Environmental Kuznets revisited

Time-series versus panel estimation: The CO_2 case

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Abstract

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According to the Environmental Kuznets Curve (EKC) hypothesis economic growth and improving environmental quality are compatible. An inverted U-shaped relationship would exist between economic performance and environmental quality suggesting that after some threshold a growing economy would cause smaller pollution. Usually the EKC hypothesis is tested for pooled panel data of some (sub)set of environmental indicators and GDP. The essential assumption behind pooling the observations of different countries in one panel is that the outcome of the economic process would be the same for all countries with respect to emissions. That is, the curvature of the Income-Emission Relation (IER) is the same for the pooled countries as far as they have the same GDP range.

In our study we show this methodology to be misleading for at least the special case of carbon dioxide (CO_2) emissions and the GDP level. Using OECD-wide data from 1960 to 1990, we find that the pooled estimation results show positive autocorrelation. Other studies, like Holtz-Eakin and Selden (1995), correct for this problem. However, as we show, it seems more likely that the estimated regression model is not correct due to the pooling of the country observations.

Testing the model per country reveals that the IER is very different for countries. While some countries show growing carbon dioxide emissions per capita with increasing income, others show a stabilizing pattern or even an EKC. This indicates that estimations based on pooling techniques can bias the conclusion about the true IER leading to unjustified inferences on the existence of the EKC. Extending the basic model may result in the justification of pooling. However, our estimations including country specific variables, like population density, openness of the economy and the3 availability of own fuel sources (endowment effects), do not make us optimistic. The autocorrelation problem remains. If a more general model can not be found the only remaining conclusion is that testing the EKC should be based on time series analysis. This has far reaching implications as time series are not widely available for many environmental indicators. Thus, existing evidence on the EKC is possibly not very sound while more rigorous testing may be impossible for many indicators. Maybe we do not know at all what we think to know about the EKC.

1. INTRODUCTION

Simon Kuznets (1955) started an interesting debate about the relation between economic growth and income inequality (p. 18): "*One might thus assume a long swing in the inequality characterizing the secular income structure; widening in the early phases of economic growth when the transition from the pre-industrial to the industrial civilization was most rapid; becoming stabilized for a while; and then narrowing in the later phases.*" His idea[1] has been discussed intensively since. According to Jha (1996) studies differ with respect to rejecting or not the Kuznets curve on an empirical basis. This seems also to be the case for the Environmental Kuznets Curve (EKC)[2].

The EKC is a special case of the general Income-Emission Relation (IER). Before the early nineties the IER was proposed to be more or less linear; more income means more production and consumption and thus emissions would rise. This relation caused considerable concern as the rich countries showed high growth rates and environmental pressure increased. But then the idea was proposed that maybe a comparable effect as Kuznets described for income and equality could be present for the relation between income and environmental pressure. As an economy expands from a farming to an industrial society emissions will grow. However, as growth continues and a more high tech and service society arises, emissions will go down again. If this idea is right the environmental problem could be less alarming in the long run, dependent on the decrease of emissions per capita and population growth.

In general, panel data are used to test the EKC hypothesis because the combination of country and time observations gives more degrees of freedom. This is especially important in the case of environmental related estimations as the availability of data is a serious problem. However, if the estimated relationships are not stable over time (or cross-section members) panel estimation techniques do not give the right answer. As Chow (1960) made clear, unjust pooling can lead to biased conclusions. Therefore, we test the legitimacy of pooling observations for an environmental problem for which enough data are available, carbon dioxide emissions.

We show that pooling observations is not legitimate for the carbon dioxide case and leads to wrong conclusions. Whereas the pooled estimations indicate a general EKC for carbon dioxide emissions, time-series estimations per country reveal significant differences between countries. Not only do countries differ with respect to the height of the turning point (from increasing to decreasing emissions), but countries differ also with respect to the curvature of

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[1] According to him it was not more than an idea (Kuznets, 1955, p. 26): "*I am acutely conscious of the meagerness 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*".

[2] The Kuznets curve is also in discussion from a theoretical perspective (see e.g. Arrow et al., 1995). However, our paper focuses on the empirical basis.

the IER. Some countries show a clear EKC, but others have stabilizing patterns or even a linear IER.

This study proceeds as follows. First, we summarize the empirical evidence on the EKC. Secondly, we discuss methodological issues with respect to testing the EKC. Next, we discuss the data used in this study. Fourth, we estimate the IER for the OECD panel and for the different OECD countries. Fifth, we perform some sensitivity analysis. Finally, conclusions are presented.

2. EVIDENCE ON THE EKC HYPOTHESIS

A proper way to test the EKC hypothesis would be a two step procedure (Grossman and Krueger, 1995, p. 359). The first step is modeling the structural equations relating environmental regulations, technology, and industrial composition to GDP. Next, the level of pollution is modeled related to regulations, technology and industrial composition. For two reasons this way is not followed in the literature. First, the procedure involves a number of estimations, reducing the reliability of the net effect of economic growth on pollution. Second, the data demand for the modeling procedure is very high as we need to collect data for environmental regulations, technology and industrial composition. To construct a reliable and comparable database is an enormous task. Therefore, the methodology used to test for the EKC hypothesis is the estimation of reduced-form equations, relating environmental pressure to economic growth. The basic model is:

$$\ln\left(EP_{it}\right)=\alpha_1\ln\left(\frac{Y_{it}}{I_{it}}\right)+\alpha_2\ln^2\left(\frac{Y_{it}}{I_{it}}\right)+\alpha_3\ln^3\left(\frac{Y_{it}}{I_{it}}\right)+\alpha_4\,\mathrm{Trend}+\alpha_5\,C \qquad (1)$$

where the term on the left side of the equation gives a measure for the environmental pressure of country i in year t per capita. Explaining variables are income per capita, technological improvements (approximated by the trend variable) and a constant.

