Master Thesis

# An Empirical Analysis of the Environmental Kuznets Curve Hypothesis Over Two Centuries: Evidence from the UK and US

**Dimitrios Paraskevopoulos**

*Supervisor : Theodore Panagiotidis*

*Assessors: Stylianos Fountas & Panagiotis Konstantinou*

**Department of Economics**

University of Macedonia
Thessaloniki

October 2009

## ACKNOWLEDGEMENTS

I would like to thank my supervisor, Theodore Panagiotidis, for his useful comments and advice. I also thank the two assessors, Stylianos Fountas and Panagiotis Konstantinou, for their valuable help.

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## CHAPTER 1: *INTRODUCTION*

The object of this Master thesis is to investigate empirically the validity of the Environmental Kuznets Curve hypothesis for two industrialized countries, USA and United Kingdom with a time span of more than two centuries.

According to the EKC hypothesis as the economy of one's country develops the degradation of the environment increases, but when the economy reaches a specific level of income per capita, known as turning point, pollution starts to decline. The EKC hypothesis implies that despite the fact that at first stages of development, pollution is unavoidable, in the end the economic growth will be one of the solutions to the pollution problem.

The concept that economic development will eventually lead to the improvement of the quality of the environment is very appealing. Growth, which has been accused as the main cause of the environmental degradation and now is seen as a "savior" of the environment has spurred the interest of policy designers. Instead of hampering the growth of the economy, measures that make economy to grow even faster is what needs.

The investigation of the validity of the EKC hypothesis is of great interest and importance due to increasing environmental problems of today. If nations continue to ignore these problems then it will be catastrophic for all humanity. It is crucial policy measures for the protection of environment to be taken before it is too late. However, environmental policy must be based on a theory which has been validated by empirical results.

The structure of the thesis is the following: Chapter 2 refers to the theory that underlines the EKC hypothesis and review previous empirical studies, Chapter 3 concerns the modeling of the EKC and methodological issues, in Chapter 4 statistical data is presented, in Chapter 5 empirical results are reported, Chapter 6 deals with policy implications and potential dangers that could arise from the acceptance of the EKC hypothesis in the case it is false and Chapter 7 concludes.

## **CHAPTER 2:** *THEORY AND LITERATURE REVIEW*

### 2.1) *Environmental Kuznets Curve*

The Environmental Kuznets Curve (EKC) is an empirical, relationship that is assumed to trace the pollution path followed by economies as their per capita gross domestic product (GDP) grows (Unruh and Moomaw, 1998) and describes the relationship between *per capita* income and indicators of environmental degradation. At early stages of development, the levels of certain pollutants rise with increases in *per capita* income, while at higher levels of development, environmental degradation is seen to decrease with further increases in *per capita* income. These results give rise to an inverted U-shaped curve relating economic growth to environmental degradation, reminiscent of the relationship hypothesized by Kuznets (1955) between economic growth and income inequality (Nahman and Antrobus, 2005). The EKC concept emerged in the early 1990s with Grossman and Krueger's (1991) path - breaking study of the potential impacts of NAFTA and the concept's popularization through the 1992 World Bank Development Report (Stern, 2004).

### 2.2) *Origins of the EKC*

The inverted-U relationship between pollution and growth derives its name from the work of Kuznets (1955) who postulated a similar relationship between income inequality and economic development (Dinda, 2004).

Kuznets (1955) predicted that the changing relationship between per capita income and income inequality is an inverted-U-shaped curve. As per capita income increases, income inequality also increases at first and then starts declining after a turning point
(TP). In other words, the distribution of income becomes more unequal in early stage of income growth and then the distribution moves towards greater equality as economic growth continues (Kuznets, 1955). This relationship between income per capita and income inequality can be represented by a bell-shaped curve. This observed empirical phenomenon is popularly known as the Kuznets Curve (Dinda, 2004). The theoretical relationship between per capita income and income inequality is shown on Figure 2.1 (next page).

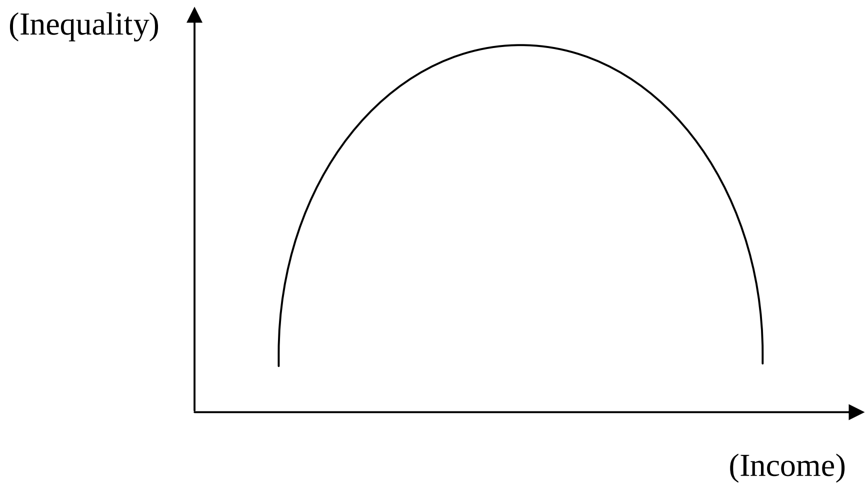

Figure 2.1. Kuznets Curve

Kuznets developed his theory by investigating the character and causes of long-term changes in the personal distribution of income. The main questions that he wanted to answer were: “*Does inequality in the distribution of income increase or decrease in the course of a country’s economic growth?. What factors determine the secular level and trends of income inequalities?.*” (Kuznets, 1955).

In order to support his theory Kuznets used data for three industrialized countries: United States, England and Germany. According to these data in the United States, in the distribution of income among families (excluding single individuals), the shares of the two lowest quintiles rise from 13.5 per cent in 1929 to 18 per cent in the years after the Second World War (average of 1944, 1946, 1947 and 1950); whereas the share of the top quintile declines from 55 to 44 per cent, and that of the top 5 per cent from 31 to 20 per cent. In the United kingdom, the share of the top 5 per cent of units declines from 46 per cent in 1880 to 43 per cent in 1910 or 1913, to 33 per cent in 1929, to 31 per cent in 1938, and to 24 per cent in 1947; the share of the lower 85 per cent remains fairly constant between 1880 and 1913, between 41 and 43 per cent, but then rises to 46 per cent in 1929 and 55 per cent in 1947. In Prussia income inequality increases slightly between 1875 and 1913 – the shares of the top quintile rising from 48 to 50 per cent, of the top 5 per cent from 26 to 30 per cent; the share of the lower 60 per cent, however, remains about the same. In Saxony, the change between 1880 and 1913 is minor: the share of the two lowest quintiles declines from 15 to 14.5 per cent; that of the third quintile rises from 12 to 13 per cent, of the fourth quintile from 16.5 to about 18 per cent; that of the top quintile declines from 56.5 to 54.5 per cent, and of the top 5 per cent from 34 to 33 per cent. In Germany as a whole, relative income inequality drops fairly sharply from 1913 to the 1920's, apparently due to decimation of large fortunes and property incomes during the war and inflation; but then begins to return to prewar levels during the depression of the 1930's (Kuznets, 1995).

The above statistics can be summarized in the below tables:

Table 2.1

| UK<br>Year | 1880 | 1910 or 1913 | 1929 | 1938 | 1947 |
|---|---|---|---|---|---|
| Share of the top 5 % | 46% | 43% | 33% | 31% | 24% |

Table 2.2

| US<br>Year | Share of the two lowest quintile | Share of the top quintile | Share of the top 5% quintile |
|---|---|---|---|
| 1929 | 13.5% | 55% | 31% |
| After WWII | 18% | 44% | 20% |

Table 2.3

| Prussia<br>Time period: 1875 to 1913 |
|---|
| Share of the top quintile rose from 48% to 50%<br>Share of the top 5% rose from 26% to 30%<br>Share of the lower 60% remained the same |
| Saxony<br>Time period: 1880 to 1913 |
| Share of the two lowest quintiles declined from 15% to 14.5%<br>Share of the third quintile rose from 12% to 13%<br>Share of the fourth quintile rose from 16.5% to 18%<br>Share of the top quintile declined from 56.5% to 54.5%<br>Share of the top 5% declined from 34% to 33% |

Kuznets's general conclusion was: "…*the relative distribution of income, as measured by annual income incidence in rather broad classes, has been moving toward equality – with these trends particularity noticeable since the 1920's but beginning perhaps in the period before the first world war*. " (Kuznets, 1955).

2.3) *Criticism and drawbacks of the Kuznets Curve*

Of course it must be mentioned that Kuznets himself wasn't satisfied with his theory. He knew from the beginning that it had many drawbacks. The time series data for example that he used , as he admitted himself, were not the appropriate one.

In the last section of his article Kuznets warned that the hypothesis about the relationship between income inequality and economic development shouldn't be taken for granted and that further investigation needed to be done. He wrote: " *In concluding this paper, I am acutely conscious of the meagreness of reliable information presented. The paper is perhaps 5 per cent empirical information and 95 per cent speculation, some of it possibly tainted by wishful thinking. The excuse for building an elaborate structure on such a shaky foundation is a deep interest in the subject and a wish to share it with members of the Association. The formal and no less genuine excuse is that the subject is central to much of economic analysis and thinking; that our knowledge of it is inadequate; that a more cogent view of the whole field may help channel our interests and work in intellectually profitable directions; that speculation is an effective way of presenting a broad view of the field; and that so long as it is recognized as a collection of hunches calling for further investigation rather than a set of fully tested conclusions, little harm and much good may result*."(Kuznets, 1995).

The brief presentation of Kuznet's theory was necessary in order to show how the Environmental Kuznets Curve hypothesis emerged but we won't try to analyze the causes of this theory because the Kuznets Curve Hypothesis is not the subject of this thesis. We now can proceed to the analysis of the central issue of our study which is the Environmental Kuznets Curve.

## 2.4) *Reasons which led to the development of the Environmental Kuznets Curve*

The increasing threat of global warming and climate change has been of major ongoing concern in the last decades. The impact of global warming on the world economy has been assessed intensively by the researchers since the 1990s. Organizations such as the United Nations have been attempting to reduce the adverse impacts of global warming through intergovernmental and binding agreements. The Kyoto protocol is such an agreement that was signed in 1997 after hefty discussions. It is a protocol to the United Nations Framework Convention on Climate Change (*UFCCC*) with the objective of reducing greenhouse gases (*GHG*) that cause climate change. The Kyoto protocol identifies constraints to environmental pollutants and requires a timetable for realizations of the emission reductions for the developed countries. It demands reduction of the GHG emissions to 5.2 % lower than the 1990 level during 2008-2012 periods. It came into force in 2005: as of April 2008, 178 states have signed and ratified the protocol (Halicoglu, 2008). Greenhouse gas emissions (*GHG*), especially carbon dioxide ($CO_2$) emissions, are considered to be the main causes of global warming. In order to prevent global warming several countries have signed the Kyoto Protocol and promised to decrease their emission levels. This in turn calls for a clear identification of the sources of $CO_2$ emissions (Hamilton and Turton, 2002).

Galeotti and Lanza (1999) point out that the refusal of some developing countries to sign the Kyoto Protocol is based on the argument that the industrialization and development process should be subject to no constraints, particularly for energy production and consumption. One possible rationale for this position is the presumption that, while pollution increases with GDP growth, there comes a point after which pollution goes down. This tenet calls for a careful analysis of the relationship between economic growth and pollution. This link is obviously very complex. It depends on many different factors such as : 1) the size of the economy, 2) the sectoral structure, including the composition of the energy demand, 3) the vintage of the technology, 4) the demand for environmental quality, 5) the level (and quality) of environmental protection expenditures. All these aspects are clearly interrelated. For example, countries with the same composition of output may have a different level of emissions if their capital stocks are different in terms of technological vintage.

Shafik (1994) reports that the relationship between economic growth and environmental quality has been a source of great controversy for a very long time. At one extreme has been the view that greater economic activity inevitably leads to environmental degradation and ultimately to possible economic and ecological collapse. At the other extreme is the view that those environmental problems worth solving will be addressed more or less automatically as a consequence of economic growth. The longevity and passion of this debate has, in part, been a reflection of the lack of substantial empirical evidence on how environmental quality changes at different income levels.

The relationship between economic growth and environmental quality has been an object of a long debate for many years. Before 1970, there was a belief that the consumption of raw materials, energy and natural resources grow almost at the same rate (viz., steady state) as economy grows. In the early 1970s, the Club of Rome's Limits to Growth view (Meadows et al., 1972) was forwarded about the concern for availability of natural resource of the Earth. Environmental economists of the Club of Rome argued that the finiteness of environmental resources would prevent economic growth and urged for a steady-state economy with zero growth to avoid dramatic ecological scenarios in the future. This view has been criticized on both theoretical and empirical grounds. Empirical works show that the ratio of consumption of some metals to income was declining in developed economies during the 1970s, which conflicts with the predictions set out in the Limits to Growth view (Maleness, 1978). This view induced to examine the relationship between the intensity of metal use and income, and an inverted-U curve was found. This inverted-U curve, known as intensity-of-use hypothesis (Duty, 1985) reveals that intensity of materials use decreases beyond a threshold level of income (Canas et al., 2003, de Bryn and Heinz, 1998). From the beginning of the 1990s, empirical data on various pollutants became available through the Global Environmental Monitoring System (*GEMS*), the environmental data compendium of the DECO, the $CO_2$ emission estimates from the Oak Ridge National Laboratory (*LORN*), etc. These data availability induced several authors to test the validity of the inverted-U curve hypothesis for income and environmental quality indicators (Dinda, 2004).

Grossman and Krueger (1991) who made the first empirical study about the relationship between environmental degradation and development were motivated by the environmental impacts of the NAFTA (*North American Free Trade Agreement*).

Apart from reasons mentioned above there are many other views which support the need to investigate the relationship between environment and economy.

Natural environment not only provide resources necessary for economic development but also it performs the essential function of supporting life. If humanity continue to exploit environment recklessly then it won't be able to support life anymore.

### 2.5) *Environmental Kuznets Curve definition and graphical representation*

The EKC takes after the name of Nobel Laureate Simon Kuznets who had famously hypothesized an inverted 'U' income-inequality relationship (Kuznets, 1955). In the 1990s economists detected this relationship between economic growth and environmental degradation. Since then this relationship is known as Environmental Kuznets Curve.

According to the EKC hypothesis as a country develops, the pollution increases, but after reaching a specific level of economic progress ($Y^*$) pollution begin to decrease (Figure 2 next page). The EKC hypothesis suggests that environmental degradation is something unavoidable at the beginning stage of economic growth, so a developing country is forced to tolerate this degradation in order to develop.

The *x*-axis represents the economic growth which is measured by GDP per capita and the *y*-axis represents the environmental degradation which is measured by many different pollution indicators such as carbon dioxide, sulfur dioxide, nitrogen oxide, deforestation etc.

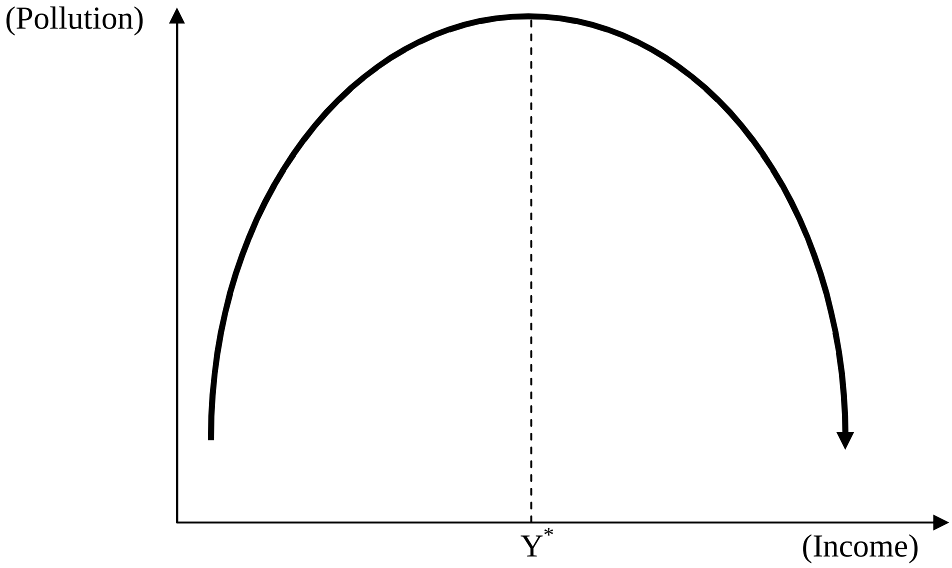


Figure 2.2: The Environmental Kuznets Curve (EKC)

It is important to note that the theoretical EKC graph does not explicitly express time as a dimension and for this reason the use of the EKC hypothesis to justify policy decision – an action that by definition incorporates time – would appear inadequate. Only by comparing two different countries can the inverted “U” shaped curve be derived as seen above. However each country possesses its own unique EKC and therefore each country’s policies should be organized accordingly. In order for the graph to show an EKC, and thereby be valid as policy justification, we must incorporate a time dimension. We find a time dimension along the x-axis. The EKC hypothesis assumes that changes in income per capita only occur over time. By including this supposition of changes in income inherently signifying time, the graph can now show an EKC for a specific country. The identification of a country’s particular EKC provides a basis for using it to influence policy[1].

Another notion about the EKC is that its shape shouldn’t be considered so perfectly smooth as shown on the Fig. 2.2 above. The diagrams sometimes give wrong impression. The aim of a diagram is to present the general idea of a hypothesis or theory and not to show how exactly things in reality are. To understand this better lets have a look on the Figure 2.3 (next page).

[1] http://christopher.darrouzet-nardi.net/experiences/ee.envirokuznetscurve.doc

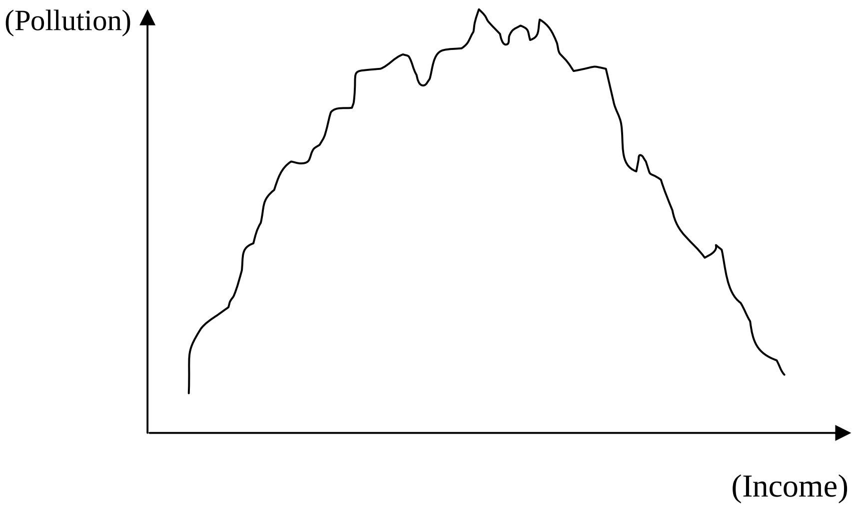


Figure 2.3: The Environmental Kuznets Curve, a more realistic approach

As we can see from the Figure 3 the relation between two variables have the shape that the EKC hypothesis implies but this shape of the inverted - U is not smooth rather than jagged.

2.6) *Explanation of the inverted U shape of the EKC hypothesis*

There are two main causes which are responsible for the shape of the EKC. The first cause is related with the history of developed countries and the economic paths that these countries followed in order to achieve development. The second cause is related with the changing preference for environmental quality as income per capita rise.

Looking back in the past we can see that the economies of all developed countries were based upon agriculture. An agriculture economy hadn't been causing great damage to the environment. After the industrial revolution the economies of developed countries shifted to a state that was environmentally damaging. In the last decades however the majority of developed countries shifted once again from traditional sectors (manufactory, construction, etc) to service and/or information based economy. As a result a reduction of the pollution of the environment was observed. During industrialization period two main factors led to the degradation of the environment. These factors were the harmful by-products of production activities and the increased consumption of natural resources through the extensive use of land, deforestation and mining of mountains. As far as the service-information based economies is concerned, during this phase it seems that many of developed countries have reached and pass they hypothetical turning point (the level of income per capita at which pollution decrease). A possible explanation for this is that in a service-based economy many ‘dirty’ economic activities are moved elsewhere.

Figure 2.2 (discussed above) reflects the move from an industrial to service-based economy. The decreasing industrial production reduces environmental damage despite the rising GDP associated with the service sector economy.

Of course it must be mentioned that reduction of the pollution of the environment is caused also by technological breakthroughs and innovations. Modern technologies are of great importance as they help industries to use more efficiently their inputs and to minimize the harmful effects on environment which come from the production of goods.

The explanation just analyzed could be depicted by Figure 2.4

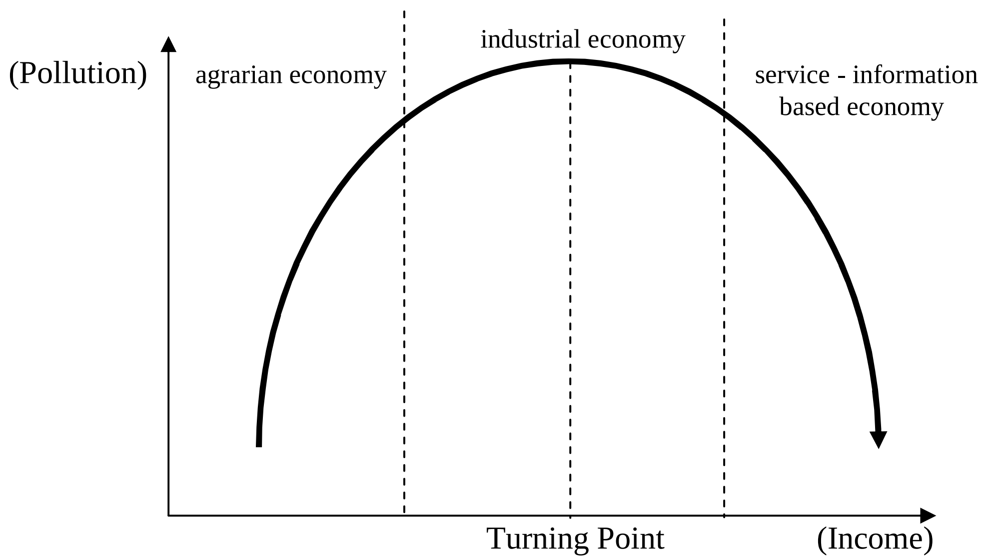


Figure 2.4. The evolution of the EKC through different stage of economic development

The second cause of the inverted U shape of the EKC is the demand from the side of consumers for cleaner environment when their incomes are high. This increasing demand is told “income effect”. As economy passes the turning point the preference of consumers change. As a matter of fact, the GDP per capita represents the point at which the preference for environmental quality outweighs the preference for additional income. One thing that should be pointed out is that changes in preferences occurs not only on private level but also on a public. These new preferences are expressed through political pressure on governments.

The above views are supported by the World Bank report (1992) which explains that the inverted U shape exists because of positive income elasticity for environmental quality. This means that as the income per capita raises the demand for cleaner environment rises too.

Panayotou (2003) suggests the following 3 reasons for the inversion of pollution:

1) The turning point for pollution is the result of more affluent and progressive communities placing greater value on the cleaner environment and thus putting into place institutional and non-institutional measures to affect this.

2) Pollution increases at the early phase of a country's industrialization due to the setting up of rudimentary, inefficient and polluting industries. When industrialization is sufficiently advanced, service industries will gain prominence. This will reduce pollution further.

3) When a country begins industrialization, the scale effect will take place and pollution increases. Further along the trajectory, firms switching to less-polluting industries results in the composition effect, which levels the rate of pollution. Finally, the technique effect comes into play when mature companies invest in pollution abatement equipment and technology, which reduces pollution.

