries. We found that, given the shortcomings in both the theoretical and empirical aspects of the analyses applied to this hypothesis, no one-fit-for-all inverted-U-shaped curve can describe adequately the relationship between growth and pollution –which does not only imply challenges but also opportunities for developing countries: indeed, they are the ones in charge for the choice of their own sustainable development trajectory in the future. If they manage to coordinate adequately their structural, institutional and technical policies, all the while making good use of the already-existing techniques in pollution abatement, they will be able to tunnel or leap-frog the EKC trajectory derived from developed countries' experience, thus making a win-win situation happen for both economy and the environment as soon as possible.

Key Words: Environmental Kuznets Curve, Pollution, Economic growth, Methodology, Theory

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1. Introduction

For the sake of human development, the real value of natural resources has often been overlooked, so that they have been subject to over-consumption in both production and consumption activities. Over the course of the 20th century, the situation has worsened to an extreme point along with the unprecedentedly quick pace of economic growth. Observing how fast the exhaustion of the non-renewable resources, how alarmingly irreversible the dangers linked to climate changes, many scholars have expressed their worries that such a remarkable economic "prosperity" may not be sustainable in the future. Supposing the future economic growth model remains unchanged and the population/industrial capital keeps growing exponentially, as claimed in *The Limit to Growth* (Meadows et al. 1972), the Club of Rome report, then the limited supply of both food and non-renewable resources will lead to the collapse of our production system and to the halt of our economic growth before 2100 (Cole, 2000).

Since the 1980's, such fears related to growth have given rise to a significant line of research regarding the possibility of some form of 'sustainable development', as "a process of change in which the exploration of resources, the direction of investment and the orientation of technological development and institutional change are all compatible and satisfy current human needs and aspirations without jeopardizing the future (generations') potential for satisfying their needs". (WCED, 1987)

The advent of the Environmental Kuznets Curve hypothesis is closely related to both the fear linked to the "limits of growth" and to the concept of "sustainable development". Originally based on empirical findings, the famous inverted-U curve predicted by this hypothesis concerning the relationship between pollution and per capita income has been interpreted in various ways. What optimists see in it is that environmental deterioration is an unavoidable stage in economic development, a mere temporary phenomenon before we become rich enough to implement seriously the necessary pollution abatement activities. In contrast, pessimists point that this hypothesis only has weak credibility given the instable estimation results yielded by over 100 studies based on the experience of various countries.

When first advocated, the concerns about the sustainability of development did not prevail in developing countries. For them, the first and foremost problems were, and still are, directly related to their 'poverty and very lack of development'–problems which, supposedly, should be overcome in the first place thanks to development and growth (Founex Report, 1971). However, as most of the developed countries have generally experienced obvious environmental improvement along with their economic growth over the last 30 years, the EKC hypothesis is actually more problematical for developing countries whose per capita income is generally far below the turning point supposed to herald the "decoupling" between economic growth and environmental deterioration. In keeping with the original Kuznets Curve, the inverted-U-shaped curve concerning the pollution-income correlation estimated from cross-country data is suspected to be a static and descriptive estimate. Hence, some economists believe it cannot predict a dynamic trajectory, not to mention the *optimal* trajectory that an individual developing country *must* follow for its future environmental situation. Therefore over the last few years, more and more studies have been dedicated to demystifying the reduced-form EKC so as to turn it into a structural policy instrument. In doing so, they investigate ways to help developing countries explore more sustainable environmental evolution trajectories during their economic growth process, given the technical, institutional and ideological constraints that they faced at the time.

It appears all the more crucial to understand the structural determination of the EKC when considering the current globalization trend. Some economists point that it permits rich developed countries to relocate their polluting industries into poorer developing countries. Were cross-country databases to prove that there was such a thing as a global inverted-U EKC pattern, it would only reveal that the pollution reduction trend in richer developed countries is counterbalanced by a pollution increase in poorer developing ones. In this perspective, the inverted-U-shaped curve yielded by international experience actually is no good to predict a dynamic EKC. For each individual developing country, a sustainable development policy requires that more attention be paid to country-specific studies.

This paper tries to trace the trends of the literature discussing the Environmental Kuznets Curve from the angle of developing countries. The second section discusses the genesis of the EKC hypothesis and section three lists the various policy interpretations derived from it. In section four, we will proceed reviewing the literature and comparing various EKC studies. Section five discusses the potential shortcomings of the studies using the EKC reduced form. Section six gradually introduces more significant structural studies based on the experience of both international and individual countries: these studies included more structural determinants and/or use other econometrical and non-econometrical analytical methods. Finally, conclusions are delineated in section 7.

2 The "Environmental Kuznets Curve": its genesis and hypothesis

For some "limits of growth" advocates such as Georgescu-Roegen (1973) and Meadows et al. (1972), the growing economic activity requires more and more energy and material inputs, all the while generating more and more waste by-products. The latter would then undermine the "carry capacity" of the biosphere and result in the degradation of the environmental quality. The degraded stock of natural resources would eventually put economic activity itself at risk and jeopardize the future growth potential. Therefore, to spare both the environment and the economy, economic growth must be halted to make a transition to a more steady state.

In contrast with this radically pessimistic view, the Environmental Kuznets Curve (EKC) assumes that the relationship between various indicators of environmental degradation and per capita income can be depicted thanks to an inverted-U-shaped curve showing that the environment degradation indicators, first boosted by economic growth, shall be decoupled from economic growth trends, and then fall once the income level has reached a given critically high level.

The genesis of the Environmental Kuznets Curve can be traced back to Kuznets (1955), who originally hypothesized that the relationship between inequality in income distribution and income growth follows an inverted-U curve. Since the early 1990s, it has re-gained academic attention. In this line of research, the pathbreaking study was that of Grossman and Krueger (1991) concerning the potential environmental impacts of NAFTA; the Shafik and Bandyopadhyay (1992) provided the background study for the *1992 World Development Report*; Panayotou (1993) wrote part of a study for the International Labour Organization. They all reached the same conclusion: it appeared out of cross-country analyses that the connection between some pollution indicators and income per capita could be described as an inverted-U curve. Panayotou (1993) first coined it the Environmental Kuznets Curve (EKC) given its resemblance to Kuznets' hypothesis.

3. The EKC hypothesis and its various interpretations policy-wise

However, from the inverted-U relationship between pollution variation and income growth, economists have derived totally different policy interpretations. At the most optimistic end of the spectrum, Beckerman (1992) argues that the easiest way to obtain environmental improvement is to carry on with the original economic growth path and endure the transient environment deterioration. Claiming both the demand and supply capacity for a better environment increase along with the income, he concludes that, "the strongest correlation between the incomes and the extent to which environmental protection measures are adopted demonstrates that in the long run, the surest way to improve your environment is to become rich". In his very controversial book *The Sceptical Environmentalist*, Lomborg (2001) also describes our future as a "beautiful world". After drawing both environmentally and economically-oriented comparisons regarding various aspects of the world over the last century, he concludes that this world "is basically headed in the right direction and that we can help to steer this development process by insisting on reasonable prioritisation (the economic growth)" (p. 350-352). Barlett (1994) goes even further in his claims about environment-growth nexus. For him, environmental regulation, as a policy tool reducing economic growth, would actually cause the environmental quality to decrease.

At the other end of the spectrum, pessimists explain that this inverted-U pattern is a consequence of trade liberalization as polluting industries are redistributed among countries of different income levels. "Trade itself is likely to increase the impacts (of pollution) in developing countries and reduce them in the developed countries and this may be another explanation for the EKC relationship" (Suri and Chapman, 1998).

The hypothesis of a "pollution haven" further supports this interpretation: developing countries have comparative advantages in the polluting sectors as their relatively lower income standards cannot cope with such stringent an environmental regulation as their richer trade-partners. Indeed, with trade liberalization, the pollution-intensive industries tend to desert developed countries and move offshore, in developing countries where pollution control is less severe. As mentioned further up, the famous inverted-U curve observed in cross-country experience would then mirror this static transfer mechanism. In this view, the overall worldwide environmental quality may even be more at risk, as developing countries generally have less efficient pollution abatement technologies. Ekins (1997) even points out that if pollution in developed countries is reduced because they discharge their pollution burden, this may not be a potential avenue for today's less developed countries. Therefore, supporting the EKC pattern may impede sustainable development in both the developing countries and the world at large.