Coefficients α_1, α_2 and α_3 define the shape of the relation between income and carbon dioxide emissions. Figure 1 gives the most important possible relationships. The log linear relationship is given by line A. Environmental pressure increases as the economy expands. Line B represents the EKC hypothesis. After some GDP level, the environmental pressure is diminishing. A third possibility is that line B is only part of the truth. It is possible that after a period with decreasing environmental pressure, recoupling gives line C.

In general it is questionable whether the included constant is equal for all countries and years. If this is not the case differences across countries and years can be captured by estimating a fixed effects model. In that case a dummy can be included for each country and year[3]. A drawback of this model is that the estimations might only be viewed as applying to the sample. Therefore, the random effects model is more general. The random effects model splits the residual term in two parts. The first part reflects a random country effect that is constant through time, while the second term represents the standard disturbance term.

Shafik and Bandyopadhyay (1992) were the first to empirically test the EKC hypothesis (see also Shafik (1994)). They use a pooled dataset for 153 countries from 1960 to 1989 to test the IER for lack of safe water, lack of urban sanitation, annual deforestation, total deforestation, dissolved oxygen in rivers, fecal coliform in rivers, ambient SPM, ambient SO_2, municipal waste per capita and carbon emissions per capita. Only fixed country effects are included in the estimations. He concludes (p. 769): "*Some very clear patterns of environmental degradation emerge from the previous analysis. Some environmental indicators improve with rising incomes (like water and sanitation), others worsen and then improve (particulates and sulfur oxides) and others worsen steadily (dissolved oxygen in rivers, municipal solid wastes, and carbon emissions). The turning points at which the relationship with income changes varies substantially across environmental indicators.*" Furthermore, he concludes that technological improvements are critical where the costs are local.

Following Shafik and Bandyopadhyay, a number of studies appeared (see table 1). Only Roberts and Grimes (1997) use cross-section estimations per year, while all other studies rely on pooled data to test for the IER. These studies differ with respect to the database, the dependent variable(s), included fixed and/or random effects. Not surprisingly, the results differ also. Curvature of the IER and turning points if an EKC is estimated differ between studies. As we will show, this could be due to the underlying estimation methodology.

3. METHODOLOGICAL ISSUES

As mentioned before, nearly all studies rely on pooled data to estimate the IER. Pooling is a powerful instrument to enlarge the degrees of freedom and thus the efficiency of estimated coefficients. In our IER case all authors make the implicit assumption that lies behind pooling: the effect of a change in GDP per capita for the cross-section members is the same[4]. Although fixed or random effects models are applied, the GDP coefficients are identical for each country. Therefore, the curvature and the turning points are identical for each country. The question, not answered by the empirical studies, is what the intuition behind this implicit assumption is. It seems strange that countries, which are very different in geographical

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[3] When fixed or random year effects are estimated, the trend variable is skipped.

[4] This argument holds not only for the studies based on pooled datasets, but also for cross-section studies (like Roberts and Grimes, 1997).

conditions, culture and history would react identical. For example, the (partly) mainport driven Dutch economy is supposed to react on the same way as a country with no harbor at all like Switzerland. Or, a small economy as Belgium with much imports and exports is supposed to react identical as a world power like the United States, which imports and exports are relatively low. Indeed, we can not find the intuition behind the pooling methodology.

Suppose, the underlying assumption behind pooling the time-series with cross-section is not valid, what are the econometric consequences? The econometric literature states that estimators are biased if the true model consists of more parameters than estimated (the model is underparameterised). For our case, if countries react different with respect to the environment if GDP per capita changes, pooling leads to biased coefficients. For example, if country A actually would have a linear IER (curve A in figure 2) and country B in reality would have an EKC (curve B) and the data for both countries are pooled to estimate the aggregated IER, curve C would result. For both countries the estimated IER is not the actual IER. As can be seen from figure 2 the residuals would show a clear pattern. Thus, positive autocorrelation can be expected when the functional form is inappropriate (Harvey, 1990, p. 156)[5].

A key assumption in estimation theory is that the disturbances are uncorrelated. When they are correlated econometric theory provides instruments to correct, for example with the AR(1) method. This is only valid when autocorrelation results from omitted variables that are not and can not be included in the estimations (like changes in tastes). As shown by Mizon (1995) in general autocorrelation correction leads to biased estimators and his advice is simply: don't.

As none of the EKC studies mention this issue (only Cropper and Griffiths, 1994 and Holtz-Eakin and Selden, 1995 simply correct for autocorrelation without discussion) and as invalid pooling can disturb conclusions we will test for autocorrelation in the carbon dioxide case.

4. CARBON DIOXIDE EMISSIONS IN OECD COUNTRIES

As Roberts and Grimes (1997, p. 192) showed, the carbon dioxide emissions case is important for testing the EKC hypothesis for four reasons. First, the relative impact on the greenhouse-warming problem is large. Second, the EKC hypothesis states that diminishing environmental pressure is the outcome of the economic process, even without explicit formulated policies.

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[5] This relation between autocorrelation and the appropriateness of the functional form is used in the literature. For example, Gagnon and Unferth (1995) use this relation to test whether a world real interest rate exists. They conclude that this rate exists, because pooled estimations show no significant autocorrelation of the residuals.

As carbon dioxide has only recently attracted attention as a main problem, historical processes are not influenced by explicit carbon dioxide policy. This is not the case for all emissions, as some environmental problems attracted attention years before the global warming problem. Third, thermodynamically carbon dioxide emission levels are not at all related to the size of the economy. Finally, the data problem is less pressing for the carbon dioxide emission case.

Carbon dioxide emissions have to be estimated as monitoring is impossible. Estimation is possible by multiplying energy use by emission factors. These factors give the amount of CO_2 emitted if a fuel source is used. The determination of emission factors for primary fuels is quite simple. A fixed relation exists between the CO_2 intensity of a fuel and the quantity of CO_2 emitted[6]. Therefore mass balance calculations are possible to quantify the emission factors for the different fuels[7].