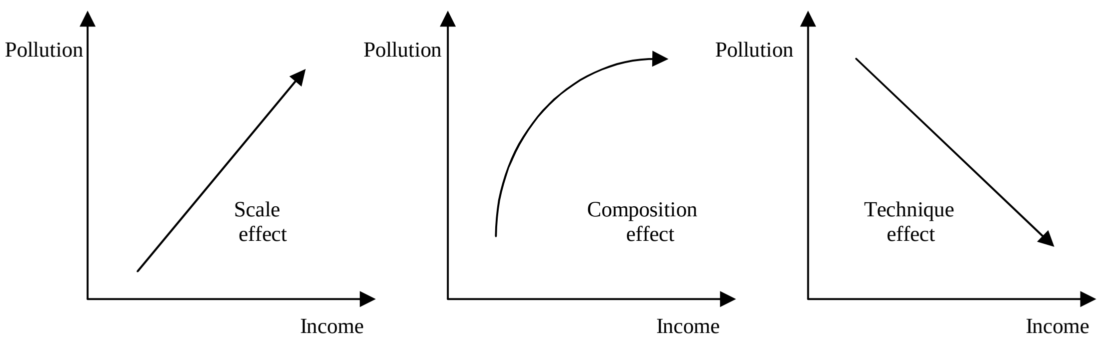


Figure 2.5. Scale, Composition and Technique effects

The composition and technique effect could be summarized in the next phrase:

" *…at higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, result in leveling off and gradual decline of environmental degradation.* " (Panayotou, 1993, p. 1).

From all the reasons that Panayotou (2003) suggested the most important is the last one. It is necessary an analysis of these three effects to be conducted in order to understand how the EKC emerges.

The first of the three effects, the scale effect, simply states that the more an economy of a nation produces the greater will be the degradation of the environment even if the structure of this economy and technology does not change. In this way the impact of the scale effect on the environment is negative.

In contrast to the scale effect, the composition effect has or could has a positive impact on the environment. This effect refers to the change of the structure of the economy through time. At the beginning of economic development when economy is dependent on agricultural sector, pollution increases as the economic structure changes from agricultural to industrial. In later stage of development the structure of the economy moves towards services decreasing in that way pollution. According to de Bruyn *et al*. (1998) the drawbacks of the composition effect hypothesis is that it doesn't take into account the fact that many activities of service sector have negative impacts on the environment such as air transport or mass tourism. Apart from that the change in the composition of production could explain the decrease of environmental impact per unit of GDP or of National Income, but not in absolute terms.

The third and last effect, the technique effect refers to the invention of new technologies which are environmental friendly and to the application of these new technologies in production which in turn lead to the reduction of the pollution of the environment. The impact of the technique effect is only positive.

After the analysis of the three effects it could be concluded that while the scale effect is expected to dominate the other two effects at the beginning stage of economic development, composition and technique effect are expected to dominate in the following stage of economic development and specifically when the turning point is reached.

Of course there are many doubts if the above conclusion reflects reality. Heerink et al. (2001) state that the extent to which these effects dominate depends on the incentives faced by economic actors and policy makers. Stern (2004) explains that in fast growing middle income countries, scale effect which increases pollution dominates the time relate effects, which try to capture technological change both on input and output sides. On the other hand, in high-income economies generally growth rates are low so that technological change may dominate the scale effect.

An explanation to why composition effect may not dominate the scale effect is given by Torras and Boyce (1998). The two authors state that: "… *while the industrial-composition effect, which accompanies rising per capita income, may lower the marginal pollution intensity of output, it cannot fully offset the scale effect (i.e. the environmental impact resulting from the level of aggregate output) unless more pollution-intensive sectors shrink absolutely. This could happen only if these sectors produce inferior goods, whose consumption falls with rising income, or if their products were replaced by imports. In general, the former condition seems unlikely to hold. The latter simply relocates pollution to other countries*."

But despite the fact that composition effect cannot alone solve the problem of increasing pollution the authors are optimistic with the idea that technique effect can do it. " *… if total pollution declines with rising income, technological change is likely to play a key role. Hicks (1932) distinguished between 'autonomous' and 'induced' innovation: the former is exogenous, the latter endogenous to economic forces. If the technology effect is strong enough to cause total pollution to decline systematically across countries as per capita income rises, induced innovation is the likely cause. Market signals can contribute to the inducement process; for example, rising resource costs may encourage resource conserving technological change, and a 'greening' of consumer demand may prompt firms to adopt cleaner technologies. But we suspect that government policies —including regulatory standards, pollution taxes and the creation of tradable emission permits—have been the most potent spur to pollution-reducing technological change.*" (Torras and Boyce, 1998). It is crucial to be mentioned that even if this was the case one could argue against the technological progress as a factor which can explain the reduction of environmental degradation.

"…*in many cases, technological innovation can harm the environment (for instance, some innovations in fishing techniques). Therefore, it cannot be assumed that the environmental balance is positive. The relationship between per capita income and technological possibilities should also be studied further: the techniques with most environmental impact are not necessarily the cheapest and most accessible to poor countries at all*." (Roca *et al*., 2001)

Besides the factors mentioned above, there are several others (not so important as scale, composition and technique effect) which are responsible to shape the EKC.

In a survey about EKC hypothesis Dinda (2004) identifies the following factors:
Income elasticity of environmental quality demand, scale, composition and technique effects, international trade, foreign direct investments, race to bottom hypothesis, diffusion of technology, international assistance, globalization, market mechanism, role of prices, role of economic agents, transition to market economy, information accessibility, regulations (formal and informal), property rights.

In another survey Lieb (2003) considers the following factors that could possibly explain the shape of the EKC : Demand for environmental quality, substitution between pollutants, technological progress, increasing returns to scale in abatement, structural change, migration of dirty industries, income distribution, shocks, irreversibility's.

As we can see many factors are common in both surveys. From all these factors however the most important are: scale, composition and technique effects, demand for environmental quality and international trade. Having made an extensive analysis of income elasticity of environmental quality demand and of three effects it is necessary to analyze the influence of the international trade on the environment as there are evidence that international trade is responsible for the inverted U shape of the EKC.

The argument in support of international trade as an explanatory variable of the environmental degradation states in general that international trade causes the size of the economy to increase and this in turns increases pollution This of course preassume that other factors remain stable. The size of the economy increases through scale effect (increasing trade volume) which negatively impacts the environment. On the other hand trade can improve environment through composition and/or technique effect (i.e., as income rises through trade, environmental regulation is tightened that spurs pollution reducing innovation). Thus the environmental degradation from the production of pollution-intensive goods declines in one country as it increases in other country via international trade. The composition effect can be explained in the framework of the Displacement and Pollution Haven hypothesises. These two hypotheses support almost the same thing but we will pay attention on the latter.

### 2.6.1) *Pollution Haven Hypothesis*

According to Dinda (2004) trade raises income levels of people in developing countries, and by raising real incomes, it will create demands for tighter environment protection because higher income individuals want a cleaner environment. But lower trade barriers could hurt environment if heavy polluters move to countries with weaker regulations. Economists call this the Pollution Haven Hypothesis (*PHH*). The *PHH* refers to the possibility that multinational firms, particularly those engaged in highly polluting activities, relocate to countries with lower environmental standards. The *PHH* argues that low environmental standards become a source of comparative advantage, and thus shifts in trade patterns. The *PHH* is basically a theory that suggests that high regulation countries will lose all the ‘dirty industries’ and poor countries will get them all.

Mathys (2003) states that pollution haven hypothesis (*PHH*) is a fundamental concept in the trade and the environment literature. The explanation of the *PHH* could be done in the framework of Hecksher – Ohlin trade theory.

The Hecksher-Ohlin trade theory suggests that, under free trade, developing countries would specialize in the production of goods that are intensive in the factors that they are endowed with in relative abundance: labor and natural resources. The developed countries would specialize in human capital and manufactured capital intensive activities. Part of the reduction in environmental degradation levels in the developed countries and increases in environmental degradation in middle income countries may reflect this specialization (Stern, 2004).

Trade entails the movement of goods produced in one country for either consumption or further processing. This implies that pollution is generated in the production of these goods is related to consumption in another country (Halicioglu, 2008).

Wyckoff and Roop (1994) estimate that 13% of the total carbon emissions of the six largest OECD countries are embodied in their imports of manufactured goods. A similar argument can be found in Mongelli *et al*. (2006).

The question as to the extent to which the relocation of pollution-intensive industries from developed to developing countries can explain the Environmental Kuznets Curve has been approached in a number of different ways in the empirical literature (Nahman and Antrobus, 2005)

Nahman and Antrobus (2005) in a literature survey of the EKC make an analytical representation of previous approaches on this issue.

The first approach try to explain the PHH based on the assumption of the weaker environmental regulations of the developing countries. According to this approach pollution intensive industries reallocate their “dirty” productive activities from developed to developing countries in order to take advantage of less stringent environmental regulations and hence lower abatement costs. The majority of studies based on this approach gave little support to the view that differences in environmental regulations are responsible for the trade flows but this doesn’t mean that trade do not explain the EKCs. Pollution intensive industries could reallocate their activities to developing countries for reasons other than environmental regulations, for example due to scarcity of natural resources. Apart from that evidence linking developing countries with weak environmental regulations and developed countries with more stringent standards are weak.

The second approach is based on the examination not of environmental regulations but instead of pollution-intensity of trade flows between developed and developing countries. According to this approach EKC can be explained by the tendency of developed countries to import their pollution-intensive goods from developing countries. If they actually do so then the exports of developing countries should be more pollution-intensive than the exports of developed countries.

The third and last approach is based on the examination of the relationship between consumption of pollution-intensive goods and per capita income. This approach is regarded as the most appropriate for investigating the impact of economic growth on the environment because consumption activities of a country are the most important factor of pollution of the environment. It takes into account production being occurred not only locally but also abroad for which a country's consumers are responsible. It must be mentioned of course that the finding that consumption increase with per capita income does not necessarily imply that environmental impact increases at higher levels of per capita income and the main reason for this is that not all manufactured goods have a similar impact on the environment. The pollution intensity differs among different goods. There is strong evidence that consumers in developed countries shifts from consuming pollution-intensive to non pollution-intensive goods at higher levels of per capita income or that they consume the same goods but with less impact on the environment due to improvements in abatement technology.

It is crucial to note that if the both hypothesis (*Displacement and PHH*) are correct and the determination of the shape of the Environmental Kuznets Curve is due to these hypothesis then the EKC doesn't help us to solve the problems which are related with the pollution of the environment. Decision makers and environmentalists cannot use the EKC as a tool to plan environmental policy.

If a movement of polluting industries from rich to poor countries has taken place, it is unlikely that this behavior can be reproduced in the future in developing countries (Roca *et al*., 2001). If we see our planet as a finite system which has its own limits then this view is rational. In our finite world the poor countries of today would be unable to find further countries from which to import resource intensive products as they, themselves, become wealthy. When the poorer countries apply similar levels of environmental regulation they would face the more difficult task of abating these activities rather than outsourcing them to other countries (Stern, 2004).

To the extent that the EKC can be explained by the relocation of pollution intensive industries from developed to developing countries, such optimism is not justified. As today's developing countries become tomorrow's developed countries, there will be increasingly fewer "pollution havens" onto which they can dump their environmental problems. If the EKC can be explained by the relocation of pollution intensive production to developing countries, then "this means of reducing environmental impacts will not be available to the latest-developing countries, because there will be no countries coming up behind them to which environmentally-intensive activities can be located". The EKC may thus be a "historical artifact" describing a development path that is no longer available to today's developing countries (Nahman and Antrobus, 2005).

The pessimistic conclusion to which the *PHH* leads is shown in Figure 2.6.

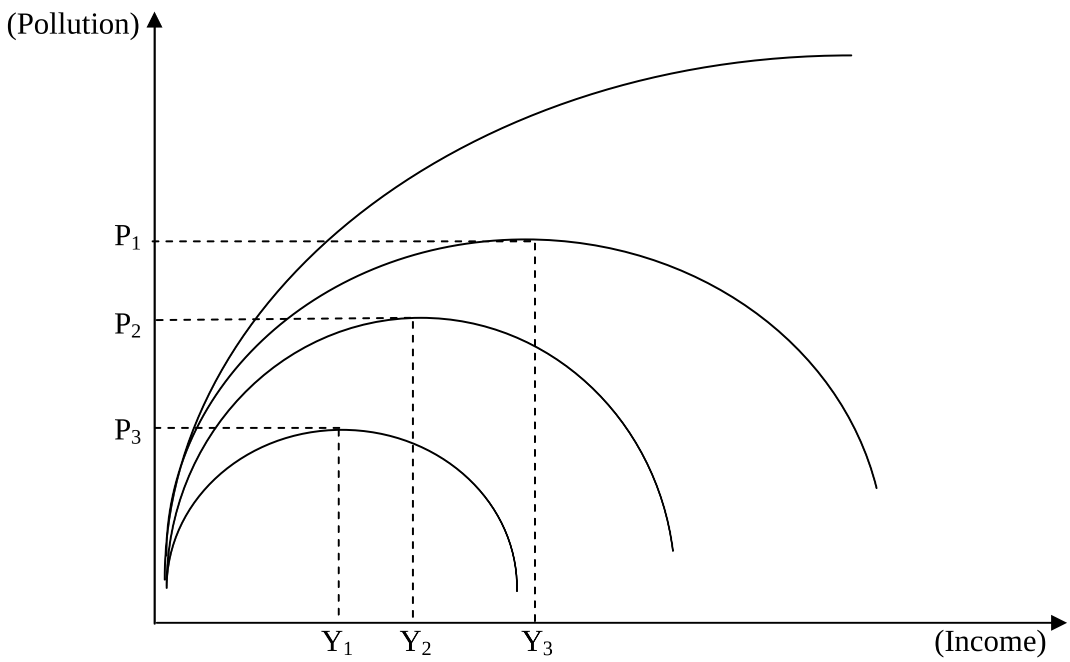


Figure 2.6. The shapes of the EKC under the Pollution Haven hypothesis

It could be argued however that there is no shortage of poor countries in the world today and thus there will continue to be opportunities for developed countries to shift their waste elsewhere for some time to come. However, poor countries are not in infinite supply, and thus a point may one day be reached where the ability to export waste is no longer feasible. The argument being advanced here is simply that such patterns of trade do exist and that they might explain the EKC, the argument about whether such patterns are viable in the long run is secondary (Nahman and Antrobus, 2005).

A possible objection to the international trade argument is that the greater demand for an improved environmental quality among wealthy consumers in developed countries extends to the global environment, and that these consumers understand the global nature of today's environmental problems and would boycott products manufactured under poor environmental standards. However, this objection is naïve and is not borne out by a simple examination of the evidence concerning the particular indicators of environmental degradation that decline at higher levels of per capita income as opposed to those which continue to rise (Nahman and Antrobus, 2005).

### 2.7) *Modeling EKC hypothesis. A micro-foundation analysis*

The aim of this thesis is an empirical analysis of the EKC hypothesis but it would be appropriate at this part to illustrate a simple theoretical model of this hypothesis elaborated by Andreoni and Levinson (2001).

We must mention that many other economists before Andreoni and Levinson tried to explain the EKC through microeconomic analysis. The common point of these analyses is the belief of an automatic emergence of the EKC once the per capita income level reaches a certain critical level.

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,

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

$$U_C^{'} 0 > 0, U_C^{''} < 0, U_P^{'} < 0, U_P^{''} > 0, U_C^{'} > 0, U_C^{''} < 0 \qquad (1)$$

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), this reasoning is called the Samuelson Rule (He, 2007).

$$U_C^{'} + U_P^{'} = 0 \quad (2)$$

The two economists developed a simple static model which is based on the simplifying assumption of an economy with only one person.

The utility function of the consumer is:

$U = U(C, P)$, Eq.(1), where:

$C$ = *consumption of one private good*

$P$ = *pollution*

$U_C > 0$, $U_P < 0$ and $U$ is quasi - concave in $C$ and $-P$

They next suppose that pollution is a byproduct of consumption, and that the consumer has the possibility to abate pollution by spending resources either to clean it up or, equivalently, to prevent it from happening at all. Call those resources *E*, for environmental effort.

The function of pollution is:

$P = P(C,E)$, Eq. (2), where:

$P_C > 0$ and $P_E < 0$

The endowment *M* of the consumer is shared between *C* and *E*.

They next consider a simple example:

$U = C - zP$, Eq. (3) where $z > 0$ is the constant marginal disutility of pollution

$P = C - C^{\alpha}E^{\beta}$, Eq. (4)

Suppose $z = 1$ and substitute Eq.(4) into Eq.(3)

The maximization problem then is:

$$\max \; U = C^{\alpha}E^{\beta}$$
$$s.t. \quad M = C + E$$

The Lagrange equation is the following:

$$L(C,E,\lambda) = C^{\alpha}E^{\beta} + \lambda(M - C - E)$$

$f.o.c.$

$$a) \quad \frac{\partial L}{\partial C} = \alpha C^{\alpha-1}E^{\beta} - \lambda = 0 \quad \Rightarrow \quad \frac{\alpha C^{\alpha}E^{\beta}}{C} = \lambda \quad d)$$

$$b) \quad \frac{\partial L}{\partial E} = \beta E^{\beta-1}C^{\alpha} - \lambda = 0 \quad \Rightarrow \quad \frac{\beta E^{\beta}C^{\alpha}}{E} = \lambda \quad e)$$

$$c) \quad \frac{\partial L}{\partial \lambda} = M - C - E = 0$$

From *d*) and *e*) solving for $E$ we get $E = \frac{C\beta}{\alpha}$ $f)$

By replacing $f)$ into *c*) we will have:

$$M - C - E = 0 \quad \Rightarrow \quad M - C - \frac{C\beta}{\alpha} = 0 \quad \Rightarrow \quad C^{*} = \frac{\alpha}{\alpha+\beta}M$$

Next replacing $C^{*}$ into $M - C - E = 0$ we get $E^{*} = \frac{\beta}{\alpha+\beta}M$

The two optimal solutions then are:

$$C^{*} = \frac{\alpha}{\alpha+\beta}M \quad (5) \quad \text{and} \quad E^{*} = \frac{\beta}{\alpha+\beta}M \quad (6)$$

Substituting Eq. (5) and Eq. (6) into Eq. (4), the optimal quantity of pollution is then:

$$P^{*}(M) = \frac{\alpha}{\alpha+\beta}M - \left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\right)^{\beta} M^{\alpha+\beta} \quad (7)$$

The derivative of Eq. (7) represents the slope of the environmental Kuznets curve:

$$\frac{\partial P^{*}}{\partial M} = \frac{\alpha}{\alpha+\beta} - (\alpha+\beta)\left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\right)^{\beta} M^{\alpha+\beta+1} \quad (8)$$

the sign of which depends on the parameters $\alpha$ and $\beta$.

When $\alpha + \beta = 1$, effort spent abating pollution has constant returns to scale, and $\partial P^{*}/\partial M$ is constant. Given $0 \leq \alpha$, $0 \leq \beta$, then $P^{*}$ rises with *M* and there is no downward sloping portion of the pollution-income curve, as depicted in Figure 2.7A.

When $\alpha + \beta \neq 1$, the second derivative of Eq. (8) is:

$$\frac{\partial^2 P^*}{\partial M^2} = -(\alpha+\beta-1)(\alpha+\beta)\left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\right)^{\beta} M^{\alpha+\beta+2} \quad (9)$$

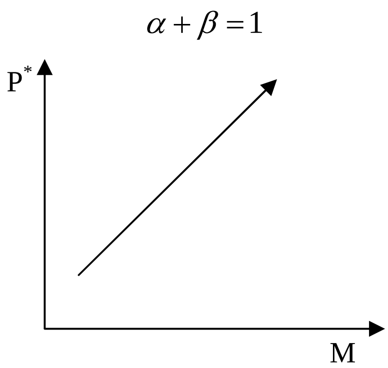

Figure 2.7A

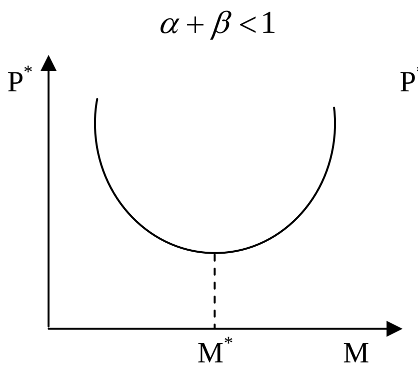

Figure 2.7B

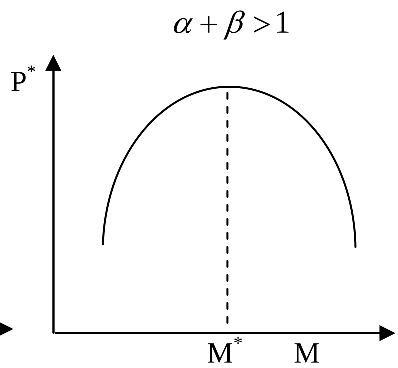

Figure 2.7C

If $\alpha + \beta < 1$, the abatement exhibits diminishing returns to scale, $P^*(M)$ is convex, as in Fig. 2.7B. If $\alpha + \beta > 1$, the abatement exhibits increasing returns to scale, then $P^*(M)$ is concave as in Fig. 2.7C. The last case is the one where EKC emerges.

## 2.8) *Pollution indicators which represent environmental degradation*

In the absence of a single criterion of environmental quality, several indicators of environmental degradation have been proposed (Cialani, 2007). Some of such pollution indicators are: carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen oxide, suspended particulate matter, lead, DDT, smog, chlorofluorocarbons, sewage, biological oxygen demand and other chemicals released directly into the atmosphere or rivers and oceans.

The problem with all these different types of environmental pollution indicators is that there is little evidence that EKC hypothesis holds for all these different indicators. As we have noticed previously there are mixed results concerning the validity of global pollutant such as carbon dioxide. This of course doesn’t mean that EKC hypothesis isn’t right.

Friedl and Getzner (2003) report four types of indicators that are commonly employed for different pollutants or sorts of environmental degradation: 1) emissions per capita, 2) emissions per gross domestic output (pollution intensity) or gross product, 3) ambient levels of pollution (concentrations; impacts on a certain area), and 4) total emissions. In cross-country studies carbon dioxide emissions per capita is the most frequently used indicator.

### 2.8.1) *Why other pollutants besides $CO_2$ have been used in the past*

According to Agras and Chapman (1999) EKC hypothesis has usually been investigated by analyzing the relationship between a specific pollutant (ambient concentrations of sulfur dioxide, suspended particulate matter (*SPM*), etc.) and income. This practice has developed, in part, because of the widely available UNEP data on pollution concentration levels in urban areas However, since emission sources are strongly influenced by location of rural natural resource extraction, a country's urban concentrations of sulfur dioxide in many cases do not reflect that country's sulfur emissions. This is particularly true with respect to copper ore smelting, oil refining and desulphurization, and natural gas processing and desulphurization.

### 2.9) *The shapes of the Environmental Kuznets Curves and the functional formation*

The relation between income and environmental pressure can be sketched in a number of different ways. On a first level one can distinguish between monotonic and non-monotonic curves representing this relationship. Monotonic curves may show either increasing pollution with rising incomes, as in the case of municipal waste per capita, or decreasing. However, non-monotonic patterns may be more likely in other cases and two types have been suggested, namely inverted-U and N-shaped curves. In addition to these, more complex patterns are possible (especially when longer time horizons are taken into account) that can be regarded as combinations of these four basic curves. The patterns discovered in empirical research depend on the types of pollutants investigated and the models that have been used for estimation. Selden and Song (1994) present four theoretical arguments in favor of an inverted-U curve for (local) air pollutants, which can be listed as: 1) positive income elasticity's for environmental quality, 2) structural changes in production and consumption associated with higher incomes, 3) increasing information on environmental consequences of economic activities as income rises and 4) more international trade and more open political systems with rising levels of income. Others, for instance Pezzey (1989) and Opschoor (1990), have argued that such inverted-U relationships may not hold in the long run. They foresee a so-called N-shaped curve which exhibits the same pattern as the inverted-U curve initially, but beyond a certain income level the relationship between environmental pressure and income is positive again. De-linking is thus considered a temporary phenomenon. Opschoor (1990), for example, argues that once technological efficiency improvements in resource use or abatement opportunities have been exhausted or have become too expensive, further income growth will result in net environmental degradation. Despite these considerations empirical evidence so far has been largely in favor of the inverted-U instead of the N-shaped relationship (de Bruyn *et al.*, 1998).