More economists take a neutral stance concerning the EKC hypothesis: they believe the inverted-U curve only captures the 'net effect' of income upon the environment, in which "income growth is used as an omnibus variable representing a variety of underlying influences, whose separate effects are obscured" (Panayotou, 2003). In this perspective, linking income growth with the easing of environmental deterioration is *not* automatic. To understand the underlying mechanisms that come with economic growth, many authors regard the inverted-U relationship as a "stylised" fact. They strive to "demystify" it, offering and verifying obscured structural explanations for it: better efficiency in production, consumption and pollution abatement; institutional development; improvements in market and institutional efficiency; strengthened public awareness of the negative effects of pollution on health; increasing willingness-to-pay for pollution abatement; and an economic structure that, from one dominated by industrial sectors, becomes dominated by tertiary sectors, etc.[1] From their point of view, economic growth is neither a necessary nor a "sufficient factor to induce environmental improvement in general". (Arrow et al., 1995, p.92) The same could be said for the turning point between economic growth and environmental degradation yielded by cross-country experience. In some pollution cases, some degree of improvement can be observed even in countries whose income level is still low currently.

4. A simple review and comparison of existing EKC empirical analyses

As soon as the statistics concerning the environmental quality become available, the EKC hypothesis can easily be tested econometrically as a reduced-form correlation between environmental indicators and income level. From the beginning of the 1990's, concentration and emission data have been compiled and published by the Global Environmental Monitoring System (GEMS), the World Bank (World Development Indicator), the World Resource Institute (WRI), the OECD and the United Nations, thus directing unprecedented academic enthusiasm to investigate the EKC hypothesis. Since the first paper by Grossman and Krueger (1991), over 100 papers have addressed this topic from different angles and many of them did confirm the existence of the EKC during the last 30 years.

However, if the EKC can be considered as a statistic artifact to summarize pollution indicators and income per capita in a two-dimensional diagram, in a strict econometrical perspective, this reduced-form correlation ignores the underlying real causality between the two indicators, and may thus be "spurious" and far from "optimal". The general criticisms faced by most of the EKC studies are therefore the lack of coherence and comparability in the forms and turning points of the pollution-income relationship (Ekins, 1997 and Stern and Common, 2001).

Table 1 lists in chronological order 27 EKC studies analyzing the sulfur dioxide (SO_2) pollution case. SO_2 is the air pollution indicator most discussed in EKC literature: it is generally believed to be the local air pollution indicator which is most likely to follow the inverted-U trajectory during income growth (Stern, 2004; Cole et Elliott., 2003; Selden and Song, 1994).

However, among the 27 studies listed in the table, only 15 find supportive evidence to back the EKC hypothesis. The number of studies providing other curve shapes for the relationship between SO_2 and economic growth has increased over time. Even among pro-EKC papers, the turning points of the inverted-U curve are assigned strikingly different positions. Detailed comparison between papers reveals that the choice of time period, country sample, estimation functions and methods may be part of the reason for such discrepancies and for the high sensitivity of these inverted-U curves.

a. The EKC shape and its sensitivity to the choice of time periods

The sensitivity of the EKC shape with respect to sample choice can first be observed concerning the time dimension, as shown in the following example. Harbaugh et al. (2000) used exactly the same estimation function form and the same database as Grossman and Krueger (1991). Yet, when they extended the database by another 10 years, they found that the estimated pollution-income relationship turned into an inverted-S shape. Thus, it appears essential to be cautious when projecting the future pollution-income trajectory from environment improvement data grounded in a given historical period: in time, some necessary and sufficient conditions resulting in the downward-bending trend may disappear.

b. The EKC shape and its sensitivity to the choice of country samples

The instability of the EKC shape is also observed when different country samples are included in the database. A telling example is Stern and Common (2001) vs. Selden and Song (1994). Using only the 22 OECD countries' data, Selden and Song (1994) found an EKC whose turning point ranged at about $8000-$10000. Stern and Common (2001) enlarged the database, including 73 countries in it and most of the new data in connection with developing countries. Their conclusion reveals that the "turning point (of the EKC) becomes quite higher when the data of developing countries are included or separately estimated". If their OECD sub-sample still yields an EKC turning point ($9181) that is similar to the one in Selden and Song (1994), the global and non-OECD countries samples actually reveal much higher turning points: $54199 (global) and $343689 (non-OECD). In Table 2.1, the two studies based on US state-level data — Carson et al. (1997) vs. List and Gallet (1999) — and the other two focusing on part of OECD and developing countries —Cole et al. (1997) vs. Kaufman et al. (1998) — also confirm this. Hence, it seems that extrapolating the developed countries' environment-income experience to predict that of developing countries is not always relevant, all the more so since the latter seem to have a harder time improving their pollution-income trajectory.

c. The EKC shape and its sensitivity to environmental measurements

Another source of sensitivity is related to the environmental indicators' measurements. The "measures of the environmental degradation fall in two general categories: emission of the pollutants and environmental concentrations of pollutants" (Kaufman et al., 1998, p210). These two measurements illustrate different aspects of the environmental degradation situation and neither of them can offer a comprehensive description. "Emission directly measures the amount of pollutants generated by economic activities during a period without regarding to the size of the area into which the pollutants are emitted". It is actually a flow measurement for the polluting capacity of economic activities. "The concentration measures the quality of pollutants per unit area without regarding to the activity that emitted them", it is more like a stock measurement describing the final result of the encounter between emission, abatement efforts and the self-purification capacities of nature. As concentration is a more direct environmental quality indicator and has more direct impact on productivity and public health, Selden and Song (1994) believe it should be easier to obtain an inverted-U curve for concentration than for emission indicators. The studies listed in Table 1 confirm this proposition, especially for the oldest studies in which the estimation methods or sample selections had not yet played a significant role in changing estimation results.

d. The EKC shape and its sensitivity to various econometrical strategies

In order to improve econometrical efficiency, more recent EKC studies have focused on estimation methods, working along four lines of research. In the first one, research is conducted to reveal the part played by country-specification in the environment-income relationship. It ranges from the very first simple cross-section OLS estimation that supposes the environment-income relationship is an internationally homogenous correlation (Panayotou, 1993 and Shafik, 1994), to the panel data estimator which includes group-specific effects into the estimation to capture the country-specific heights in EKC, and finally to the random coefficient panel data model which yields country-specific coefficients for income and income square terms (List and Gallet, 1999; Halos, 2003). It can be generally observed that improvements regarding estimation efficiency are counterbalanced by two negative effects: first, less coherence is observed between countries regarding the environment-income relationship; second, the one-form-fit-for-all EKC curve derived from international experience proves less efficient as a prediction tool. The main goal of the second category of studies is to "demystify" the EKC hypothesis (Panayotou, 1997). It essentially investigates the underlying structural factors obscured by income growth, such as structural changes, population density, technological progress, institutional development, inequality, etc. As mentioned in the conclusion of these studies, including other factors into estimations does affect the simple environment-income correlation predicted by the EKC hypothesis, therefore enhancing the instability in the form and turning point of the EKC (Cole and Elliott, 2003; Cole 2004; Roca et al. 2001; Heerink et al., 2001; Barrett and Graddy, 2000; Gale and Mendez, 1998; Kaufman et al., 1998 and Torras and Boyce, 1998, Panayotou, 1997, etc.) In the third group of studies, pollution indicator and income level are regarded as two time series originally sharing the same uniformly increasing trend: in this view, the decoupling between these two series is accounted for by the fact that technical progress in pollution abatement activities supposedly dominates the economic scale enlargement leading to a pollution increase (De Bruyn et al.,1998 and Perman and Stern, 2003). The last econometrical line of research focuses on the potential estimation bias related to the fact that the estimation function is predetermined as either a square or cubic shape. By simply comparing the estimation results obtained from different function shapes or using more rigorous statistical methods such as semi- or non-parametrical models, these studies find the decision to include or not the polynomial income term largely affects the location of the EKC turning point (Bradford et al., 2000; Milimet et al., 2003).

e. Other factors also affecting EKC shape

The sensitivity regarding the turning point of the EKC hypothesis can also be explained by the economic sources of pollution. In their study, Dinda et al. (2000) found that the turning point of the EKC in residential areas proved much higher than in areas with intense commercial activity. The reason for this discrepancy is that in residential areas, the trade-off between the consumption-related utility increase and the pollution-related disutility that comes with consumption is more difficult.