Used emission factors in this study are given in table 2. These factors approach the real factors. The carbon intensity of coal varies per sort and per producing area. However, no estimations are available per country. For coal only different estimations are available per region. The carbon intensity of oil and gas is much more constant than for coal. IEA (1991) gives an uncertainty margin of about 3%. Furthermore, these emissions factors are assumed to be constant in time as no estimations per year or period are available[8].

If the carbon intensity per fuel is known, we can calculate the quantity of emitted CO_2 by multiplying the factors by the total primary energy supply (TPES) per fuel. Summing over fuels gives the national emission of CO_2. To calculate CO_2 emissions we use the OECD (1997) data for TPES per fuel. Corrections are made for non energy use of fuels as no CO_2 is emitted if fuels are not burned. The most important part of this non-energy use are fuels used for chemical feedstocks. Fuels incorporated in the calculations are coal, other solid fuels (for

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[6] For a number of other emissions this relation is dependent on the burning process and filter techniques.

[7] The mass balance formulae to calculate CO_2 emission factors is:

$$\mathrm{PEEF} = \mathrm{MWCO_2}\left(\frac{\%\mathrm{C}}{\mathrm{HV}} * \frac{1}{\mathrm{MWC}} - \frac{\mathrm{EFCO}}{\mathrm{MWCO}} - \frac{\mathrm{EFCH_4}}{\mathrm{MWCH_4}}\right)$$

where:

- PEEF	CO_2 emission factor (g/GJ)	- $MWCO_2$:	weight of CO_2 (44 g/mol)
- %C :	% carbon in fuel, weight (%)	- HV:	heating value fuel (GJ/g)
- MWC:	weight carbon (122 g/mol)	- $EFCH_4$:	CH_4 emission factor (g CH_4 16g/gmol)
- EFCO:	CO emission factor (g/GJ)	- MWCO:	weight CO (28 g/gmol)

[8] The energy efficiency of the national energy production system and the changes in input use are automatically included in our calculations as the emissions factors are applied to primary energy supply.

example wood), crude oil, petroleum products and natural gas. As we use TPES, emissions are corrected for exports and imports of fuels. Total energy use per country is diminished by the exports of fuels and increased by imports. Furthermore, corrections are made for stock changes and international marine bunkers. The sample reaches from 1960 to 1990 and includes all OECD countries.

Figure 3 gives the CO_2 emissions per capita for the OECD and for some individual countries. For all countries the CO_2 emissions per capita are higher at the end of the period than in 1960. However, the effects of the oil crises are clearly present. Though income has grown over time the emissions per capita are in the nineties about the same as in the early seventies. Not surprisingly the countries differ in the magnitude of emissions per capita. Especially the USA has high emissions compared to the other countries. Striking is the result for Sweden. With the bold eye a clear EKC relation seems present, while the other countries need lower emissions in the future to prove an inverted U shaped curve. However, testing whether an EKC relationship is present for carbon dioxide should be a matter of econometrics.

5. TESTING THE IER RELATION FOR OECD COUNTRIES

We test the basic model:

$$\ln\left(\frac{CO_{2it}}{I_{it}}\right) = \alpha_1 \ln\left(\frac{Y_{it}}{I_{it}}\right) + \alpha_2 \ln^2\left(\frac{Y_{it}}{I_{it}}\right) + \alpha_3 \ln^3\left(\frac{Y_{it}}{I_{it}}\right) + \alpha_4 T_{6072} + \alpha_5 T_{7375} + \tag{2}$$

$$+ \alpha_6 T_{7678} + \alpha_7 T_{7981} + \alpha_8 \mathrm{Trend} + \alpha_9$$

for the OECD panel[9].

First, we estimate equation (2) for the one constant case[10] (see table 3, model 1). As the coefficient of the third power is not significant the cubic form hypothesis is rejected. Therefore, we estimate again without the third power term (table 3, model 2). The quadratic form hypothesis is not rejected. Coefficients of the time variables are diminishing in time. That is, carbon dioxide emissions are higher in the pre oil crisis period than after the first oil crisis and higher before the second oil crisis. The trend variable is not significant, indicating no

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[9] Included are all OECD countries except Luxembourg and Iceland, because of lack of data.

[10] GDP figures (in thousands of 1990 dollars per capita) are from OECD Economic Outlook.

exogenous technological improvements. The estimated coefficients of the GDP terms indicate an EKC, but the turning point (measured as GDP per capita as a percentage of the maximum GDP level in the panel) is very high and far out of the range of the panel (more than 30 times the maximal GDP level).

Secondly, equation (2) is estimated with fixed country effects[11] (table 3, model 3). An F-test rejects the one constant model against the fixed country effects model. This can also be seen from the far higher R^2. All estimated coefficients are significant on a 95% confidence interval. Again the magnitude of the time dummies are diminishing. The trend variable is significant and positive. We tested the fixed country and year effects model against the fixed country effects model, but this last model is not rejected on a 99% confidence interval (table 3, model 4). The fixed country effects model shows a turning point which lies at 57% of the maximum panel GDP. This would indicate a clear EKC for most countries. The difference between the fixed country effects model and the one constant model with respect to the IER is highly significant (see figure 4). Therefore, choosing the right econometric form is important for finding the true IER.

The Durbin-Watson statistic is very low in all estimations. The no positive autocorrelation hypothesis is rejected for all estimated equations. Most countries show a clear pattern in the residuals (see figure 5). For the pooled estimation with fixed country effects table 4 gives the Durbin-Watson statistic per country. For 18 countries the no positive autocorrelation hypothesis is clearly rejected (lower bound at 95% confidence is 0.88), while 4 countries have a statistic in the inconclusive region.