The general functional form of the EKC is the following:

$$f(ED_{it}) = a_0 + a_1 g_1(Y_{it}) + a_2 g_2(Y_{it}^2) + a_3 g_3(Y_{it}^3) + a_4 g_4(Y_{it-a}^n) + \beta.B + \gamma t + \varepsilon_{it} \quad (1)$$

where $ED_{it}$ is an environmental indicator for country $i$ at time $t$; $\alpha, \beta, \gamma$ are the parameters to be estimated; $Y_{it}$ is the per capita income of country $i$ at time $t$, with $Y_{it-a}^n$ being some polynomial of lagged income; $B$ is a vector of other explanatory variables (such as population density or trade openness) that influence the relationship between $E_{it}$ and $Y_{it}$, possibly including dummies to capture specific influences of demography, geography or particular years (Ekins, 2000). Additional explanatory variables for investment shares, electricity tariffs, debt per capita, political rights, civil liberties and trade have also been used (Agras and Chapman, 1999). Lastly *f(.), g(.)* are functional forms which are predominantly, but not exclusively, logarithmic or linear, $\varepsilon_{it}$ is the normally distributed error term and $\gamma$ is used to de-trend the series.

If $\alpha_3 \neq 0$, then the equation is cubic in income; if $\alpha_3 = 0$, $\alpha_2 \neq 0$ then the equation is quadratic; if $\alpha_3 = \alpha_2 = 0$ and $\alpha_1 \neq 0$, then the equation is linear. The overall shape of the curve generated by the relationship will depend on the signs and relative values of $\alpha_1, \alpha_2, \alpha_3$.

For example:

*a* linear, downward sloping: $a_1 \prec 0, a_2 = a_3 = 0$

*b* linear, upward sloping: $a_1 \succ 0, a_2 = a_3 = 0$

*c* quadratic, inverted U: $a_1 \succ 0, a_2 \prec 0, a_3 = 0;\ |a_2| \ll |a_1|$

The turning point of this representation of the inverted – U curve is obtained by setting the derivative of Eq. (1) equal to zero, which yields: $Y_t = -\frac{a_1}{2a_2}$

*d* quadratic, normal U: $a_1 \prec 0, a_2 \succ 0, a_3 = 0;\ |a_2| \ll |a_1|$

*e* cubic: $a_1 \succ 0, a_2 \prec 0, a_3 \succ 0;\ |a_3| \ll |a_2| \ll |a_1|$

*f* cubic: $a_1 \prec 0, a_2 \succ 0, a_3 \prec 0;\ |a_3| \ll |a_2| \ll |a_1|$

Moomaw and Unruh (1997) employing the so-called structural transition models indicate an inverted – V shape of the environmental Kuznets Curve instead of the inverted – U shape that EKC models assume.

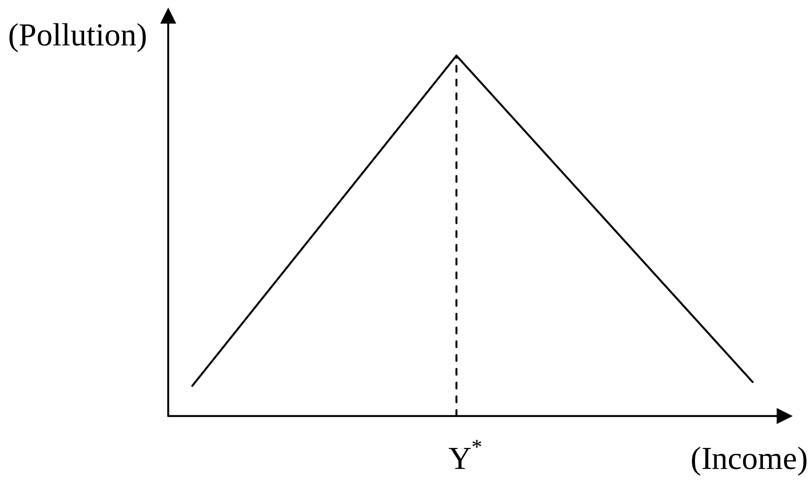


Figure 2.8. An inverted V - shaped EKC

2.9.1) *N - shaped EKC vs inverted U - shaped EKC*

The N shape EKC imply that environmental degradation increases as an economy develops, start to decrease once the turning point is reached but after next turning point begin to increase again. If this is the actual shape of the EKC then the economic growth cannot considered anymore as a solution of the pollution of the environment.

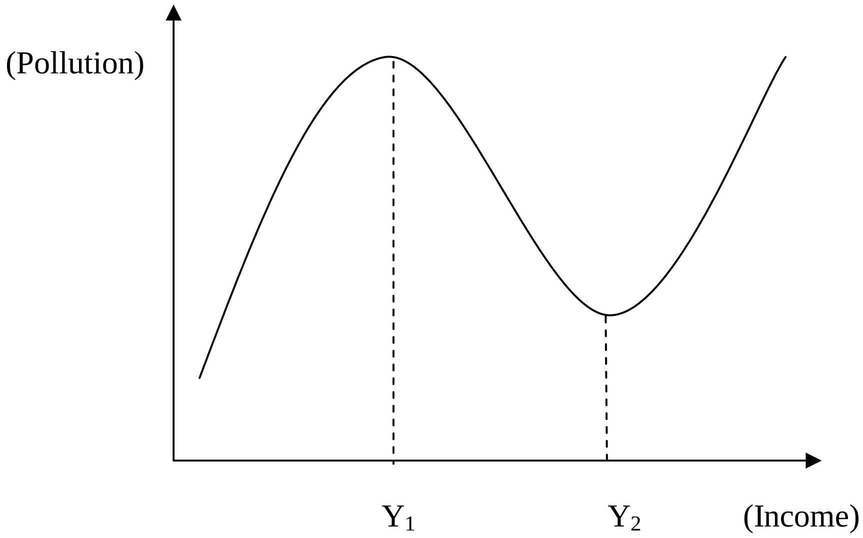


Figure 2.9. An N-shaped EKC

Neither the linear nor the cubic relationship allows for an optimistic interpretation of economic growth as being beneficial for the environment (Friedl and Getzner, 2003).

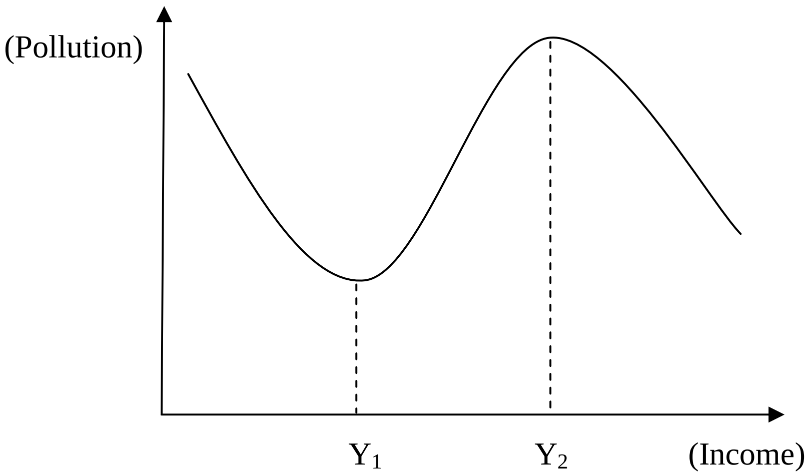


Figure 2.10. N-shaped EKC : An optimistic view

### 2.10) *The shortcomings of EKC analysis*

#### 2.10.1) *Theoretical critique*

Since 1991 a number of studies on the validity of the EKC hypothesis have been published. All these studies have applied different theoretical and econometrical methodologies.

One of the main criticisms of the EKC models is the assumption that environment and growth are not interrelated. In simple words the EKC hypothesis assumes no feedback between income and the pollution of environment.

Stern (2004) refers that environmental damage does not reduce economic activity sufficiently to stop the growth process and that any irreversibility is not so severe that it reduces the level of income in the future. In other words, there is an assumption that the economy is sustainable. But, if higher levels of economic activity are not sustainable, attempting to grow fast in the early stages of development when environmental degradation is rising may prove counterproductive.

Ekins (2000) says that the potential pathways of influence between economic growth and the environment are many and various and act in either direction.

He (2007) also points out this weakness of the analysis in only one direction. As he say: " *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.* "

Fare *et al*., (2001) refer that the non-availability of actual data on environmental quality is the major limitation of all EKC studies. Environmental quality is something that is not measured accurately. Therefore, an index of environmental quality, which could be better measurement, should be developed and used to examine the EKC hypothesis.

According to Ekins (2000), consideration in assessing the robustness of the estimation is the reliability of the data used. However, there is little indication that the data problems are serious enough to cast doubt on the basic environment-income relationship for any particular environmental indicator, but the results in fact suggest that this might be the case.

Stern (2004) pay attention to the mean – median problem. He underlines that early EKC studies showed that a number of indicators: $SO_2$ emissions, $NO_x$, and deforestation, peak at income levels around the current world mean per capita income. A cursory glance at the available econometric estimates might have lead one to believe that, given likely future levels of mean income per capita, environmental degradation should decline from the present onward. Income is not however, normally distributed but very skewed, with much larger numbers of people below mean income per capita than above it. Therefore, it is median rather than mean income that is the relevant variable.

Most of the studies have used cross-section data to examine the EKC hypothesis for group of countries and enough attention has not been given to country-specific EKC. The basic assumption behind pooling the data of different countries in one panel is that economic development trajectory would be the same for all. This assumption should be criticized because wide cross-country variations are observed in social, economical, political and biophysical factors that may affect environmental quality. (For example, the percentage of forest covered area in total area varies from country to country.) Under such heterogeneity of conditions, the use of random effect model may be appropriate for examining shape of economic growth–environment relationship based on cross-country, cross-sectional data (Koop and Tole, 1999).

Another problem related with the EKC studies is the little attention that have been paid to the statistical properties of time series. Very few studies in the past investigated the presence of unit root in time series of variables used to investigate the validity of the EKC.

### 2.10.2) *Econometric critique*

Stern (2004) in a survey argues that the econometric criticisms of the EKC fall into four main categories: heteroscedasticity, simultaneity, omitted variables bias, and cointegration issues.

Lieb (2003) on the other hand says that econometric criticism is related with simultaneity bias, other functional forms, time trends, multicollinearities, lagged effects and homogeneity tests. According to him a simultaneity bias may impair the results, other functional forms than the polynomial may fit the data better, the use of a time trend may be problematic, the regression may suffer from multicollinearity, income may not have an immediate but only a lagged effect on pollution and a homogeneity test may reveal that the slope coefficients are not identical in all countries.

By using various lines of evidence Stern (2004) concludes that the majority of studies have found the EKC to be a fragile model suffering from severe econometric misspecification. Use of more appropriate methods tends to indicate higher turning points and possibly a monotonic curve for emissions of major pollutants. A better model may result from including additional variables to represent either proximate or underlying causes of change in emissions.

## 2.11) *Literature review and empirical findings*

The EKC literature is abundant in studies that test for linear, as well as quadratic and cubic relationships between per capita income and pollution emissions. These studies treat environmental degradation measure(s) as the dependent variable(s) and income as the independent variable and provide mixed results (Soytas *et al.*, 2007).

Aslanidis (2009) refers that most of the EKC literature, apart from some exceptions, is statistically weak. The reason for this is that the baseline models estimated in the literature which as mentioned above are linear polynomial models that include quadratic (and sometimes also cubic) terms of income as explanatory variables are too restrictive.

The polynomial model is purely descriptive and does not answer the question whether the reduction in pollutants is achieved by more ambitious environmental policies (that may even be unrelated to economic growth) or by autonomous structural and technological changes (de Bruyn *et al*., 1998).

Dinda (2004) further criticized the use of polynomial models because these kind of models are unable to provide insight into the underlying causes of the EKCs. Thus the designing of specific policy implications from an EKC is a difficult task. This inability makes the analysis of the EKC incomplete.

Hung and Shaw (2002) support that polynomial models should be avoided because of the simultaneity. Income and environmental degradation are endogenous variables which impact each other so the estimation of the single equation will give rise to results that are biased and inconsistent.

According to Stern (1998) there were four types of contributions to the EKC literature between 1991 and 1998: 1) estimation of ‘basic’ EKCs, 2) studies of the theoretical determinants of the EKC, 3) studies of the empirical determinants of the EKC, and 4) critique of EKCs. (Nahman and Antrobus, 2005).

Literature on the EKC thus developed along three strands between 1991 and 1998, namely estimation of EKC relationships based on empirical data, investigations of the theoretical and empirical determinants of the EKC pattern, and critiques of the aforementioned investigations (Nahman and Antrobus, 2005). These studies do not report cointegration or other statistics that might tell us if omitted variables bias is likely to be a problem or not. Therefore, it is not clear what we can infer from this body of work (Stern, 2004).

Since 1998, estimation of specific EKC relationships has continued, although the methodology has been applied to a far wider range of environmental problems, such as hazardous wastes, greenhouse gas emissions and biodiversity loss.

Perhaps the most important developments in more recent (post-1998) literature on the EKC have occurred in the remaining strands of literature, namely investigations of the theoretical and empirical determinants of the EKC pattern, and critiques of the aforementioned investigations. There has been a decline in the number of theoretical explanations of the EKC pattern and a rise in the number of empirical explanations. Furthermore, empirical explanations have been far more critical of the way in which the EKC pattern emerges. These trends reflect a fall in confidence regarding the robustness of the EKC (Nahman and Antrobus, 2005).

The main divergence in the EKC literature is between optimists, who take the EKC as implying that economic growth is ultimately good for the environment and critics, who point to a number of methodological flaws evident in deriving the EKC or advocate caution in interpreting its causes and implications (Nahman and Antrobus, 2005).

The arguments of the optimists states that although at the beginning of the economic development pollution of the environment is something that cannot be avoided in the end the reduction of the environmental degradation is something almost possible as economy continue to grow.

But despite all the optimistic views many of the economists who were involved with the research of the validity of the Environmental Kuznets Curve warned that this hypothesis shouldn't be taken for granted and that further analysis and investigation in this field of environmental economics must be done.

The fact that nations which formerly had or currently have low per capita income are experiencing increasing pollution while industrialized countries are successful in abating emissions does not imply that economic development will solve environmental problems quasi automatically (Friedl and Getzner, 2003).

After all the empirical studies that have been done in order to prove the validity of the EKC hypothesis there are questions that need to be answered. For example, it is very interesting to know how much of the environmental pollution will incur before the economy reach the turning point. Should policy makers encourage through their decisions the economic growth to bring the economy to the turning point?. What kind of institutional reforms should be implemented in order to hasten the improvement of the environment?.

### 2.11.1) *Panel data studies*

The early studies of the EKC are based on panel data analyses which make use of random, fixed and pooled effects.

According to Aslanidis (2009) an important issue in panel data studies is the underlying assumption of homogeneity of income effects across countries (regions). As some studies show not all countries display the same relationship between emissions and income. This is particularly true when developed and developing countries are compared, with the EKC holding for some developed countries only.

The first study of the relation between environmental degradation and economic growth was conducted as we referred above by Grossman and Krueger (1991). The two economists used pollution indicators such as suspended particles matter (SPM), dark matter (smoke) and sulfur dioxide. More specifically in their panel data analysis which allows for random effects the data concern 42 countries for sulfur dioxide, 19 countries for dark matter and 29 countries for suspended particles. The years of investigation are 1977, 1982 and 1988. The results were not very optimistic because EKC weren't confirmed in the case of sulfur dioxide and dark matter which found to follow an N-shape pattern and an inverted U shape. SPM on the other confirmed the EKC hypothesis. The turning points for sulfur dioxide were $ 4,500 and $15,000 approximately, for dark matter $ 5,000 and $ 10,000 approximately and for SPM around $ 9,000.

Seldon and Song (1993) analyze the relation between growth and pollution indicators such as sulfur dioxide, nitrogen oxide, carbon oxide, suspended particles matters (SPM) for three different periods of time: 1973-1975, 1979-1981 and 1982-1984. Panel data analysis with cross section, fixed and random effects confirm the validity of the EKC hypothesis. The turning points for SPM and sulfur dioxide range between $8,000-$10,300, for nitrogen oxide between $11,200-$21,800 and for $5,900-$19,100.

Seldon and Song (1994) examine the validity of EKC hypothesis between carbon dioxide emissions and GDP for the period 1951- 1986. The number of countries in their sample is 130. The panel data analysis that they apply allows for fixed and country specific effects. EKC hypothesis is confirmed for levels with turning point $ 35,428. For logs EKC is not confirmed because the turning point is very high $ 8,000,000 approximately.

Shafic (1994) explores the relation between GDP and environmental degradation for 149 countries covering time period from 1960 to 1990. Panel data analysis based on OLS estimates show that from pollution indicators such as lack of clean water, lack of urban sanitation, suspended particles matters (SPM), sulfur dioxide, dissolved oxygen, fecall coliforms in river, carbon emissions, municipal waste and deforestation the EKS hypothesis is confirmed only for sulfur dioxide and SPM with turning points for SPM and sulfur dioxide to be around $ 3,280 and $ 3,670 respectively.

Grossman and Krueger (1995) examine the reduced-form relationship between per capita income and various environmental indicators such as urban air pollution, the state of the oxygen regime in river basins, fecal contamination of river basins and contamination of river basins by heavy metals. The years and time periods that this study concerns are 1977, 1982, 1988 and 1979-1990. Panel data analysis with random effects confirms the validity of the EKC hypothesis with turning points varying but in most cases they come before a country reaches a per capita income of $ 8,000.

Tucker (1995) investigated EKC hypothesis for 137 countries for the period 1971-1991 in panel data analysis. For the majority of the countries the findings show that EKC is confirmed.

Moomaw and Unruch (1997) use a sample of 16 developed OECD countries for the period 1950-1992. The relationship between carbon dioxide emissions and GDP is examined in the panel data framework and with help of so called structural transition model. The results confirmed the EKC hypothesis for the period under examination but with inverted-V shape and not inverted-U shaped curve. Turning points for each country vary between $ 8,884 - $ 15,425.

Torras and Boyse (1998) explore the validity of the EKC in a panel data analysis for the period from 1977 to 1991. The pollution indicators which they use are: sulfur dioxide, smoke, heavy particles, dissolve $O_2$ and fecal coliform access to sanitation.

Many other explanatory variables beside GDP are used such as population density etc. According to authors it is not clear if EKC is confirmed so results are mixed.

Lantz and Feng (2006) investigate EKC hypothesis using a five-region panel data set in Canada over the period 1970-2000. The explanatory variables are income, population, technology and carbon dioxide emissions are the pollution indicator. Panel data analysis with pooled and fixed effects is employed. The results show that income per capita doesn’t cause carbon dioxide emissions but an inverted U-shaped relationship exists when population is included and that a U-shaped relationship exists when technology include also.

### 2.11.2) *Cross-section analysis*

Cole et al. (1997) in a cross-section analysis examine the validity of the EKC hypothesis. The sample consists of a number of OECD countries and the period of analysis is from 1970 to 1992. They use variety of pollution indicators such as nitrogen dioxide, sulfur dioxide, suspended particle matters, carbon monoxide and dioxide, methane, municipal waste, CFCs and halons. The findings show that meaningful EKCs exist only for local air pollutants whilst indicators with a more global or indirect impact either increase monotonically with income or else have predicted turning points at high per capita income levels.

### 2.11.3) *Studies based on time series models*

Taking into account the fact that it is not right to treat developing and developed countries in same way many studies focused to the investigation of relationship between income and pollution applying time series regressions. The problem with these studies is that they give spurious results because the variables such as income and pollution are non-stationary so only if these variables are co-integrated one can rely on EKC results.

Tests for unit root (in the case for example of $CO_2$ and GDP per capita) find that these variables are integrated, although not always co-integrated, what casts doubt on the validity of the EKC (Aslanidis, 2009).

De Bruyn et al. (1998) investigate the relation between pollution and income in four countries (UK, USA, Western Germany and Netherlands) from 1961 to 1993. The three types of pollution indicators are carbon dioxide, nitrogen oxide and sulfur dioxide. They find that the time patterns of these emissions correlate positively with economic growth and that emission reductions may have been achieved as a result of structural and technological changes in the economy.

Roca *et al*. (2001) investigate the validity of EKC hypothesis for Spain. In order to do this the authors make use of six atmospheric pollutants: carbon dioxide ($CO_2$), methane ($NH_4$), nitrous oxide ($N_2O$), sulfur dioxide ($SO_2$), nitrogen oxide ($NO_x$), and non-methanic volatile organic compounds (NMVOC). In the case of carbon dioxide time series covers the period from 1972 to 1996. For the other five pollutants the data which is used covers the period from 1980 to 1996. The OLS estimation of cubic functional specification confirms the validity of the EKC hypothesis only in the case of sulfur dioxide.

Friedl and Getzner (2003) explore the relationship between economic development and carbon dioxide emissions for a small open and industrialized country, Austria. The data covers period from 1960 to 1999. Besides GDP, imports and share of the tertiary (service sector) are utilized as explanatory variables. The results don't confirm EKC hypothesis because N-shaped relationship between income and pollution is found to fit data most appropriately.

Soytas *et al*. (2007) investigate the effects of energy consumption and output on carbon emissions in the United Sates for the period 1960 – 2004. As additional explanatory variables apart from GDP, labor and gross fixed capital formation is used. The authors employ the relatively new time series technique known as the Toda-Yamamoto procedure to test for long run Granger causality. The results show that income does not cause carbon dioxide emissions and so economic growth may not become a solution to problem as suggested by the EKC hypothesis.

Cialoni (2007) explores the relationship between carbon dioxide emissions and income for Italy. The period of the research is from 1861 to 2002. Apart from OLS estimation of the reduced form model, the author also applies the Index Decomposition Analysis (IDA) in order to investigate changes in emissions between

1990 to 2002. The findings don’t confirm the EKC hypothesis. There is a positive relationship between economic growth and $CO_2$ emissions. Following the trend, the maximum emission of $CO_2$ emissions per capita in Italy would be reached when GDP per capita will be about $ 26,900.

Ang (2008) examines the dynamic causal relationships between pollutant emissions, energy consumption, and output using cointegration and vector error-correction modeling techniques. The country under examination is France and the period that the study covers is from 1960 to 2000. The causality results support the EKC hypothesis. Unidirectional causality running from GDP growth to growth of pollutant emissions in the long-run is found.

Halicioglu (2008) investigates the validity of the EKC hypothesis for Turkey for the period 1960-2005. A carbon dioxide emission is used as pollution indicator. Apart from GDP other explanatory variables such as trade openness and energy consumption are utilized. ARDL cointegration approach and Granger causality test are applied in order to validate the relationship between income and pollution. The author concludes that there is some support of the EKC hypothesis which is strong enough. He finds that there is bidirectional short and long-run causality between carbon dioxide emissions and GDP. From all the explanatory variables the empirical results suggest that income is the most significant variable in explaining the carbon emissions which is followed by energy consumption and foreign trade.

Annichiarico *et al*. (2009) examine the relationship between economic growth and carbon dioxide emissions in Italy. The period the study covers is from 1861 to 2003. In order to check the existence of the EKC the authors apply several different techniques such as cointegration, rolling regression and error correction modeling. The results show that growth and carbon dioxide emissions are strongly interrelated and elasticity of pollutant emissions with respect to income has been decreasing over time. More specifically the EKC hypothesis is confirmed for total period with turning point at $ 39,000 which is a quite reasonable. EKC hypothesis is rejected for the first sub-period 1861-1958 and accepted for the second sub-period 1960-2003 with turning point reaching $ 20,000 approximately.