The EKC turning points may also be different when the interested pollution indicators reflect the average environment situation of a whole country and when they merely illustrate the situation in urban areas. Considering many EKC studies are based on the GEMS data collected in the cities of 30 countries all over the world, Selden and Song (1994) indicate that the turning points revealed by these studies might be lower than those revealed by the studies showing the national average environmental trends in connection with income growth because it is in urban areas that environment quality control activities are set up in the first place.

5. The shortcomings of current EKC analysis

The issues of instability and incomparability that affect the aforementioned EKC studies actually reveal several aspects of that model's shortcomings.

(1) Incoherence between the theoretical assumptions of micro-foundation and the reality

Most of the micro-foundation theoretical analyses succeed in explaining how the EKC is as an automatic trend once the per capita income level reaches a certain critical level (Lopèz, 1994; Antel and Heidebrink, 1995; Kriström and Rivera, 1995; Selden and Song, 1995; McConnell, 1997; Andreoni and Levinson, 2001; Munashinghe, 1999 and Antweiler et al., 2001). The reasoning of all these theoretical models is based on the utility maximization problems faced by a representative consumer. Their utility functions are generally made up of two components –the utility that comes from the consumption of standard good, C, and the disutility caused by pollution, P. It can be expressed as,

$$\underset{C}{Max}U=U(C,P(C))$$

$$U'_C>0,\ U''_C<0,\ U'_P<0,\ U''_P>0,\ P'_C>0, P''_C<0\ . \qquad (1)$$

The consumption of C can both cause the utility to increase and decrease since production and/or consumption of the standard good also causes pollution problems. For a representative consumer, utility maximization requires that the marginal utility of the last unit of normal goods consumption U'_C be equalized with the marginal disutility of pollution caused by the emission related to this last unit of consumption U'_P. Presented in equation (2.2), this reasoning is called the Samuelson Rule.

$$U'_C+U'_P=0 \qquad (2)$$

The basic idea of utility maximization for a representative consumer can be illustrated in Figure 1. Before consumption reaches level C* where the marginal utility of consumption equals the marginal disutility of pollution, the consumption increase brings more marginal utility than disutility. Therefore, the consumer' consumption keeps growing with income growth while facing the necessary utility decrease caused by pollution. As there is no pollution abatement activity at that point, a positive relationship can be observed between economic growth and pollution, as shown in the lower panel of Figure 1.

(Please insert Figure 1 about here)

However, this positive income-pollution relationship will only be valid when the consumption level is below C*, and correspondingly when income is lower than Y*. Beyond these points, the utility maximization objective will make the investment in pollution abatement activities necessary measures. The ensuing consumption increase will be less than the income growth, with part of the income growth allocated to pollution abatement activities, consumption and income growth can thus be decoupled from pollution increase; the inverted-U-shaped curve relating income growth to pollution can then be formed.

Different theoretical analyses use different ways to express the pollution abatement activities in their models. Selden and Song (1995) describe the pollution abatement investment as a direct income-split flow aimed at pollution abatement activities, while Lopèz (1994) represents pollution by substituting polluting factors by the conventional production factors capital/labor.[1] At the core of both analyses is the idea that pollution abatement activities are costly, thus explaining why an inverted-U relationship is automatically formed only after the per capita income reaching certain high level.

Although theoretical explanations imply the automatic decoupling between economic growth and environmental deterioration is a rational dynamic trend for economies, this claim is actually conditioned by the following underlying assumptions : the marginal pollution-related disutility increases with income growth; the availability of the abatement technology increases with economic development; and finally the existence of an efficient institutional system guarantees that the economy follows the neoclassical reasoning. Unfortunately, these three assumptions are not uniformly valid for all countries: they are actually dependent on other concrete facts that characterize a given economy.

Firstly, income growth may not necessarily trigger an observable increase in the marginal pollution-related disutility. This actually depends on whether the information about the pollution situation and its negative impact can be completely disclosed to the public. Economic growth is not the only factor for these conditions to be met. Concerning the pollutants whose existence can not be easily detected or whose negative impact has not yet been proved by scientific studies, the marginal related disutility may not necessarily increase with income growth. Hilton and Levinson (1998) found evidence that the reduction in vehicle lead emission was less linked to income growth than to scientific findings showing how atmospheric lead concentration could jeopardize children's mental development. Bimonte (2002) also confirmed how access to pollution-related information was significant for the inverted-U-shaped curve to be formed.

Secondly, the disclosure of pollution-related information is not, neither, a sufficient condition for the inverted-U EKC to be formed for two major reasons. The first reason is that the supposed automatic link between the increase in pollution disutility and pollution control policy adjustments can be undermined by either government failure or social structure characteristics.

[1] The capital and labour transferred into pollution abatement activities present the opportunity cost for the producer since, if they were not dedicated to pollution abatement activities, these factors could be used to increase production

Barrett and Graddy (2000) points out the environmental quality of one country does not only "depend on its prosperity", but also "on the capacity of the citizens to acquire environment information, to assemble and organize, and to give voice to their preference for environmental quality", and on whether "its government has incentives to satisfy these preferences by changing policy, perhaps the most powerful incentive being the desire to get elected or re-elected." In countries with relatively low civil and political freedom, people may not be able to express their dissatisfaction with the environmental quality. Also, when governments are not enticed by re-election concerns, they may not feel the urge to respond actively to public demand for a better environment. Secondly, even when governments act as efficient social planners, keeping the maximization of social welfare as their objective, the link between pollution-related disutility and environment control policy adjustments may still be distorted. As pointed by Torras and Boyce (1998), pollution's negative external effect is generally distributed equally among people; but not so for the distribution of decision-making power regarding social issues. Hence, the benefits derived from pollution-generating activities may be highlighted while the pollution disutility suffered by the people with less power may be overlooked. This may actually delay the development of pollution control activities, thus postponing the advent of the EKC's turning point. Using income inequality as an approximation for the distribution of social decision-making power, both Torras and Boyce (1998) and Bimonte (2002) found that higher income inequality and higher pollution levels go together.

Finally, even when the two previous conditions are met, other institutional shortcomings may still prevent the advent of a pollution-income decoupling trend. For instance, pollution control policies may be undermined by the incompetence of environmental protection agencies when it comes to pollution monitoring and policy enforcement. Take China: its pollution

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quantity-wise.

monitoring and control policies are only applied efficiently in the large-scale state-owned enterprises (SOE), while the remarkable growth of its market-oriented economy is largely driven by private sectors that are often characterized by small scale. Therefore the obvious progress in China's nominal pollution control stringency during the 1990's does not necessarily means the improvement of its overall pollution control capacity. When investigating the determinants of the research and development investment in pollution abatement in different countries, Magnani (2000) concludes that in order to analyze pollution indicators' trends in poorer countries, other factors should be considered on top of the absolute income level factor, notably those factors impeding technology improvements in pollution abatement activities. Bhattarai and Hammig (2001) also point the critical role of some institutions and macro policies –such as the exchange rate regime, debt and interest rate policies, black market premium etc.– in affecting the governments' investment in pollution abatement research and development.

Hence, it appears that mere income growth is neither a necessary nor a sufficient condition for a decoupling trend between environmental deterioration and economic growth to appear. For different countries with different institutional and structural characteristics, there can be stark contrasts in their income-pollution relationship.