As positive autocorrelation can indicate that the basic model is not correct and thus that the slope coefficients are variable, we test the basic model by estimating equation (2) per country on the basis of time-series estimation (see table 5). The structure of the GDP coefficients (in the panel positive for the linear term and negative for the quadratic and cubic term) is very different for all countries. For only three countries the cubic form is not rejected (on 95% confidence). Even in these three cases the structure is different from the panel estimations. Furthermore, only 10 of the 22 countries show an EKC, while the others have a linear IER. The turning points differ also between countries and from the panel (see table 6). Only Spain and Finland show a comparable turning point with the panel estimations. Nearly all turning points are at the end or even out of the own GDP range. For three countries (Ireland, Italy and Norway) the turning points are even out of the panel GDP range. The coefficients of the time variables are also very different between countries and from the panel estimations. Especially the trend coefficients are significantly different. Even signs differ

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[11] We tested for random effects, but the estimated results do not significantly change.

between countries (compare for example Germany and Denmark with the New Zealand and Greece). Last but not least does the Durbin-Watson statistic for none of the countries reject the no positive autocorrelation hypothesis. Only four countries face a Durbin-Watson statistic between the lower and upper bound. Thus, the modeling problem with panel estimations is not present for time series analysis. An F-test between the pooled and time-series model clearly rejects the pooled model at a 99% confidence interval.

To summarize, all these inter-country differences in coefficients and IER curvature and the Durbin-Watson statistics indicate that pooling is dangerous. Our evidence suggests that estimating the IER with panel data results in biased estimations. As figure 6 indicates, this conclusion has nothing to do with differences in GDP ranges. First and second order derivatives of the IER, based on fitted values for the time series estimation, differ significantly between countries with the same GDP range. For most countries the panel estimation results in an unjustified EKC conclusion.

This conclusion raises doubt on most EKC studies. For example, Holtz-Eakin and Selden (1995) correct for autocorrelation with the quasi-difference method without checking the validity of their model[12]. Most studies, for example Grossmann and Krueger (1995) and Ekins (1997) in his summary article of EKC studies do not discuss autocorrelation or present Durbin-Watson statistics at all. On the other hand Selden and Song (1994) present Durbin-Watson statistics, but their sample comprises only three periods. Stern *et all* (1996) end their critical EKC survey with an interesting statement (p. 1159): "*We believe that a more fruitful approach to the analysis of the relationship between economic growth and environmental impact would be the examination of the historical experience of individual countries, using econometric and also qualitative historical analysis*". Our findings show that such an approach is maybe not only more fruitful but time-series analysis might be the only right way to test the EKC hypothesis. If this is the case none of the cited studies is reliable. The standard implicit assumption of all cross-section tests, parallel Kuznets curves, is falsified[13]. If this conclusion holds for all substances, our empirical knowledge of the EKC would be back to basic as all studies are based on pooling or cross-section techniques.

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[12] The only other example is Cropper and Griffiths (1994) who correct for autocorrelation with the Prais-Winsten technique without discussing the autocorrelation problem.

[13] Interestingly, the original Kuznets curve (between income and equality) has been estimated using cross-section studies. The only exceptions are Papanek and Kyn (1986) and Jha (1996) who use pooled data to test the Kuznets curve. These studies do not discuss autocorrelation problems.

6. SENSITIVITY ANALYSIS

The first sensitivity analysis relates to used data. Our results might be influenced by our database. Therefore we tested the sensitivity of our results in two ways. First, instead of the GDP figures from Economic Outlook, we used figures from the Penn World Table. This data source is used by most authors in testing the EKC hypothesis. Second, we used carbon dioxide emission data from the ORNL (Marland, 1989). None of our conclusions changed with these data.

A second sensitivity test is based on the Shafik and Bandyopadhyay (1992) study. We used their carbon dioxide database[14] to test the autocorrelation hypothesis. As we need a balanced panel to test this hypothesis, we skipped all countries with lacking data for one of more years between 1960 and 1985. The estimation results were not significant different from the results presented in Shafik (1994). The Durbin-Watson statistic (0.08) implies that the autocorrelation hypothesis could not be rejected [15]. Therefore, our conclusions are confirmed by this analysis.

Thirdly, it would be possible that the differences between countries result from differences in exogenous variables. Therefore we also tested for exogenous variables possibly influencing the IER. Most important time specific variables tested are characteristics related to population density, openness of the economy and the availability of own fuel sources (endowment effects). First, population per square kilometer is included as explaining variable. Not only do less populated countries have, in general, longer travel distances, but a less densely populated country can also give less priority to environmental problems as effects are more diffused. Second, openness of the economy is of importance as countries exporting more (energy intensive) goods can be expected to have higher emissions per capita. The reverse is also true with more imports of (energy intensive) goods lowering emissions. Finally, the endowment effect is included by using a number of variables representing the availability of low-CO_2 energy sources as well as CO_2 sources like oil, gas and coal in the own country. As our database includes the own production of energy sources we can correct for the production of hydro and nuclear power, oil, gas, coal and other solid fuels. While the GDP coefficients are influenced by these variables, the Durbin-Watson statistic and the graphical plots show no improvement of the autocorrelation problem.

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[14] Downloadable from http://cdiac.esd.ornl.gov:80/ftp/ndp030/nation95.ems.

[15] Interestingly, estimation results for the coefficients were completely different when the fixed or random effects model was estimated. The quadratic and cubic term were not significant anymore, while the time trend was significant and had an positive sign. Shafik (1994) did not tested for the random effects model. The Durbin-Watson statistic did not improve to acceptable height (0.32).