Akbostanci *et al*. (2009) investigate the relationship between GDP and environmental quality for Turkey. The pollution indicators in their study are $CO_2$, $SO_2$ and $PM_{10}$ emissions. The relationship between the $CO_2$ emissions and GDP is examined by the use of a time series model employing cointegration techniques. On the other hand the relationship between GDP and $SO_2$ and $PM_{10}$ measurements is estimated by panel data techniques. The time series model covers the period from 1968 to 2003 and the panel data model covers the period from 1992 to 2001 including observations from 58 provinces. The results show that there is a monotonically increasing relationship between $CO_2$ and GDP in the long-run according to time series analysis and N-shaped relationship between GDP and $SO_2$ and $PM_{10}$ according to panel data analysis. Therefore the EKC hypothesis is not confirmed neither for time series model nor panel data model.

A more detailed analysis of the panel data and time series model studies of the EKC could be found in the surveys of Lieb (2003), Dinda (2004) and Stern (2004).

2.11.4) *New functional forms and new econometric techniques*

On the functional form issue, some studies have addressed the non-linearity of the income – emissions relationship by using a spline (piecewise linear) function. The spline model has the advantage over the polynomial specification in that the approximation error is generally smaller. Others papers have considered Weibull distributions and smooth transition regression models as alternative, and more flexible specifications, to the polynomial model. The non – parametric models, which do not require the specification of a functional form, constitute one of the latest econometric tools used. Yet, these new econometric approaches have not yielded conclusive results regarding the existence of the EKC for carbon emissions for instance (Aslanidis, 2009).

Recent studies allow for spatial dependence in emissions across countries to account for the possibility that countries' emissions are affected by emissions in neighboring countries. The results so far support the use of spatial econometric models over the polynomial EKC specification (Aslanidis, 2009).

Martinez-Zarzoso and Bengochea-Morancho (2004) examine the relationships between carbon dioxide emissions and GDP in panel data analysis by using 22 OECD countries for the period from 1975 to 1998. They employ the ARDL cointegration technique for this purpose. The general result is that EKC hypothesis is not confirmed because for the majority of countries a N-shaped curve is found.

Aslanidis and Xepapadeas (2006) explore the idea of regime switching as new methodological approach in the analysis of the emission-income relationship. The basic idea according to authors is that when some threshold is passed, the economy could move smoothly to another regime, with the emission-income relationship being different between the old and the new regime. The period the study covers is from 1929 to 1994 and refers to the 48 states of the USA. The methodology is applied in a panel data analysis. The pollution indicators that they use are state-level emissions of sulfur dioxide and nitrogen oxide. EKC hypothesis is confirmed only for sulfur dioxide. They researchers find a robust smooth inverse-V shaped pollution-income path for sulfur dioxide.

For a more detailed analysis of the new functional forms and econometric techniques see the survey of Aslanidis (2009).

Tables 2.4 – 2.6 next summarize the estimation results of the above empirical studies.

Table 2.4

| Author(s) | Data | Methodology | Results |
|---|---|---|---|
| Grossman and Krueger (1991) | 1977, 1982 and 1988, annual frequency, $SO_2$, suspended particles matters (SPM), dark matter (smoke), 42 countries for $SO_2$, 19 countries for dark matter, 29 countries for suspended particles | Panel data analysis, random effects, cubic specification | EKC hypothesis confirmed only for SPM. $SO_2$ and dark matter follow a N-shaped pattern. Turning points for $SO_2$ $ 4,500 and $ 15,000 approximately, for dark matter $ 5,000 and $ 10,000 approximately and for SPM around $ 9,000 |
| Seldon and Song (1993) | 1973-1975, 1979-1981, 1982-1984, sample of developed and developing countries, annual frequency, $SO_2$, $NO_x$ (oxides of nitrogen), SPM, CO, GDP, population density | Panel data analysis, cross section, fixed and random effects, quadratic specification | EKC hypothesis is confirmed. Turning points for SPM and $SO_2$ range between $ 8,000 - $ 10,300, for $NO_x$ between $ 11,200 - $ 21,800 and for CO between $ 5,900 – $ 19,100 |
| Seldon and Song (1994) | 1951-1986, 130 countries, annual frequency, $CO_2$, GDP | Panel data analysis, fixed and country specific effects, quadratic and cubic specifications in levels and logs | EKC hypothesis confirmed for level with turning point at $35,428. For logs EKC not confirmed, the turning point is very high approximately at $ 8,000,000 |
| Shafic (1994) | 1960 – 1990, 149 countries, annual frequency, lack of clean water, lack of urban sanitation, SPM, $SO_2$, dissolved oxygen, fecall coliforms in river , carbon emissions, municipal waste, deforestation, GDP | Panel data analysis based on OLS estimates, linear, quadratic and cubic specifications in logs | EKC hypothesis confirmed only for $SO_2$ and SPM. Turning points for SPM and $SO_2$ are $ 3, 280 and $ 3,670 respectively |
| Grossman and Krueger (1995) | 1977, 1982, 1988, 1979-1990, annual frequency, urban pollution, state of the $SO_2$, SPM, oxygen regime in river basins, fecal contamination of river basins and contamination of river basins by heavy metals | Panel data analysis, random effects, cubic specification | EKC hypothesis is confirmed for the majority of indicators. The turning points vary but in most cases they come before a country reaches a per capita income of $ 8, 000 |
| Tucker (1995) | 1971-1991, 137 countries, annual frequency, $CO_2$, GDP | Panel data analysis | EKC is confirmed for the majority of countries |
| Moomaw and Unruh (1997) | 1950-1992, 16 OECD countries, annual frequency, GDP, $CO_2$ | Panel data analysis, fixed effects, cross section effects and country specific regression model, structural transition model | EKC hypothesis confirmed but with inverted – V shape. Turning points for each country vary between $ 8,884 - $ 15,425 |

Table 2.5

| Author(s) | Data | Methodology | Results |
|---|---|---|---|
| Cole et al. (1997) | 1970-1992, OECD countries, annual frequency, $NO_2$, $SO_2$, SPM, CO, $CO_2$, methane, municipal waste, CFCs and halons, GDP, total energy use | Cross-country panel data analysis, quadratic specification in levels and logs | EKC exist only for local air pollutants whilst indicators with a more global or indirect impact either increase monotonically with income or else have predicted turning points at high per capita income levels |
| de Bruyn et al. (1998) | 1961-1993, Netherlands, UK, USA, Western Germany, annual frequency, $CO_2$, $NO_x$, $SO_2$, GDP, energy price index | Estimation of a dynamic OLS model | Economic growth has a direct positive effect on the levels of emissions |
| Torras and Boyce (1998) | 1977-1991, annual frequency, $SO_2$, smoke, heavy particles, dissolved $O_2$, fecal coliform access to sanitation, GDP, population density, etc. | Panel data analysis | Mixed |
| Roca et al. (2001) | 1972-1996 for $CO_2$ and 1980 – 1996 for $SO_2$, $CH_4$, $N_2O$, $NO_x$, NMVOC (non-methanic volatile organic compounds) Spain, annual frequency | Time series model, OLS estimation, cubic specification | EKC hypothesis confirmed only for $SO_2$ |
| Friedl and Getzner (2003) | 1960 – 1999, Austria, annual frequency, $CO_2$, GDP, imports, share of the tertiary (service) sector | Time series model, cointegration test, structural model, linear, quadratic and cubic specifications | EKC hypothesis not confirmed. N-shaped relationship between GDP and $CO_2$ is found to fit the data most appropriately |
| Martinez-Zarzoso and Bengochea-Morancho (2004) | 1975-1998, annual frequency, 22 OECD countries, $CO_2$, GDP | Panel data analysis, pooled mean group estimation, ARDL cointegration approach, cubic specification | EKC hypothesis is not confirmed. For the majority of countries N-shaped curve is found |
| Lantz and Feng (2006) | 1970-2000, Canada (five region), annual frequency, $CO_2$, GDP, population, technological change | Panel data analysis, pooled and fixed effects, quadratic specification | Inverted – U shaped relationship exists with population and technology as explanatory variables. EKC not confirmed when only GDP and $CO_2$ as explanatory variable |

Table 2.6

| Author(s) | Data | Methodology | Results |
|---|---|---|---|
| Aslanidis and Xepapadeas (2006) | 1929-1994, USA, 48 states, $SO_2$, $NO_x$, GDP | Panel data analysis, static smooth transition regression model (STR) | EKC hypothesis is confirmed for $SO_2$ only. There is a robust smooth inverse-V shaped pollution income path for $SO_2$ |
| Soytas et al. (2007) | 1960-2004, USA, annual frequency, $CO_2$, GDP, energy, labor, gross fixed capital formation | Time series model, Granger causality (Toda and Yamamoto procedure) | Income does not cause $CO_2$. Economic growth may not become a solution to problem as suggested by the EKC hypothesis |
| Cialoni (2007) | 1861-2002, Italy, annual frequency, $CO_2$, GDP | Time series model, OLS estimation and index decomposition analysis, linear, quadratic and cubic specifications in logs | Results do not support the EKC hypothesis. The development pathway has not yet reached the turning point |
| Ang (2008) | 1960-2000, France, annual frequency, $CO_2$, GDP, commercial energy use | Time series model, ARDL cointegration approach, Granger causality, quadratic specification | There is support in favor of the EKC hypothesis. Unidirectional causality running from GDP growth to growth of pollutant emissions in the long run |
| Halicoglu (2008) | 1960-2005, Turkey, annual frequency, $CO_2$, GDP, trade openness, energy consumption | Time series model, ARDL cointegration approach, stability tests, Granger causality, quadratic specification | There is some support of the EKC hypothesis. Bidirectional short and long-run causality between $CO_2$ and GDP |
| Annicchiarico et al. (2009) | 1861-2003, Italy, annual frequency, $CO_2$, GDP | Time series model, Engel-Granger cointegration test, rolling regression and error correction modeling technique, GLS, log quadratic specification | EKC hypothesis confirmed for total sample with turning points at $ 39,000 approximately. EKC for sub-period 1861-1959 is rejected and for the sub-sample 1960-2003 is accepted with turning points at $ 20,000 approximately |
| Akbostanci et al. (2009) | 1968-2003 and 1992-2001, Turkey, 58 provinces, annual frequency, $SO_2$, $CO_2$, $PM_{10}$, GDP, population density | Time series model and panel data analysis, Johansen cointegration test, cubic specification | EKC hypothesis is not confirmed neither for time series model nor panel data model |

2.11.5) *Why studies have led to different outcomes about the EKC hypothesis*

There are many factors which are responsible for this and none of them can be regarded as the main one. Some of these could be the following:

1) Different pollution indicators such as carbon dioxide, sulfur dioxide, nitrogen oxide, suspended particle matters, lead, deforestation, DDT, biological oxygen demand, water contamination etc.

2) Different functional forms e.g. quadratic, cubic etc.

3) Different econometric techniques

4) Different sets of explanatory variables. Apart from standard variables such as income other explanatory variables such as energy use, levels of education, freedom rights, population density, regulations, pressure groups etc.

5) Different framework analysis: panel data, cross-country, time series regressions etc.

6) Different time periods and sets of sample size

7) Different measures such as taking the variable in intensive or non intensive form e.g. GDP, GDP per capita, pollutant level, pollutant per capita and of course the logarithms of these measures.

## CHAPTER 3: *ECONOMETRIC METHODOLOGY*

### 3.1) *Model specification*

Following the empirical literature the long-run relationship between carbon dioxide emissions, economic growth, foreign trade and population density could be formed in a linear logarithmic cubic form as follows:

$$co_{2t} = a_0 + a_1 y_t + a_2 y_t^2 + a_3 y_t^3 + a_4 f_t + a_5 pd_t + \varepsilon_t \qquad (1)$$

where $co_{2t}$ is carbon dioxide emissions per capita, $y_t$ is per capita real income, $y_t^2$ is square of per capita real income, $y_t^3$ is cube of per capita real income, $f_t$ is openness ratio which is used as a proxy for foreign trade, $pd_t$ is population density and $\varepsilon_t$ is the regression error term. The lower case letters in equation (1) demonstrates that all variables are in their natural logarithms.

As for the expected signs in equation (1) under the EKC hypothesis, the signs must be : $a_1 \succ 0, a_2 \prec 0, a_3 = 0;$ $|a_2| \ll |a_1|$. The turning point is $y_t^* = \exp\left(-\frac{a_1}{2a_2}\right)$. The expected sign of $a_4$ is mixed depending on the level of economic development stage of a country. In the case of developed countries, it is expected to be negative as countries develop, they cease to produce certain pollution intensive goods and begin to import these from other countries with less restrictive environmental protection laws. This sign expectation is reversed in the case of developing countries as they tend to have dirty industries with heavy share of pollutants (Halicoglu, 2008).

According to Agras and Chapman (1998) variable $f_t$ is the most basic measure of trade intensity, the so-called ‘‘trade *openness* ’’ that is the ratio of exports plus imports to GDP or $\left(\frac{X+M}{GDP}\right)$. According to this trade variable is the most often used. This variable captures total trade, but may not reflect the impact of the differential competition imports and exports. Wycoff and Roop (1994) emphasized this point when they found that the total carbon embodied in imports for six countries was one-fifth of the amount produced annually by the US, more than is generated by Japan, and double that produced by France or Canada. The percentage of carbon embodiment in imports of manufactured goods to total carbon emissions ranges from just 8% for Japan and the US to over 40% for France. This illustrates the importance of including trade as an explanatory variable for changing pollution levels within nations.

Suri and Chapman (1998) included the ratios of imports and exports of all manufactured goods to domestic production of manufactured goods as separate variables $\left(\frac{M_{mfg}}{GDP_{mfg}}\right)$ and $\left(\frac{X_{mfg}}{GDP_{mfg}}\right)$ in an EKC framework. The coefficients of these two variables were expected to be negative and positive, respectively lower emission with increased manufactured imports and higher emissions with increased exports. With per capita energy use as the dependent variable, they found turning points at per capita income levels from \$140,000 to over \$200,000 with the inclusion of the trade variables. For the most part, the trade variables were of the correct signs and highly significant. Their work shows that trade in manufactured goods has an important structural effect on per capita energy use (Agras and Chapman, 1998).

Population density $pd_t$ is another explanatory variable that must be included in the empirical analysis due to the fact that interactions between population growth and environment had been recognized since long past. One well known theory which relates population and environment is that of Malthus.

According to Malthus, a growing population exerts pressure on agricultural land, forcing the cultivation of land of poorer and poorer quality. This environmental degradation lowers the marginal product of labor and, through its effect on income, reduces the rate of population growth. The result is an equilibrium population that enjoys low levels of both income and environmental quality (Cropper and Griffiths, 1994).

An important question for policy is whether, holding constant per capita income and other relevant factors, population pressures have a significant effect on environmental degradation (Cropper and Griffiths, 1994).

Population density is measured simply by dividing country's population with land area which is expressed in square kilometers. The land area of UK since 1830 until today remained almost the same but this is not the case for USA.

In 1800 the land area of USA in square kilometers was around 2,239,692. In 2000 the land area rose to almost 9,160,000 square kilometers. The conclusion is that population density rose in both countries, but in United Kingdom population density rose more quickly. Because of the fact that land area remained unchanged intuitively it could be argued that this variable will be more important in explaining the degradation of the environment (if it really causes environmental degradation) in United Kingdom rather than in USA.

### 3.2) *Pollution indicator and the choice between single country and panel data analysis*

#### 3.2.1) *Arguments in favor of the* $CO_2$

According to Roberts and Grimes (1997) the use of carbon dioxide as the most suitable pollution indicator is justified by the followings reasons:

1) Carbon dioxide is now understood to account for over half of the effect of greenhouse warming

2) Until very recently carbon dioxide, was considered a harmless by-product of clean and efficient combustion. Therefore unlike pollutants which irritate humans directly (such as urban smog-producing compounds and water pollutants), efforts to control carbon dioxide, emissions have come only in the last few years and have been limited to a few European countries. The existence of an inverted U-curve for carbon dioxide, emissions intensity would suggest that pollution reduction might be expected to occur as a natural by-product of economic development improving efficiency, especially in the use of energy.

3) There is apparently no thermodynamically necessary level for the amount of carbon dioxide, a country must emit to have an economy or population of a certain size. Across the world's countries in 1990, national carbon intensity varied by nearly

one hundred fold, while emissions of carbon dioxide per capita varied by over two thousand fold.

4) Estimates of carbon dioxide, emissions are available for far more countries and years than are measures of other types of pollution. This simple problem of data availability has kept many analysts from understanding how the relation has evolved over time.

Friedl and Getzner (2003) in their study about the determinants of carbon dioxide emissions in Austria support the use of annual levels of total carbon dioxide emission as pollution indicator because of the four following reasons:

1) Kyoto reduction targets relate to percentage decreases in annual GHG (Green House Gasses) emission levels (and not decreases in per capita emissions or emissions per unit of output). As has been shown in various studies, total emissions can still increase even when emissions per unit of output decrease. More precisely, the scale effect of economic growth outweighs the composition effect (structural change of the economy) and the technological effect due to higher productive efficiency

2) For a single country (such as Austria) with roughly constant population across the previous decades (annual population growth rates of less than one percent), dividing total emissions by population merely results in scaling down the numbers.

3) Since one of the main contributors to carbon dioxide emissions is (freight and private) transport, emissions should not be related to industrial output.

4) Concentration levels are suitable for local pollutants but not for global pollutants, which cannot be described in local impact levels.

It is important to be mentioned that these arguments in favor of the carbon dioxide is not so strong as those cited above by Roberts and Grimes because they refer to a specific country (Austria) with specific characteristics such as small size and constant population e.t.c, so these arguments cannot be generalized.

3.2.2) *Arguments against the use of the $CO_2$*

As far as studies on carbon dioxide emissions are concerned, the existence of a bell-shaped relationship between pollutant and income, postulated by the EKC hypothesis, has only been confirmed in some panel studies for OECD countries. However, many authors claim that the EKC hypothesis does not hold for global pollutants that have long-lasting effects, and for which abatement costs tend to be high, such as carbon dioxide emissions (Annicchiarico *et al*., 2009). From a theoretical point of view, the inverted-U relationship is less likely for carbon dioxide emissions than for 'traditional' air pollutants such as nitrogen oxide or sulfur dioxide. While these air pollutants have local effects, carbon dioxide emissions cause problems on a global scale, and the social costs of global warming accrue both across time and nations. Therefore, free-rider behavior might lead to a close relationship between carbon emissions and income at all levels of per capita income (Arrow et al., 1995) (Friedl and Getzner, 2003).

Moomaw and Unruh (1997) also observe the problems which emerge when the econometric studies use carbon dioxide time-series. They pay attention on the physical and chemical properties of carbon dioxide. These properties of carbon dioxide including its non-toxicity at present atmospheric concentrations and its diffuse spatial and temporal impacts, make it unlikely that consumers will demand controls of carbon dioxide emissions as a result of local problems. Carbon dioxide is a special pollutant that creates global, not local, disutility. As individual policies cannot solve the global problem through unilateral action, economic theory would hold that the incentive would be to free-ride. Therefore one would not expect, a priori, EKC-like relationships in carbon dioxide emissions data.

Dinda (2004) in a survey of the EKC studies by making distinction between local and global pollution refers that the EKC relationships are more likely to hold for certain types of environmental damage, e.g., pollutants with more short-term and local impacts, rather than those with more global, indirect and long-term. The significant EKCs exist only for local air pollutants like sulfur dioxide, suspended particulate matter, nitrogen oxide and carbon monoxide and urban air concentrations with a peak at lower income levels than total per capita emissions. In contrast, the global environmental indicators (indirect impact) like refers that, municipal waste, energy consumption and traffic volumes, either increase monotonically with income or have high turning points with large standard errors.

Further to this Rothman (1998) and Stern (1998) argue that the EKC pattern is usually found to hold for pollutants with local impacts, such as $SO_2$ and particulate matter, which cannot easily be externalized. However, the same can be argued for the carbon dioxide and municipal waste. The key point is that carbon dioxide emissions and municipal solid waste, two indicators that do not decline at higher income levels, are relatively easy to externalize.

The reason why this happens is because wealthy consumers in developed countries develop a demand for a cleaner environment which leads to more stringent environmental regulations and to the relocation of dirty industries abroad. The result of this is a decline in the levels of pollutants arising from production. However, pollutants arising from consumption, such as solid waste and carbon dioxide emissions (arising from automobile use and the burning of fossil fuels for the generation of electricity) continue to rise because they are easily externalized and thus not subject to regulations. Carbon dioxide emissions have an impact on the global environment, rather than the immediate environment. Thus, it is not the case that wealthy consumers become more conscious of the global environment; rather, they develop a taste for a cleaner immediate environment, hence the regulations that are enforced on firms producing pollutants with local impacts such as sulfur dioxide and particulate matter. The fact that only the levels of these pollutants, which cannot be easily externalized, fall with PCI, whilst the levels of easily externalized pollutants such as solid waste and carbon dioxide continue to rise, suggests that, as far as wealthy consumers are concerned, '*out of sight is out of mind* '. (Nahman and Antrobus, 2005)

3.2.3) *Justification of empirical analysis in the framework of individual country instead of panel.*

Historical studies of individual countries offers an advantage over cross-section approaches in bringing the analyses closer to the dynamics that cause the EKC pattern. Even though time series have been used, the time periods have been brief in comparison to the total length of the fossil fuel era, which for contemporary high-income countries dates from the industrialization of the 19th or even 18th centuries. It has also been suggested that EKCs based on time series data show much less stable development paths as compared with EKCs derived from cross-section data. In a study from 1998, Unruh and Moomaw (1998) examine apparent EKCs for $CO_2$ by using a non-linear approach. Their investigation suggests that the EKC trajectories exhibit behaviour that they call punctuated equilibrium. This means that a shock for example, in this case the OPEC crisis of 1973, caused the pollution trajectory to move towards a new attractor. Unruh and Moomaw point out the difficulties in applying ordinary analytical methods under such circumstances since dynamic systems, in practice non-linear feedback systems, may display complex behavioural patterns. The general conclusion that can be drawn from Unruh and Moomaw’s investigation is, therefore, that historical context is of primary importance in EKC analyses (Lindmark, 2002).

According to Soytas *et al*. (2007) individual countries may have different economic characteristics that may yield different causality directions. Even countries at the same level of economic development may have differing economic dynamics through which inputs interact. Depending on the direction of causality, different policy options may be available to these countries (Soytas *et al*., 2007).

Friedl and Getzner (2003) also support the idea of investigating the EKC hypothesis in the individual country framework. As they say: “*Two of the main points of criticism of the EKC hypothesis are, first, that the inverted U-shape is merely a statistical result (a juxtaposition) and not a common development path holding for the subsets of industrialized or developing countries since it is derived from cross-section data), and second, that by abstracting from other causalities besides income and emissions the EKC hypothesis does not account properly for crucial historic developments and unique events such as the oil crisis in the mid-seventies. Therefore, investigations of the EKC relationship for one single country could shed some light on the validity of the claim that economic development might improve environmental quality.*”

Ang (2008) supports his view in using individual country because this allows capturing and accounting for the complexity of the economic environments and histories of each individual country.

### 3.3) *Econometric techniques*

In the empirical analysis we first apply a variety of unit root and stationarity tests in order to examine if our variables are integrated or not. Secondly we estimate the time series model. Next we conduct cointegration tests in order to find out if the results of the OLS estimated model are spurious. Apart from that we employ Symmetric, Asymmetric and Non-Linear Error Correction Models. AECM helps us to investigate if speed of adjustments towards long-run equilibrium depends crucially on whether deviations from equilibrium are positive or negative. On the other hand NLECM refers to non-linear adjustment to long-run equilibrium. Non-Linear adjustments by contrast allows for faster adjustments when deviations from the equilibrium level get larger.

