Economic Development and Environmental Protection

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Summary

There is a long-standing debate on the relationship between economic development and environmental quality. From a sustainable development viewpoint there has been a growing concern that the economic expansion of the world economy will cause irreparable damage to our planet. In the last few years several studies have appeared dealing with the relationship between the scale of economic activity and the level of pollution. In particular, if we concentrate on local pollutants several empirical studies have identified a bell shaped curve linking pollution to per capita GDP (in the case of global pollutants like CO2 the evidence is less clear-cut). This behaviour implies that, starting from low per capita income levels, per capita emissions or concentrations tend to increase but at a slower pace. After a certain level of income (which typically differs across pollutants) – the "turning point" – pollution starts to decline as income further increases. In analogy with the historic relationship between income distribution and income growth, the inverted-U relationship between per capita income and pollution has been termed "Environmental Kuznets Curve". The purpose of this chapter is not to provide an overview the literature: there are several survey papers around doing precisely that. We instead reconsider the explanations that have been put forth for its inverted-U pattern. We look at the literature from this perspective. In addition, without resorting to any econometric estimation, we consider whether simple data analysis can help to shed some light on the motives that can rationalize the Environmental Kuznets Curve.

Keywords: Climate Policy, Environmental Modeling, Integrated Assessment, Technical Change.

JEL: H0, H2, H3

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1. Introduction: What is the Environmental Kuznets Curve?

When investigating the empirical relationship between income inequality and per capita income levels in 1965, Simon Kuznets could not possibly have imagined that his name would have been subsequently associated to *any* empirical relationship involving income levels and having a bell (or inverted-U) shape. One of the most thoroughly analyzed to date is the empirical reduced-form relationship between (a country or world's) economic development and the environment.

Admittedly, the relationship between economic growth and pollution is very complex, depending upon a host of different factors. Among these are: the size of the economy; the sectoral structure, including the composition of energy demand; the vintage of the technology; the demand for environmental quality; the level (and quality) of environmental protection expenditures. All these aspects are interrelated. For example, countries with the same sectoral composition of output may have a different level of emissions if their capital stocks are different in terms of technological vintage. More generally, while the study of the impact of economic growth on the environment is a significant endeavor, the analysis of feedback effects of the environment on a country well being is even more challenging a task.

The above considerations are the likely explanation of why this research field has been explored firstly on empirical grounds and only afterwards with the help of theoretical models. Indeed, the study of the causes and effects of a country's economic growth is probably one of the most challenging of the whole economic discipline. Investigating the bi-directional link between development and environment adds further difficulties to an already complex phenomenon.

Much has been written on the growth-environment relationship and on the Environmental Kuznets Curve (EKC hereafter). The literature has been mushrooming in the last decade and literature surveys are already numerous. Our updated list includes: Stern, Common, and Barbier (1996), Ekins (1997), Stern (1998), Stagl (1999), Borghesi (1999), Panayotou (2000), Levinson (2001), de Bruyn (2000), Ekins (2000), Dasgupta, Laplante, Wang, and Wheeler (2002), Harbaugh, Levinson, and Molloy Wilson (2002), Hill and Magnani (2002).

Given all these contributions it is difficult to say something new or original. At the same time, it is not the goal of this paper to carry out the most updated review of the literature. Instead, we would like to consider the issue of the relationship between economic development and the environment from a different tack. We will review the traditional explanations put forth for an inverted-U EKC relationship and consider them with the help of both specific contributions to the literature and of data analysis. In this last respect we follow Levinson (2001) who notes that one needs not sophisticated econometrics in order to demonstrate that environmental quality deteriorates with economic growth. "All one needs to do is show that there are some countries and some pollutants for which a time series of pollution plotted against GDP per capita shows a downward trend" (Levinson, 2001, p.2).

The paper is organized as follows. In the next section we ask why the EKC is relevant and to whom. We briefly review the nature of the relationship between economic growth and environment and the notion of EKC. Section 3 carries out a very selective review of the EKC literature highlighting the aspects the various studies have in common and their limitations and drawbacks. Section 4 is the main part of the paper and considers alternative explanations offered for the inverted-U relationship linking pollution to economic growth. Here some data analysis will be undertaken. Some conclusions will be drawn in the closing section.

2. Why the Environmental Kuznets Curve is of Interest to Experts and Non-experts Alike

As is well known, at the 1997 Kyoto summit the industrialized countries agreed upon an overall 5% reduction in greenhouse gas emissions from 1990 levels over a first commitment period lasting from 2008 to 2012. No such commitment was however taken by developing countries, the usual argument in favor of this position being that the industrialization process should require no constraint particularly for energy production and consumption.

Underlying this position, there is a long-standing debate on the relationship between economic development and environmental quality. From a sustainable development viewpoint there is no doubt that there has been a growing concern that the economic expansion of the world economy will cause irreparable damage to our planet. That concern stems from two rather intuitive concepts (see, for instance, Grossman, 1995): first, more output requires more inputs so that the earth's natural resources (including also exhaustible energy sources) will be quickly depleted (exhaustibility issue); second, more output causes more emissions and waste: the earth could soon exceed the carrying capacity of the biosphere (carrying capacity issue).

In the early phases of the debate, thirty years ago, the prevailing view was that economic growth was a threat to the environment. The world will not be able to sustain economic growth indefinitely without running into resource constraints or despoiling the environment beyond repair. The implication was that there is no room for endless economic development, rather we should start thinking in terms of a zero-growth situation. This was the view primarily of a number of respected social and physical scientists such as Georgescu-Roegen (1971), Ehrlich and Holdren (1971), Meadows, Meadows, Randers, and Behrens (1972), Ehrlich and Holdren (1973), Meadows, Meadows, and Randers (1992). Some authors date this view as far back as Boulding (1966) and to the materials-balance model of Ayres and Kneese (1969).

In the famous book *The Limits to Growth* (Meadows, Meadows, Randers, and Beherens, 1972), the members of the Club of Rome noted that higher levels of economic activity (production and consumption) require larger inputs of energy and materials, and generate larger quantities of waste byproducts. Increased extraction of natural resources, accumulation of waste, concentration of pollutants would exceed the carrying capacity of the biosphere and result in the degradation of environmental quality and decline in human welfare, despite rising incomes (Daly, 1991). Furthermore, it is argued that degradation of the resource base would eventually put economic activity itself at risk (Jansson, Hammer, Folke, and Costanza, 1994). To save the environment and even economic activity from itself, economic growth must cease and the world must make a transition to a steady-state economy (see Ekins, 2000, for a more thorough discussion of this position).

At the opposite extreme, the ecologists' pessimistic view was counteracted by a position according to which the fastest road to environmental improvement is along the path of economic growth: higher incomes increase the demand for less material-intensive goods and services; at the same time higher incomes bring about an increased demand for environmental protection measures. Famous is the quotation from Beckerman (1992): "The strong correlation between incomes, and the extent to which environmental protection measures are adopted, demonstrates that in the longer run the surest way to improve your environment is to become rich" (p.495). And again: "Furthermore there is clear evidence that, although economic growth usually leads to environmental degradation in the early stages of the process, in the end the best – and probably the only – way to attain a decent environment in most countries is to become rich" (p.496).

As noted by Shafik (1994), the above debate lacked empirical evidence to support one argument or the other, remaining on a purely theoretical basis for a long time. The main reason was the unavailability of environmental data for many years. However, it also reflected the difficulty of defining how to measure environmental quality. In the absence of a single criterion of environmental quality, several indicators of environmental degradation were used to measure the impact of economic growth on the environment. Obviously, the problem is that the use of various indicators implies the possibility of ambiguous answers as to the impact of growth on environment.

In a spat of initial influential studies, twenty years later the beginning of the debate (and ten years ago) Grossman and Krueger (1991, 1995), Shafik and Bandyopadhyay (1992), Panayotou (1993, 1995), Shafik (1994), Selden and Song (1994) hypothesized that the relationship between economic growth and environmental quality, whether positive or negative, is not fixed along a country's development path; rather, it can switch from positive to negative as a country reaches a level of income at which people demand and afford more efficient infrastructure and a cleaner environment. The implied inverted-U relationship between environmental degradation and economic growth came to be known as the "Environmental Kuznets Curve.

The Grossman and Krueger (1991) study was conducted as a part of a more general investigation on the potential environmental impacts of NAFTA. The Shafik and Bandyopadhyay (1992) contribution served as background paper for the World Bank's 1992 World Development Report (IBRD, 1992). Although the EKC terminology was not used, reference to those results was made by the Report which was subtitled "Development and the Environment" which, among other things noted: "The view that greater economic activity inevitably hurts the environment is based on static assumptions about technology, tastes, and environmental investments" (p.38) and "As incomes rise, the demand for improvements in environmental quality will increase, as will resources available for investment" (p.39).

Although – the Report showed – in terms of actual experience the evidence was in some cases consistent with the EKC, while in others was not, and although the Report was careful and cautious in its conclusions stressing – among other things – that the reduced-form nature of the EKC is ill-suited for drawing policy implications, the bell-shaped relationship generated quite a lot of enthusiasm between experts and non-experts alike. To economists it provided the evidence they lacked to support their basic conviction: that growth and environment can be made compatible, they are not necessarily in conflict, they can be *delinked*. Politicians and policy makers were instead quick to forget all the caveats that typically accompany empirical reduced-form investigations and often concluded that economic growth is a panacea from this point of view, that growth is both the cause and the cure of the environmental problem, that it is possible to "grow out" of environmental problems. A more extreme view of the policy implications was the suggestion to press the accelerator pedal of growth *unconditionally*. Achieving economic growth rather than implementing environmental policies is to be preferred because growth is perceived to be able to reach both economic and environmental goals, while environmental policy may actually impede growth. A milder view sees faster growth as *part* of the solution, while active environmental policies are still needed. These considerations could, for example, explain why developing countries did not enter the Kyoto agreement and accept to put a limit on their greenhouse gas emissions. It could also contribute to explain why a view against ratifying the Protocol has prevailed in the U.S. administration.

3. A Very Selective Survey of the Literature

In order to understand why the EKC hypothesis has become so popular, in particular among researchers, it is necessary to spend a few words on the empirical literature concerning the environment-development relationship. As said, we do not intend to give here a comprehensive review of what has been written on the topic. Rather, we will offer a succinct summary starting from the initial work, considering the common ingredients of this literature, moving then to the open questions.

The first empirical study is Grossman and Krueger (1991), later published in 1993 (see also Grossman and Krueger, 1995). The authors estimated EKCs for SO_2, dark matter (fine smoke), and suspended particulate matter (SPM) using the GEMS (Global Environmental Monitoring System) data. This data set is a panel of ambient measurements from a number of locations in cities around the world for a number of years. Shafik and Bandyopadhyay (1992) (see also Shafik, 1994) fitted EKCs for ten different indicators: lack of clan water, lack of urban sanitation, ambient levels of SPM, ambient SO_2, change in forest area between 1961 and 1986, the annual observations of deforestation between 1961 and 1986, dissolved oxygen in rivers, fecal coliforms in rivers, municipal waste per capita, CO_2 emissions per capita. Subsequent studies have used pollution emissions data rather than ambient concentration data. For instance, Panayotou (1993, 1995) estimated EKCs between per capita GDP and per capita emissions of SO_2, NO_X, and SPM, as well as deforestation. Finally, Selden and Song (1994) considered airborne emissions of SO_2, NO_X, SPM, and CO using longitudinal data from the World Resource Institute. The findings of these and other studies are reported in Table 1, which we have adapted from Panayotou (2000)'s extensive, but by now inevitably outdated, study. The table also reports the estimated value of turning points, the level of income at which the EKC – if so shaped - starts turning downward.

Indeed, virtually all EKC studies address the following common questions: (i) is there an inverted-U relationship between income and environmental degradation? (ii) if so, at what income level does environmental degradation start declining? As it can be seen from Table 1, both questions have ambiguous answers. The main reason has already been mentioned: in the absence of a single environmental indicator, the estimated shape of the environment-income relationship and its possible turning point generally depend on the pollutant considered.