7. CONCLUSIONS

In this paper we tested the EKC hypothesis using an OECD panel database for carbon dioxide emissions. It showed that this hypothesis could not be rejected. However, our estimations did suffer from autocorrelation. Testing the basic model for the individual countries reveals that the IER is different for the countries. For some countries the EKC hypothesis could not be rejected, but other countries show only stabilizing carbon dioxide emission patterns or even increasing emissions. Therefore, pooling countries in one panel can bias the estimates. As nearly all studies on the EKC hypothesis use cross-section or panel data, it is very doubtful whether these results are reliable. This conclusion could us bring back at the beginning of empirically testing the EKC hypothesis. Two ways can bring relief. First, estimations per country with time-series data can give useful information about the true IER as the autocorrelation problem does not play an important role at this estimation level. Second, maybe that extending the basic model with explicit exogenous variables can abolish the autocorrelation problem. In that case studies should focus on discovering the relevant exogenous variables. However, as we tested for the effects of differences in population density, openness of the economy and energy endowments, we are not optimistic in the prospects of this road. However, we tested only for the carbon dioxide case. It could be possible that for other emissions the autocorrelation problem is less threatening. Given the value politicians adhere to the Kuznets effect[16], checking the autocorrelation problem for other substances seems necessary and essential.

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[16] Ayres (1997, p. 423) observes: "Since the theoretical argument seems to support the empirical observations, the World Bank accepted the entire package as gospel truth and pushed it hard as an argument against environmental constraints on economic development".

FIGURES

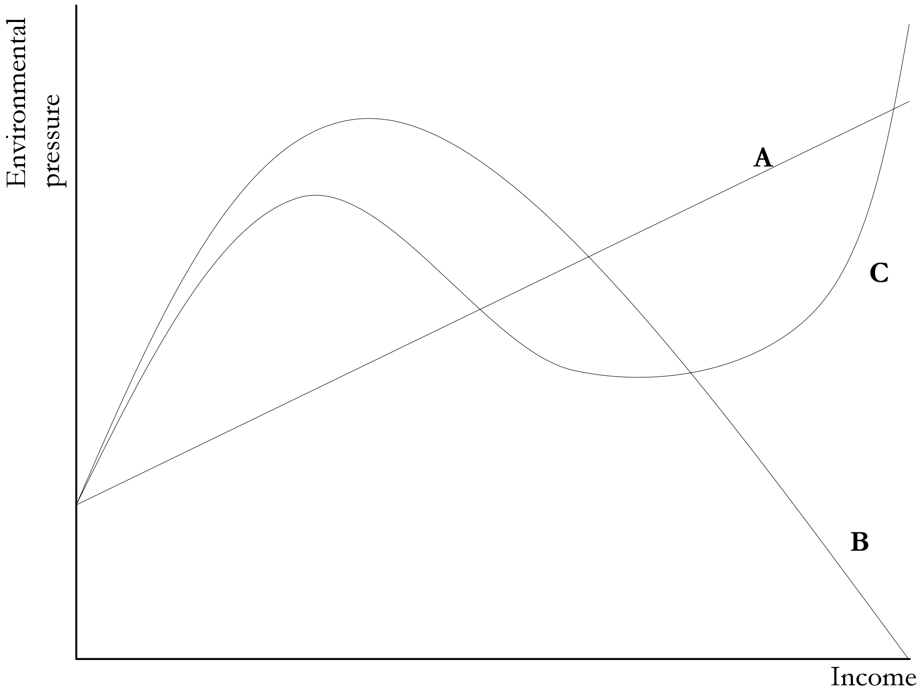


Figure 1. Possible relationships income versus environmental pressure.

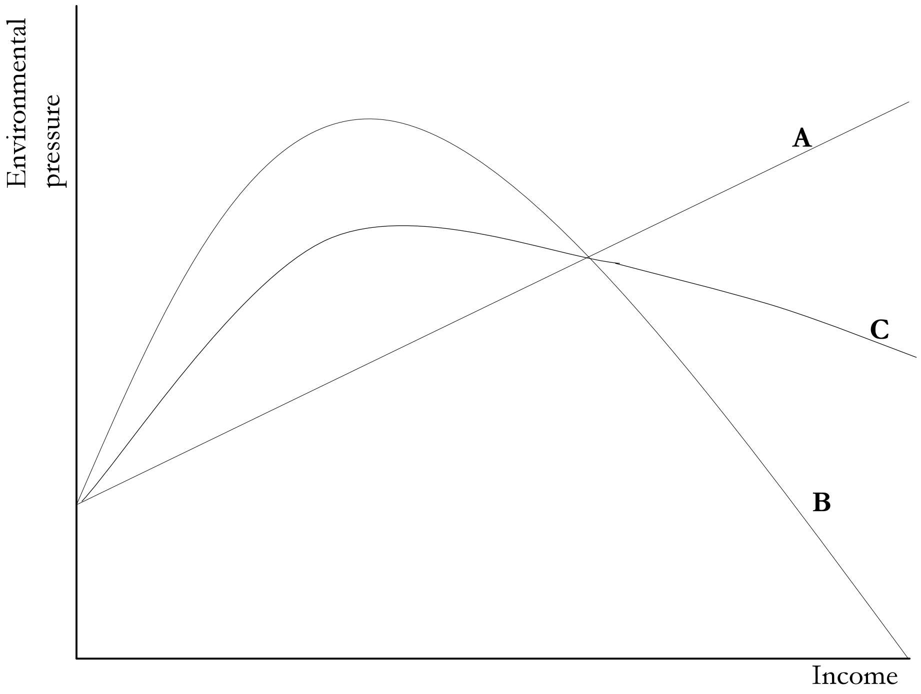


Figure 2. Consequences of invalid pooling for the estimated IER.