#### 3.3.1) *Unit root tests*

##### 3.3.1.1) *ADF test*

The first unit root test that we will apply is ADF (1979) test. The ADF test constructs a parametric correction for higher-order correlation by assuming that the series follows an AR(*k*) process and adding lagged difference terms of the dependent variable to the right-hand side of the test regression (Waheed *et al*., 2006). The unit root hypothesis ($a = 0$) can be tested according to the following models:

$$\Delta y_t = a y_{t-1} + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \qquad (1)$$

$$\Delta y_t = c + a y_{t-1} + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \qquad (2)$$

$$\Delta y_t = c + a y_{t-1} + \beta_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \qquad (3)$$

The second model is called ADF test with drift because it includes a constant term and the third model is called ADF test with drift and trend. Model 2 tests for the null of a unit root against a mean-stationary alternative in $y_t$ where $y$ refers to the time series examined, and model 3 tests the null of a unit root against a trend-stationary alternative. The term $\Delta y_{t-j}$ is lagged first differences to accommodate serial correlation in the errors (Waheed *et al*., 2006). The optimal lag length is selected according to information criteria.

#### 3.3.1.2) *DF-GLS test*

Elliot, Rothenberg and Stock (1996) propose a simple modification of the ADF approach to construct DF-GLS test, in which the time series are de-trended so that explanatory variables are "taken out" of the data prior to running the test regression (Waheed *et al*., 2006). Ng and Perron (2001) argue that this test is the more powerfull.

#### 3.3.1.3) *KPSS test*[2]

Kwiatkowski, Phillips, Schmidt, and Shin (KPSS, 1992) proposed another test in order to check if time-series are integrated or not.

The KPSS test differs from the other unit root tests in that the series is assumed to be trend-stationary under the null. The KPSS statistic is based on the residuals from the OLS regression $y_t$ of on the exogenous variables $x_t$ :

$$y_t = x_t'\delta + u_t \quad (4)$$

The LM statistic is be defined as:

$$LM = \sum_t \frac{S(t)^2}{(T^2 f_0)} \quad (5)$$

where $f_0$, is an estimator of the residual spectrum at frequency zero and where $S(t)$ is a cumulative residual function:

$$S(t) = \sum_{r=1}^{t} \hat{u}_r \quad (6)$$

based on the residuals $\hat{u}_t = y_t - x_t'\hat{\delta}(0)$. We point out that the estimator of $\delta$ used in this calculation differs from the estimator for $\delta$ used by GLS de-trending since it is based on a regression involving the original data and not on the quasi-differenced data.

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3.3.1.4) *Zivot – Andrews test*

An important drawback of the conventional unit root tests such as the ADF and DF - GLS tests, is that they do not allow for the possibility of a structural break. It is important however to check the data for structural breaks. This can be done by using the test proposed by Zivot and Andrews (1992).

Zivot and Andrews proceed with three models to test for a unit root:

$$\Delta y_t = c + ay_{t-1} + \beta t + \gamma DU_t(\lambda) + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \qquad (7)$$

$$\Delta y_t = c + ay_{t-1} + \beta t + \theta DT_t(\lambda) + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \qquad (8)$$

$$\Delta y_t = c + ay_{t-1} + \beta t + \gamma DU_t(\lambda) + \theta DT_t(\lambda) + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \qquad (9)$$

where:

$\lambda = T^B / T$ is the break fraction;

$DU_t(\lambda) = 1$ if $t > T\lambda$

$DU_t(\lambda) = 0$ otherwise;

$DT_t(\lambda) = t - T\lambda$ if $t > T\lambda$

$DT_t(\lambda) = 0$ otherwise; and

$y_t$ is the time series being tested.

In this testing procedure, the null hypothesis ($a = 0$) is a unit root process without any structural breaks and the relevant alternative hypothesis ($a < 0$) is a trend stationary process with possible structural change occurring at an unknown point in time.

The $t$ th regression allows both the slope and intercept to change at date $T^B$. Hence it can accommodate both a discontinuous jump in the trend line and a continuous trend with a kink at date $t = T^B$. Eq. (1) estimated with $\gamma$ equal to zero allows for a brak in the intercept, while Eq. Estimated with $\theta$ equal to zero allows for a break in the slope.

The estimation strategy is to estimate the models allowing both the break points and the lag length to vary endogenously (Sadorsky, 1999).

The Zivot – Andrews (1992) method regards every point as a potential break-date ($T^B$) and runs a regression for every possible break-date sequentially. From amongst all possible break-points ($T^B$), the procedure selects as its choice of break-date ($T^B$) the date which minimizes the one-sided t-statistic for testing $\hat{a}(=a-1)=1$. According to Zivot and Andrews, the presence of the end points cause the asymptotic distribution of the statistics to diverges towards infinity. Therefore, some region must be chosen such that the end points of the sample are not included. Zivot and Andrews suggest the 'trimming region' be specified as (*0.15T, 0.85T*) (Waheed *et al*., 2006).

Waheed *et al*. (2006) refers that Perron suggested that most economic time series can be adequately modelled using either model 1) or model 3). As a result, the subsequent literature has primarily applied model A and/or model C. Sen (2003) shows that if one uses model 1) when in fact the break occurs according to model 3) then there will be a substantial loss in power. However, if break is characterized according to model 1), but model 3) is used then the loss in power is minor, suggesting that model 3) is superior to model 1).

3.3.1.5) *Unit root test with structural break*

A stationary time-series may look like nonstationary when there are structural breaks in the intercept or trend, leading to false nonrejection of the null hypothesis. Therefore, a shift function *f* may be added to the deterministic term of $q_t$. Hence, a model

$$q_t = a + \eta t + \gamma f_t(\theta)' + \varepsilon_t \qquad (10)$$

is considered, where $\theta$ and $\gamma$ are unknown parameters. The first one is confined to the positive real line, whereas the second one may assume any value. The shift function can be viewed as a rational function in the lag operator applied to a shift dummy $d_{1t}$,

$$f_t(\theta) = \left[\frac{d_{1,t}}{1-\theta L} : \frac{d_{1,t-1}}{1-\theta L}\right]' \qquad (11)$$

Here the actual shift term is $\left[\gamma_1(1-\theta L)^{-1} + \gamma_2(1-\theta L)^{-1}\right]d_{1t}$, where $\theta$ is a scalar parameter between 0 and 1 and $\gamma = (\gamma_1 : \gamma_2)'$ is a two dimensional parameter vector.

Saikkonen and Lutkepohl (2002) and Lanne, Lutkepohl and Saikkonen (2002) propose unit root tests for the model (10) which are based on estimating the deterministic term first by a generalized least squares (GLS) procedure under the unit root null hypothesis and subtracting it from the original series. Then an ADF type test is performed on the adjusted series which also includes terms to correct for estimation errors in the parameters of the deterministic part. As in the case of the ADF statistic, the asymptotic null distribution is nonstandard. Critical values are tabulated in Lanne et al. (2002).

### 3.3.2) *Cointegration tests*

#### 3.3.2.1) *Engle-Granger test*

The finding that many macro time series may contain a unit root has spurred the development of the theory of non-stationary time series analysis. Engle and Granger (1987) pointed out that a linear combination of two or more non-stationary series may be stationary. If such a stationary linear combination exists, the non-stationary time series are said to be co-integrated. The stationary linear combination is called the cointegrating equation and may be interpreted as a long-run equilibrium relationship among the variables.

This test is conducted in two-steps. First we estimate the OLS regression between dependent and explanatory variables. Second we conduct unit root tests in the residuals of a first-stage regression. If residuals don't have unit root then the variables are co-integrated. On the other hand if residuals are not stationary the variables are not co-integrated.

More specifically, as a first step we estimate the $y_t = c + ax_t + u_t$. As a second step we receive the estimated residuals $\hat{u}_t = y_t - \hat{c} - \hat{a}x_t$ and conduct unit root tests.

#### 3.3.2.2) *Johansen cointegration test*[3]

This cointegration test is based on the methodology developed by Johansen (1991, 1995).

[3] Eviews 5 User's Guide

Consider a VAR of order $p$ :

$$y_t = A_1 y_{t-1} + ... + A_p y_{t-p} + Bx_t + \varepsilon_t \quad (12)$$

where $y_t$ is a $k$-vector of non-stationary I(1) variables, $x_t$ is a $d$-vector of deterministic variables, and $\varepsilon_t$ is a vector of innovations. We may rewrite this VAR as,

$$\Delta y_t = \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + Bx_t + \varepsilon_t \quad (13)$$

where:

$$\Pi = \sum_{i=1}^{p} A_i - I \ \ (14)\ ,\ \Gamma_i = -\sum_{j=i+1}^{p} A_j \ \ (15)$$

Granger's representation theorem asserts that if the coefficient matrix $\Pi$ has reduced rank $r < k$, then there exist $k \times r$ matrices $a$ and $\beta$ each with rank $r$ such that $\Pi = \alpha\beta'$ and is I(0). $r$ is the number of cointegrating relations (the *cointegrating rank*) and each column of $\beta$ is the cointegrating vector. As explained below, the elements of $a$ are known as the adjustment parameters in the VEC model. Johansen's method is to estimate the $\Pi$ matrix from an unrestricted VAR and to test whether we can reject the restrictions implied by the reduced rank of $\Pi$. Johansen proposes two different likelihood ratio tests of the significance of reduced rank of the $\Pi$ matrix: the trace test and maximum eigenvalue test, shown in equations (17) and (18) respectively.

$$J_{trace} = -T \sum_{i=r+1}^{n} \ln(1-\hat{\lambda}_i) \quad (16) \quad \text{and} \quad J_{\max} = -T \ln(1-\hat{\lambda}_{r+1}) \quad (17)$$

$T$ is the sample size and $\hat{\lambda}_i$ is the $i$:th largest canonical correlation. The trace test tests the null hypothesis of $r$ cointegrating vectors against the alternative hypothesis of $n$ cointegrating vectors. The maximum eigenvalue test, on the other hand, tests the null hypothesis of $r$ cointegrating vectors against the alternative hypothesis of $r$ +1 cointegrating vectors. Neither of these test statistics follows a chi square distribution in general; asymptotic critical values can be found in Johansen and Juselius (1990)

3.3.2.3) *Cointegration test with structural break*

*Johansen et al.* (2000) discuss the test specification in case of structural breaks, where the observed time series is divided into sub-samples according to the position of the break points. The model in this case is defined by the equation:

$$\Delta y_t = \Pi y_{t-1} + Bx_t + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \sum_{i=1}^{p} \sum_{j=2}^{q} k_{j,i} D_{j,t-i} + \varepsilon_t \qquad (18)$$

where the $k_{j,i}$ dummy parameters are defined as:

$$D_{j,t} = \begin{Bmatrix} 1, t = T_{j-1} \\ 0, otherwise \end{Bmatrix}, \quad j = 1,....,q; \quad t = ...,-1,0,1,...,$$

so that $D_{j,t-i}$ is an indicator function for the $i-th$ observation in the $j-th$ period and $T_j$ is the break point.

The likelihood ratio test statistic for the hypothesis of at most *r* cointegrating relations is still given by equation

$$LR(r/k) = -T \sum_{i=r+1}^{k} \log(1-\lambda_i)$$

3.3.2.4) *Saikkonen & Lutkepohl cointegration test*

The cointegration test is based on the following general model:

$$y_t = D_t + x_t$$

where $y_t$ is a *K*-dimensional vector of observable variables, $D_t$ is a deterministic term, e.g., $D_t = \mu_0 + \mu_1 t$ may be a linear trend term, and $x_t$ is a VAR(*p*) process with vector error correction model (VECM) representation.

Saikkonen & Lutkepohl (2000 a,b,c) have proposed test which proceed by estimating the deterministic term $D_t$ first, subtracting it from the observations and applying a Johansen type test to the adjusted series. In other words, the test is based on a reduced rank regression of the system

$$\Delta \tilde{x}_t = \Pi \tilde{x}_{t-1} + \sum_{j=1}^{p-1} \Gamma_j \Delta \tilde{x}_{t-j} + \tilde{u}_t \qquad (19)$$

where $\tilde{x}_t = y_t - \tilde{D}_t$ and $\widetilde{D}_t$ is the estimated deterministic term. The parameters of the deterministic term are estimated by the GLS procedure proposed by Saikkonen and

Lutkephol. The critical values depend on the kind of deterministic term included. It should be noticed that trend breaks are ignored by this test.

3.3.2.5) <u>*Error correction models*</u>

Single – Equation Error correction models (ECM), symmetric, asymmetric (AECM) and non-linear error correction model (NECM) are considered also.

If $x_t, y_t$ are both $I(1)$ then it is typically true that any linear combination $x_t + by_t$ will also be *I*(1). However, for some pairs of *I* (1) series there does exist a linear combination $z_t = x_t - Ay_t$ that is *I*(0). When this occurs, $x_t, y_t$ are said to be co-integrated. If $x_t, y_t$ are co-integrated they may be considered to be generated by a symmetric error-correcting model of the form :

$$\Delta x_t = \rho_1 z_{t-1} + lagged(\Delta x_t, \Delta y_t) + \varepsilon_{xt} \quad (20)$$

where at least one of $\rho_1, \rho_2$ is non-zero and $\varepsilon_{xt}$, are jointly white noise.

The error corrections in the models considered above are symmetric so that the extent of the effect $|z_{t-1}|$ is the same regardless of the sign of $z_{t-1}$. However, when the current level of shares (or indices) is determined, it may well matter whether $z_{t-1}$ (the disequilibria from the previous day/week/month/year) was positive or negative. To investigate these possibilities further sets of error correction models (*asymmetric error correction models*) were examined, using the notation (Granger and Lee, 1989), $z = z^{+} + z^{-}$, $z^{+} = max\ (z, 0)$ and $z^{-} = min\ (z, 0)$.

$$\Delta x_t = \rho_{11} z_{t-1}^{+} + \rho_{12} z_{t-1}^{-} + lagged(\Delta x_t, \Delta y_t) + \varepsilon_{xt} \quad (21)$$

Lastly, we are going to briefly discuss the non-linear error correction model. This basically refers to non-linear adjustment to long-run equilibrium economic relationships. This type of non-linear adjustment allows for faster adjustment when deviations from the equilibrium level get larger. Further, it allows for the possibility of more than one equilibrium when the additional regressors, that is $z_{t-1}^2$ and $z_{t-1}^3$, are statistically significant. In that sense, the cubic error correction model is more flexible than the Granger and Lee (1989) type of asymmetric adjustment. This model can be viewed as an approximation of the Smooth Transition model (see Terasvirta and Eliason, 2001).

Following Escribano and Granger (1998), the non-linear error correction model may be written as:

$$\Delta x_t = \rho_{11} z_{t-1} + \rho_{12} z_{t-1}^2 + \rho_{13}^3 + lagged(\Delta x_t, \Delta y_t) + \varepsilon_{xt} \qquad (22)$$

Escribano and Granger (1998) point out that "The non-linear error correction terms should be considered as local approximations to the true non-linear specifications if it occurs. In particular, if $z_{t-1}$ enters as a cubic it would produce a non-stable difference equation for $x_t$, since for large values $z_{t-1}$ the cubic polynomial is unbounded, and so would not be appropriate as this series is supposed to be I(0)." (Panagiotidis, 2009)

3.3.3) *Phase diagrams*

According to EKC hypothesis a developing country go through "stages of economic growth" such as moving from agricultural economy to industrial as they develop.

Unruh and Mooway (1998) say that if it is true that all countries pass through these developmental stages and that these stages and the transitions between them correlate with specific per capita income ranges, then it is plausible that pollution levels could first rise and then fall as average incomes increase. However, it is not certain whether 'stages of economic growth' is a deterministic process that all countries must pass through, or a description of the development history of a specific group of countries in the 19th and 20th centuries that may or may not be repeated in the future.

This question is important because much of the EKC literature explicitly assumes that the emissions and income data for many countries can be reduced to a single pollution-GDP development trajectory (Unruh and Mooway, 1998).

Both authors believe that there is no convincing evidence that all countries must, or will, replicate the experience of the presently industrialized countries, which themselves have followed economic development and pollution paths as different as those of the USA, France and Japan.

The emphasis on correlating environmental degradation with GDP growth depends upon the implicit assumption of ‘income determinism’. There are important policy reasons to evaluate whether this is a valid assumption and whether EKC is a useful mode of analysis for policy purposes. Is it really the common experience of reaching a particular income level that causes all countries to turn the corner and begin reducing their pollution levels, and should the emphasis of the analysis be on identifying a particular value for the income turning point? Or are such transitions induced by specific policies, economic incentives and historic events that could be replicated by countries regardless of their income levels?

In order to understand the methodology applied by Unruh and Mooway (1998) definitions of dynamical systems, attractors and punctuated equilibrium required.

Dynamical systems are nonlinear feedback systems that can produce complex behavior from relatively simple functions. Research on such systems has become well known as ‘chaos’ studies. These systems are generally characterized by multiple or even an infinite number of solutions, indicating that a multitude of states are possible. Because there is no single solution, analytic methods are often difficult to apply. Researchers have therefore relied on phase space diagrams to identify possible limits to the range of potential solutions (Cambel, 1993). A useful approach for this analysis is a time-evolving space that compares emissions in the previous year (*y*-axis) with those in the current year (*x*-axis). The dynamics of a selected system, in this case per capita CO2 emissions from a national economy, traces out a trajectory in phase space which can reveal whether the measure is changing in a systematic or irregular fashion. Systems will sometimes be ‘attracted’ to a region of the phase space indicating that emissions are fluctuating around an average value. It should be noted that attractors and chaos have precise mathematical definitions. Chaos has been demonstrated mostly in well defined physical systems in which experimentation can be repeated and from which detailed, frequent measurements can be made (Tong, 1990 and Murray, 1990). Due to the nature of economic and pollution data and their measurement, repeated experiments and measurements are not available for many socioeconomic systems. Therefore, in this paper, phase diagrams will be used qualitatively to illustrate the dynamics of pollutant emissions from selected countries. Systems sometimes exhibit a behavior term called ‘punctuated equilibrium’, borrowed from the evolutionary theory which bears the name. Periods of stable attractors are considered to be in figurative ‘equilibrium’ and are ‘punctuated’ by shocks which break the trajectory out of one attractor and possibly into new attractor equilibria. Inspection of the attached phase diagrams and the discussion that follows illustrates these concepts. Whereas the EKC hypothesis seeks correlations between temporally paired variables such as emissions and income, phase diagram analysis reveals the behavior of an individual emissions variable through time. Hence complete time series data are most useful for the purposes of analysis. However, there are few national data sets which include time series with measures of emissions before and after a transition to stable or declining levels (Unruh and Moomaw, 1998).

# CHAPTER 4: *STATISTICAL DATA*

The time series data utilized in this thesis covers long period, since 19th century until today. More specifically, the data for the USA is from 1800 to 2005 and for the United Kingdom from 1830 to 2005. All observations are in annual frequency and are transformed into logarithms.

Carbon dioxide emissions measured in millions of metric tons is the pollution indicator and dependent variable. These time series data are taken from the Carbon Dioxide Information Analysis Center (http://cdiac.ornl.gov). Data on population since 1830 to to 2005 is taken from the website (www.historicalstatistics.org). For the USA data on population since 1800 to 1829 is taken from International Historical Statistics (Mitchell, 2003). Real GDP and Real GDP per capita data measured in dollars for USA and in pounds for UK is taken from the website (www.measuringworth.com). Base year for the USA is 2000 and for UK is 2003. Data on imports and exports are taken from International Historical Statistics (Mitchell, 2003). Time series of land area measured in square kilometers are taken from website (http://www.infoplease.com) for UK and from Census Bureau (www.census.gov) for USA.

## CHAPTER 5: *EMPIRICAL RESULTS*

We begin our analysis by presenting some descriptive statistics of our variables. We prefer to present statistics only for Real GDP per capita and carbon dioxide emissions because these two variables are of great importance. As can be seen from tables below per capita GDP rose dramatically over the past two centuries in both countries. This reflects the high progress of the industrialized countries of the “West” which have been achieved during this long period. On the other hand per capita emissions rose too. The differences between minimum and maximum values are big enough. The mean value of per capita emissions is however almost the same in both countries.

Table 5.1. Summary Statistics, 1800-2005, USA

| Variable | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|
| Per capita carbon dioxide emissions | 2.562 | 2.149 | 0.013 | 6.236 |
| Per capita real GDP | 8902.07 | 9507.12 | 1219 | 37122 |
| Observations | 206 | | | |

Emissions measured in metric tons. GDP per capita measured in 2000 US dollars.

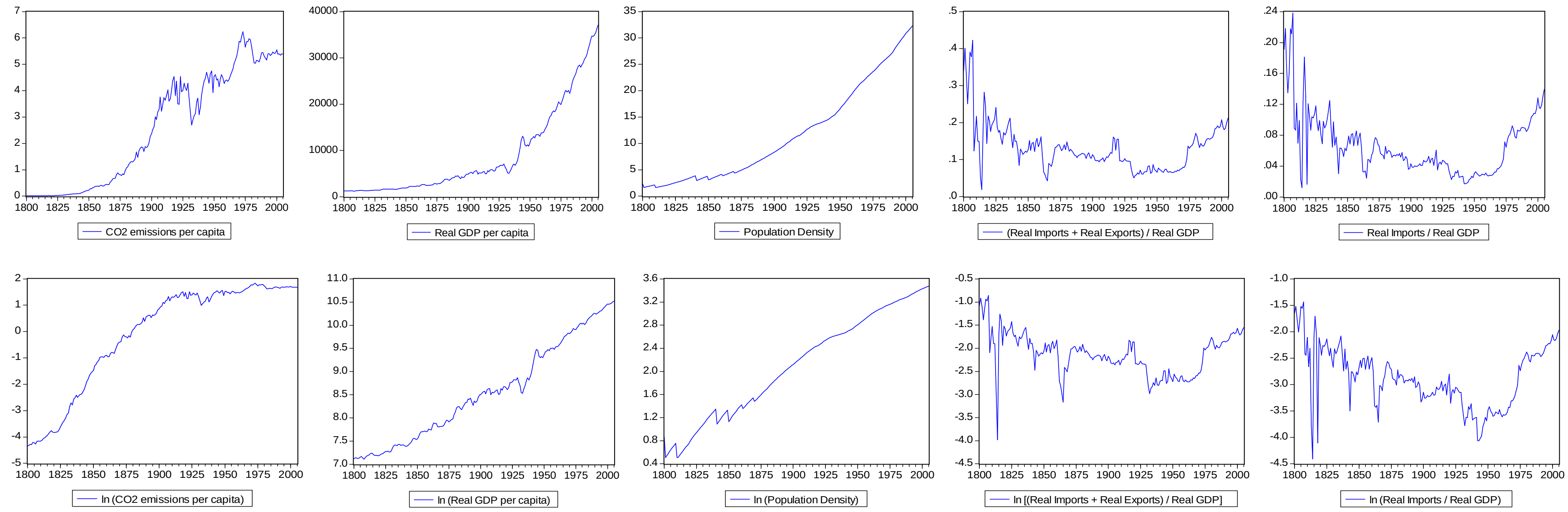
Table 5.2 . Summary Statistics, 1830-2005, UK

| Variable | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|
| Per capita carbon dioxide emissions | 2.363 | 0.709 | 0.699 | 3.223 |
| Per capita real GDP | 6017.91 | 4430.92 | 1661.09 | 19521.17 |
| Observations | 176 | | | |

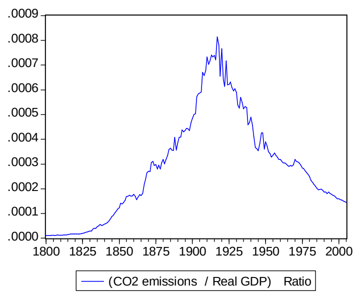
Emissions measured in metric tons. GDP per capita measured in 2003 UK pounds.

After brief discussion of statistical properties a graphical representation of time series of variables is necessary in order to see how variables evolved over the period we study. More attention should be paid to those diagrams which depict variables expressed in logarithmic form.