(2) Weaknesses of the EKC hypothesis in connection with empirical analysis assumptions

Besides the naïve theoretical assumptions of current EKC analyses that take perfect economic and institutional efficiency for granted, their weaknesses also come from their empirical assumptions.

a. Economic and pollution growth can be simultaneous

The EKC hypothesis implicitly assumes that the relationship between economic growth and pollution only goes one way, ignoring the fact that there can be simultaneity and feedback effects between the two. Coondoo and Dinda (2002) tested the causality process between income and CO_2 emission and showed that it could go either and even both ways according to the country considered. Indeed, it appears that only for a very limited number of countries in South America, Oceania and Japan have the causality run from income to emission, in accordance with the EKC hypothesis, while for most of the developed countries in North America and Western Europe, causality goes from emission to economic growth. For most of the developing countries, the process actually goes both ways. This bi-directional causality is also tested by a simultaneous system function for the case of China in He (2006) and Shen (2006). Therefore, given that an "economy and its environment are jointly determined" (Perrings, 1987), it is inappropriate to estimate a single equation model that presupposes a unidirectional type of causality going from economy to environment (Stern, 1998).

b. Confusing a cross-country static relationship for the dynamic processes of a single country

The original EKC hypothesis theoretically describes an essentially dynamic path –a single country's environmental situation trends when faced with economic growth. However, given the data availability constraints regarding both the environmental and economic aspects, most of the empirical EKC analyses use cross-country databases. Hence, from a strictly econometrical point of view, what the inverted-U curve thus found represents is a merely static and synchronic description of the environmental situation in countries having different income levels. To equate this static descriptive curve with the dynamic income-pollution trajectory in a single country, one extra assumption is required : countries included in the same sample should follow the same income-pollution trajectory. Provided this assumption is valid, the low income and bad environmental situation of a developing country in the 1990's can be paralleled with the conditions faced by now-developed countries 50 or 100 years ago; conversely, the high income and good environment situation of a developed country in the 1990's can be taken as a landmark for the forthcoming income and environmental situation of a currently-developing country once its development process has been completed. However, De Bruyn et al. (1998) point that "there is nothing to expect that each country in the sample will move along such an estimated (cross-country static) EKC path". Figure 2 represents this idea.

From the reduced-form estimation function most frequently used in EKC literature and exemplified in equation (3), we know the curvature of the inverted-U *EKC* derived from international experience (now called "global EKC") is to be measured by the two coefficients for the income terms, while its turning point is equal to $-(\alpha_1/2\alpha_2)$. The height of the global EKC is determined by the linear time trends $\alpha_3 T$ (T is the time trend variable) and some further country-specific adjustment in the height of this EKC for each country is done by the country-specific constant α_0.

$$E_{it}=\alpha_0+\alpha_1 Y_{it}+\alpha_2 Y_{it}^{\ 2}+\alpha_3 T+\varepsilon_{it} \qquad (2.3)$$

Following this reasoning, an inverted-U-shaped global EKC can be delineated in each period as a snapshot showing the actual location of the income and pollution situation for all the countries in the sample during this period, once the country-specific constant has been removed. To obtain a country-specific dynamic EKC (*ind EKC*), we need to connect all the diachronic points related to the same country. In panel a, Figure 2, a common negative trend valid for all countries is assumed, so global EKCs shift downward over time. We use T1, T2, T3 and T4 in figure 2 to show the four global EKCs in time order. For country A, supposing the situation of a country can be represented by dots, its individual EKC curve can actually be drawn on top of the general EKC. It clearly appears that although both the global and individual EKCs are inverted-

U-shaped curves, the turning point of the individual EKC (I*) is actually smaller and lower than that of the global EKC (I_g).[2]

(Please insert Figure 2 about here)

De Bruyn et al. (1998) further indicated that the individual EKC may take on a totally different shape, even if the global EKC keeps the inverted-U shape, as illustrated in panel b Figure 2. In this panel, we relax the assumption of common negative linear time trends, so the 4 global EKCs are no longer shift downwards over time. Due to some external shock (such as a very cold and long winter), we suppose the global EKC for period 4 to shift above the periods 2 and 3 EKCs. In that case, although the global EKC may keep the inverted-U shape, the dynamic individual EKC will increase uniformly with income growth.

c. Local and/or global pollution-related effects : trade liberalization and its tricks

Another assumption underlying the EKC hypothesis is that the inverted-U curve relationship is only "valid for pollutants involving local short-term costs (for example, sulfur, particulates and fecal coliforms), but not for the accumulation of stocks of waste or for pollutants involving long-term and more dispersed (or transboundary) costs (such as CO_2, GHG)" (Arrow et al., 1995, pp.92). Indeed, it proves easier to limit the extent of the negative impact of local pollution to its country of origin, which shows that it is necessary to carry out pollution control measures. As for global pollution, its negative impact being dispersed evenly all over the world, the pollution country of origin had rather act as a "free-rider" since the marginal cost to reduce the pollution tends to be much higher than the marginal benefit that can be harvested from pollution reduction results.

[2] Likewise, if we suppose that the global EKC shifts upwards over time, we will find the individual EKC has a higher turning point than that predicted by the global EKCs.

With trade liberalization and the divide it instituted between production and consumption, it gets harder to tell global from local pollution affairs. Some authors suspect that unlimited transboundary exchanges of goods and services enabling rich developed countries to relocate their polluting industries' production in developing countries (Lucas et al., 1992; Arrow et al., 1995, Stern et al., 1996; Rothman, 1998 and Suri and Chapman, 1998, etc.). Thus, developed countries actually manage to maintain their original consumption utility, all the while discharging the pollution burden to less developed countries. The same happens in global pollution cases: true pollution emitters' benefit fully from the utility increase; yet they are hardly affected by the negative consequences issuing from the pollution related to that utility. Diwan and Shafik (1992) point that "the availability of technologies that delink local and global pollution eliminated many of the automatic benefits for the global environment from addressing local concerns. The north can now achieve improvements in local environmental quality while continuing to impose negative externalities internationally". Or, as Pearce and Wardford (1993) put it : "it is perfectly possible for a single nation to secure sustainable development—in the sense of not depleting its own stock of natural capital assets—at the cost of procuring unsustainable development in another country."

If, as described above, the pollution decrease in developed countries is actually counterbalanced by a pollution increase in developing countries and the inverted-U-shaped curve only represents the outcome of this process, then the EKC hypothesis can only be a transient phenomenon and can only be observed in a specific time period, for specific country samples. In time, more and more developing countries will experience income growth and improved material well-being, thus becoming themselves pollution dischargers, while fewer and fewer countries will remain pollution burden receivers. Hence, the pollution-discharging channel set up by trade liberalization will prove more and more insufficient, and the turning point of the inverted-U EKC will be located both higher and farther... until the last pollution receiver completes its own growth process. At that point, each country will have to take care of its own pollution. As consumption is positively correlated with income, in this extreme case, the final income-pollution relationship will become a uniformly increasing trend. The following Figure 3 illustrates this idea. PD stands for developed countries and PVD for developing countries.[3]

(Please insert Figure 3 about here)

d. EKC estimation and historical coincidence

On top of the EKC analyses weakness related to cross-country estimation, some authors also suspect that a country-specific dynamic inverted-U curve may simply be formed due to specific historical events that catalyze the forces demanding and/or supplying a better environmental situation. Unruh and Moomaw (1998) investigate the relationship between the income growth and CO_2 emission in France, Finland and the USA during the 1950-1990 period. They found that although these countries had various income/growth paths, the downward emission trend appeared during the 1970's for all of them, at the moment when the oil crisis caused the oil price to skyrocket. Robert and Grimes (1997) used a much larger database including both developing and developed countries, and they also found the inverted-U shape reached statistical significance briefly in the early 1970's, and that increasing trends had reappeared since 1982. Thus, if all countries are not affected by historical events to the same extent, EKC analyses focusing on different countries are bound to yield different results.