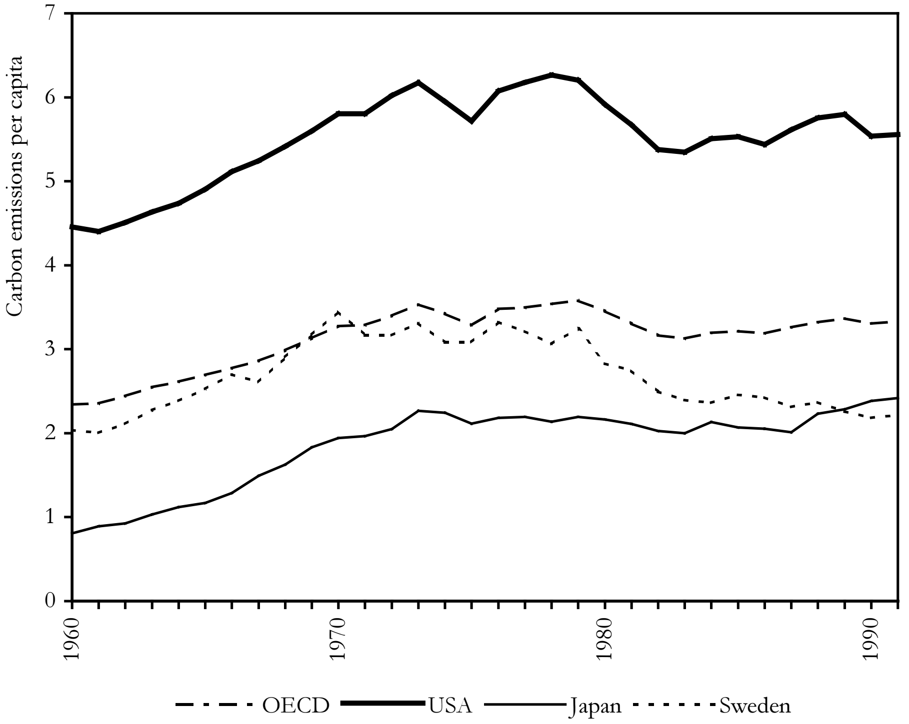


Figure 3. Carbon dioxide emissions per capita, 1960-1991

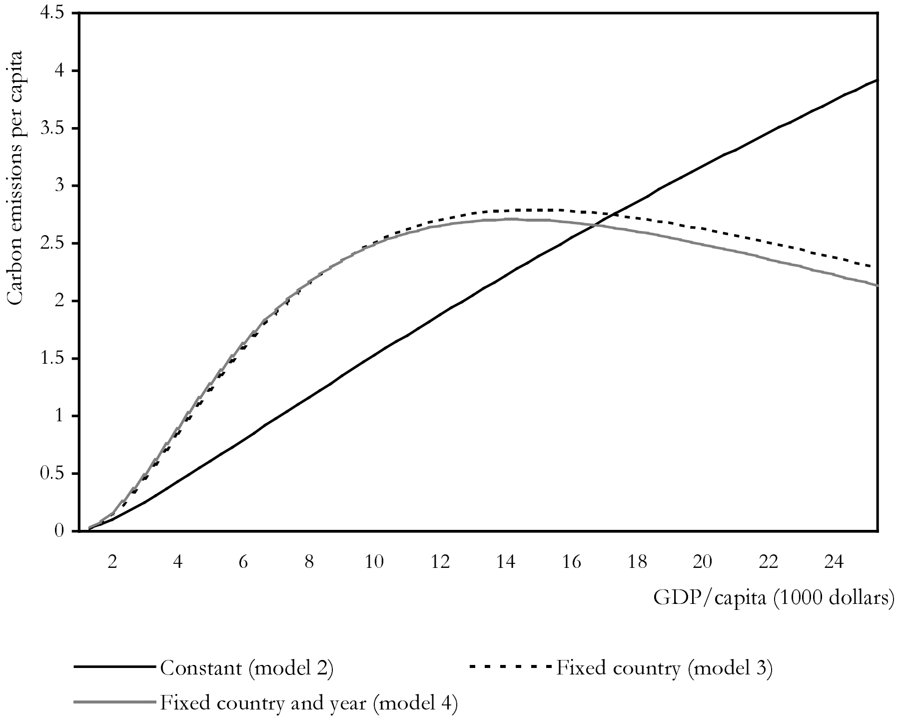


Figure 4. Estimated carbon dioxide emissions per capita