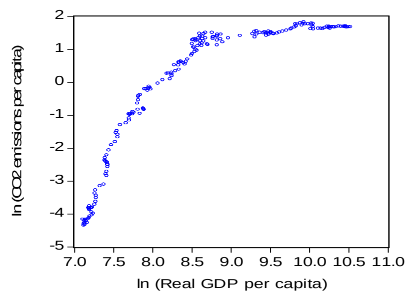
Graphical representation of time series of variables  and of the EKC, USA



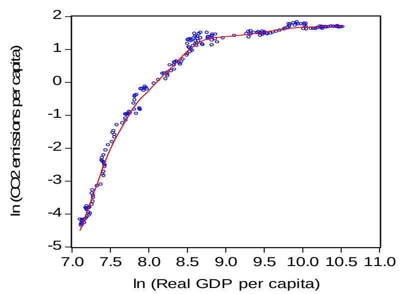

$CO_2$ emissions intensity



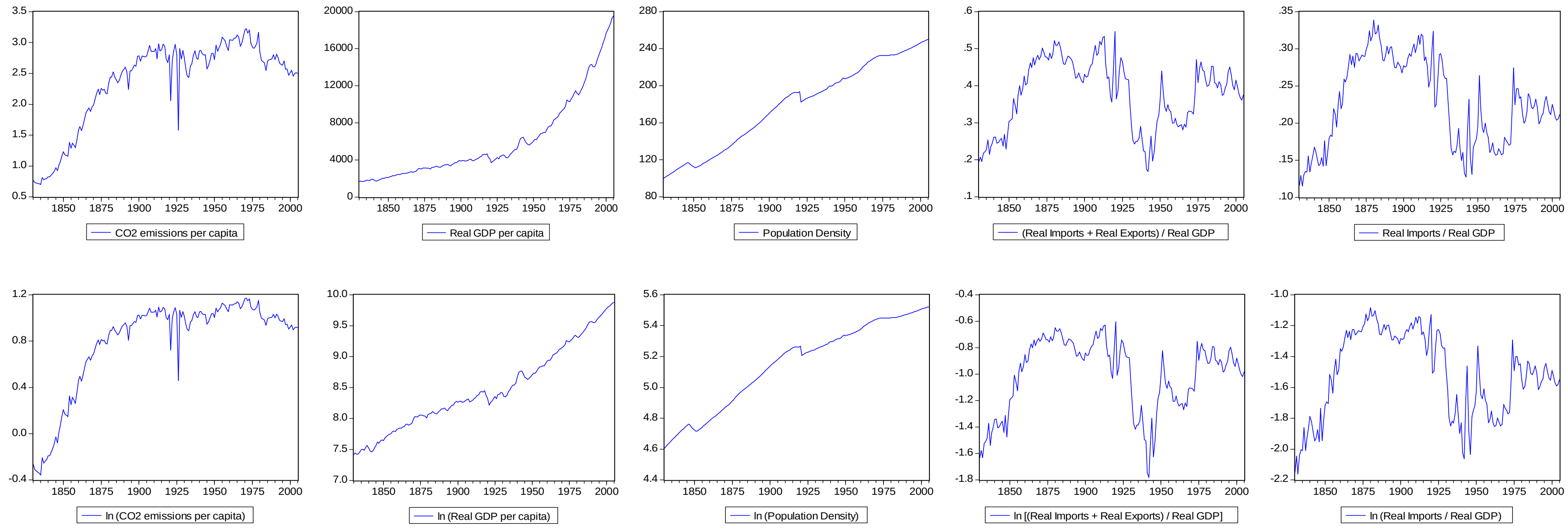

EKC of the USA



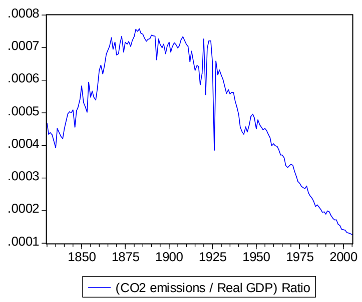

Nearest neighbor fit



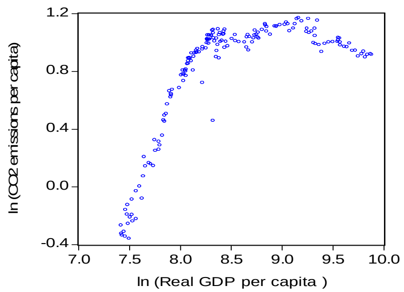
Graphical representation of time series of variables and of the EKC, UK



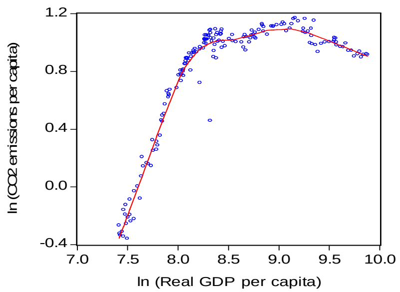

CO$_2$ emissions intensity




EKC of the UK




Nearest neighbor fit



The first thing that one can notice from diagrams above is that almost all series are nonstatioary in levels  and as can be seen from table 5.3 they show a significant trend. An exception could be the variables of trade openness for both countries which seems to be stationary despite the presence of outliers especially in the case of USA. Of course it is wrong to make speculations about stationarity of series by observing only their diagrams. Statistical results of unit root and stationarity tests will provide clearer picture.

As far as concerned the graphs of the Environmental Kuznets Curves they do not show the shape that EKC hypothesis supports. In both cases we see an increase of per capita emissions of carbon dioxide as the real per capita GDP rises. In case of the UK of course the trajectory seems to have reached the turning point and begin to decline. We can't observe the same in case of the USA where carbon dioxide stops to rise but don't decline, instead they stabilize.

An important thing to be mentioned is that the absence of the relation between pollution and growth that EKC hypothesis supports graphically doesn't mean that this hypothesis is wrong. It could be argued that we will observe this decline in pollution in near future. The trajectory simply has covered the half-way.

We can proceed now to the analysis of unit root and stationarity tests. Table 5.3 show that for the majority of tests trend is statistically significant so those unitr root and stationarity test which take this characteristic into account are more reliable. It would be more wise to base our conclusion to the results of these tests. By not incorporating trend in tests could lead to misleading results. Tables 5.4 and 5.5 summarize the results of unit root and stationarity tests in levels and first difference.

Table 5.3. Trend Significance Test

| | USA | UK |
|---|---|---|
| | t-statistic for trend coefficient | t-statistic for trend coefficient |
| ln (CO2 emissions per capita) | 32.93*** | 15.35*** |
| ln (Real GDP per capita) | 94.09*** | 66.41*** |
| ln(Real GDP per capita squared) | 73.32*** | 57.41*** |
| ln(Real GDP per capita cubic) | 59.16*** | 49.97*** |
| ln (Population Density) | 147.12*** | 63.31*** |
| ln (trade Openness 1) | -5.000*** | 1.559 |
| ln (trade Openness 2) | -4.410*** | -0.518 |

***, **, * denote statistical significance at 1%, 5% and 10% respectively

| Table 5.4 . Unit Root and Stationarity Tests for Levels ln, USA | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO2 per capita | | Real GDP per capita | | Population Density | | Trade Openness 1 | | Trade Openness 2 | |
| | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year |
| ADF | -3.798*** | | 0.660 | | 0.063 | | -4.502*** | | -3.929*** | |
| ADF (trend) | -0.0968 | | -3.063 | | -4.333*** | | -4.496*** | | -4.644*** | |
| DF-GLS | 2.646*** | | 3.024*** | | 3.123*** | | -1.937* | | -1.719* | |
| DF-GLS (trend) | 0.4901 | | -1.818 | | -2.012 | | -3.291** | | -2.718* | |
| KPSS | 1.843 | | 2.069 | | 2.099 | | 0.620* | | 0.597* | |
| KPSS (trend) | 0.514 | | 0.368 | | 0.2186 | | 0.276 | | 0.331 | |
| Zivot - Andrews | -2.656 | 1825 | -5.136** | 1938 | -3.675 | 1880 | -6.824*** | 1972 | -7.064*** | 1972 |
| Zivot - Andrews (trend) | -3.706 | 1878 | -5.769*** | 1938 | -3.760 | 1885 | -7.061*** | 1972 | -8.056*** | 1941 |

| Table 5.5 . Unit Root and Stationarity Tests for First Differences, USA | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CO2 per capita | | Real GDP per capita | | Population Density | | Trade Openness 1 | | Trade Openness 2 | |
| | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year |
| ADF | -14.130*** | | -10.632*** | | -18.627*** | | -14.571*** | | -15.924*** | |
| ADF (trend) | -15.345*** | | -10.698*** | | -18.570*** | | -14.629*** | | -16.011*** | |
| DF-GLS | -14.040*** | | -10.658*** | | -0.3887 | | -12.380*** | | -12.769*** | |
| DF-GLS (trend) | -14.478*** | | -10.701*** | | -1.701 | | -12.482*** | | -14.574*** | |
| KPSS | 1.139 | | 0.2351*** | | 0.148*** | | 0.421** | | 0.332*** | |
| KPSS (trend) | 0.099*** | | 0.0334*** | | 0.135** | | 0.114*** | | 0.049*** | |
| Zivot - Andrews | -11.557*** | 1822 | -9.380*** | 1932 | -12.049*** | 1810 | -15.659*** | 1813 | -16.656*** | 1813 |
| Zivot - Andrews (trend) | -11.662*** | 1854 | -9.532*** | 1932 | -12.716*** | 1810 | -16.828*** | 1813 | -17.442*** | 1813 |

***,**,* denote significance at 1%, 5% and 10% respectively. The optimal lag length (not reported) was selected through Schwarz information criteria. The critical values of the tests for 1%, 5% and 10% significance level are: -3.462, -2.875, -2.574 and -4.003, -3.431, -3.139 (when trend is taken into account) for ADF, -2.576, -1.942, - 1.611 and -3.460, -2.929, -2.638 (when trend is taken into account) for DF-GLS, 0.739, 0.463, 0.347 and 0.216, 0.146, 0.119 (when trend is taken into account) for KPSS and -5.34, -4.80, -4.58 (when break in intercept is allowed) and -5.57, -5.08, -4.82 (when break in intercept and trend is allowed ) for Zivot and Andrews. For the KPSS we follow Hobiju et al. (2004) who suggest applying the Newey and West (1994) automatic bandwidth selection procedure for the Quadratic Spectral Kernel.

Table 5.6. Unit Root and Stationarity Tests for Levels ln, UK

| | CO2 per capita | | Real GDP per capita | | Population Density | | Trade Openness 1 | | Trade Openness 2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year |
| ADF | -5.267*** | | 1.114 | | -2.144 | | -2.813* | | -2.575* | |
| ADF (trend) | -2.108 | | -1.163 | | -1.012 | | -2.721 | | -2.690 | |
| DF-GLS | 0.1704 | | 3.911*** | | 1.975** | | -0.9108 | | -0.600 | |
| DF-GLS (trend) | -0.6230 | | -1.308 | | -0.615 | | -1.662 | | -1.109 | |
| KPSS | 1.222 | | 1.795 | | 1.814 | | 0.193*** | | 0.275*** | |
| KPSS (trend) | 0.395 | | 0.356 | | 0.400 | | 0.203* | | 0.260 | |
| Zivot - Andrews | -3.663 | 1846 | -2.536 | 1962 | -2.830 | 1872 | -4.187 | 1920 | -4.210 | 1926 |
| Zivot - Andrews (trend) | -4.031 | 1859 | -6.028*** | 1918 | -3.369 | 1920 | -3.955 | 1920 | -3.646 | 1926 |

Table 5.7. Unit Root and Stationarity Tests for First Differences, UK

| | CO2 per capita | | Real GDP per capita | | Population Density | | Trade Openness 1 | | Trade Openness 2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year | t-statistic | Break Year |
| ADF | -19.940*** | | -10.130*** | | -6.053*** | | -12.025*** | | -13.683*** | |
| ADF (trend) | -12.664*** | | -10.248*** | | -6.413*** | | -12.097*** | | -13.796*** | |
| DF-GLS | -15.269*** | | -8.859*** | | -3.115*** | | -3.922*** | | -2.784*** | |
| DF-GLS (trend) | -17.634*** | | -9.525*** | | -6.089*** | | -11.392*** | | -11.046*** | |
| KPSS | 0.565* | | 0.401** | | 0.508* | | 0.172*** | | 0.297*** | |
| KPSS (trend) | 0.100*** | | 0.136** | | 0.056*** | | 0.091*** | | 0.135** | |
| Zivot - Andrews | -13.895*** | 1925 | -8.493*** | 1931 | -6.985*** | 1914 | -13.393*** | 1941 | -14.559*** | 1941 |
| Zivot - Andrews (trend) | -13.452*** | 1925 | -8.517*** | 1920 | -7.816*** | 1850 | -13.372*** | 1941 | -14.524*** | 1941 |

***,**,* denote significance at 1%, 5% and 10% respectively. The optimal lag length (not reported) was selected through Schwarz information criteria. The critical values of the test for 1%, 5% and 10% significance level are: -3.462, -2.875, -2.574 and -4.003, -3.431, -3.139 (when trend is taken into account) for ADF, -2.576, -1.942, - 1.611 and -3.460, -2.929, -2.638 (when trend is taken into account) for DF-GLS, 0.739, 0.463, 0.347 and 0.216, 0.146, 0.119 (when trend is taken into account) for KPSS and -5.34, -4.80, -4.58 (when break in intercept is allowed) and -5.57, -5.08, -4.82 (when break in intercept and trend is allowed ) for Zivot and Andrews. For the KPSS we follow Hobiju et al. (2004) who suggest applying the Newey and West (1994) automatic bandwidth selection procedure for the Quadratic Spectral Kernel.

As can be seen from the tables above almost all series are not stationary in levels despite the fact that the different tests do not agree always. Trade openness variables of the USA are the only variables for which stationarity in levels could be accepted. The picture is totally different in case of first difference where all tests are in agreement. The variables are staionary. RGDP per capita squared and cubic (not reported) were found also to be non stationary.

It is crucial to note that until today there is no unit root or stationary test that can provide with accuracy of one hundred percents results about stationarity of series. But we know that some tests are more powerful than other tests. From the tests that we have applied in this study KPSS is the most powerful so results from this test should be accounted as the most reliable.

Having made brief analysis of unit root and stationarity tests the next task is to estimate the reduced form model. This model has cubic specification as we explained previously. We call Model 1 the regression which incorporates variable Trade Openness 1 as explanatory variable and Model 2 when variable Trade Openness 2 is used as explanatory. Table 5.8 summarizes the results from OLS estimation.

The results in both cases don't provide support for the EKC hypothesis as the coefficients of Real GDP per capita are statistically significant showing that the relationship between growth and pollution is described by an N-shaped curve and not inverted-U shaped curve. Trade openness is significant also but the coefficients don't have negative signs which is necessary for the Pollution Haven Hypothesis to be correct. On the other hand population density is significant only in the case of the USA. This comes in contrast to the view that we supported when population density variable was analyzed. This variable intuitively should play significant role in explaining pollution in case of UK where land area remained the same for the last two hundred years. From diagnostic tests we see that the values of $R^2$ are very high indicating the existence of multicollinearity. Generally speaking there is strong evidence that results may be spurious. Of course this is something that we have noticed above so the interpretation of results must be done very carefully.

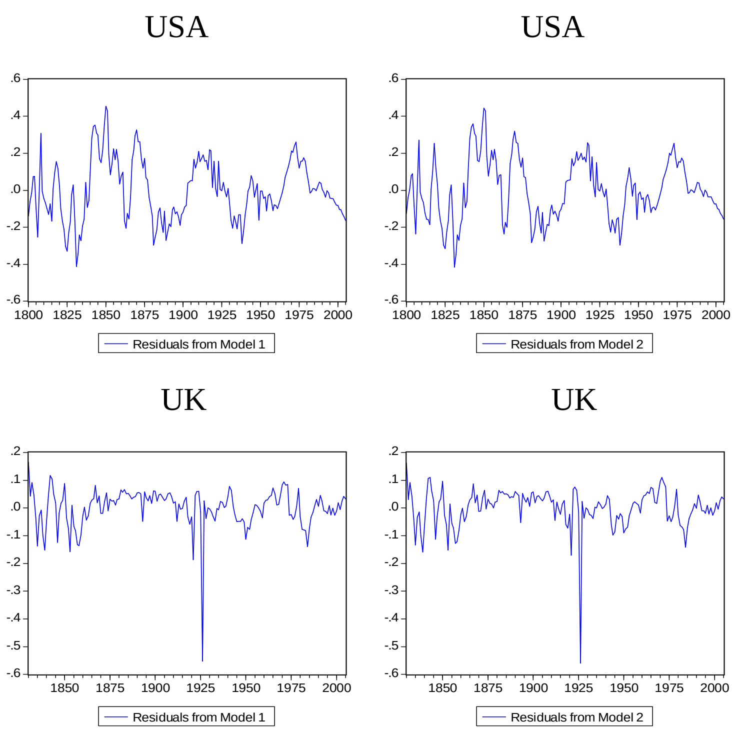
Table 5.8. EKC Models (Cubic Specification), OLS Estimations

| | Model 1 USA | Model 2 USA | Model 1 UK | Model 2 UK |
|---|---|---|---|---|
| Dependent variable | ln ($CO_2$ emissions per capita) | ln ($CO_2$ emissions per capita) | ln ($CO_2$ emissions per capita) | ln ($CO_2$ emissions per capita) |
| Regressors | | | | |
| Constant | -308.03*** | -306.18*** | -152.87*** | -132.97*** |
| | (-31.21) | (-29.99) | (-10.39) | (-7.97) |
| ln (Real GDP per capita) | 96.47*** | 95.81*** | 48.40*** | 41.56*** |
| | (28.26) | (26.99) | (9.40) | (7.14) |
| ln (Real GDP per capita squared) | -10.02*** | -9.95*** | -5.05*** | -4.27*** |
| | (-25.52) | (-24.19) | (-8.45) | (-6.34) |
| ln (Real GDP per capita cubic) | 0.346*** | 0.343*** | 0.174*** | 0.145*** |
| | (23.03) | (21.68) | (7.561) | (5.58) |
| ln (Populaion Density) | 0.511*** | 0.508*** | 0.140 | 0.122 |
| | (5.26) | (5.18) | (1.31) | (1.14) |
| ln (Trade Openness 1) | 0.1008*** | - | 0.186*** | - |
| | (2.90) | - | (7.14) | - |
| ln (Trade Openness 2) | - | 0.070*** | - | 0.210*** |
| | - | (2.19) | - | (7.04) |
| $R^2$ | 0.99 | 0.99 | 0.97 | 0.97 |
| Adj. $R^2$ | 0.99 | 0.99 | 0.97 | 0.97 |
| F statistic | 6328.25 | 6217.45 | 1146.07 | 1138.29 |
| AIC | -0.767 | -0.750 | -2.423 | -2.417 |
| BIC | -0.671 | -0.653 | -2.315 | -2.309 |
| Log-likelihood | 85.10 | 83.29 | 219.28 | 218.70 |
| BG (1) | 148.62*** | 150.28*** | 23.367*** | 22.326*** |
| Q (1) | 148.09*** | 150.07*** | 23.513*** | 22.476*** |
| ARCH (1) | 88.643*** | 86.709*** | 0.031045 | 0.030164 |

***, **, * denote statistical significance at 1%, 5% and 10% respectively. BG (1) is the Breusch-Godfrey LM test for the presence of first order autocorrelation; Q(1) is the Ljung-Box's test for autocorrelation of order one, ARCH (1) is the Engle's LM test for autoregressive conditional heteroskedasticity of order 1

Because OLS estimations are not very supportive of the EKC hypothesis we apply two kind of cointegration tests Engel-Granger and Johansen in order to validate the theory. Cointegration methodology is necessary in order to reassure that the results from OLS estimation are not spurious. If series are not cointegrated then OLS estimation is spurious, it gives inconsistent results. In the other if cointegration exists among series then OLS estimation doesn’t have the above problem.

We will begin the analysis of Engel-Granger methodology by depicting the graphs of the residuals from OLS estimation. From this graphs it is clearly that in case of UK the residuals are stationary but this is not the case for the USA. The series of residuals show mean-reverting behavior but the length of cycles are big enough. It takes very long for the trajectory to revert to the equilibrium.




| Table 5.9. Trend Significance Test for Residuals | | |
|---|---|---|
| | USA | UK |
| | t-statistic for trend coefficient | t-statistic for trend coefficient |
| Residuals from Model 1 | 0.1973 | -0.3817 |
| Residuals from Model 2 | 0.1726 | -0.3245 |

***, **, * denote statistical significance at 1%, 5% and 10% respectively

Table 5.10. Engel - Granger cointegration test, USA

| Residuals from Model 1 | | Residuals from Model 2 | |
|---|---|---|---|
| | t-satisitc | | t-satisitc |
| ADF (1) | $-4.040^{**}$ | ADF (1) | $-3.967^{**}$ |
| ADF (1) (with trend) | $-4.023^{*}$ | ADF (1) (with trend) | $-3.950^{*}$ |
| KPSS | 0.0517 | KPSS | 0.0489 |
| KPSS (de-meaned) | 0.0517 | KPSS (de-meaned) | 0.0489 |
| KPSS (de-trended) | 0.0517 | KPSS (de-trended) | 0.0488 |

$^{***}$, $^{**}$, $^{*}$ denote statistical significance at 1%, 5% and 10% respectively. The critical values for the tests are from Phillips-Ouliaris (1990) and are: -4.31, -3.77, -3.45 and –4.65, -4.16, -3.84 (when trend is included) for ADF, critical values for KPSS are from Shin (1994) and are: 0.025, 0.035, 0.046, for KPSS (de-meaned) 0.017, 0.024, 0.029 and for KPSS (de-trended) 0.014, 0.018, 0.021

Table 5.11. Autocorrelation of the residuals, USA

| Ljung-Box | Model 1 | Model 2 |
|---|---|---|
| Q (1) | $148.09^{***}$ | $150.07^{***}$ |
| Q (2) | $245.31^{***}$ | $246.63^{***}$ |
| Q (3) | $317.02^{***}$ | $314.46^{***}$ |
| Q (4) | $364.94^{***}$ | $357.03^{***}$ |
| Q (5) | $399.17^{***}$ | $385.59^{***}$ |

$^{***}$, $^{**}$, $^{*}$ denote statistical significance at 1%, 5% and 10% respectively

Table 5.12 . Engel - Granger cointegration test, UK

| Residuals from Model 1 | | Residuals from Model 2 | |
|---|---|---|---|
| | t-satisitc | | t-satisitc |
| ADF (1) | $-9.142^{***}$ | ADF (1) | $-9.219^{***}$ |
| ADF (1) (with trend) | $-9.107^{***}$ | ADF (1) (with trend) | $-9.185^{***}$ |
| KPSS | 0.0929 | KPSS | 0.0948 |
| KPSS (de-meaned) | 0.0929 | KPSS (de-meaned) | 0.0948 |
| KPSS (de-trended) | 00887 | KPSS (de-trended) | 0.0913 |

$^{***}$, $^{**}$, $^{*}$ denote statistical significance at 1%, 5% and 10% respectively. The critical values for the tests are: -4.31, -3.77, -3.45 and –4.65, -4.16, -3.84 (when trend is included) for ADF, critical values for KPSS are from Shin (1994) and are: 0.025, 0.035, 0.046, for KPSS (de-meaned) 0.017, 0.024, 0.029 and for KPSS (de-trended) 0.014, 0.018, 0.021

Table 5.13 . Autocorrelation of the residuals, UK

| Ljung-Box | Model 1 | Model 2 |
|---|---|---|
| Q (1) | $23.513^{***}$ | $22.476^{***}$ |
| Q (2) | $31.547^{***}$ | $29.354^{***}$ |
| Q (3) | $32.153^{***}$ | $29.566^{***}$ |
| Q (4) | $32.391^{***}$ | $29.606^{***}$ |
| Q (5) | $38.782^{***}$ | $35.765^{***}$ |

$^{***}$, $^{**}$, $^{*}$ denote statistical significance at 1%, 5% and 10% respectively

The results from unit root and stationary tests give two opposite results. According to ADF test the series of residuals are stationary, on the other hand KPSS test (which is more powerful) show that the series are not stationary so cointegration cannot be accepted according to Engel-Granger methodology.