[3] Cole (2004) actually provides empirical evidence supporting this idea based on the OECD countries' experience between 1980 and 1997: 'simple' EKCs yield relatively lower turning points than the EKC estimated after the dirty import and export to and from non-OECD countries as a proportion of their total consumption have been included in the estimation function. (pp.78)

e. The part played by the dynamic attributes of the environmental resource stock in EKC instability

Grounding his reasoning in environmental resource stock trends, Tisdell (2001) shows how the EKC hypothesis may not always guarantee a sustainable development procedure. Hence, a country had better not exhaust its environment's carry capacity before reaching the point where the income/level turning point is predicted to appear. If it did, the maximum level of pollution predicted by the EKC curve would be higher than the carry capacity threshold of the ecosystem, and the environmental change may depress income sharply and stymie economic growth. As illustrated in Figure 4, in that case, the income-pollution relationship would be a *reversed-C-shaped* curve as the ecosystem's reduced carry capacity would have a negative "feedback" impact on the economy's growth capacity.

Therefore, a one-form-fit-for-all EKC hypothesis does not reflect the reality and the shape of the income-pollution relationship should also take into account the dynamic trends of an individual country's carry capacity and of its environmental quality stock. The initial environmental situation for developing countries today is on the whole worse than it was for countries that embarked on their development process 100 years ago. Hence, they need to make more pollution abatement efforts to ease environmental pressure during their economic growth process. This may be another reason why Selden and Song (1995) conclude that the EKC turning points tend to increase as more developing countries are included into the database.

(Please insert Figure 4 about here)

6. Country-specific EKC analyses: is the EKC standard pattern relevant for developing countries ?

The idea that the inverted-U-shaped EKC derived from historical and international experience is not an optimal or standardized trajectory and should not necessarily be followed by all countries actually reveals the hopes and challenges that developing countries are faced with concerning sustainable development.

Let's first focus on the challenges. With their income standards remaining relatively low nowadays, the way developing countries choose to monitor their income-pollution trajectory will critically affect the future environmental situation worldwide. The EKC hypothesis generally predicts the environmental situation improves once the per capita income reaches the range of 4000-8000 USD (1985 price, PPP). Yet, although the world mean income level in year 2001 is close to the lower bound of the turning point, only 21% of the world population in relatively rich countries has attained this income level.[4] If the EKC hypothesis is valid, it means almost four-fifths population in the world –including all the developing countries— currently stay on the increasing track of the inverted-U curve. If a general improvement trend can only appear once the economic growth process is completed for this 80% of the world population, the EKC hypothesis actually predicts a very dismal future for the global environmental situation. Moreover, as current trade liberalization trend may work as a pollution-discharging channel for richer developed countries, therefore for the developing world, it might take an even higher income level to reconcile economic growth and environmental protection. In addition, even if the turning point of the EKC could be reached, we have no concrete idea about the maximum pollution level corresponding to this turning point: it might already be too high and could totally destroy the

[4] Calculated by author according to statistic information from World Development Indicator (2003).

ecosystem's carry capacity. Finally, as most EKC estimations investigate the relationship between per capita income and per capita emission, reaching the turning point with this environmental indicator does not necessarily mean the total emission will immediately decrease quantity-wise. The SO_2 emission projection made in Stern et al. (1996), following the EKC estimate by Panayotou (1993) predicted that the world-average per capita SO_2 emission would attain its highest level around year 2025. However, at that time, according to the UN and to the World Bank, the rapid population expansion in developing countries may still overwhelm the emission reduction trend expressed in per capita terms. Stern et al. (1996) believe total emission will keep increasing until 2050. Hence, if there is a threshold for the carry capacity of the ecosystem, as described in Tisdell (2001), following the international EKC model –i.e. enduring the pollution increase and waiting for the advent of a supposed harmony between economic growth and pollution reduction— would be an unrealistic, nay, a dangerous strategy for the whole planet.

With the current technical progress in developed countries and heighteneded institutional conscientization all over the world concerning environmental control, some authors have started discussing the opportunity for developing countries to, as suggested by Munashinghe (1999), "tunnel through" or "leapfrog" past the periods of increasing environmental impact and resource use, so as to avoid paying too high an environmental price during the economic growth process. Existing EKC empirical studies following this reasoning focus on country-specific income-pollution trajectories.

The papers in this line of research can be seen to fall into three groups. In the first group, the cross-country inverted-U curve is still accepted as an artefact for the dynamic environment-income relationship of a single economy; yet, given the "heterogeneous structural, technical characters between countries" (Stern, 1996), they distrust the method that consists in merely extrapolating from international experience to predict an individual country's dynamic process. As a consequence, the original reduced-form EKC is enriched : they add extra country-specific pollution determinant factors besides the income and squared income terms into the cross-country EKC estimation function –namely industrial structure, technical progress, open relationships, income distribution, population density, political and institutional development, etc.[5] The inclusion of such country-specific determinants helps considering part of the pollution variation causality in isolation from income growth. Yet, that can only make the EKC move up- or downwards, leaving the turning point and basic shape of the EKC curve to be solely determined by income changes, so that different countries still share a common income-pollution relationship and turning points.

The second group of authors also ground their estimations in international or regional panel data, but they use the multi-function system estimation method for panel data that enables them to assign country-specific random coefficients to the income and squared income terms (List and Gallet, 1999; Koope and Tole, 1999 and Halkos, 2003). These studies generally show stark discrepancies between countries (or states) regarding their EKC shapes and turning points. However, given the complexity of the estimation method itself, these studies have not managed to explain concretely how these country-specific EKCs are further determined by country-specific structural or technical characteristics.

Bearing in mind these limits of country-specific EKC studies based on international panel data, it appears the EKC derived from international experience is only useful as a "descriptive statistic", while "a more fruitful approach to the analysis of the relationship between economic growth and environmental impact would be the examination of the historical experience of

[5] Detailed surveys on the other pollution determinants included into EKC analyses can be found in the most recent EKC surveys of Dinda (2004) and Stern (2004).

individual countries, using econometric and also qualitative historical analysis" (Stern et al., 1996). As a response to this proposition, numerous analyses discussing the EKC relevance in specific countries came up. Some papers operate the EKC regression from the country's time series data. However, most of the available environmental data only trace back to the 1960's; hence, the income variation range is relatively limited as it only spans the last 30 years, so that capturing both the increasing and decreasing stages of pollution trends proves quite difficult. Only three studies confirm the EKC hypothesis over relatively long historical data series for a single country –namely Roca et al (2001) on Spain (1973-1996), Friedl and Getzner (2003) on Austria (1960-1999) and Lindmark (2002) on Sweden (1870-1997). Besides confirming the sharp contrasts regarding country-specific EKC shapes and turning points, these papers also reveal that the advent of a decoupling trend between pollution and income is actually determined by country-specific characteristics that happened during the investigated time periods: technical and structural progress or external shocks such as the oil crisis.

At a country-level, several studies also focus on some developing countries' experience. In order to overcome the time-limited data availability constraint, they make use of the regional disparity in the same country concerning economic growth and environmental quality: that way, they can carry out regional-level panel data estimations. As opposed to the studies based on cross-country experience, these studies directly focus on developing countries. Their assumption about a common trajectory for the income-pollution relationship between regions on the same country is more acceptable as the regional characteristics are similar, be they institutional, technical or structural. Focusing on all the regions belonging to the same country, these studies also avoid the critics like omission of some countries or incomparability of data on a cross-country level.[6] The very country-specific income-pollution relationships revealed in these studies do not have much in common with most of the inverted-U curves derived from cross-country experience. Vincent (1997) uses the state-level panel data in Malaysia from the late 1970's until the early 1990's while de Groot et al. (2004) analyze China's province-level data regarding air, wastewater and solid waste from 1982-1997. Both studies find that different pollution indicators follow totally different trajectories during the economic growth process. The former concludes that the concentration indicators of some pollutants predicted to decline according to international experience have actually increased (namely TSP and ammoniacal nitrogen) while others that were predicted to increase have actually decreased (BOD). For China over the last two decades, De Groot et al. (2004) obtain an ever-decreasing trend concerning industrial wastewater and increasing trends concerning both industrial waste gas and solid waste.