In this regard, a useful classification of pollutants is offered by Frankel (2002). The first group of environmental damage is pollution that is *internal* to the household or firm. Perhaps 80% (by population) of world exposure to particulates is indoor pollution in poor countries - smoke from indoor cooking fires - which needs not involve any externality. Besides the usefulness of public warnings against the long-term health impacts that are not immediately evident, what is needed by these households is the economic resources to afford stoves that run on cleaner fuels. Some other categories of environmental damage pose potential externalities, but could be internalized by assigning property rights. The biggest problems arise when the legal system fails to enforce clear divisions of property rights. As an example, tropical forest land that anyone can enter to chop down trees will be rapidly over-logged. A second category, *national externalitie*s, includes most kinds of air pollution, such as NO_x and SO_2, and water pollution, the latter a particularly great health hazard in the third world. The pollution is external to the individual firm or household, and often external to the state or province as well, but most of the damage is felt within the country in question. Intervention by the government is necessary to control such pollution. Increasingly environmental problems cross national boundaries. Acid rain is an example. In these cases, some cooperation among countries is necessary. The strongest examples are purely *global externalitie*s: chemicals that deplete the stratospheric ozone layer, greenhouse gases that lead to global climate change, and habitat destruction that impairs biological diversity. In these cases, individual countries should not expect to be able to do much on their own.

As an alternative, it is possible to distinguish three main categories of environmental indicators that have been used in the literature: air quality, water quality and other environmental quality indicators. Borghesi (1999) nicely summarizes the evidence by grouping pollutants in this way. As to *air quality indicators*, there is strong, but not overwhelming evidence of an EKC. A distinction is conventionally made in the literature between local and global air pollutants (e.g. Grossman, 1995; Barbier, 1997). The measures of urban and local air quality (sulphur dioxide, suspended particulate matters, carbon monoxide and nitrous oxides) generally show an inverted-U relationship with income. This outcome, that emerged in all early studies, seems to be confirmed by more recent work (Cole, Rayner, and Bates, 1997). However, there are major differences across indicators as to the turning point of the curve: carbon monoxide and especially nitrous oxides show much higher turning points than sulphur dioxide and suspended particulate matters. Differences occur also for the same pollutant across alternative studies. When emissions of air pollutants have little direct impact on the population the literature generally finds no evidence of an EKC. In particular, both early and recent studies find that emissions of global pollutants - such as carbon dioxide (CO_2) - either monotonically increase with income or start declining at income levels well beyond the observed range.

For *water quality indicators*, the empirical evidence on EKCs is even more mixed. However, when a bell-shaped curve does exist, the turning point for water pollutants is generally higher than for air pollutants. Three main categories of indicators are used as measures of water quality: (i) concentration of pathogens in the water (indirectly measured by fecal and total coliforms), (ii) amount of heavy metals and toxic chemicals discharged in the water by human activities (lead, cadmium, mercury, arsenic and nickel) and (iii) measures of deterioration of the water oxygen regime (dissolved oxygen, biological and/or chemical oxygen demand). There is evidence of an EKC for some indicators (especially in the latter category), but many studies reach conflicting results as to the shape and peak of the curve. Several authors (Shafik, 1994; Grossman and Krueger, 1995; Grossman, 1995) find evidence of an N-shaped curve for some indicators: as income grows water pollution first increases, then decreases and finally rises again. Thus, the inverted-U curve might correspond just to the first two portions of this more complex pattern. The existence of an N-shaped curve seems to imply that at very high income levels, the scale of the economic activity becomes so large that its negative impact on the environment cannot be counterbalanced by the positive impact of environment-friendly technological change and of a shift toward greener economic activities such as services.[1]

Finally, in the absence of a single definitive measure of environmental quality, many *other environmental indicators* have been put to test the EKC hypothesis. In general, for most of these indicators there seems to be little or no evidence of an inverted-U pattern. Both early and recent studies (Shafik, 1994; Cole, Rayner, and Bates, 1998) find that environmental problems having direct impact on the population (such as access to urban sanitation and clean water) tend to improve steadily with growth. On the contrary, when environmental problems can be externalized (as in the case of municipal solid wastes) the curve does not even fall at high income levels. As to deforestation, the empirical evidence is controversial.[2] Some studies find an inverted-U curve for deforestation with the peak at relatively low income levels (e.g. Panayotou, 1993), whereas others conclude that “per capita income appears to have little bearing on the rate of deforestation” (Shafik, 1994, p.761). Finally, even when an EKC seems to

[1] Shafik (1994, p.765) has advanced the hypothesis that the increase in rivers pollution at high-income levels typical of an N-shaped curve might occur because "people no longer depend directly on rivers for water and therefore may be less concerned about river water quality".

[2] As Panayotou (1993) pointed out, the rate of deforestation is particularly important as a measure of environmental degradation for two reasons. Firstly, it can be taken as a proxy variable for the depletion of natural resources. Secondly, according to the World Resource Institute deforestation, together with land use changes, accounts for about 17-23% of total anthropogenic carbon dioxide emissions..

apply (as in the case of traffic volume and energy use), the relative turning points are far beyond the observed income range.

By and large, the above mentioned contributions, along with some of the more recent ones, share a number of common features which can be summarized as follows.

(i) The typical relationship considered relates per capita emissions or concentrations of a pollutant to per capita income. In general, and with the possible exception of a time trend, no extra explanatory variables are included.

(ii) The analysis is usually conducted on a panel data set of individual countries around the world. For CO_2 emissions data almost invariably have come from a single source, namely the Oak Ridge National Laboratory. For most of the other pollutants, the GEMS data set is employed.[3]

(iii) The functional relationship considered is either linear or log-linear one, with a number of studies considering both.

(iv) Due to the almost complete coverage of world countries, the estimation technique is typically the least square dummy variable method, allowing for both fixed country and time effects.[4]

The first wave of contributions in the EKC literature has typically focused upon the empirical emergence of the EKC, whether it has indeed an inverted-U shape, and has typically discussed its implications with special reference to the level of the income turning point. Often out-of-sample projections of pollutant emissions or concentrations have been a subject of interest. More recently, a large, second wave of studies has instead concentrated on the robustness of the previous empirical practice and criticized, from various standpoints, the previous work and findings. The most recurrent criticism is the omission of relevant explanatory variables in the basic relationship. Thus, besides income and time trend, we ought to include trade because of the so-called “pollution heaven” or “environmental dumping” hypothesis (Hettige, Lucas, and Wheeler, 1992; Kaufmann, Davidsdottir, Garnham, and Pauly, 1998; Suri and Chapman, 1998), energy prices to account for the intensity of use of raw materials (de Bruyn, van den Bergh, and Opschoor, 1998), and a host of other variables if we care about political economy considerations due to the public good nature of the environment (Torras and Boyce, 1998). In addition, allowance should be made for changes in either the sectoral structure of production or the consumption mix (Rothman, 1998; Hettige, Mani, and Wheeler, 2000) or for the distinction, when data permit, between polluting activity and pollution intensity which, when related to GDP, work in opposite directions (Hilton and Levinson, 1998). A few studies check the robustness of the approach to alternative or more comprehensive datasets (Galeotti and Lanza, 2002; Harbaugh, Levinson, and Molloy Wilson, 2002); others consider alternative functional forms, including non-parametric approaches (Schmalensee, Stoker, and Judson, 1998; Taskin and Zain, 2000; Azomahou and Van Phu, 2001; Galeotti and Lanza, 2002). Finally, a more fundamental criticism is that of “income determinism” of empirical EKCs which implicitly hold that the experience of a country is equal to that of all other (Unruh and Moomaw, 1998). Indeed, a few studies have questioned the practice of pooling various countries together and carried out EKC investigations on data from individual countries.[5] Thus, for instance, Vincent (1997) examines the link between per capita income and a number of air and water pollutants in Malaysia from the late 70s to the early 90s. de Bruyn, van den Bergh, and Opschoor (1998)

[3] The data for real per capita GDP are typically drawn from the Penn World Table and are on a PPP basis.

[4] de Bruyn, van den Bergh, and Opschoor (1998) show how a bell shaped EKC may spuriously obtain as a result of the interplay between time effect and aggregation across countries. Roberts and Grimes (1997) estimate individual cross sections for several years.

[5] One of the most recent and thorough investigations of the EKC that carries out a number of robustness checks is Harbaugh, Levinson, and Molloy Wilson (2002).

investigate emissions of several air pollutants (sulphur dioxide, carbon dioxide and nitrous oxides) in four OECD countries (Netherlands, West Germany, U.K., and U.S.A.) between 1960 and 1993. Carson, Jeon, and McCubbin (1997) study the Unites States using data on per capita emissions of air toxics collected by the Environmental Protection Agency from the 50 U.S. states. Dijkgraaf and Vollebergh (1998) consider CO_2 emissions for individual OECD countries over the period 1960 to 1990. Finally, Egli (2001) considers per capita emission data of eight pollutants in the case of Germany 1966-1998.

Econometric techniques have been the dominating tool for studying the relationship between environment and economic growth. They offer a number of well known advantages, although departures from the basic approaches often requires the availability of more data on more variables or imposes a price in terms of reduced number of degrees of freedom.[6] In the next section we focus on the pattern of the basic data without resorting to econometrics. As noted by Levinson (2001), "Demonstrating this point [that environmental quality deteriorates steadily with economic growth] does not require sophisticated econometrics. All one needs to do is show that there are some countries and some pollutants for which a time series of pollution plotted against GDP per capita shows a downward trend. Pooled estimates with fixed effects or random effects, polynomials, lagged values of GDP, and multiple control variables distract from the fundamental empirical question: are there pollutants that have declined with economic growth for some countries?" (Levinson, 2001, p.2).

4. Traditional Explanations of the Environment and Growth Relationship

The first and most common explanation of an inverted-U Kuznets relationship is the "*stages of economic growth*" economies go through as they make a transition from agriculture-based to industry and then post-industrial service-based systems. The transition from an agricultural to an industrial economy results in increasing environmental degradation as mass production and consumption grow. The transition from an industrial to a service-based economy is instead assumed to result in decreasing degradation due to the lower environmental impact of service industries. As Panayotou (1993, p.14) points out, environmental degradation tends to increase as the structure of the economy changes from rural to urban, from agricultural to industrial, but it starts falling with the second structural change from energy-intensive heavy industry to services and technology-intensive industry.

A slightly modified view holds that economies pass through technological life cycles, moving from polluting technology to high technology. Obsolete and dirty technologies are substituted with cleaner ones, and this also improves the quality of the environment. *Technological progress* often occurs with economic growth since a wealthier country can afford to spend more on research and development.[7]

A third explanation holds that the Kuznets behavior is an income effect resulting from the *environment being a luxury good*. Early in the economic development process of a country individuals are unwilling to trade consumption for investment in environmental protection: environmental quality declines as a result. Once individuals reach a given level of consumption

[6] Some authors have noted the problem of lack of good data on environmental indicators themselves: see Borghesi (1999) and the references cited therein.

[7] For instance, Komen, Gerkin, and Folmer (1997) examine data on 19 OECD countries between 1980 and 1994 and show that the income elasticity of public research and development expenditures for environmental protection is approximately equal to one. Notice that technological progress can be seen as both the cause and the effect of economic growth.

(or income), they begin to demand increasing investments in an improved environment. Thus, after the “income turning point”, environmental quality indicators begin to display reductions in pollution and environmental degradation. The income elasticity of environmental demand is often invoked in the literature as the main reason to explain this process. As income grows, people achieve a higher living standard and care more for the quality of the environment they live in. The demand for a better environment as income grows induces structural changes in the economy that tend to reduce environmental degradation. On one hand, increased environmental awareness and “greener” consumer demand contribute to shift production and technologies toward more environmental-friendly activities. On the other hand, they can induce the implementation of enhanced environmental policies by the government (such as stricter ecological regulations, better enforcement of existing policies and increased environmental expenditure). This also contributes to shift the economy towards less polluting sectors and technologies. Hence, the demand for a better environment and the resulting policy response are the main theoretical underpinnings behind the decreasing path of the EKC (Grossman, 1995 p.43).[8]

In the previous section it was noted that time series, cross-country studies uncover inverted-U EKCs only for a subset of all possible environmental indicators. Carbon emissions, for example, seem to increase at ever decreasing rates, but predicted peaks are far outside reasonable income levels. Some researchers find an "N-shaped" path relative to income -- increasing at low levels of income, decreasing at high levels, and then increasing again at even higher levels of national income. Finally, some pollutants appear only to decline with income, but this must by definition be a result of the data available. The researchers merely do not have data from earlier periods in which the pollution presumably increased, and only document the period of decline. In other words, in those cases documenting monotonic declines in pollution, the long-run pollution-income path must be roughly inverse-U-shaped (Levinson, 2001).