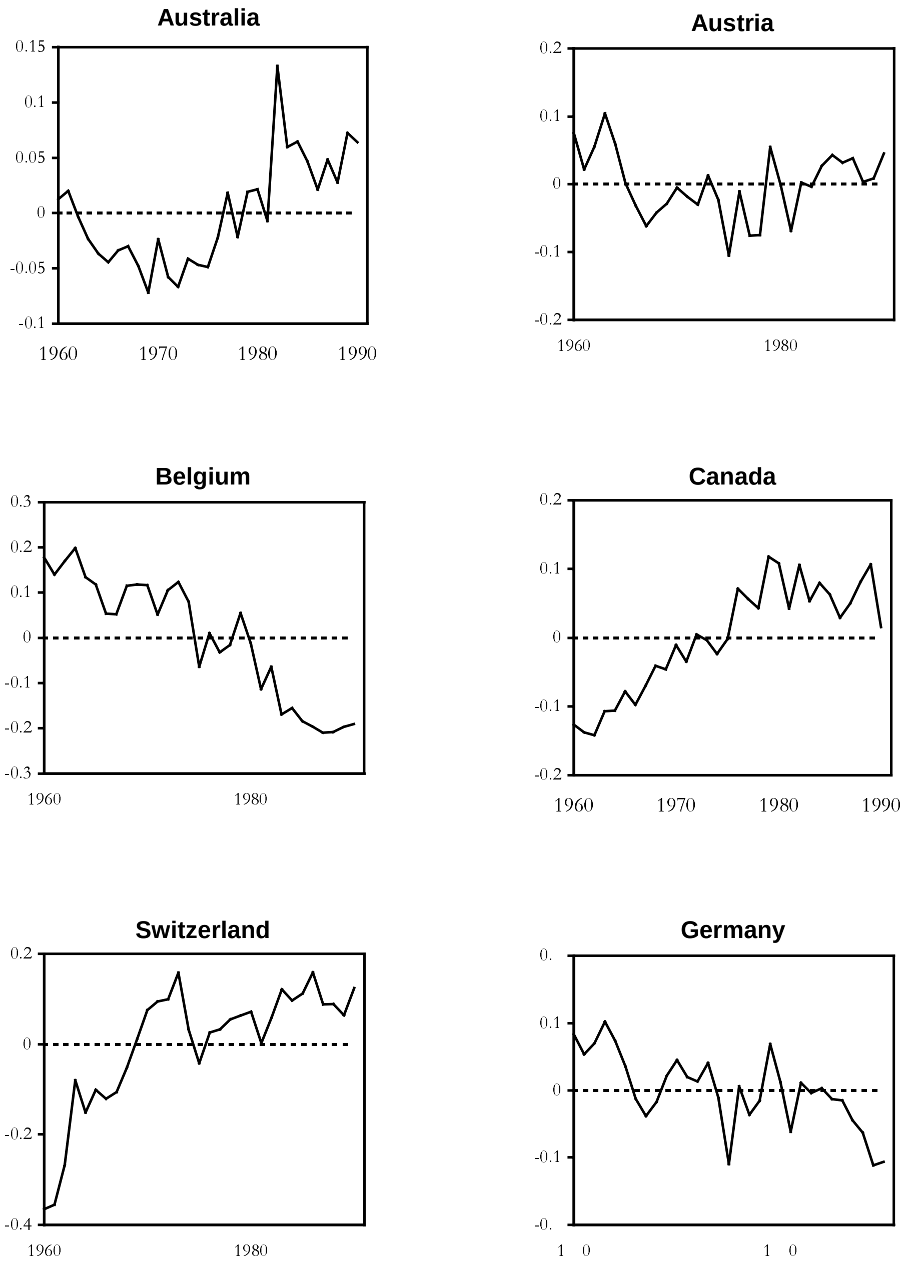


Figure 5. Residuals pooled estimations per country (fixed country effects model)

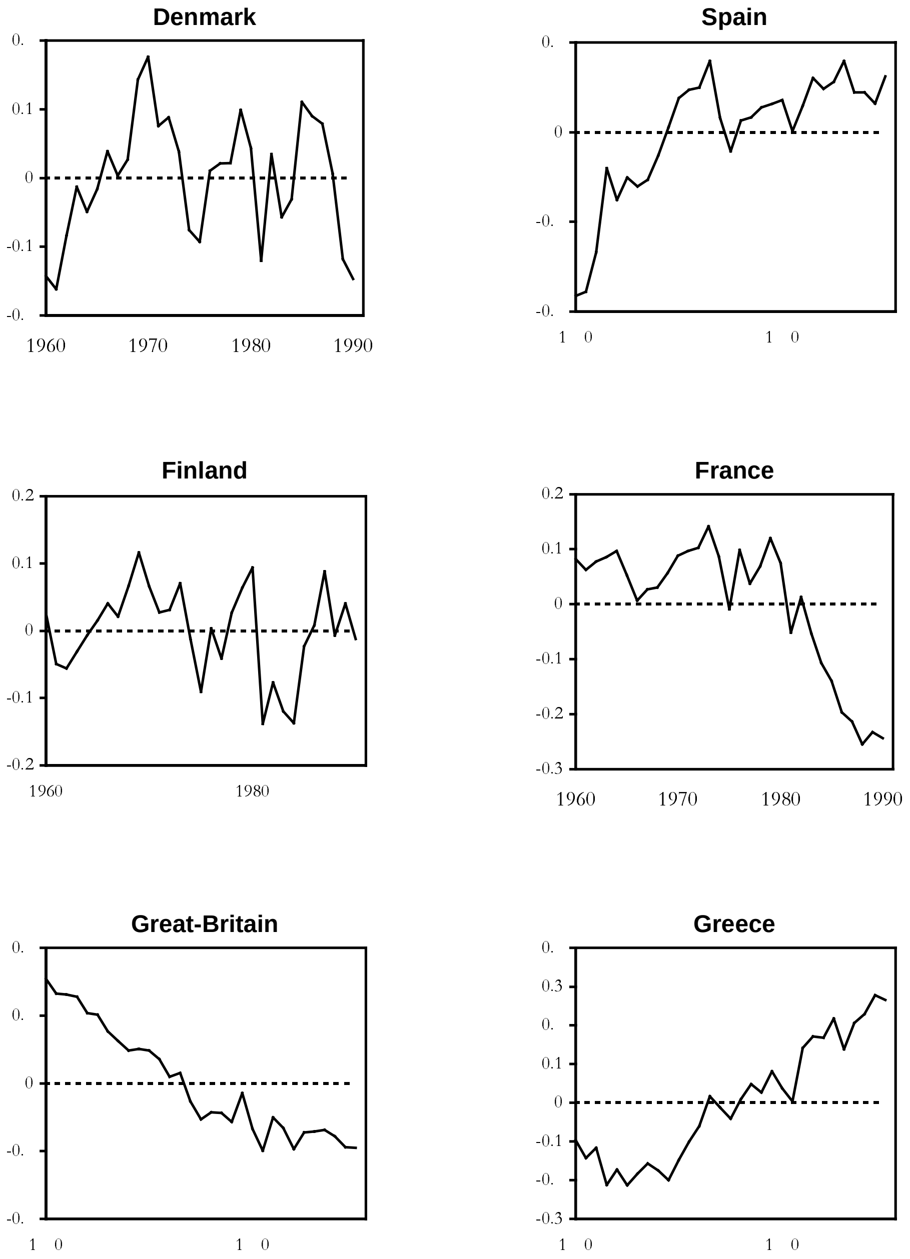
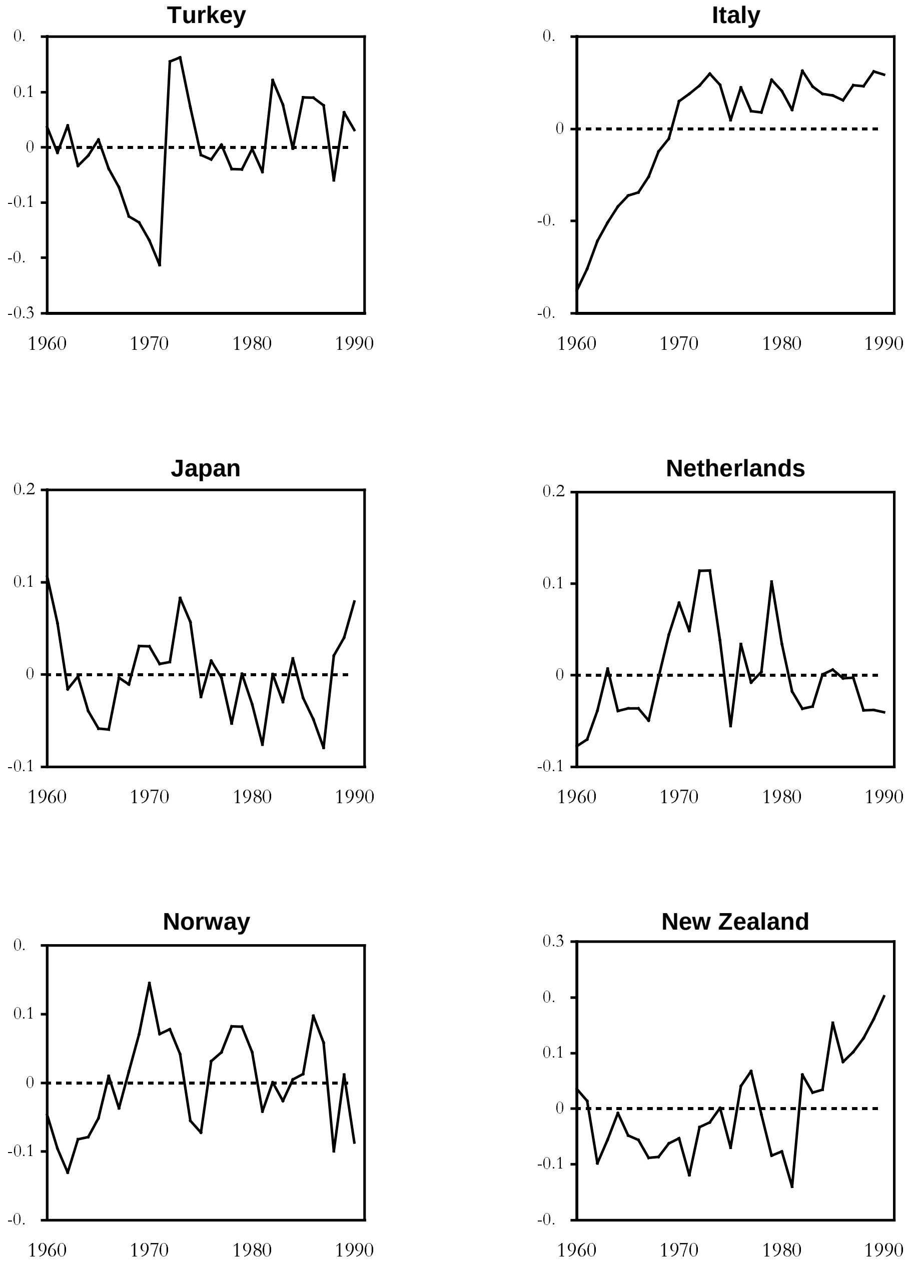