7. Making the EKC hypothesis an environmental policy instrument

Despite the fact that over 100 studies on the Environmental Kuznets Curve hypothesis have been published over the last 25 years, information is still missing to gain full understanding regarding the actual relationship between economic growth and environmental situation. Although the inverted-U-shaped curve seemed to reflect cross-country experience accurately, more and more scholars believe each country has its own environmental and economic trajectory whose shape depends on its natural, economic and even social characteristics.

Over the last decade, research has brought new developments to account for the advent of the EKC in connection with the structural determinants of environmental indicators. Most of them fall into the three categories of structural pollution determinants proposed by Grossman (1995): the scale effect ("all else equal, an increase in output means an equiproportionate increase

[6] As indicated in Stern (2004) the choice of the exchange rate to deflate the per capita income in different countries

in pollution", the composition effect (all else equal, if the sectors with high emission intensities grow faster than sectors with low emission intensities, then composition changes will result in an upward pressure upon emission); finally, the technical effects (they describe the decrease of sector emission intensities as resulting from the use of more efficient production and abatement technologies) can reduce emission's increasing pressure, all the while yielding the same quantity of economic growth and fixed industrial composition mix. Since emission appears as the end-result combining these three aspects, pollution variations generally can be decomposed into the factors of scale enlargement, composition changes and technical progress. Panayotou (1997) pioneered this line of research. The original theoretical model and econometrical analysis proposed by Antweiler et al. (2001) is also based on these three structural determinants, although their approach focuses more on how international trade impacts the environment through the composition effect. Stern (2002) further examined this issue so as to track the source of technical progress in pollution reduction through new decomposition and frontier models. His analyses illustrate the importance of technical progress in both input and output as they cancel out the gross scale effect and, in turn, change the emission trend and finally cause emission to be reduced when economic growth starts to slow down. With the Solow growth model as their basis, Brock and Taylor (2005) also emphasize how scale enlargement and abatement technical progress are two major but conflicting forces in determining the process of pollution convergence towards it steady status.

8. Conclusion

can largely influence the estimated turning point.

The developments of EKC literature reveal both the challenges and opportunities faced by each developing country for the choice of its sustainable development path. It has gradually been acknowledged that there was no one-fit-for-all growth-pollution relationship. Hence, developing countries can, nay must choose for themselves a unique and specific trajectory for their economic growth and environmental path. On the one hand, this entails developing countries should not wait until they reach the high turning points suggested by global EKC studies to reconcile economic growth and environmental improvement. On the other hand, each country has to be responsible in determining its own economic development pattern.

Albeit via indirect decomposition methods, the latest studies reveal the various structural determinants that can affect the EKC shape for an individual country. Given the general technical and/or data availability difficulties, current EKC studies are still unable to link directly the EKC shape with the country specific scale, structural and technical characteristics. As a consequence, they cannot yet really help each developing country choose its sustainable development strategy.

Such a decision becomes even more difficult given the dynamic characteristic of the environmental situation which is actually the final net effect, which is accumulated over all the previous periods, of various determinants factors such as economic growth, structural transformation and technical growth. Therefore, merely correlating current economic growth with current pollution emission/concentration, we can only reveal a small part of the story. To uncover the dynamics behind the simple static inverted-U relationship predicted by the EKC hypothesis, more studies should foucs on the “double-convergence” hypothesis, trying to devise how an economic stationary status could go with a stabilized environmental quality.

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Table 1 EKC empirical analyses based on SO_2 pollution case

Authors	EKC form	Turning point[1]	Countries, periods[2]	Emis/ Conc	Func. form	Other variables	Estimation methods	Interesting findings	Data source
Grossman and Krueger (1991)	N curve	Peak: $5000 Trough: $14000 (1985 USD)	27-52 cities in 14-32 countries, 1977, 1982, 1988	Conc.	Level, Cubic	Site dummy, population density, time trend, trade intensity, communist country dummy	Panel data (Random effect)	First paper discussing the pollution-income relationship	GEMS
Panayotou (1993)	Inverted U	$3137 (1990 USD, nominal exchange rate)	30 countries, 1982-1994	Emis.	Log., square	Population density	OLS	First paper coined the pollution-income relationship by Environmental Kuznets Curve	GEMS
Shafik (1994)	Concentration: Inverted U Emission: increasing relationship	Concentration: $8000 (1990 USD PPP)	149 counties, 1961-1986	Emis. and Conc.	Log., cubic	Time trend, site dummy	OLS	Concentration indicators are more easily to show inverted U curve with income growth.	World Bank
Grossman and Krueger (1994)	Inverted U curve	Peak: $4053, trough: $14000	Numerous cities in 30 countries in 1977, 1982, 1988	Conc.	Level, cubic	Population density, site dummy, time trend	Panel data estimator random effect		GEMS
Selden and Song (1994)	Inverted U curve	OLS: no results FE:$8916-8709 RE: $10500 (1985 USD)	30 countries (22 high-income , 6 middle-income and 2 low-income countries), 1973-1975, 1979-1981, 1982-1984	Emis.	Level, square	Population density and period fixed effect	Panel data estimators (pooling, fixed and random effect)	Although find EKC, the authors believe the total emission will not decrease in very long term, as most of the population are living in the relatively poor countries	GEMS, WRI
Shukla and Parikh (1996)	Monotonically negative relationship	--	City-level cross-country data,	Conc.	Level, square	City population, squared city population		The inverted U relationship is found between city population and pollution	WRI
Cole et al. (1997)	Inverted U curve,	Log: $6900 Level: $5700	11 OECD countries, 1970-1992	Emis.	level & Log., square	Trade intensity, time trend	GLS, random effect	Including other factors has little impact on EKC form	OECD
Panayotou (1997)	Inverted U before and U curve after structural determinants included	Inverted U: $5000 U curve: though: $27528	30 developing and developed countries, 1982-1994	Conc.	Level, cubic	Growth rate, population density, quality of institution, scale effect, composition effect, time trend,	Unbalanced panel of cross-section panel data (Fixed and random effect)	Inclusion of the structural determinants can change the form of EKC. Paper offers more policy implication to EKC hypothesis	GEMS
Carson et al. (1997)	Monotonically decreasing relationship	--	US, 1990	Emis.	Linear form	Population density, percentage of urban population	OLS for cross-country data	It is more interesting to see percentage change instead of absolute change of emission in EKC studies as different initial pollution situation induce difficulties of different level in pollution reduction	US

Table 1 EKC empirical analyses based on SO_2 pollution case (continue)

Authors	EKC form	Turning point[1]	Countries, periods[2]	Emis/Conc	Func. form	Other variables	Estimation methods	Interesting findings	Data source
De Bruyn et al. (1998)	EKC is not generally fit for all the countries	--	4 countries, Netherlands, UK, USA and Western Germany, between 1960-1993	Emis.	Growth rate	Composition changes, energy price, economic growth path,	OLS, each country separately estimated	EKC does not generally fit for all countries, each country has its own technological, structural, energy price and economic growth path, so specific emission situation	Netherland, UK, USA, Western Germany
Gale and Mendez (1998)	Monotonically decreasing	--	Re-estimate the GK (1994), same database but restricted in 1979, 34 cities in 25 countries	Conc.	Level, cubic	City economic scale, the relative importance of city population, relative factor abundances (capital, labour and land), trade policy, time trend	OLS	Pollution-income relationship becomes monotonically decreasing after the other structural factors included into estimation	GEMS
Kaufman et al. (1998)	U-curve	OLS: $11577 FE: $12500 RE:$12175	23 countries (13 developed, 10 developing countries) 1974-1989, ***	Conc.	Level, square	Economic activity density, iron steel export ratio and time effect	Cross-country OLS, panel data estimator (fixed and random effect)	Paper Indicates the asymmetric characters of the relationship between income and pollution before and after the turning points. As the other factors as fuel mix might not following same evolution trend in the developing countries as in developed ones.	UN
Torras and Boyce (1998)	N curve	Peak: $3306 with and $3890 without inequality, Trough: $14034 with and $15425 without inequality	18-52 cities in 19-42 countries, 1977-1991 (Almost same database as GK, 1994)	Conc.	Level, cubic	GINI, literacy, political right and civil liberty, Urbanization, location specific dummy (residence, commercial, industrial regions), population density	OLS	The inclusion of income inequality into the estimation function generally reduces the turning point of EKC	GEMS
List and Gallet (1999)	Inverted U or N	General system inverted U: $16828, cubic: 15502 Individual EKC for different states: $1162-$22462	US data, 1929-1994, 48 states	Emis.	Level, square/cubic	No other determinants considered since the environment-income coefficient is state-specific	Random coefficient panel data model	Inverted U or N according to the estimation function form, each state has its own EKC form and turning points	US
Perman and Stern (1999)	Each country has its EKC curve, monotonically increasing or U curve are very often	--	74 countries (25 developed and 49 developing countries), 1960-1990	Emis.	Level, square		Take care of the time series characters of the data, cointegration	Study is based on a dynamic model in which the EKC form is included as a long run stable relationship into the cointegration vector of each country	A.S.L. and Association