Table 5.14. Cointegration test (Johansen)

Unrestricted cointegration rank test (Trace and maximum eigenvalue)

| USA Model 1 | | | | | USA Model 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Hypothesized no.of CE(s) | Eigenvalue | Trace Statistic | 0.05 CV | Prob. | Hypothesized no.of CE(s) | Eigenvalue | Trace Statistic | 0.05 CV | Prob. |
| None | 0.247738 | 170.7701 | 95.75366 | 0.0000 | None | 0.256326 | 174.3368 | 95.75366 | 0.0000 |
| At most 1 | 0.213463 | 112.6973 | 69.81889 | 0.0000 | At most 1 | 0.213958 | 113.9217 | 69.81889 | 0.0000 |
| At most 2 | 0.143543 | 63.71369 | 47.85613 | 0.0008 | At most 2 | 0.14213 | 64.80961 | 47.85613 | 0.0006 |
| At most 3 | 0.090939 | 32.10372 | 29.79707 | 0.0267 | At most 3 | 0.09126 | 33.53594 | 29.79707 | 0.0177 |
| At most 4 | 0.058516 | 12.65365 | 15.49471 | 0.1281 | At most 4 | 0.065118 | 14.01388 | 15.49471 | 0.0826 |
| At most 5 | 0.001729 | 0.352965 | 3.841466 | 0.5524 | At most 5 | 0.00136 | 0.277552 | 3.841466 | 0.5983 |
| Hypothesized no.of CE(s) | Eigenvalue | Max-Eigen Statistic | 0.05 CV | Prob. | Hypothesized no.of CE(s) | Eigenvalue | Max-Eigen Statistic | 0.05 CV | Prob. |
| None | 0.247738 | 58.07283 | 40.07757 | 0.0002 | None | 0.256326 | 60.41518 | 40.07757 | 0.0001 |
| At most 1 | 0.213463 | 48.98361 | 33.87687 | 0.0004 | At most 1 | 0.213958 | 49.11205 | 33.87687 | 0.0004 |
| At most 2 | 0.143543 | 31.60998 | 27.58434 | 0.0143 | At most 2 | 0.14213 | 31.27367 | 27.58434 | 0.016 |
| At most 3 | 0.090939 | 19.45007 | 21.13162 | 0.0845 | At most 3 | 0.09126 | 19.52206 | 21.13162 | 0.0827 |
| At most 4 | 0.058516 | 12.30068 | 14.2646 | 0.0999 | At most 4 | 0.065118 | 13.73633 | 14.2646 | 0.0605 |
| At most 5 | 0.001729 | 0.352965 | 3.841466 | 0.5524 | At most 5 | 0.00136 | 0.277552 | 3.841466 | 0.5983 |

Trace test indicates 4 cointegrating eqn(s) at 0.05 CV and the Max-eigenvalue test indicates 3 cointegrating eqn(s) at 0.05 CV for both Models. MacKinnon et al. (1999) *P* values.

Table 5.15. Cointegration test (Johansen)

Unrestricted cointegration rank test (Trace and maximum eigenvalue)

| UK Model 1 | | | | | UK Model 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Hypothesized no.of CE(s) | Eigenvalue | Trace Statistic | 0.05 CV | Prob. | Hypothesized no.of CE(s) | Eigenvalue | Trace Statistic | 0.05 CV | Prob. |
| None | 0.258933 | 133.971 | 95.75366 | 0.0000 | None | 0.263577 | 137.7476 | 95.75366 | 0.0000 |
| At most 1 | 0.207611 | 81.8293 | 69.81889 | 0.0041 | At most 1 | 0.206527 | 84.51232 | 69.81889 | 0.0022 |
| At most 2 | 0.127454 | 41.339 | 47.85613 | 0.1781 | At most 2 | 0.129551 | 44.25999 | 47.85613 | 0.1046 |
| Hypothesized no.of CE(s) | Eigenvalue | Max-Eigen Statistic | 0.05 CV | Prob. | Hypothesized no.of CE(s) | Eigenvalue | Max-Eigen Statistic | 0.05 CV | Prob. |
| None | 0.258933 | 52.14168 | 40.07757 | 0.0014 | None | 0.263577 | 53.23529 | 40.07757 | 0.001 |
| At most 1 | 0.207611 | 40.49034 | 33.87687 | 0.007 | At most 1 | 0.206527 | 40.25234 | 33.87687 | 0.0076 |
| At most 2 | 0.127454 | 23.72312 | 27.58434 | 0.1447 | At most 2 | 0.129551 | 24.14186 | 27.58434 | 0.1299 |

Trace test indicates 2 cointegrating eqn(s) at 0.05 CV and the Max-eigenvalue test indicates 2 cointegrating eqn(s) at 0.05 CV for both Models. MacKinnon et al. (1999) *P* values.

Table 5.16 Johansen cointegration test with structural break

| USA Model 1 | | | | | | USA Model 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hypothesized no.of CE(s) | Trace Statistic | Prob. | 90% | 95% | 99% | Hypothesized no.of CE(s) | Trace Statistic | Prob. | 90% | 95% | 99% |
| None | 301.56 | 0.0000 | 118.75 | 123.84 | 133.76 | None | 315.55 | 0.0000 | 118.75 | 123.84 | 133.76 |
| At most 1 | 183.21 | 0.0000 | 89.66 | 94.12 | 102.88 | At most 1 | 197.2 | 0.0000 | 89.66 | 94.12 | 102.88 |
| At most 2 | 107.38 | 0.0000 | 64.47 | 68.31 | 75.92 | At most 2 | 118.74 | 0.0000 | 64.47 | 68.31 | 75.92 |
| At most 3 | 63.56 | 0.0004 | 43.21 | 46.43 | 52.86 | At most 3 | 71.53 | 0.0000 | 43.21 | 46.43 | 52.86 |
| At most 4 | 27.86 | 0.0569 | 25.75 | 28.32 | 33.57 | At most 4 | 28.14 | 0.0527 | 25.75 | 28.32 | 33.57 |
| At most 5 | 10.62 | 0.1631 | 12.03 | 13.9 | 17.86 | At most 5 | 10.64 | 0.1621 | 12.03 | 13.9 | 17.86 |

Trace test indicates 4 cointegrating eqn(s) at 0.05 CV for both Models. 1921 was chosen as a date break.

Table 5.17.Unit Root Test with Structural Break – USA

| Variables | CO2 per capita | Real GDP per capita | Real GDP per capita squared | Real GDP per capita cubic | Population Density | Trade Openness 1 | Trade Openness 2 |
|---|---|---|---|---|---|---|---|
| Suggested Break Date | 1921 | 1908 | 1908 | 1908 | 1841 | 1815 | 1815 |
| Value of Test Statistic | -0.1173 | -2.5415 | -2.0927 | -1.7419 | -2.888 | -1.9153 | -1.9762 |

$^{***,**,*}$ denote significance at 1%, 5% and 10% respectively. The optimal lag length (not reported) was selected through Schwarz information criteria. The critical values of the test (Lanne et al. 2002) for 1%, 5% and 10% significance level are: -3.55%, -3.03% and -2.76 (when trend is taken into account)

Table 5.18. Johansen cointegration trace test with structural break

| UK Model 1 | | | | | | UK Model 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hypothesized no.of CE(s) | Trace Statistic | Prob. | 90% | 95% | 99% | Hypothesized no.of CE(s) | Trace Statistic | Prob. | 90% | 95% | 99% |
| None | 325.29 | 0.0000 | 118.94 | 124.03 | 133.96 | None | 336.19 | 0.0000 | 118.94 | 124.03 | 133.96 |
| At most 1 | 154.6 | 0.0000 | 89.78 | 94.25 | 103.02 | At most 1 | 166.06 | 0.0000 | 89.78 | 94.25 | 103.02 |
| At most 2 | 95.93 | 0.0000 | 64.54 | 68.38 | 75.99 | At most 2 | 107.4 | 0.0000 | 64.54 | 68.38 | 75.99 |
| At most 3 | 50.66 | 0.018 | 43.23 | 46.44 | 52.88 | At most 3 | 61.028 | 0.0008 | 43.23 | 46.44 | 52.88 |
| At most 4 | 19.08 | 0.4147 | 25.73 | 28.3 | 33.56 | At most 4 | 18.83 | 0.4321 | 25.73 | 28.3 | 33.56 |

Trace test indicates 4 cointegrating eqn(s) at 0.05 CV for both Models. 1927 was chosen as a date break.

Table 5.19. Unit Root Test with Structural Break - UK

| Variables | CO2 per capita | Real GDP per capita | Real GDP per capita squared | Real GDP per capita cubic | Population Density | Trade Openness 1 | Trade Openness 2 |
|---|---|---|---|---|---|---|---|
| Suggested Break Date | 1927 | 1921 | 1921 | 1921 | 1921 | 1921 | 1974 |
| Value of Test Statistic | -0.8609 | -1.6638 | -1.4251 | -1.2412 | -0.8153 | -2.5551 | -2.0164 |

$^{***,**,*}$ denote significance at 1%, 5% and 10% respectively. The optimal lag length (not reported) was selected through Schwarz information criteria. The critical values of the test (Lanne et al. 2002) for 1%, 5% and 10% significance level are: -3.55%, -3.03% and -2.76 (when trend is taken into account). Trend was found to be statistically significant in all cases except of Trade Openness 1 and 2.

Table 5.20. Saikkonen & Lutkephol cointegration test

| USA Model 1 | | | | | | USA Model 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hypothesized no.of CE(s) | Trace Statistic | Prob. | 90% | 95% | 99% | Hypothesized no.of CE(s) | Trace Statistic | Prob. | 90% | 95% | 99% |
| None | 193.27 | 0.0000 | 86.64 | 90.95 | 99.4 | None | 208.51 | 0.0000 | 86.64 | 90.95 | 99.4 |
| At most 1 | 75.07 | 0.0067 | 62.45 | 66.13 | 73.42 | At most 1 | 76.32 | 0.0049 | 62.45 | 66.13 | 73.42 |
| At most 2 | 47.55 | 0.0288 | 42.25 | 45.32 | 51.45 | At most 2 | 51.52 | 0.0098 | 42.25 | 45.32 | 51.45 |
| At most 3 | 24.89 | 0.1359 | 26.07 | 28.52 | 33.5 | At most 3 | 32.87 | 0.0124 | 26.07 | 28.52 | 33.5 |
| | | | | | | At most 4 | 17.61 | 0.0241 | 13.88 | 15.76 | 19.71 |
| | | | | | | At most 5 | 5.85 | 0.0822 | 5.47 | 6.79 | 9.73 |

Trace test indicates 3 cointegrating eqn(s) at 0.05 CV for Model 1 and 5 cointegrating eqn(s) at 0.05 CV for Model 2

Table 5.21. Saikkonen & Lutkephol cointegration test

| UK Model 1 | | | | | | UK Model 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hypothesized no.of CE(s) | Trace Statistic | Prob. | 90% | 95% | 99% | Hypothesized no.of CE(s) | Trace Statistic | Prob. | 90% | 95% | 99% |
| None | 205.37 | 0.0000 | 86.64 | 90.95 | 99.4 | None | 216.08 | 0.0000 | 86.64 | 90.95 | 99.4 |
| At most 1 | 113.93 | 0.0000 | 62.45 | 66.13 | 73.42 | At most 1 | 121.91 | 0.0000 | 62.45 | 66.13 | 73.42 |
| At most 2 | 42.2 | 0.1011 | 42.25 | 45.32 | 51.45 | At most 2 | 46.9 | 0.0399 | 42.25 | 45.32 | 51.45 |
| | | | | | | At most 3 | 26.9 | 0.0796 | 26.07 | 28.52 | 33.5 |
| | | | | | | At most 4 | 3.2 | 0.9752 | 13.88 | 15.76 | 19.71 |

Trace test indicates 2 cointegrating eqn(s) at 0.05 CV for Model 1 and 3 cointegrating eqn(s) at 0.05 CV for Model 2

Figure 5.1. Plots of the main time series all together,USA

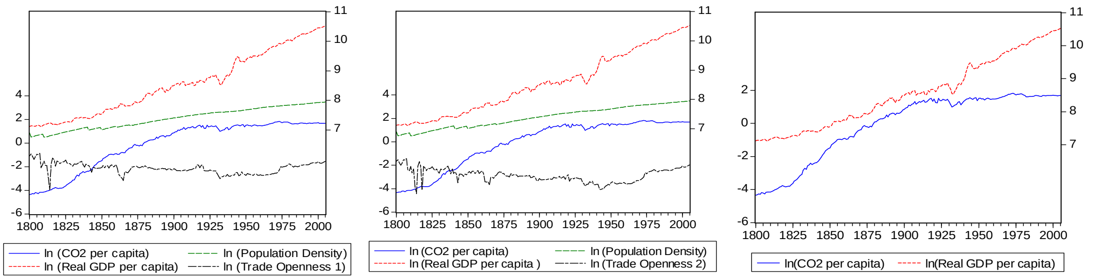
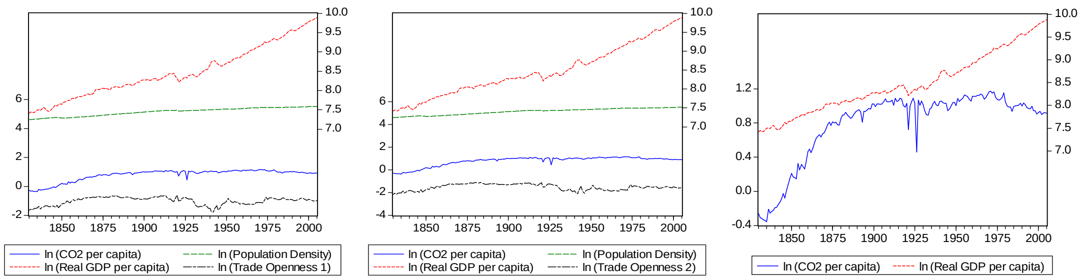



Figure 5.2. Plots of the main time series all together, UK




From the results that we received from the three cointegration tests (Johansen, Johansen with structural break, Saikkonen and Lutkepohl) we see that all tests confirm the existence of cointegration among the series. This means that the OLS estimation are not spurious and prove in this way that the Environmental Kuznets Curve  is N-shaped, a pessimistic result because as we mentioned above environmental policy cannot rely on this kind of curve. One point to mention is that in the Johansen cointegration test with structural break we used as a break date the date that the second unit root test gave us and not the Zivot-Andrews. The second test is more powerful than Zivot-Andrews. Also as a date break we chose that of CO2 emissions per capita because this variable is of great importance, it is the indicator of the environmental degradation.

In Figures 5.1-5.2 we didn't plot the series of Real GDP per capita squared and Real GDP per capita cubic because of the scale effect. The values of these series are very high so the depiction of plots wouldn't be good.

Apart from the cointegration tests we estimate three kinds of error correction models. Linear, Asymmetric and Non-Linear. Table 5.22 – 5.25 summarize the results from these estimations. We inform that the variables Trade Openness 1 and Trade Openness 2  were treated once as endogenous an once as exogenous in both cases (USA and UK). The reason for this is that unit root and stationarity tests didn't lead to clear conclusions about the stationarity of these series. The results show that there are no differences at all.

Table 5.22. Error Correction Modeling

| Error Correction Modeling 1 USA | | | | Error Correction Modeling 2 USA | | | |
|---|---|---|---|---|---|---|---|
| | ECM 1 | AECM 1 | NLECM 1 | | ECM 2 | AECM 2 | NLECM 2 |
| Dependent Variable | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | Dependent Variable | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) |
| Regressors | | | | Regressors | | | |
| Constant | 0.0275*** | 0.0015 | 0.0107 | Constant | 0.029*** | 0.0031 | 0.0112 |
| | (5.066) | (0.1811) | (1.654) | | (5.351) | (0.359) | (1.698) |
| $z_{t-1}$ | -0.0795** | - | -0.0841* | $z_{t-1}$ | -0.084*** | - | -0.0735 |
| | (-2.570) | - | (-1.686) | | (-2.774) | - | (-1.498) |
| $z_{t-1}^{+}$ | - | 0.1295** | - | $z_{t-1}^{+}$ | - | 0.1127* | - |
| | - | (2.151) | - | | - | (1.856) | - |
| $z_{t-1}^{-}$ | - | -0.2962*** | - | $z_{t-1}^{-}$ | - | -0.2744*** | - |
| | - | (-4.572) | - | | - | (-4.235) | - |
| $z_{t-1}^{2}$ | - | - | 0.741*** | $z_{t-1}^{2}$ | - | - | 0.697*** |
| | - | - | (4.733) | | - | - | (4.393) |
| $z_{t-1}^{3}$ | - | - | -0.1366 | $z_{t-1}^{3}$ | - | - | -0.231 |
| | | - | (-0.233) | | - | - | (-0.386) |
| lags of D(ln ($CO_2$ p.c.)) | yes | yes | yes | lags of D(ln ($CO_2$ per capita)) | yes | yes | yes |
| lags of D(ln (Real GDP p.c.)) | yes | yes | yes | lags of D(ln (Real GDP p.c.)) | yes | yes | yes |
| lags of D(ln (Real GDP p.c.squared)) | yes | yes | yes | lags of D(ln (Real GDP p.c. squared)) | yes | yes | yes |
| lags of D(ln (Real GDP p.c.cubic)) | yes | yes | yes | lags of D(ln (Real GDP p.c. cubic)) | yes | yes | yes |
| lags of D(ln (Population Density)) | yes | yes | yes | lags of D(ln( Population Density)) | yes | yes | yes |
| lags of D(ln (Trade Openness 1)) | yes | yes | yes | lags of D(ln (Trade Openness 2)) | yes | yes | yes |
| Sample Size | 202 | 202 | 202 | Sample Size | 202 | 202 | 202 |
| Adjusted R^2 | 0.14 | 0.19 | 0.22 | Adjusted R^2 | 0.15 | 0.18 | 0.21 |
| SCH | -2.380 | -2.386 | -2.399 | SCH | -2.370 | -2.373 | -2.383 |
| S.E. of regression | 0.070 | 0.068 | 0.066 | S.E. of regression | 0.070 | 0.068 | 0.067 |

Notes for Table. ***, **, * denote statistical significance at1%, 5% and 10% respectively. The variables Trade Opennes1 and Trade Opennes 2 are treated as being endogenous. Three types of error correction models are estimated. ECM is the linear error correction model. NLECM is the non-linear error correction model. AECM is the asymmetric eror correction model where an explicit distinction is made between positive and negative deviations from long-run equilibrium. t-statistics are given in parentheses.

Table 5.23. Error Correction Modeling

| Error Correction Modeling 1 USA | | | | Error Correction Modeling 2 USA | | | |
|---|---|---|---|---|---|---|---|
| | ECM 1 | AECM 1 | NLECM 1 | | ECM 2 | AECM 2 | NLECM 2 |
| Dependent Variable | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | Dependent Variable | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) |
| Regressors | | | | Regressors | | | |
| Constant | 0.0275*** | 0.0015 | 0.0107 | Constant | 0.029*** | 0.0031 | 0.0112 |
| | (5.066) | (0.1811) | (1.654) | | (5.351) | (0.359) | (1.698) |
| $z_{t-1}$ | -0.0795** | - | -0.0841* | $z_{t-1}$ | -0.084*** | - | -0.0735 |
| | (-2.570) | - | (-1.686) | | (-2.774) | - | (-1.498) |
| $z^{+}_{t-1}$ | - | 0.1295** | - | $z^{+}_{t-1}$ | - | 0.1127* | - |
| | - | (2.151) | - | | - | (1.856) | - |
| $z^{-}_{t-1}$ | - | -0.2962*** | - | $z^{-}_{t-1}$ | - | -0.2744*** | - |
| | - | (-4.572) | - | | - | (-4.235) | - |
| $z^{2}_{t-1}$ | - | - | 0.741*** | $z^{2}_{t-1}$ | - | - | 0.697*** |
| | - | - | (4.733) | | - | - | (4.393) |
| $z^{3}_{t-1}$ | - | - | -0.1366 | $z^{3}_{t-1}$ | - | - | -0.231 |
| | | - | (-0.233) | | - | - | (-0.386) |
| lags of D(ln ($CO_2$ p.c.)) | yes | yes | yes | lags of D(ln $CO_2$ per capita) | yes | yes | yes |
| lags of D(ln( Real GDP p.c.)) | yes | yes | yes | lags of D(ln Real GDP p.c.) | yes | yes | yes |
| lags of D(ln (Real GDP p.c. squared)) | yes | yes | yes | lags of D(ln (Real GDP p.c. squared)) | yes | yes | yes |
| lags of D(ln (Real GDP p.c. cubic)) | yes | yes | yes | lags of D(ln (Real GDP p.c. cubic)) | yes | yes | yes |
| lags of D(ln( Population Density)) | yes | yes | yes | lags of D(ln Population Density) | yes | yes | yes |
| lags of ln (Trade Openness 1) | yes | yes | yes | lags of ln Trade Openness 2 | yes | yes | yes |
| Sample Size | 202 | 202 | 202 | Sample Size | 202 | 202 | 202 |
| Adjusted R^2 | 0.14 | 0.19 | 0.22 | Adjusted R^2 | 0.15 | 0.18 | 0.21 |
| SCH | -2.380 | -2.386 | -2.399 | SCH | -2.370 | -2.373 | -2.383 |
| S.E. of regression | 0.070 | 0.068 | 0.066 | S.E. of regression | 0.070 | 0.068 | 0.067 |

Notes for Table. ***, **, * denote statistical significance at1%, 5% and 10% respectively. The variables Trade Opennes1 and Trade Opennes 2 are treated as being exogenous. Three types of error correction models are estimated. ECM is the linear error correction model. NLECM is the non-linear error correction model. AECM is the asymmetric eror correction model where an explicit distinction is made between positive and negative deviations from long-run equilibrium. t-statistics are given in parentheses.

Table 5.24. Error Correction Modeling

| Error Correction Modeling 1 UK | | | | Error Correction Modeling 2 UK | | | |
|---|---|---|---|---|---|---|---|
| | ECM 1 | AECM 1 | NLECM 1 | | ECM 2 | AECM 2 | NLECM 2 |
| Dependent Variable | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | Dependent Variable | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) |
| Regressors | | | | Regressors | | | |
| Constant | 0.0085 | 0.0078 | -0.0045 | Constant | 0.0085 | -0.0135$^{**}$ | -0.00445 |
| | (1.631) | (0.874) | (-0.651) | | (1.633) | (-2.517) | (-0.638) |
| $z_{t-1}$ | -0.520$^{***}$ | - | -0.187$^{*}$ | $z_{t-1}$ | -0.500$^{***}$ | - | -0.216$^{**}$ |
| | (-5.946) | - | (-1.850) | | (-5.676) | - | (-2.220) |
| $z_{t-1}^{+}$ | - | 0.2263 | - | $z_{t-1}^{+}$ | - | -0.004 | - |
| | - | (0.958) | - | | - | (-0.565) | - |
| $z_{t-1}^{-}$ | - | -0.0261$^{*}$ | - | $z_{t-1}^{-}$ | - | -0.923$^{***}$ | - |
| | - | (-1.718) | - | | - | (-10.16) | - |
| $z_{t-1}^{2}$ | - | - | 4.143$^{***}$ | $z_{t-1}^{2}$ | - | - | 3.969$^{***}$ |
| | - | - | (3.096) | | - | - | (3.003) |
| $z_{t-1}^{3}$ | - | - | 4.372$^{*}$ | $z_{t-1}^{3}$ | - | - | 4.201$^{*}$ |
| | - | - | (1.849) | | - | - | (1.804) |
| lags of D(ln ($CO_2$ p.c.)) | yes | yes | yes | lags of D(ln ($CO_2$ per capita)) | yes | yes | yes |
| lags of D(ln (Real GDP p.c.)) | yes | yes | yes | lags of D(ln (Real GDP p.c.)) | yes | yes | yes |
| lags of D(ln (Real GDP p.c. squared)) | yes | yes | yes | lags of D(ln (Real GDP p.c. squared)) | yes | yes | yes |
| lags of D(ln (Real GDP p.c. cubic)) | yes | yes | yes | lags of D(ln (Real GDP p.c. cubic)) | yes | yes | yes |
| lags of D(ln (Population Density)) | yes | yes | yes | lags of D(ln (Population Density)) | yes | yes | yes |
| lags of D(ln (Trade Openness 1)) | yes | yes | yes | lags of D(ln (Trade Openness 2)) | yes | yes | yes |
| Sample Size | 173 | 173 | 173 | Sample Size | 173 | 173 | 173 |
| Adjusted R^2 | 0.32 | 0.24 | 0.42 | Adjusted R^2 | 0.31 | 0.39 | 0.43 |
| SCH | -2.433 | -2.131 | -2.497 | SCH | -2.427 | -2.521 | -2.481 |
| S.E. of regression | 0.068 | 0.072 | 0.063 | S.E. of regression | 0.068 | 0.063 | 0.062 |

Notes for Table. $^{***}$, $^{**}$, $^{*}$ denote statistical significance at1%, 5% and 10% respectively. The variables Trade Opennes1 and Trade Opennes 2 are treated as being endogenous. Three types of error correction models are estimated. ECM is the linear error correction model. NLECM is the non-linear error correction model. AECM is the asymmetric eror correction model where an explicit distinction is made between positive and negative deviations from long-run equilibrium. t-statistics are given in parentheses.