A problem noted is that the EKC that emerges in the cross-section analysis “may simply reflect the juxtaposition of a positive relationship between pollution and income in developing countries with a fundamentally different, negative one in developed countries, not a single relationship that applies to both categories of countries” (Vincent 1997, p. 417).[9] To document this point, Figure 1 is reproduced from Levinson (2001) who considers airborne sulphur pollution across countries and monitoring stations taken from the GEMS data base for the year 1980.[10] This is the pollutant most frequently found to have an inverted-U patterns and the one

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[8] Another argument has been advanced in the literature to explain the bell-shaped environment-income pattern. It has been suggested (IBRD, 1992; Unruh and Moomaw 1998) that the existence of an endogenous *self-regulatory market mechanism* for those natural resources that are traded in markets might prevent environmental degradation from continuing to grow with income. In fact, early stages of growth are often associated with heavy exploitation of natural resources due to the relative importance of the agricultural sector. This tends to reduce the stock of natural capital over time. The consequent increase in the price of natural resources reduces their exploitation at later stages of growth as well as the environmental degradation associated with it. Moreover, higher prices of natural resources also contribute to accelerate the shift toward less resource-intensive technologies (Torras and Boyce, 1998). Hence, not only induced policy interventions, but also market signals can explain the alleged shape of the EKC.

[9] This criticism may be valid even for results obtained from panel data because of a lack of overlap between developed and developing country data series: all high income observations are from developed countries; all low-income observations are from developing countries (Vincent, 1997).

[10] Figure 1b from Levinson (2001). The GEMS data contain 2401 annual observations from 285 monitoring stations in 102 cities in 45 countries, from 1971 to the present. Because the Summers and Heston data only extend to 1992, this analysis stops at that date. The figure depicts the average SO_2 reading across all monitoring stations within a country for a cross-section of 45 countries for the year 1980, plotted against GDP per capita.

internationally best monitored. Looking at the picture, the claim that pollution declines at higher level of incomes does not come out naturally.

When the econometric analysis is instead, as in most cases, carried out by pooling time series and cross section data, the assumption of homogeneity in the slope coefficients in usually made. Rarely the hypothesis has been tested, but a number of recent contributions have concentrated on individual country evidence. Grossman and Krueger (1995) estimate panel data models with random effects. In this case the crucial GDP coefficients are identified partly from the cross section variation of the data across countries in a given year and partly from the time series variation within given countries. Particularly for local pollutants the time series evolution of the data should be sufficient in order to assess any decline as a country develops. Figure 2 again reproduces a picture proposed by Levinson (2001, Figure 2) which plots average SO_2 readings from the U.S. 22 monitoring stations continuously active from 1979 to 1992, plotted against GDP per capita. An unequivocal declining pattern emerges.

Clearly, a "stages of growth" explanation for the EKC necessitates of much longer continuous time series. It turns out that such data are available for the case of CO_2 emissions. They date back to 1751 and are developed by Marland, Andres, Boden, Johnson, and Bernkert (1996), while income data series that cover the period from 1870 to 1994 are available from Maddison (1995). These data are available for seventeen OECD countries including U.K., U.S.A., and Japan. Most countries have undergone the transition from a rural to a service economy during the period considered here. The plots are presented sequentially in Figure 3. A non parametric kernel has been used to interpolate the data points.[11] The evidence is pretty clear. For nearly all the countries considered an increasing, albeit concave, environment-GNP relationship can be identified. Sometimes an inverted-U shape can be seen (e.g. Belgium, Canada, Sweden, France): in this cases, however, it seems that at very high income values CO_2 emissions start to peak up again.[12]

The case of global pollutants such as CO_2 emissions, is clearly rather special. The inability of finding a bell shape relationship lies in the global nature of such pollutant, which involves cross-border externalities, so that no one country has sufficient incentive to regulate emissions. The free rider problem may simply be more troublesome with carbon than any other pollutant. With this caveat in mind, it appears that the graphs presented are not incompatible with a stages of growth explanation of the environment-development relationship. At a similar conclusion we arrive when analyzing SO_2 emissions per capita as in Figure 4. Here the countries considered are those for which we had the longest available time series of data.[13]

However, authors such as Roberts and Grimes (1997) question the existence of EKCs even for indicators that seem to follow this pattern. For instance, they observe that the relationship between per capita GDP and carbon intensity changed from linear in 1965 to an inverted-U in 1990. Carbon intensity is defined as CO2 emissions per unit of GDP. They observe this pattern

[11] The log per capita emissions data of each country have been regressed on year dummies corresponding to the two World Wars.

[12] This evidence is consistent with a "N-shaped" path relative to income: increasing at low levels of income, decreasing at high levels, and then increasing again at even higher levels of national income. Grossman and Krueger (1995) dismiss the upper tail of this pattern as an artificial construct of the fact that they use a cubic functional form. The upper tail contains sparse data, and its shape is driven by the pattern of data at lower incomes.

[13] The data are those employed by Shafik and Bandyopadhyay (1992) and are available at http://www.worldbank.org/research/growth/ddshaban.htm. SO_2 emissions per country-year are the average across the cities within a country considered in the dataset.

is the result of environmental improvement in developed countries in these last decades and "not of individual countries passing through stages of development, but of a relatively small number of wealthy ones becoming more efficient since 1970 while the average for the rest of the world worsens" (Roberts and Grimes, 1997, p.196). In fact, the data set shows that carbon intensity fell steadily among high income countries in the period 1965-1990, but increased among middle- and low-income nations, with a marked increment in the latter group.

Some authors have stressed the fact that economies undergo structural changes over time and these may have an impact on the link between economic growth and environmental quality. A natural candidate for such changes is technological change, although exogenous shocks – such as oil crisis – can also be important. Indeed, Unruh and Moomaw (1998) point out that the increase in the oil price that occurred during the 1970s promoted the shift to alternative sources of electric power production. Technical change may consist of a more efficient use of inputs, substitution of less for more environmentally intensive inputs, less generation of waste, transformation of wastes to less environmentally harmful forms, containment or recycling of wastes, a shift within a sector toward new, less environmentally harmful products or processes. A rough way to assess if the explanation of EKC behavior based on the role of technical progress has any relevance is to look at cross-sections of data. An exercise of this sort is performed by Roberts and Grimes (1997) and their findings are reproduced in Figure 5. As previously said, it appears that the relationship between per capita GDP and carbon intensity changed from linear in 1965 to an inverted-U in 1990. Note however that the authors relate income per capita to CO_2 emission intensity, not emission levels. Moreover they consider all the world countries together. If we cross plot per capita income and emissions for relatively homogenous groups of countries observed at certain time intervals we obtain, again using smoothing kernels, the situation portrayed in figure 6. Panel (a) of the figure presents the evidence for 29 OECD countries observed at the beginning of the last five decades. It is difficult to make out a consistent story, also because the data points are too few. Perhaps the most recent graph suggests that emissions are decreasing at a slower pace relative to the previous cases. While one cannot really discern an inverted-U pattern in the post oil shock data, it is possible to conclude that the relationship is not stable over time: static econometric models are therefore unsuited for the analysis. For the sake of comparison we also present in panel (b) the evidence concerning 104 non-OECD countries (all countries are considered together in panel (c) of the figure): again, quite a different picture emerges when comparing the situation in 1991 with that of ten years before and, similarly, seven years later. Hill and Magnani (2002) split their data into separate cross sections: 1970, 1980, and 1990 for CO_2; 1975, 1980, 1985, and 1990 for SO_2 and NO_X. They run standard econometric regressions for a sample of 156 world countries. For the first pollutant an inverted-U curve is found for all three cross sections. Similar results also emerge for the other pollutants. It also appears that in the case of carbon dioxide the curve has shifted downward in the last two decades. Splitting the sample between low- middle- and high-income countries the authors appear to confirm the conclusions of Roberts and Grimes (1997) reported above. Finally, some authors have challenged the standard environment-income relationship altogether and proposed alternative formulations. Of particular note, are structural transition models and non-linear dynamic systems. Moomaw and Unruh (1997) formulated structural transition models for 16 OECD countries and showed that the transition of these countries from positive to negative emission elasticities correlate better with historical events such as oil price shocks, and related structural transitions than with income growth.

Viewed from the vantage point of technical progress, which is inherently a dynamic phenomenon, the various panels of Figure 7 seem to remind us that the process of technological change has many facets, as it can both be beneficial and unfriendly to the environment. There are therefore no substitutes for policy in directing the innovation efforts toward fostering economic growth and helping the environment at the same time.

The first explanation of the EKC, stressing the stages through which economic development goes through, places most of the emphasis upon non-environmental policies designed to foster growth – environmental improvement being a sort of welcomed, inevitable consequence. The explanation based on the role of technological change, or more generally on structural changes affecting economies, has instead showed us that conscious environmental policies may be needed in order to direct the environment-growth relationship toward a downward trend. Indeed, technological innovation is increasingly seen as one of the main practical keys for reconciling the current fundamental conflict between economic activity and the environment. It is however important to bear in mind that technical change is not per se always beneficial for the environment.

A third explanation hinges upon the role played by increasing levels of education and environmental awareness as factors that contribute to the emergence of an EKC. As put by Hill and Magnani (2002), rather than being a natural consequence of economic development, the EKC is a consequence of choosing priorities. As people get richer, they become more concerned about the environment, and hence exert pressure on politicians to introduce environmental regulations and firms to use more polluting abatement technologies. Such pressure is more likely to translate into a concerted program of pollution abatement in a country where there exists a democratic government, the rule of law and a free press. Thus, Torras and Boyce (1996) look at how various indicators of democracy may influence the formation of preferences and mediate between private preferences and public policy. Panayotou (1997) incorporates policy considerations into the estimated income-environmental relationship. His main finding, at least for ambient SO_2, is that effective policies and institutions can effectively reduce environmental degradation at low income levels and speed up improvements at higher incomes, thereby reducing the environmental cost of growth. De Bruyn (1997) finds a significant role for environmental policy, but not for structural change in the economy, when investigating the EKC for a sample of OECD and former socialist economies. Finally, Hettige, Mani, and Wheeler (2000) find that stricter environmental regulation is the main factor bringing about some improvement in water quality when per capita income is rising.

The evidence just mentioned induces Dasgupta, Laplante, Wang, and Wheeler (2002) to argue that the shape of the EKC is likely not to be fixed, but be determined by how many parties react to economic growth and its side effects, including citizens, businesses, policy makers, regulators, NGOs, and other market participants. The authors contend that countries may be able to experience a EKC that is flatter and lower than the conventional measures would suggest. The authors note that there appear to be three main reasons why richer countries regulate pollution more strictly. First, pollution damage gets higher priority after society has completed basic investments in health and education. Second, higher income societies have better technical personnel and wider budgets for monitoring and enforcement activities. Third, higher income and education empower local communities to enforce higher environmental standards. It should also be noted that in developed countries pressure for environmental protection created by market agents is likely to be stronger. Thus, for instance, banks may refuse credit if worried about environmental liability; consumers may avoid products of firms known to be heavy polluters. Evidence is building up showing, for instance, that multinationals are sensitive and positively react to the close scrutiny from consumers and environmental organizations (Dowell, Hart, and Yeung, 2000). Finally, investors appear to play an important role in encouraging especially quoted companies to adopt clean production processes (Konar and Cohen, 1997; Lanoie, Laplante, and Roy, 1998). Note that similar effects of environmental news on stock prices have been identified in developing countries such as Argentina, Chile, Mexico, and the Philippines (Dasgupta, Laplante, and Mamigi, 2001). By the same token, it is observed that low income communities frequently penalize dangeorus pollutants even when formal regulation is weak or absent. Evidence from Asia and Latin America documents that neighboring communities can strongly influence factories' environmental performance (Pargal and Wheeler, 1996; Hettige, Huq, Pargal, and Wheeler, 1996). Thus, the role of regulation is important in low income countries, not only in rich ones.