Table 1 EKC empirical analyses based on SO_2 pollution case (continue)

Authors	EKC form	Turning point[1]	Countries, periods[2]	Emis/Conc	Func. form	Other variables	Estimation methods	Interesting findings	Data source
Barrett and Graddy (2000)	N curve	Peak: $4200 Trough: $12500	Same database as GK (1994): 27-52 cities in 14-32 countries, 1977, 1982, 1988	Conc.	Level, cubic. lagged income included	Civil liberty dummy, site dummy, time effect, population density, site dummy and time trend	Random effect, GLS, panel data	The inclusion of civil freedom dummy only influences the height of the EKC Almost same results as GK (1994) (1985USD PPP)	GEMS
Bradford et al. (2000)	Inverted U or N curve	Inverted-U: $3055 N: Peak: $1891, Trough: $1531250	Same database of GK (1994), Numerous cities in 26 countries, 1977,1982 and 1988,	Conc.	New model	Time effect and technology	Panel data estimator (fixed and random effect)	Inverted U or N curve depending on the polynomial order of per capita income included	GEMS
Dinda et al. (2000)	U curve	Trough: $12500 (1985 USD)	39 cities in 33 countries, 3 period, 1979-1982, 1983-1986 and 1987-1990, 6 low-income, 11 middle-income and 16 high-income countries	Conc.	Level and Log., square	Sectoral composition (capital abundance, K/L), growth rate and time effect, distinguishing site characters (commercial, residential, etc.)	OLS according to different area and least absolute error method	Study includes the scale, composition and technique effects defined by Grossman (1995) into estimation of EKC curve	World Development Report, world Bank, 1992
Harbaugh et al. (2000)	Inversed S curve	Peak: $13741-$20081 Bottom: $7145-$9142	GK (1994) database+10 years' more data (1971-1976 before and 1989-1992 after)+25 new cities	Conc.	Level, cubic	Site dummy and time trend	Panel data estimator (Fixed and Random effect)	The changes in data sample, both in time and country dimension, can have important influence on the EKC estimation results.	GEMS
Gangadharan and Valenzuela (2001)	Insignificant inverse S curve or N curve	Trough: $939 Peak: $12038	51 countries (29 developing and 22 OECD countries) China included	Emis.	Level, cubic	Population density, literacy rate and income inequality	Reduced form from a two equation system, TSLS	Paper discusses the potential feedback effect of pollution on people's health situation	WDI
Heerink et al. (2001)	Inverted U curve	$1929 without and $2233 with GINI	Shafik (1994) database, only 33 countries are included due to inequality data	Urban Conc.	Log., square	Income inequality (GINI), believe reduction in inequality increase the turning point of EKC	Cross-country data. OLS	Increase in income inequality might improve environmental quality	
Stern and Common (2001)	Global sample: monotonically increasing. High-income subsample: inverted U curve	Whole sample: $29360 OECD only: $48920 Non-OECE only: $303133	73 countries for 31 years, (1960-1991) (24 developed and 49 developing countries),	Emis.	Log., square	Time fixed effect	Panel data estimator (Fixed and random effect)	Paper mentioned the potential sensitivity of the EKC form with respect to country sample in the database. The relatively low turning points found by many EKC studies might be due to the fact that only the rich OECD countries were included in the estimation data sample. Turning point becomes very much larger when developing countries are included	A.S.L. and Association

Table 1 EKC empirical analyses based on SO_2 pollution case (continue)

Authors	EKC form	Turning point[1]	Countries, periods[2]	Emis/Conc	Func. form	Other variables	Estimation methods	Interesting findings	Data source
Roca et al. (2001)	Monotonically decreasing	--	1973-1996, Spain	Emis.	Log.	Share of nuclear power and coal in total primary energy	Time series method, co-integration	The EKC hypothesis is generally weaken when additional variables are added besides income.	Spain
Egli (2002)	No inverted-U curve found	--	West Germany, 1966-1998	Emis.	Level, square	Trade, structure and growth rate	Error correction model, GLS	Believe the EKC to be a long-run relationship.	Federal Republic Germany
Cole and Elliott (2003)	Inverted U or N curve	Global data: FE: $5367-$7483 RE: $8406-11168 Only OECD: $5431-$10521	26 countries, 5 year period average data from 1975-1990	Emis.	Level, cubic	Trade impact, relative capital abundance (K/L), multiplicative terms between trade and other determinants of emission, GINI, literacy rate	Panel data estimator (Fixed and random effect),	Trade's impact on EKC differs from country, since each country have different comparative advantage and environmental regulation situation. Sample difference does not influence the estimation results. Author believes EKC is a robust relationship; trade only plays marginal impact on it.	
Halos (2003)	EKC is not rejected by A-B GMM, but rejected in the random coefficient model	Random coefficient model: Total: $2850-6230, OECD: $9239-9181, Non OECD: $908178-343689 A-B GMM: Global: $4381 OECD: $5648 Non-OECD: $3439	73 OECD and non-OECD countries for 31 years (1960-1990), same database as Stern and Common (2001)	Emis.	Log., square	Electricity tariff, debt per capita, trade, political right and other listed in Agras and Chapman (1999)	Random coefficient panel data model, Arellano and Bond GMM estimator	Results are totally different from Stern and Common (2001) by using different methods. Choice of econometrical method is crucial in the extraction of turning point and associated policy implications. The coefficients are significantly different between rich and poor countries samples	A.S.L. and Association
Milimet et al. (2003)	Inverted-U curve	$8000	48 US state, 1929-1994	Emis.	Undefined func. form	none	Semi-parametrical PLR model	The location of the peak of EKC is quite sensitive to modelling assumptions	US
Cole (2004)	Inverted U	$3742 without and $5426 with dirty import and export factors included in estimation,	1980-1997, 18 OECD countries	Emis.	Log, cubic	Net export as a proportion of consumption, country and time specific effect, share of manufacturing sector in GDP, share of dirty export of non-OECD countries in total export and share of dirty import from non-OECD countries, trade intensity	Fixed effect, panel data	Author cannot exclude the possibility that the displacement and migration of dirty industries do not contribute to the formation of inverted U curve	OECD

Note: 1. All the turning points are transformed to the 1985 USD calculated from the parity of purchasing power. (The transformation information between dollars of different year is from WDI, 2002)
2. Most of the databases used in EKC literatures include China in their sample.