Table 5.25. Error Correction Modeling

| Error Correction Modeling 1 UK | | | | Error Correction Modeling 2 UK | | | |
|---|---|---|---|---|---|---|---|
| | ECM 1 | AECM 1 | NLECM 1 | | ECM 2 | AECM 2 | NLECM 2 |
| Dependent Variable | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | Dependent Variable | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) | D(ln ($CO_2$ per capita)) |
| Regressors | | | | Regressors | | | |
| Constant | 0.0019 | -0.0089 | -0.0129 | Constant | 0.0084 | -0.0118 | -0.0164 |
| | (0.095) | (-0.387) | (-0.666) | | (0.279) | (-0.408) | (-0.561) |
| $z_{t-1}$ | $-0.517^{***}$ | - | $-0.1823^{*}$ | $z_{t-1}$ | $-0.500^{***}$ | - | $-0.206^{**}$ |
| | (-5.873) | - | (-1.788) | | (-5.623) | - | (-2.093) |
| $z_{t-1}^{+}$ | - | 0.2351 | - | $z_{t-1}^{+}$ | - | -0.004 | - |
| | - | (0.993) | - | | - | (-0.564) | - |
| $z_{t-1}^{-}$ | - | $-0.0265^{*}$ | - | $z_{t-1}^{-}$ | - | $-0.918^{***}$ | - |
| | - | (-1.743) | - | | - | (-10.04) | - |
| $z_{t-1}^{2}$ | - | - | $4.061^{***}$ | $z_{t-1}^{2}$ | - | - | $3.686^{***}$ |
| | - | - | (3.001) | | - | - | (2.726) |
| $z_{t-1}^{3}$ | - | - | $4.192^{*}$ | $z_{t-1}^{3}$ | - | - | 3.659 |
| | - | - | (1.745) | | - | - | (1.526) |
| lags of D(ln ($CO_2$ p.c.)) | yes | yes | yes | lags of D(ln ($CO_2$ per capita)) | yes | yes | yes |
| lags of D(ln (Real GDP p.c. )) | yes | yes | yes | lags of D(ln (Real GDP p.c.)) | yes | yes | yes |
| lags of D(ln (Real GDP p.c. squared)) | yes | yes | yes | lags of D(ln (Real GDP p.c. squared)) | yes | yes | yes |
| lags of D(ln (Real GDP p.c. cubic)) | yes | yes | yes | lags of D(ln (Real GDP p.c. cubic)) | yes | yes | yes |
| lags of D(ln (Population Density)) | yes | yes | yes | lags of D(ln (Population Density)) | yes | yes | yes |
| lags of ln (Trade Openness 1) | yes | yes | yes | lags of ln (Trade Openness 2) | yes | yes | yes |
| Sample Size | 173 | 173 | 173 | Sample Size | 173 | 173 | 173 |
| Adjusted R^2 | 0.31 | 0.24 | 0.42 | Adjusted R^2 | 0.31 | 0.38 | 0.42 |
| SCH | -2.404 | -2.105 | -2.468 | SCH | -2.397 | -2.512 | -2.472 |
| S.E. of regression | 0.068 | 0.072 | 0.063 | S.E. of regression | 0.068 | 0.064 | 0.060 |

Notes for Table. $^{***}$, $^{**}$, $^{*}$ denote statistical significance at1%, 5% and 10% respectively. The variables Trade Opennes1 and Trade Opennes 2 are treated as being exogenous. Three types of error correction models are estimated. ECM is the linear error correction model. NLECM is the non-linear error correction model. AECM is the asymmetric eror correction model where an explicit distinction is made between positive and negative deviations from long-run equilibrium. t-statistics are given in parentheses.

Figure 5.3. Error correction components for USA

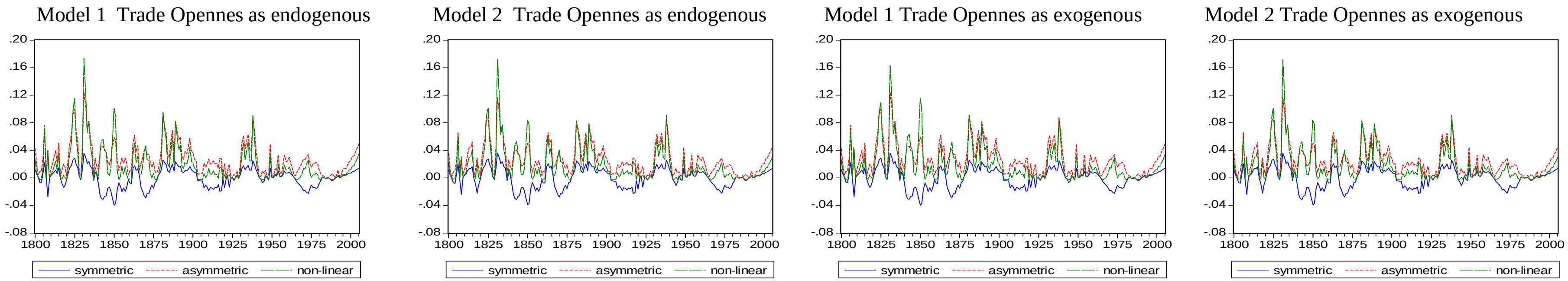
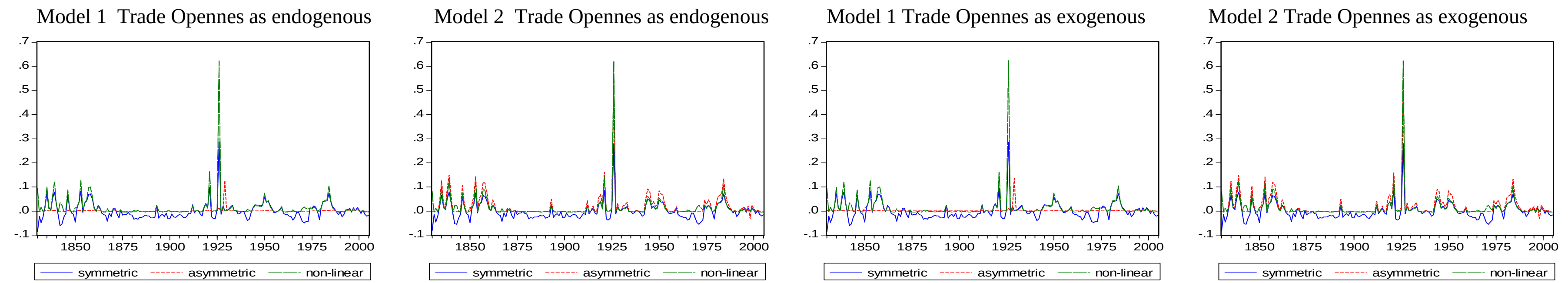



Figure 5.4. Error correction components for UK




The estimation of error correction was done through the following procedure: symmetric components = coefficient of error correction term $\times\ z_t$, asymmetric components = coefficient of error correction term $\times\ z_t^{+}$ + coefficient of error correction term $\times\ z_t^{-}$, non-linear components = coefficient of error correction term $\times\ z_t$ + coefficient of error correction term $\times\ z_t^{2}$ + coefficient of error correction term $\times\ z_t^{3}$

The last analysis refers to the examination of evolution of per capita $CO_2$ emissions through phase diagrams.

Figure 5.5. Phase diagram for USA

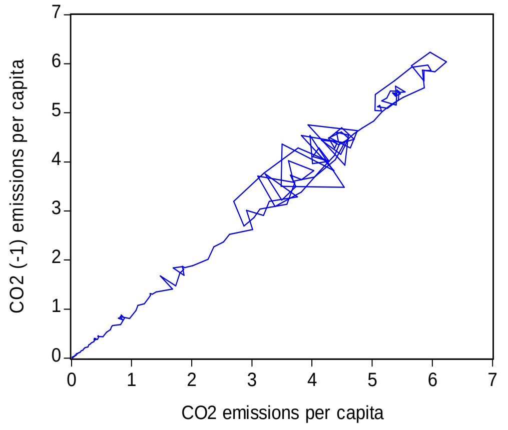
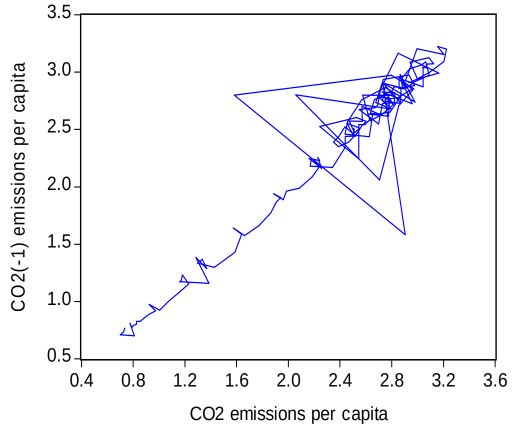



Figure 5.6. Phase diagram for UK




Phase diagrams help us to reveal interesting emissions dynamics which include attractor like behavior. As can be seen from the figures above the attractors that is observed are quite complex for both countries, especially in the case of UK. The emissions of both countries rise in a regular fashion but at some period of time we have stabilization of emissions which fluctuates around the attractor.

# CHAPTER 6: *POLICY IMPLICATIONS*

The EKC hypothesis has stimulated considerable discussion within and between the economics and environmental communities, and debate continues over the validity, and more importantly, the policy implications of EKC studies (Unruh and Moomaw, 1998).

If the EKC exists, one can say that economic growth is compatible with improvements in environmental quality if appropriate policy responses have been taken (Van Phu, 2008).

The problem would then be how best to accelerate those processes and policies so that all countries could experience production and living conditions found now only in the wealthy countries. If the curve trend is in error or misinterpreted and the most polluting technologies cannot be expected to disappear without explicit intervention, then policies promoting only accelerated economic growth might be a course for disaster (Roberts and Grimes, 1997).

Richmond and Kaufmann (2006), state that if the EKC hypothesis is valid then policy makers could use the turning point (the level of income per capita at which pollution starts to decline) as a tool to design the environmental policy. A turning point suggests that high living standards and clean environment are not two opposite gold's.

The World Bank World Development Report (World Bank, 1992) point out that environmental policy which protect nature and promote economic development could slow the pollution of the environment.

Anderson and Cavandish (2001) pay attention to the fact that understanding the impact of economic growth on environmental quality is becoming increasing important as environmental concerns are making their way into main public policy agenda.

According to Beckerman (1992) policy implication of EKCs is that promoting economic growth are sufficient criteria to safe guard the environment. In the long run, the surest way to improve the environment is to become rich.

Shafik and Bandyopadhyay (1992) warn that it is not only the validity of the EKC that matters but if the environmental policies do actually being applied also. They say that as country develops these policies may or may not be implemented.

It is important to be mentioned that it is not possible to derive a clear policy conclusion from the EKC hypothesis because there are some unanswered questions which are related with this hypothesis. For instance, it is not clearly known if the EKC is a permanent phenomenon or if EKC is valid for all types of environmental pressure. Further to this there are doubts about the validity of the EKC both for individual countries and the World. Another question which needs to be answered is if the EKC follows a sustainable development path. The answer to this last question is of a crucial importance. If the EKC are not compatible with sustainable growth then it cannot used for policy decisions.

Following the above thoughts, Dinda (2004) in his survey about the EKCs studies makes a reference to the fact that the EKC could not be so useful as a tool for designing environmental policy. "The *Environmental Kuznets Curve model has elicited conflicting reactions from researchers and policymakers. The stakes in the EKC debate are high for both developing and developed countries. It is clear that EKC can take shape from a multiplicity of possible outcomes of economic development. So, proper attention is required for multiple factors that form the economic–environmental system, rather than a single dominant one. Since these factors are interdependent, it is difficult to determine the factors that may dominate and govern the shape of EKC. The uses of reduced form models, as explained above, deny any insight into the underlying causes of EKCs. The lack of insight into the process that causes pollution to curve downwards beyond a particular income level makes designing of specific policy implications from an EKC difficult*."

### 6.1) *Dangers that could arise from the acceptance of the EKC hypothesis in case it is false*

When a country tries to develop the pollution of the environment is an unavoidable effect of this development. Economists all over the world assert that if a country can achieve sufficient economic growth in a short period of time then the degradation of the environment should be accepted and tolerated. It is a cost that country must pay.

However this doesn't mean that the development of one nation's economy should simply grow out of environmentally damaging activity. Many dangers could arise if the EKC hypothesis is taken for granted. Some of the concerns regarding the EKC hypothesis are the following:

1) It is not clear until today if all the pollution indicators follow the pattern that EKC postulates. It could be argued that local pollutants such sulfur dioxide follow the inverted U shape but the same cannot be supported for global pollutants such as carbon dioxide.

2) The ability of our planet to absorb pollution or the “absorptive capacity” is still unknown. Tisdell (2001) notes that the models related with the EKC hypothesis face pollution as flows rather than stocks. A comparison between flows and stocks of pollution reveal that the latter sometimes consist a greater problem. If the rate of emissions of pollutants exceeds the capacity of the natural environment to 'absorb' or neutralize them, then stocks of pollutants accumulate in the environment. Depending upon accumulation thresholds, pollution emissions may cause the stocks of pollutants in the natural environment to continue to rise even when pollution emission intensities have passed their peak and even when the total level of emissions per period of time have declined. Furthermore, in many cases, the greater the level of accumulated stocks of a pollutant in the natural environment, the lower is the capacity of the environment to absorb extra pollution. In such cases, a level of pollution intensity above the peak of an EKC will be more damaging environmentally than the same level below it.

3) The turning point could be very high and the period of increasing environmental degradation too long. This mean that the pollution of the environmental could have catastrophic and irreversible effects before even the turning point is reached.

According to Hill and Magnini (2002) many damaging agents may respond to income levels, but not until GDP per capita approaches out-of-reach levels. If in a developed country, the turning point for a damaging agent is above, say, $50,000 then neglecting to react will create damage for a considerable amount of time. Over the time it takes to achieve the turning point, the environmental damage may prove more costly than it’s worth.

4) The EKC hypothesis can be used as a policy tool only in a proper and suitable back round. This implies that many countries are unable to use the EKC due to the lack of this back round.

Based on this concern Lekanis and Kousis (1999) say that even if developing countries can achieve high levels of income per capita they may not possess a political back round conducive to environmental protection. Assuming that the aggregate turning point is in a country reached, that country it is not necessarily going enacts protection. Countries that possess sufficient demand for environmental quality still only achieve it with policy revisions. The most successful avenues for obtaining environmental quality are lobbyists.

Tisdell (2005) warns that care is needed in drawing inferences from the inverted U shape relationship in the case that the EKC hypothesis is accepted. He points out that it is wrong to believe that once a turning point is passed total emissions per period of time will decline. The intensity of pollution emissions is an average relationship. Given the type of relationship shown in Figure 9, the marginal level of pollution emissions will still be positive at $Y_1$ and is only likely to become zero for a level of income well in excess of $Y_1$, say $Y_2$ (Tisdell, 2001). Thus total pollution emissions per unit of time will continue to rise until income levels reach $Y_2$. It is only for income levels higher than this that total emissions of pollutants per unit of time will decline.

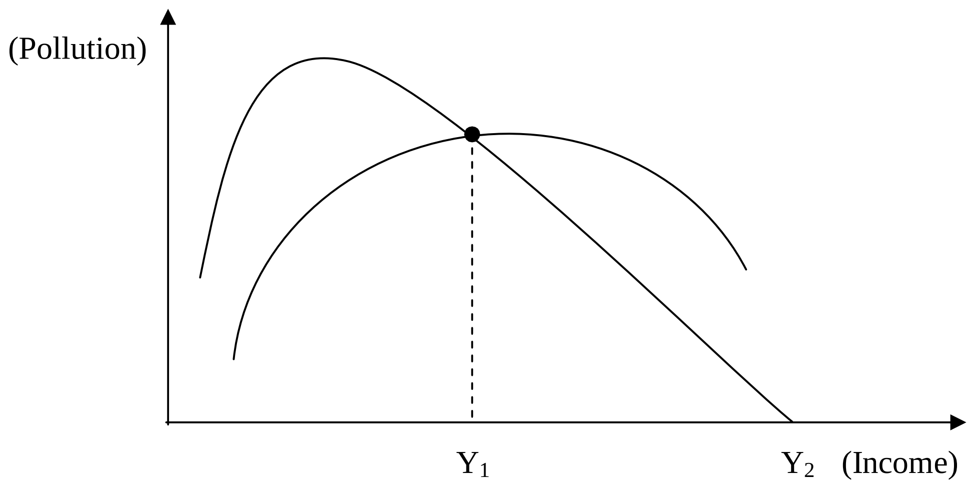



Figure 6.1. The Environmental Kuznets Curve is an average, not a marginal curve.

Another feature that is easily overlooked when using EKC analysis is its assumption of perfect reversibility. This arises primarily because this analysis does not take account of stocks of pollutants, and in the case of living recourses because it ignores the essential irreversibility of genetic loss. When these various limitations are considered, doubts seem justified about the EKC-based hypothesis that economic growth provides the solution to environmental problems, particularly global environmental problems (Tisdell, 2005).The final conclusion is that all these concerns must be exanimate very carefully.

## *CHAPTER 7:* CONCLUSIONS

The aim of this Master thesis was to investigate through empirical analysis the validity of the Environmental Kuznets Curve Hypothesis which supports the view that at the early stages of development the pollution of the environment is something unavoidable but at some level of income per capita, which is called turning point, the degradation of the environment begin to decline as income per capita continue to rise. In this way economic growth which is responsible for the pollution could be seen later as solution or as part of solution of the environmental problems.

The empirical results of our study unfortunately don’t seem to support the EKC hypothesis. OLS estimation results show that instead of inverted-U shaped curve, the relation between pollution and income is described by a N-shaped curve. This is a pesimistic result because if this is the case then EKC cannot used by policy makers to design environmental policies. Apart from OLS estimations (which could give rise to a spurious results and to lead to wrong conclusions) coinegration analysis was applied too. Cointegration tests of Engel-Granger, Johansen (with or without structural break) and Saikkonen and Lutkepohl provided not absolutely clear results but they gave strong evidences for the existence of a N-shaped Environmental Kuznets Curve.

The main conclusion that should be drawn from this study is that EKC hypothesis shouldn’t be taken for granted and that further investigation need to be done. Parametric methodologies which were used have many drawbacks and can misleads us. It is necessary the EKC hypothesis to be examined further but in a non-parametric framework.

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# APPENDIX A

We report the results taken from DF-GLS and KSS (non-linear unit root test) on the residuals from OLS estimation. We won't draw however any conclusion because we don't know the critical values under which the null hypothesis of unit root is rejected or accepted.

| Engel - Granger cointegration test, USA | | | | | |
|---|---|---|---|---|---|
| Residuals from Model 1 | | | Residuals from Model 2 | | |
| | | t-satisitc | | | t-satisitc |
| DF-GLS (1) | | -3.265 | DF-GLS (1) | | -3.324*** |
| DG-GLS (1) | (with trend) | -3.738 | DG-GLS (1) | (with trend) | -3.723 |
| KSS (1) | | -4.157 | KSS (1) | | -4.418 |
| KSS | (de-meaned) | -4.157 | KSS | (de-meaned) | -4.418 |
| KSS | (de-trended) | -4.163 | KSS | (de-trended) | -4.422 |

| Engel - Granger cointegration test, UK | | | | | |
|---|---|---|---|---|---|
| Residuals from Model 1 | | | Residuals from Model 2 | | |
| | | t-satisitc | | | t-satisitc |
| DF-GLS (1) | | -2.486 | DF-GLS (1) | | -2.583 |
| DG-GLS (1) | (with trend) | -4.170 | DG-GLS (1) | (with trend) | -4.304 |
| KSS (1) | | -7.416 | KSS (1) | | -7.401 |
| KSS | (de-meaned) | -7.416 | KSS | (de-meaned) | -7.401 |
| KSS | (de-trended) | -7.416 | KSS | (de-trended) | -7.401 |

# APPENDIX B

We report also the results for the long-run relationships. The OLS estimations for Engel-Granger and the estimations from Johansen cointegration test. In the case of the Johansen we found more than 1 cointegrating relation so we cannot be absolutely sure if the results confirm the N-shaped EKC. We have to impose restrictions.

| Long-run relationships | | | | | | |
|---|---|---|---|---|---|---|
| Engel-Granger | | | | | | |
| | ln(Real GDP per capita) | ln(Real GDP per capita squared) | ln(Real GDP per capita cubic) | ln(Population Density) | ln(Trade Openness 1) | ln(Trade Openness 2) |
| Model 1 USA | 96.47*** | -10.02*** | 0.346*** | 0.511*** | 0.1008*** | - |
| s.e. | (3.413) | (0.392) | (0.015) | (0.097) | (0.034) | - |
| Model 2 USA | 95.81*** | -9.95*** | 0.343*** | 0.508*** | - | 0.070*** |
| s.e. | (3.549) | (0.411) | (0.015) | (0.098) | - | (0.031) |
| Model 1 UK | 48.40*** | -5.05*** | 0.174*** | 0.140 | 0.186*** | - |
| s.e. | (5.146) | (0.598) | (0.023) | (0.107) | (0.026) | - |
| Model 2 UK | 41.56*** | -4.27*** | 0.145*** | 0.122 | - | 0.210*** |
| s.e. | (5.815) | (0.673) | (0.025) | (0.106) | - | (0.029) |
| Johansen | | | | | | |
| | ln(Real GDP per capita) | ln(Real GDP per capita squared) | ln(Real GDP per capita cubic) | ln(Population Density) | ln(Trade Openness 1) | ln(Trade Openness 2) |
| Model 1 USA | 42.507* | -3.259 | 0.073 | -0.369 | 1.171*** | - |
| s.e. | (22.730) | (2.626) | (0.100) | (0.630) | (0.239) | - |
| Model 2 USA | 22.045 | -0.788 | -0.0251 | -0.211 | - | 1.229*** |
| s.e. | (24.327) | (2.835) | (0.109) | (0.646) | - | (0.234) |
| Model 1 UK | 51.486*** | -5.470*** | 0.192*** | 0.267 | 0.201*** | - |
| s.e. | (8.512) | (0.995) | (0.038) | (0.166) | (0.041) | - |
| Model 2 UK | 39.18*** | -4.066*** | 0.139*** | 0.275 | - | 0.264*** |
| s.e. | (10.022) | (1.166) | (0.045) | (0.172) | - | (0.050) |

Note: standard errors in brakets.ln ($CO_2$ emissions per capita) are the dependent variable in all cases for Engel-Granger case. Normalization with regard to ln($CO_2$ emissions per capita) adopted in the Johansen case.