If the role of environmental protection in shaping the inverted-U relationship between growth and environment, and if developed countries are already beyond the hump, then we should expect widespread overall improvements in environmental quality to have taken place in recent years, and especially in those countries which are more zealous from this standpoint. Ekins (1997) discusses this aspect and begins by noting that both the OECD and the European Commission have produced detailed surveys of the state of their members' environments (OECD, 1991; CEC, 1992). The OECD report acknowledges that progress has been made by member countries "in dealing with a number of the most urgent environmental problems identified over the last two decades" (OECD, 1991, p.283), although problems remain across all areas of environmental concern. The CEC report assesses the state of European environment looking at air, water, soil, waste, quality of life, high risk activities, and biological diversity. As for air, progress has been made in reducing emissions of SO_2, SPM, lead, and CFCs; however serious problems remain or are emerging for GHGs (CO_2, NO_X, CH_4, atmospheric ozone). Despite past investments, the state of water resources has not improved. Physical degradation of soil is widespread. The volume of waste is generally increasing far faster than treatment and disposal capacity. Howe to reconcile these conclusions with evidence from EKC studies? According to Ekins (1997), EKCs typically refer mostly to those pollutants for which progress has been recorded. At the same time, the conclusions of the official institutions refer to recent developments, whereas EKCs weigh past performance against the most recent one.

Another aspect worth mentioning is the ranking compiled by MacGillivray (1993), who considers twenty-two OECD countries and obtains a measure of environmental performance aggregating eleven different indicators.[14] The results are reported in Table 2, which is reproduced from Ekins (1997, 2000). The first panel of the table shows that no strong relationship between environmental performance and income is discernible. If anything, performance seems to drift downward with income, but this movement is unlikely to be statistically significant. Thus, no support for an EKC explanation seems to emerge from these data, while ample room for environmental policy remains. At similar conclusions we arrive when conducting another simple exercise: matching the ranking of the second panel of the table with the curves interpolated from CO_2 time series data in Figure 2: it is difficult to establish a correlation between these two sets of information.

5. Wrapping Up

People interested for various reasons in the relationship between economic development and environmental quality seem to have accepted in the last decade the fundamental conviction of economists: increase in the former does not necessarily mean deterioration of the latter; in current jargon, a de-coupling or de-linking is possible, at least after certain levels of income. This is the basic tenet at the heart of the Environmental Kuznets Curve, as that relationship has become familiarly known.

Three explanations are typically mentioned to rationalize the inverted-U shape of pollutant-income relationships. The one first is referred to as "stages of growth"; the second one

[14] These are: per capita CO_2 emissions, per capita NO_X emissions, per capita SO_2 emissions, per capita water abstraction, percentage of population with sewage treatment, protected areas as percentage of total land area, threatened species of mammals and birds as percentage of all species in the country; generation of municipal solid waste, energy intensity, private road transport, nitrate fertilizer application per square kilometer of arable land, and permanent cropland.

emphasizes the role of technical progress, especially the one taking place through discrete innovations, and more generally of structural change occurring within economies; the third reason instead refers to the increased environmental consciousness that develops when people get richer and the increased environmental regulation that such process brings about.

In this paper we have briefly considered the econometric evidence that has been and is accumulating on the EKC. It has been noted that, because the EKC literature is generally based on no underlying theory, it is particularly susceptible to various critiques. In addition, based on the assumption that a look at the data may be the first thing to do when looking for a decreasing trend in environmental quality as income rises, we have considered the case of CO_2 for which suitable data are available. We have tried to ascertain the relative role of the above explanations by means of data analysis. Although the tool is very rough, it seems that a stages of growth rationale is not incompatible with long time series of data for a number of (currently) developed countries. The analysis of cross-country data across four decades for the group of OECD countries suggests that a story based on technical progress or structural change is not borne out by the visual inspection of the data. Finally, the pattern of emission data displayed here fails to bear any correlation with reported measures of country environmental performance. Indeed, careful analysis of the data by official institutions suggests that even in rich countries there is still ample room for environmental policy. According to recent evidence, policies currently in place are not sufficient to provide an explanation of inverted-U relationships for a number of important pollutants.

Busy with pursuing the goal of eventually uncovering the inverted-U relationship, if existing, the EKC literature for the most part has lost sight of other important questions that come with the environmental-income relationship. Panayotou (2000) provides a list: (i) how much damage would have taken place by the time a turning point is reached and can it be reduced? (ii) would any ecological thresholds be violated and irreversible damages take place before environmental degradation turns down, and how can they be avoided? (iii) is environmental improvement at higher income levels automatic, or does it require conscious institutional and policy reforms? (iv) how to accelerate the development process so that poor countries can experience the same improved economic and environmental conditions enjoyed by developed countries?

Focusing on the level of per capita income at which the slope of the EKC changes, contributions have tended to forget that, for many pollutants, levels of emissions and concentrations maybe be intolerably high even before the income turning point. In this event, an inverted-U EKC is clearly of little use. Moreover, since it may take several years for a low-income country to cross from the upward to the downward sloping part of the curve, the accumulated damages in the meanwhile may far exceed the present value of higher future growth and a cleaner environment. This implies that active environmental policy to mitigate emissions and resource depletion in the earlier stages of development may be justified on purely economic grounds. In the same vein, current prevention may be more cost effective than a future cure, even in present value terms; for example, safe disposal of hazardous waste as it is generated may be far less costly than future cleanups of scattered hazardous waste sites. Shifts in production patterns to less polluting sectors, such as services, raise the question of what comes after the "virtual economy"; by the same token, moving polluting production processes abroad to countries with weaker regulatory regimes begs the question of which other countries will be available after all developing nations have been affected by that process. Finally, even if one accepts the evidence with well-known conventional pollutants, there is still the question about other less-known pollutants and environmental hazards that are likely to be the result of the process of economic development and that may be rising with income. Indeed, the OECD report mentioned above point to the emergence of new problems, both from a change in substances of concern and the emergence of new sectors and industries with new kinds and degrees of pollution problems, so that "in the 1990s OECD countries will have to face more intractable problems than those solved in the previous decades" (OECD, 191, p.287). The CEC report states that "with regard to high-risk activities, no areas of risk reduction are identified, whereas several industries and activities are highlighted as posing 'new risks'" (CEC, 1992, p.44). One specific example is emissions of toxic organic chemicals into the air and water. In this respect, as noted by Dasgupta, Laplante, Wang, and Wheeler (2002), the international community has begun to responding: in May 2001 127 countries signed a treaty to ban international production and trade in twelve persistent organic pollutants, including PCBs, dioxins, DDT, and other pesticides that have been shown to contribute to birth defects and cancer. The example is a useful reminder of the scope of environmental policy which cannot be limited to conventional pollutants for which a success may be declared.

Environmental Kuznets Curves are probably the most important and thoroughly analyzed issue in the econometrics of the environment. Alternative data sets, various individual pollutants and aggregate indicators, different estimation techniques, multiple functional forms, non-parametric analyses, dynamic considerations, transition, regime-shifts and other sorts of non-linearities are all aspects that can be and have been entertained, all with the ultimate goal of assessing if a fundamental hump-shaped relationship between a pollutant and economic growth survives.

Nevertheless, an EKC relationship can only serve as an ex-post check of the tendency for a pollutant to behave with economic growth. Whatever its pattern, it can neither serve as the conceptual basis for policies favoring economic growth *unconditionally* nor can it represent a model that can be exported to other countries and pollutants.

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Table 1: Empirical Relationship between Per Capita GDP (IPC) and Selected Indicators of Environmental Degradation (IED)

	CO_2	SO_2	SPM	NO_X	BOD/MSW	Lack of Clean Water	Lack of Urban Sanitation	Deforestation
Shafik and Bandyopadhyay (1992)		3.0 ($85 p)	n.a.	n.a.	w			5.5 ($85)
Panayotou (1993)	n.a.	3.0 ($85)	4.5 ($85)	5.5 ($85)	n.a.	n.a.	n.a.	5.5 ($85)
Grossman and Krueger (1993)	n.a.	4.1 ($85 p)	6.0 ($85 p)	n.a.	n.a.	n.a.	n.a.	n.a.
Shafik (1994)		3.6 ($85 p)	3.2 ($85 p)	n.a.	w			5.5 ($85 p)
Selden and Song (1994)	n.a.				n.a.	n.a.	n.a.	n.a.
Grossman and Krueger (1995)	n.a.	4.0 ($85)	n.a.	n.a.	7.8 ($85)	n.a.	n.a.	n.a.

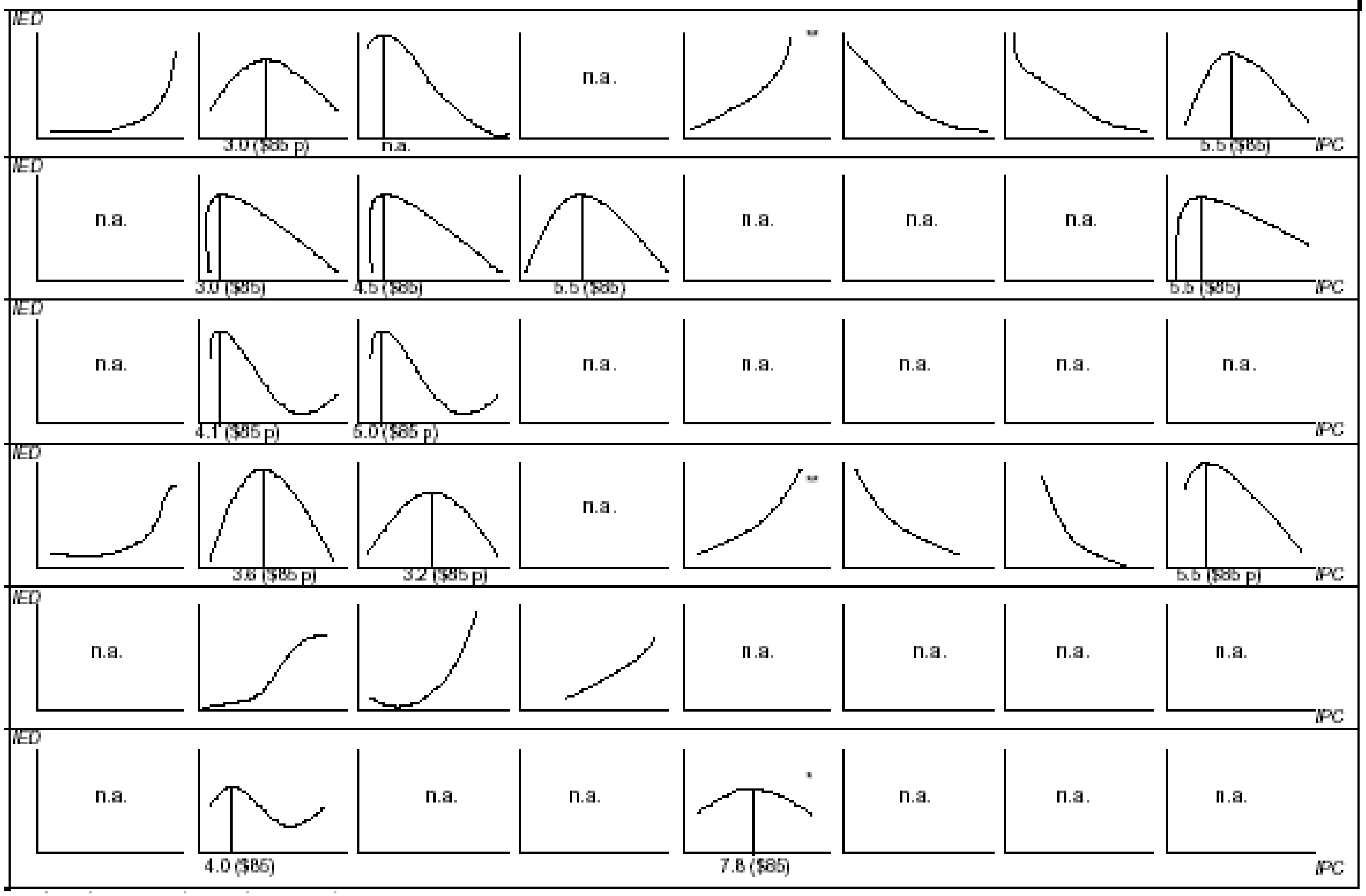
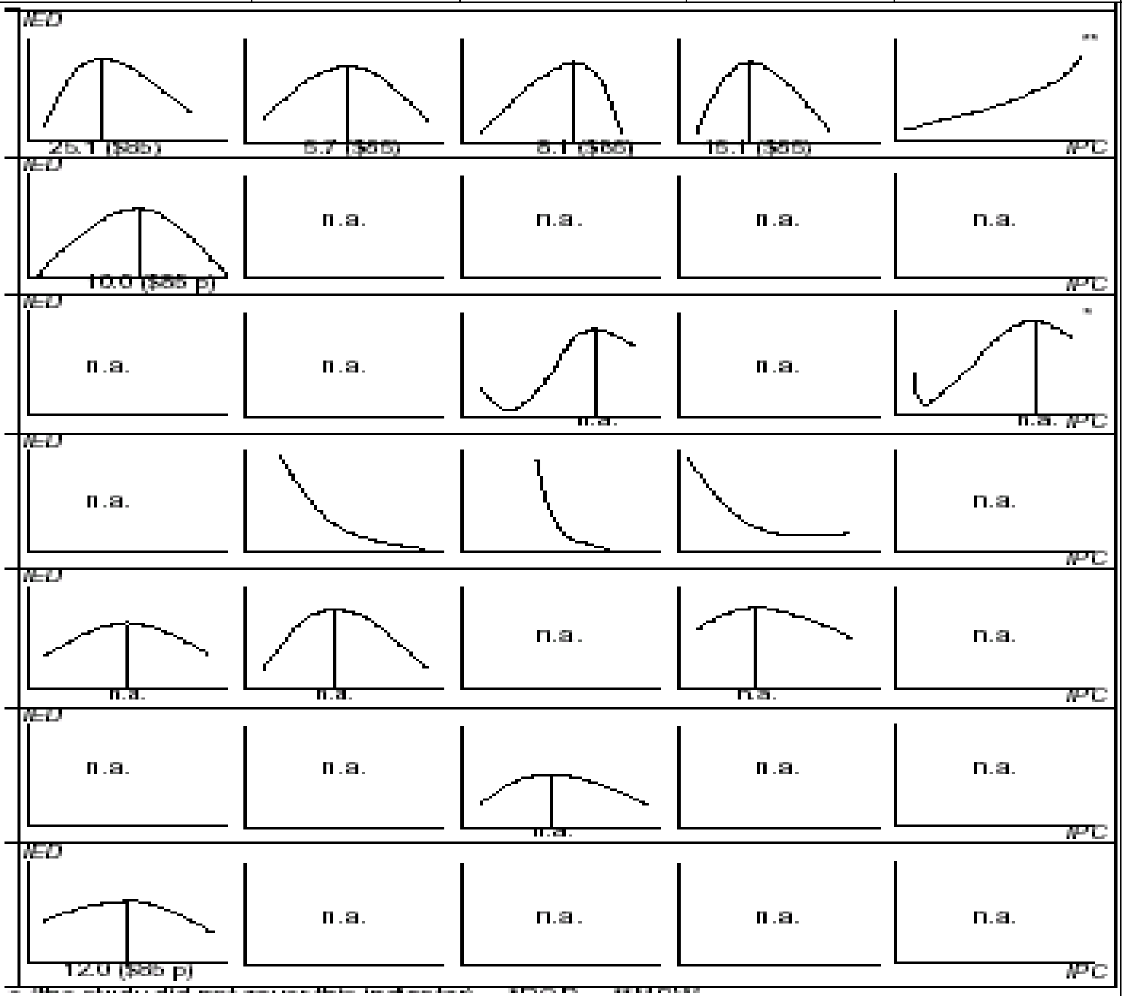