Figure 1. Micro theoretical foundation for EKC formation

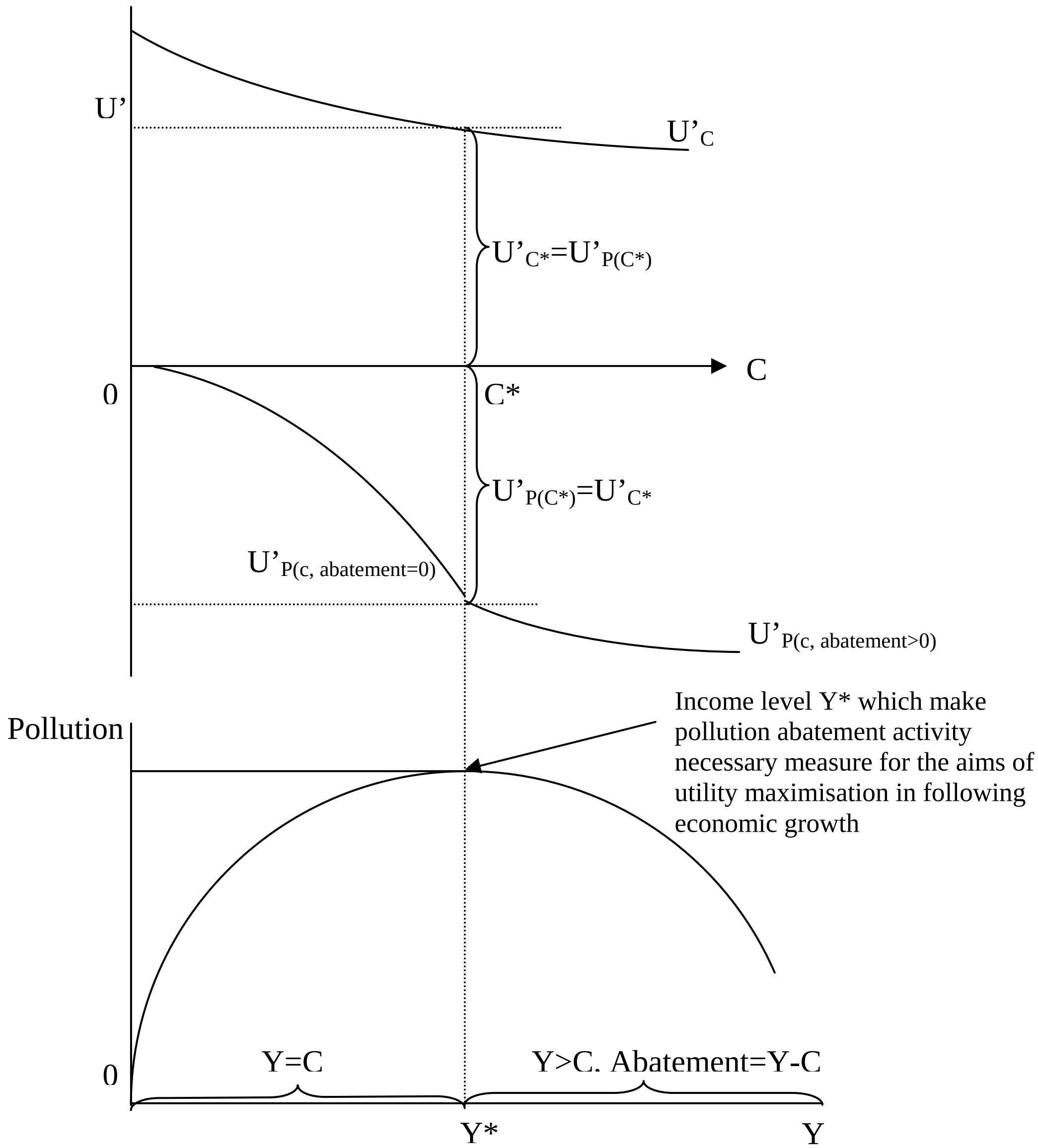
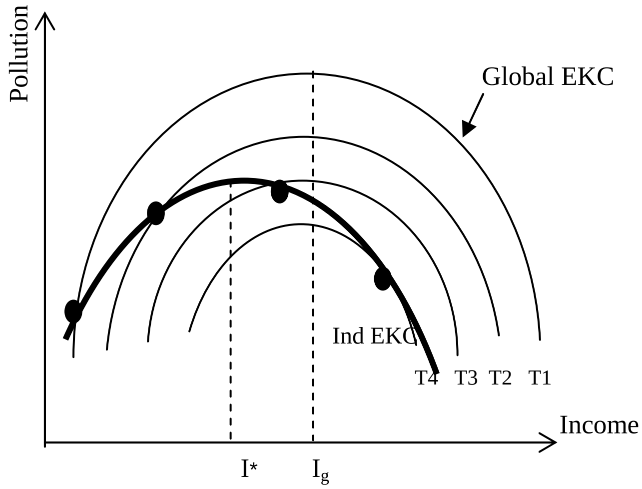
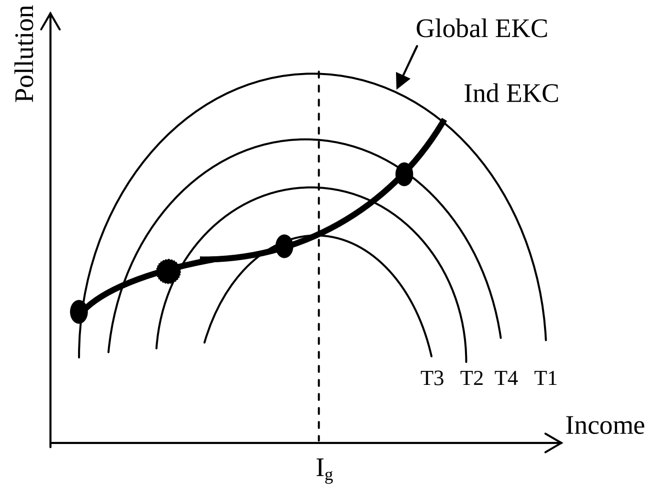


Figure 2 Global EKC vs. Individual countries' EKC



Panel a. Negative linear time trends



Panel b. Without a negative linear time trend

Figure 3 Evolution of income-pollution relationship under the existence of the pollution-discharging channel from developed to developing country through international trade

Note: numbers behind PVD and PD indicates numbers of developing and developed countries in different moment.

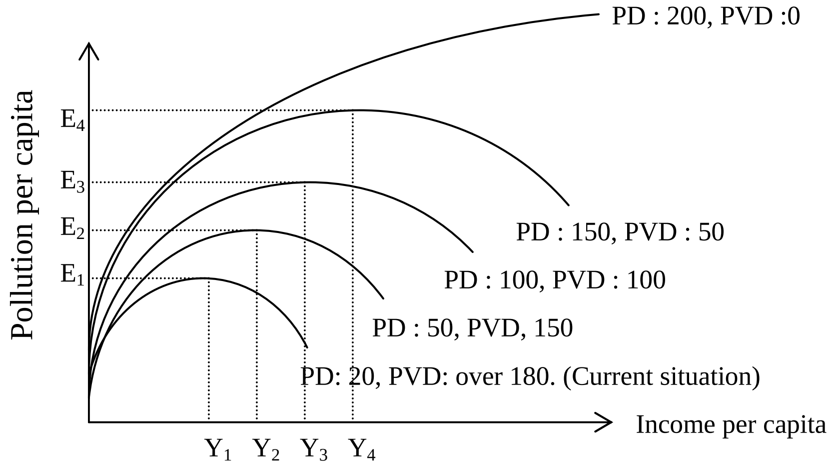
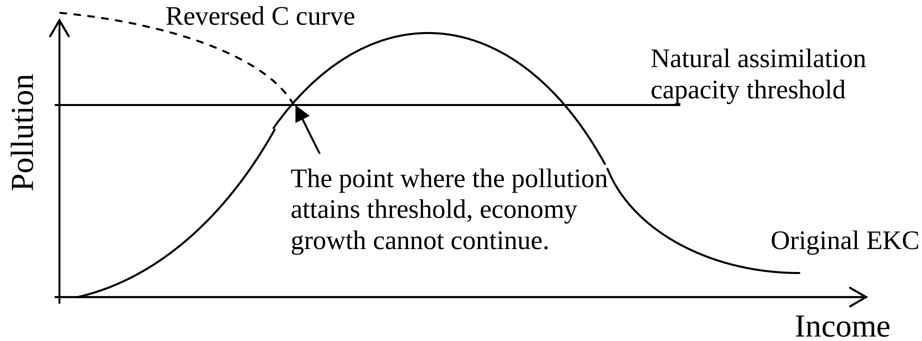


Figure 4 The inversed C curve

(Original figure is from Tisdell (2001))



[1] More details are discussed in Panayotou (1997), Stern (2004) and Dinda (2004).