Table 1 cont'd

	CO_2	SO_2	*SPM*	NO_X	*BOD/MSW*	
Cole, Rayner, and Bates (1997)						Notes:
Schmalensee, Stoker, and Judson (1998)						
Vincent (1997)						
Carson, Jeon, and McCubbin (1997)						
Bruyn, Bergh, and Opschoor (1998)						
Islam, Vincent, and Panayotou (1999)						
Panayotou, Sachs, and Peterson (1999)						



Notes:

CO_2 = Carbon dioxide
SO_2 = Sulphur dioxide
SPM = Suspended Particulate Matter
NO_X = Nitrogen Oxides
BOD = Biochemical Oxygen Demand
MSW = Municipal Solid Waste

* BOD
** MSW
n.a. = not available: the study did not cover this environmental indicator

Turning Points:

The fist two digits are to multiplied by 1,000
($85) means that per capita GDP is expressed in 1985 U.S. dollars
($85p) means that per capita GDP is expressed in 1985 U.S. dollars on a PPP basis

Table 2: Environmental Performance and Income

Country	Environmental Performance Indicators (total points)	GDP per capita		Country	Score (%)
Austria	847.5	17,690		Austria	77.0
Portugal	805.5	9,450		Portugal	73.2
Japan	789.9	19,390		Japan	71.8
Spain	785.5	12,670		Spain	71.4
Turkey	753.8	4,840		Turkey	68.5
Norway	752.3	17,170		Norway	68.4
Italy	751.7	17,040		Italy	68.3
Switzerland	737.6	21,780		Switzerland	67.1
Sweden	736.5	17,490		Sweden	67.0
U.K.	718.5	16,340		U.K.	65.3
Denmark	717.5	17,880		Denmark	65.2
France	696.9	18,430		France	63.4
Germany	665.2	19,770		Germany	60.5
Greece	642.6	7,680		Greece	58.4
Ireland	603.7	11,430		Ireland	54.9
Netherlands	596.8	16,820		Netherlands	54.3
Finland	583.2	16,130		Finland	53.0
Australia	541.7	16,680		Australia	49.2
Belgium	533.2	17,510		Belgium	48.5
Canada	436.7	19,320		Canada	39.7
U.S.A.	408.7	22,130		U.S.A.	37.2

Notes to the Table:

(i) Table adapted from Ekins (1997) on the basis of MacGillivray (1993).

(ii) GDP data are expressed in PPP 1991 U.S. dollars.

(iii) The score is the percentage of total points obtained out of 1100 (11 indicators considered).

Figure 1: SO_2 vs Per Capita GDP - Country Cross-section, 1980

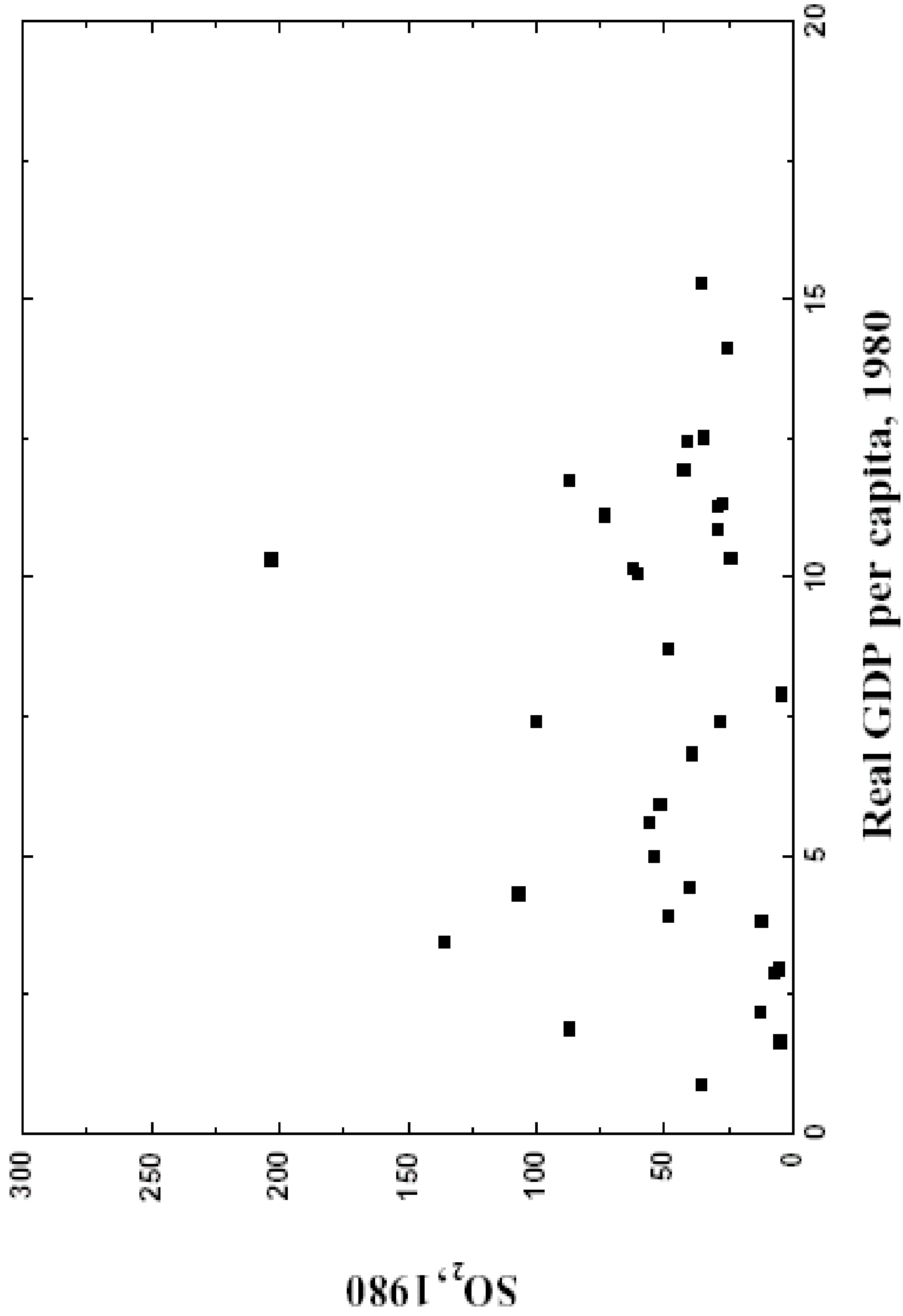


Figure 2: Per Capita SO_2 vs Per Capita GDP - Time Series Analysis, U.S. 1979-1992

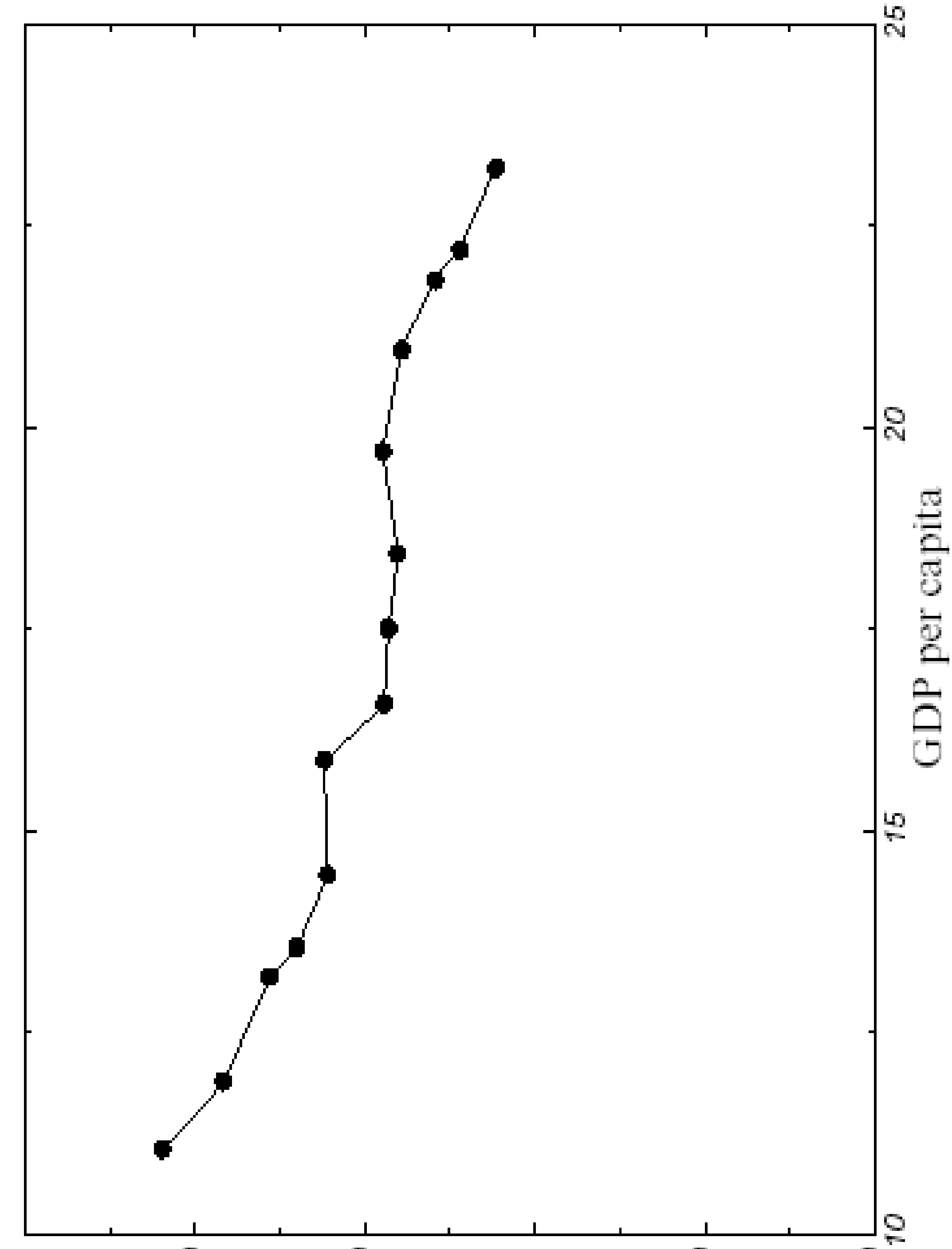
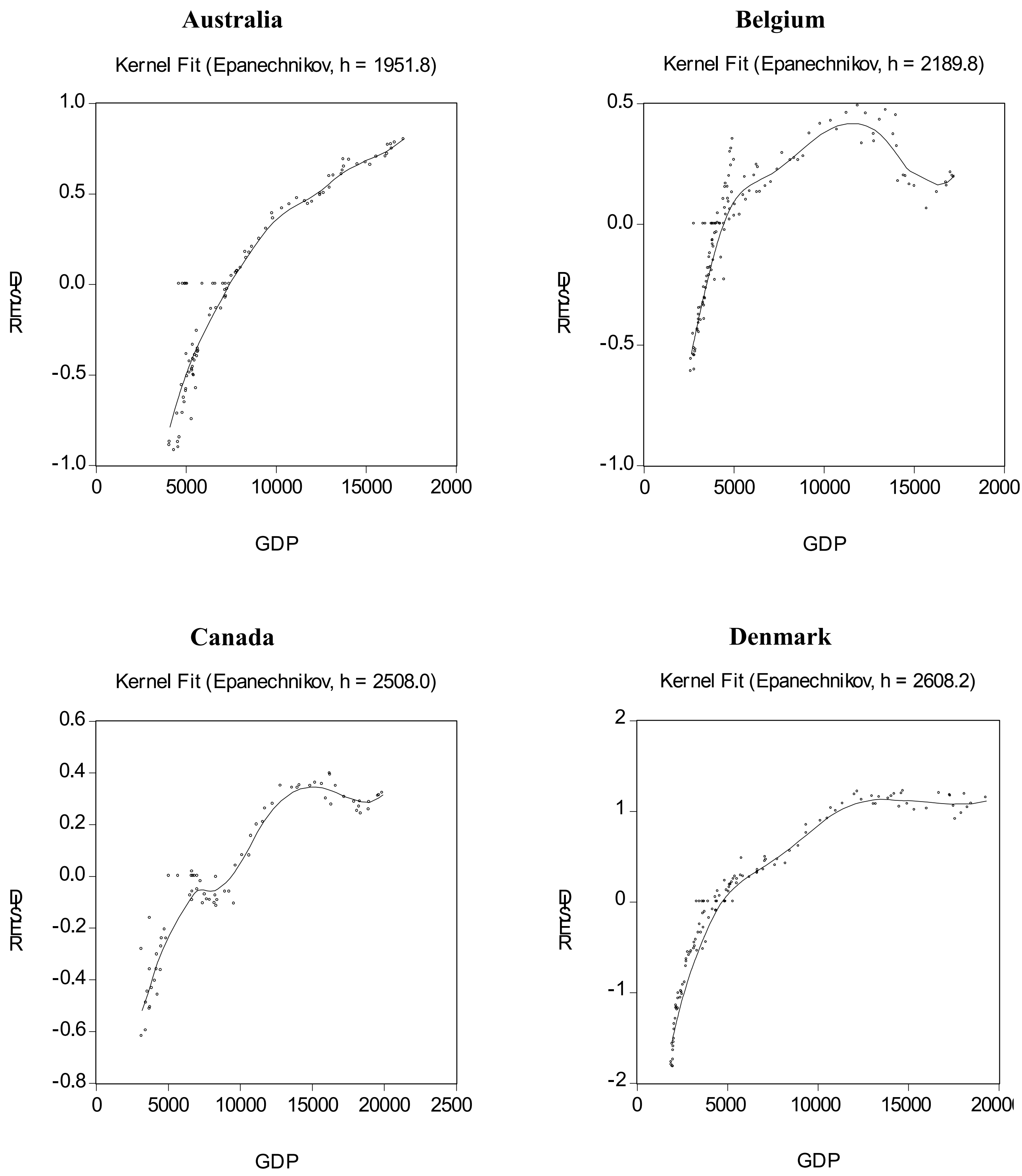
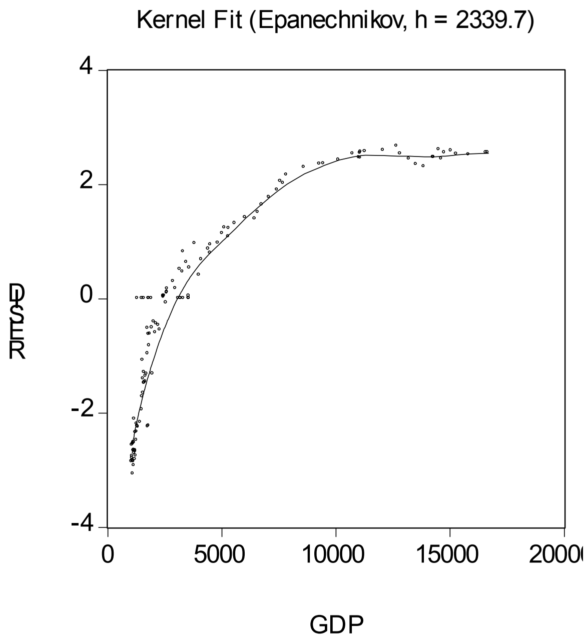


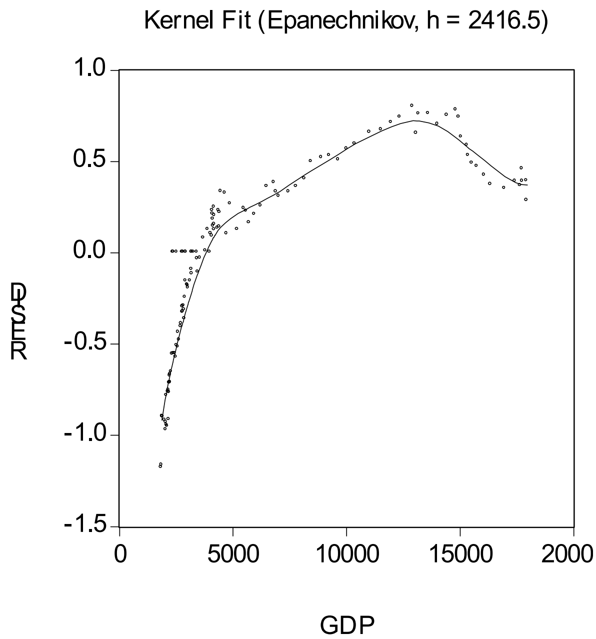
Figure 3: Per Capita CO_2 vs Per Capita GDP - Time Series Analysis, Various OECD Countries 1870-1994



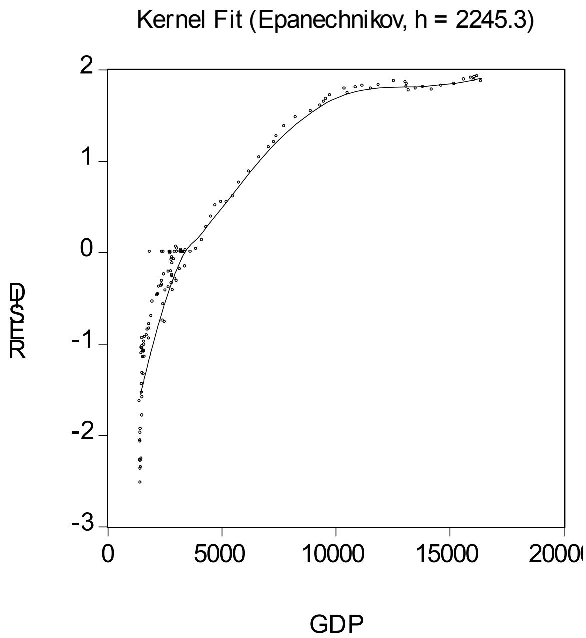
Finland



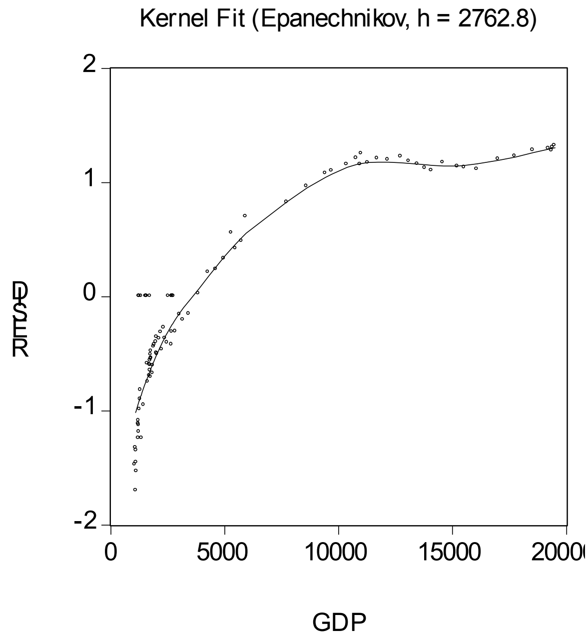
France



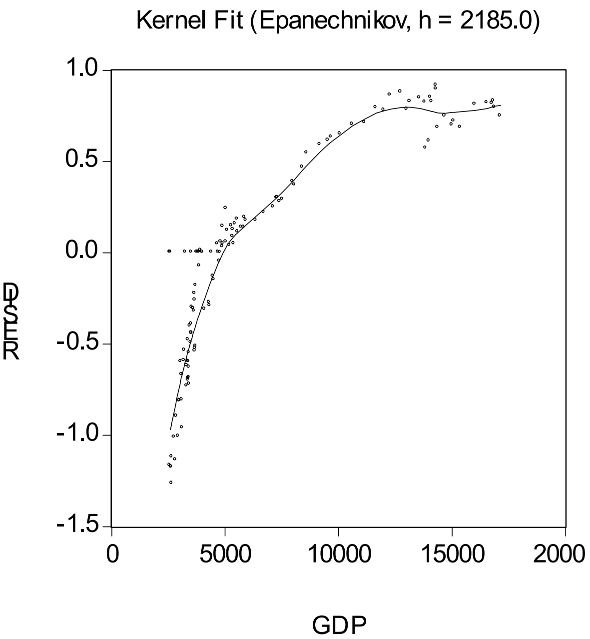
Italy



Japan



Netherlands



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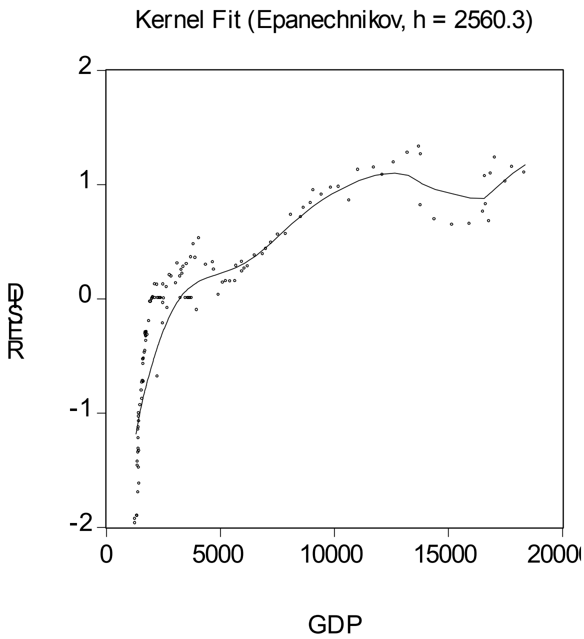
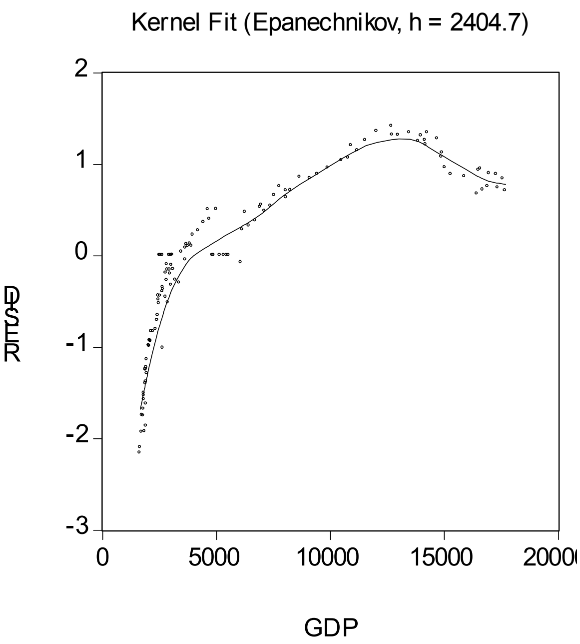
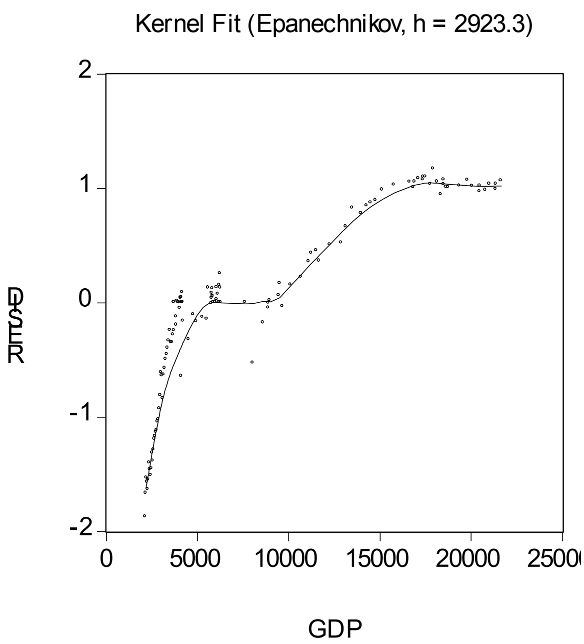


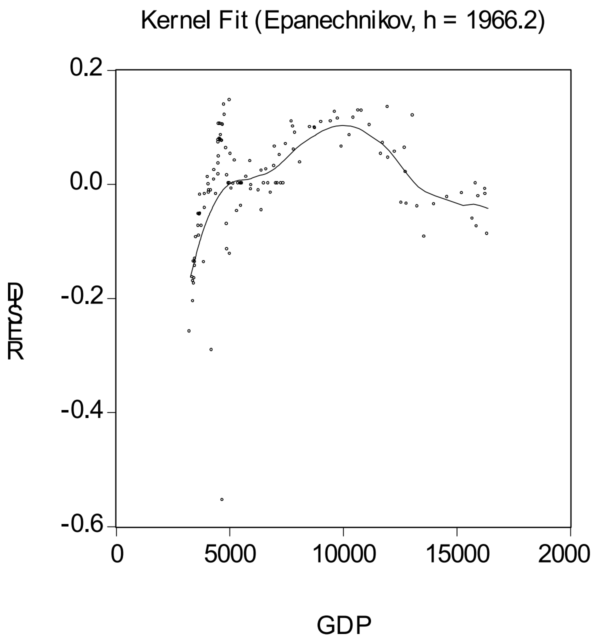
Sweden



Switzerland



U.K.


Kernel Fit (Epanechnikov, h = 1966.2)
0.2
0.0
-0.2
-0.4
-0.6
0
5000
10000
15000
2000
GDP

U.S.A.

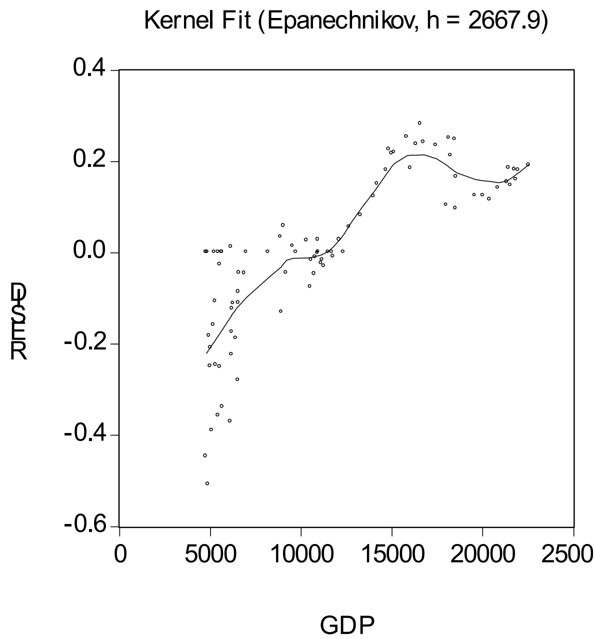

Kernel Fit (Epanechnikov, h = 2667.9)
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
5000
10000
15000
20000
2500
GDP

Figure 4: Per Capita SO_2 vs Per Capita GDP - Time Series Analysis, Selected OECD Countries 1990-1998

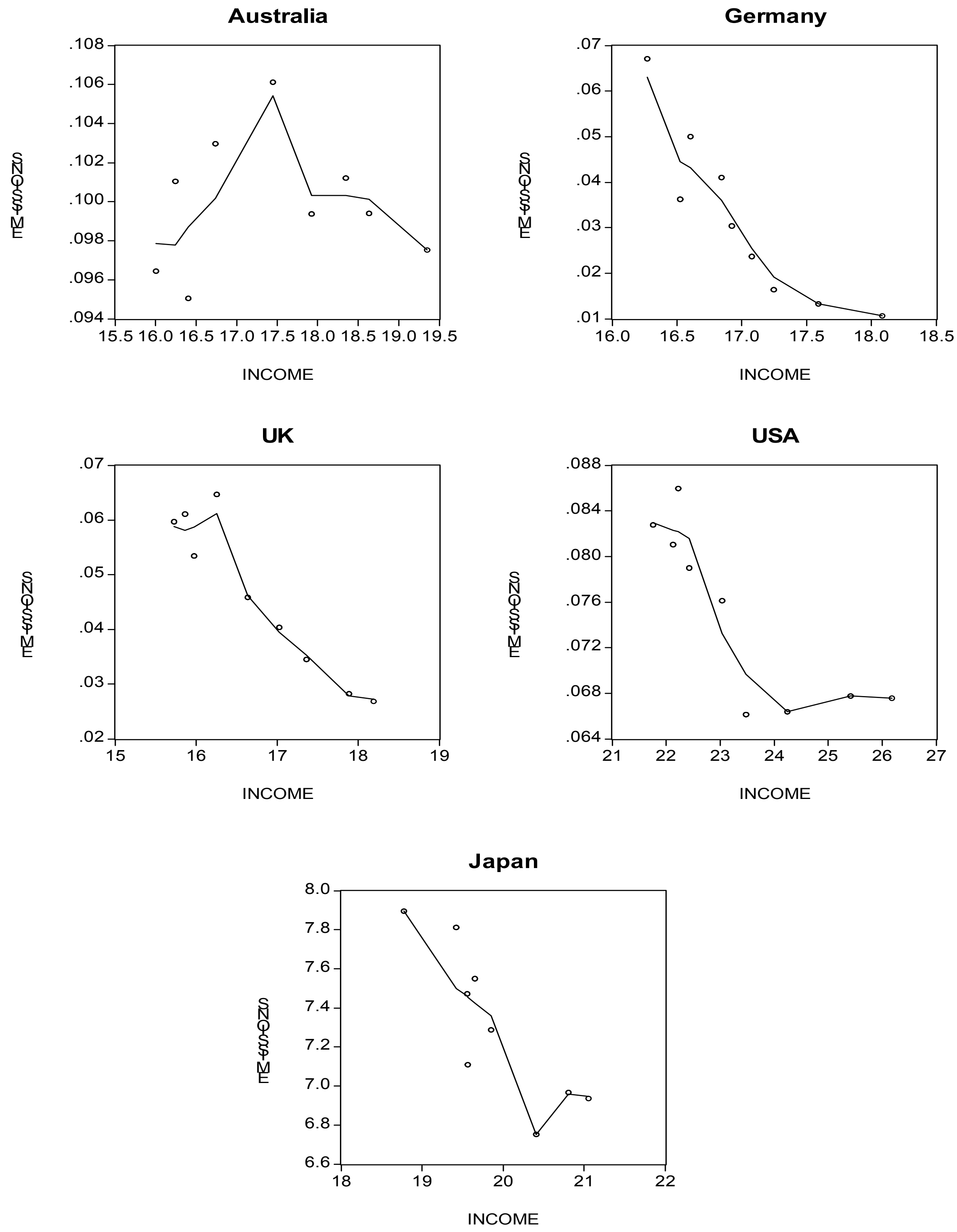


Figure 5: CO_2 Emission Intensity vs Per Capita GDP – Country Cross Sections

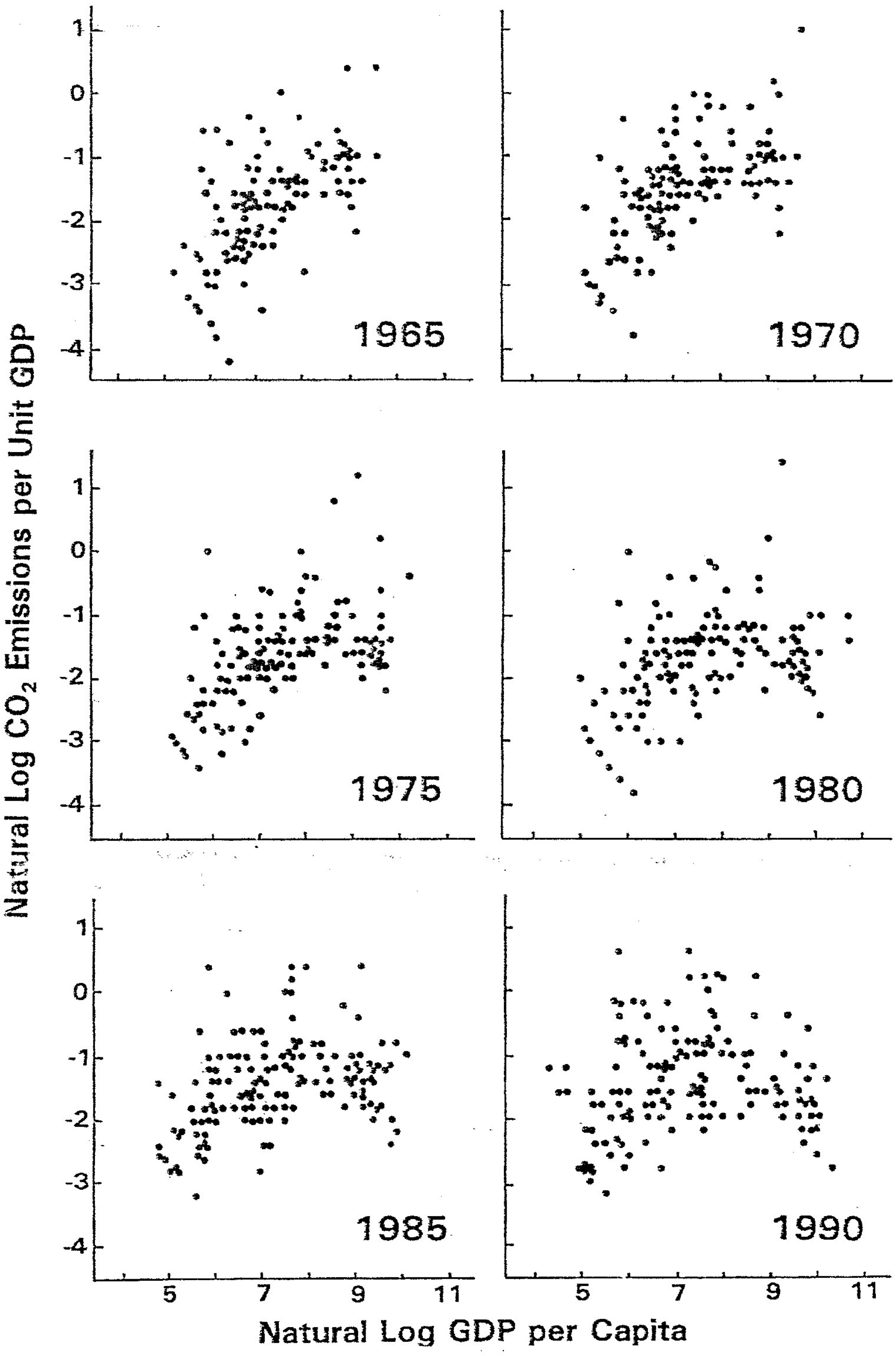
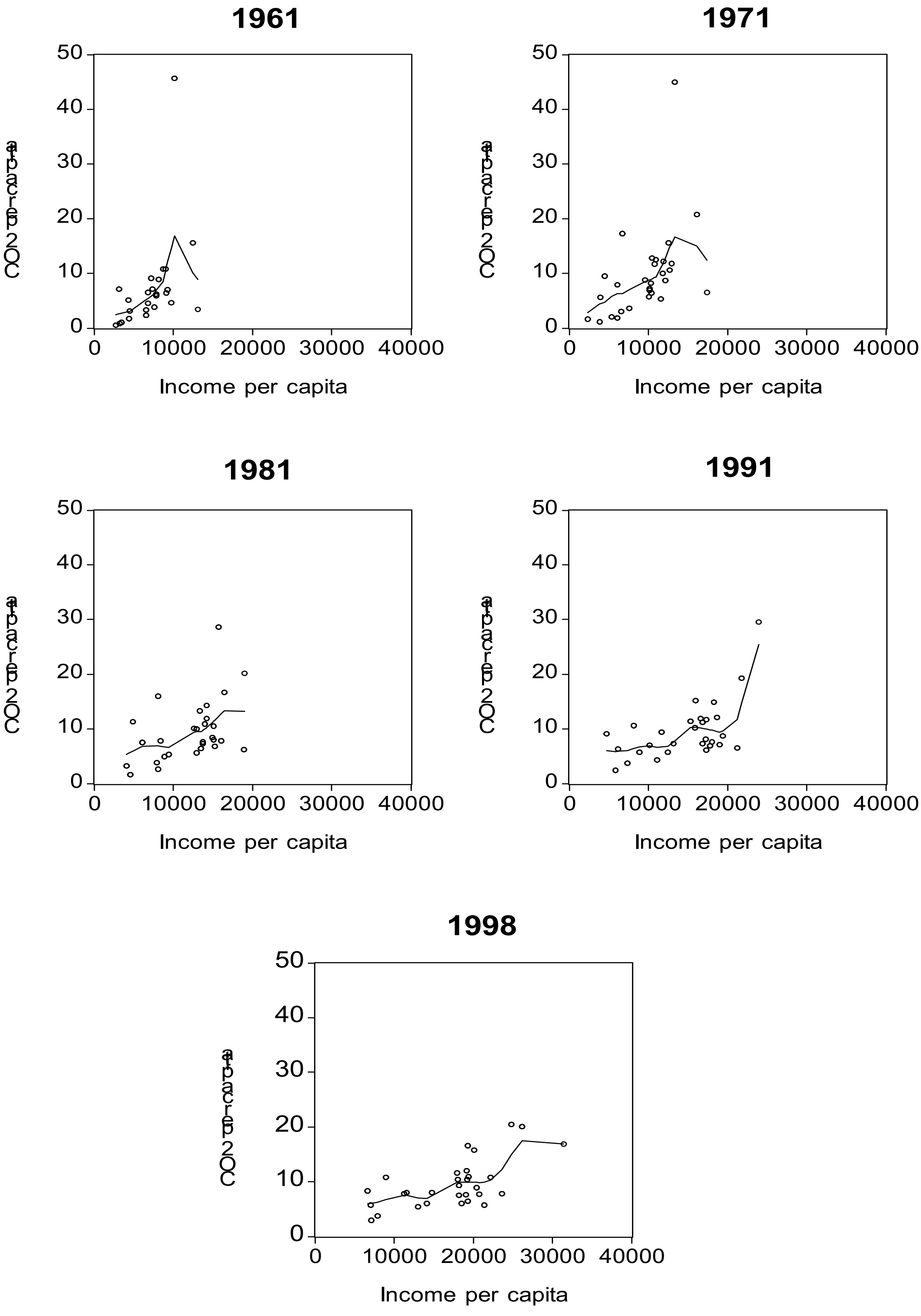
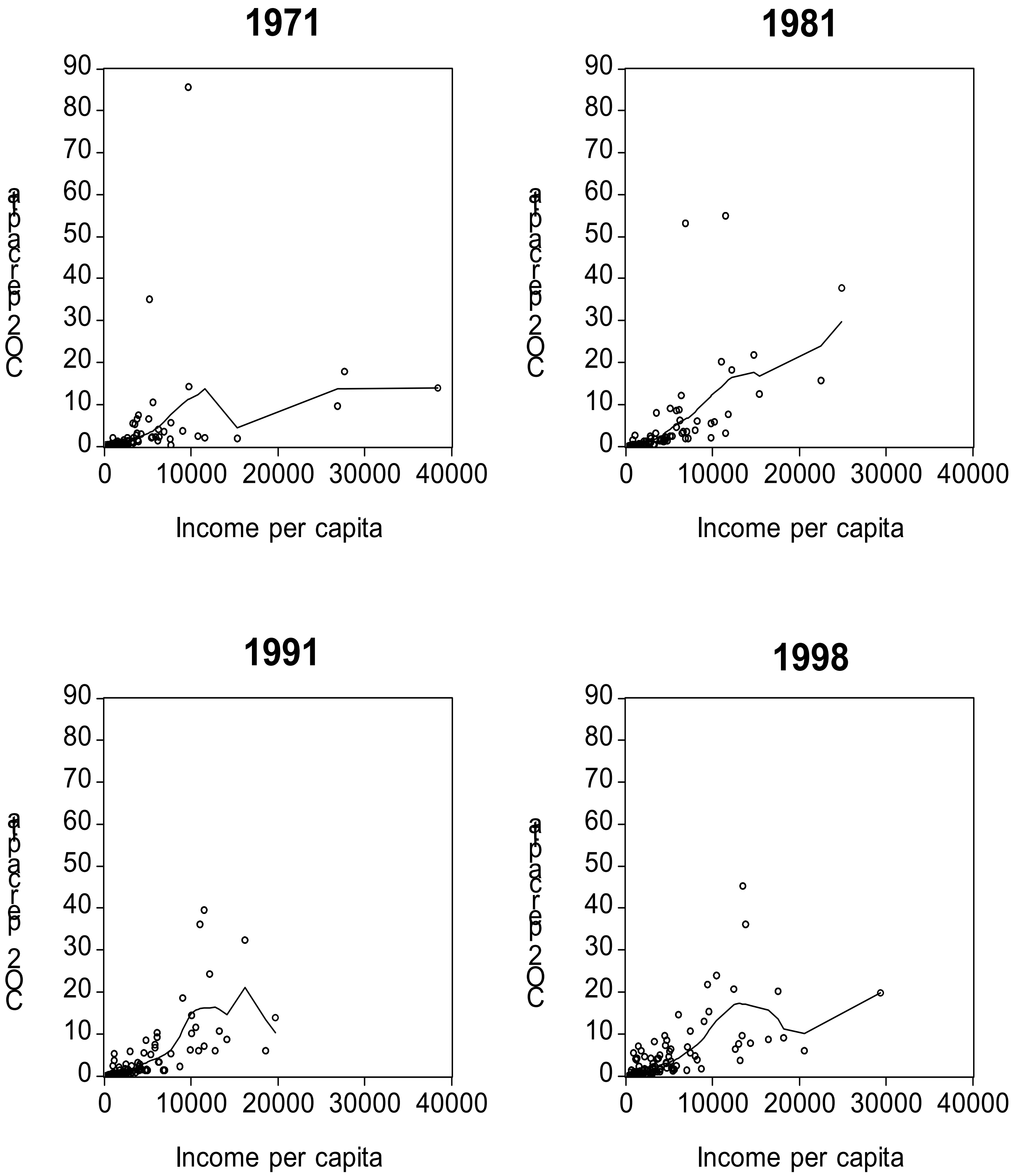


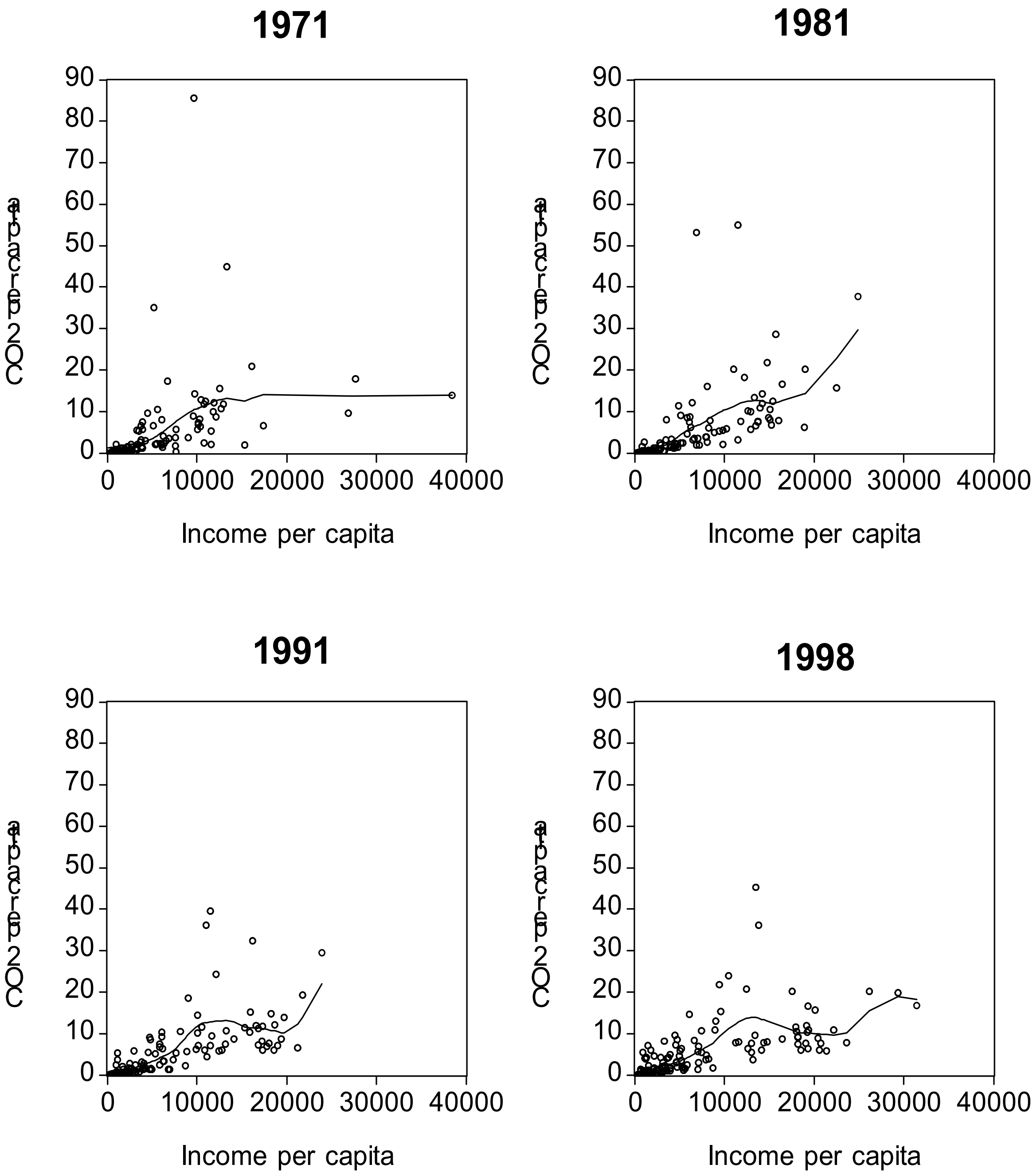
Figure 6: Per Capita CO_2 vs Per Capita GDP - Cross Section Analysis
(a) 29 OECD Countries



(b) 104 Non-OECD Countries



(c) 133 World Countries



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