Figure 5 (continued).



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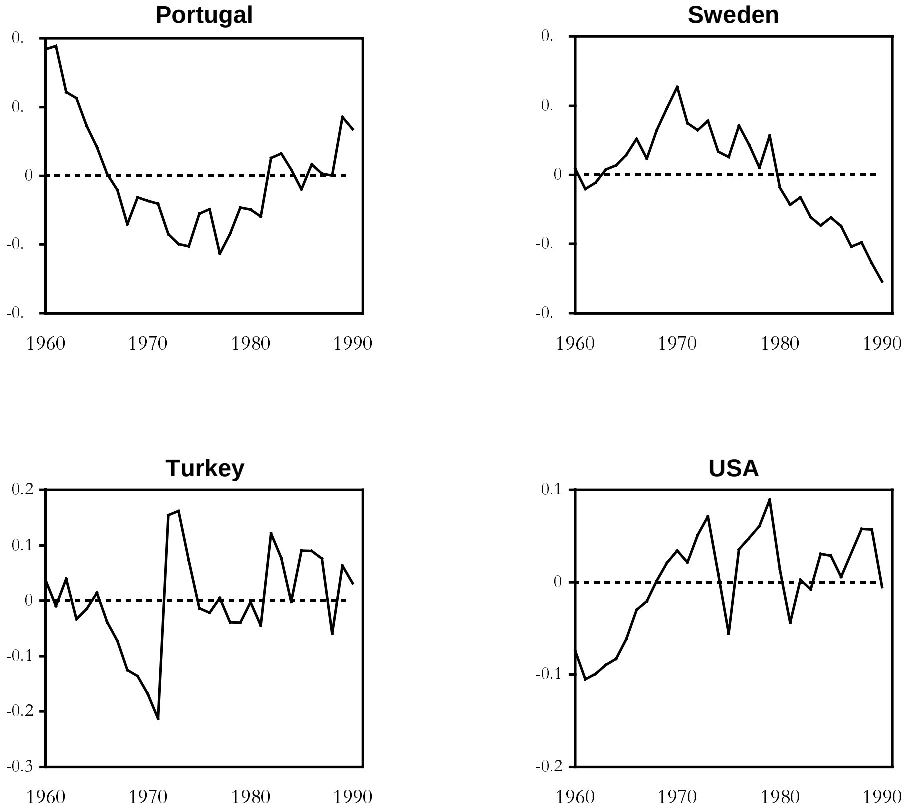

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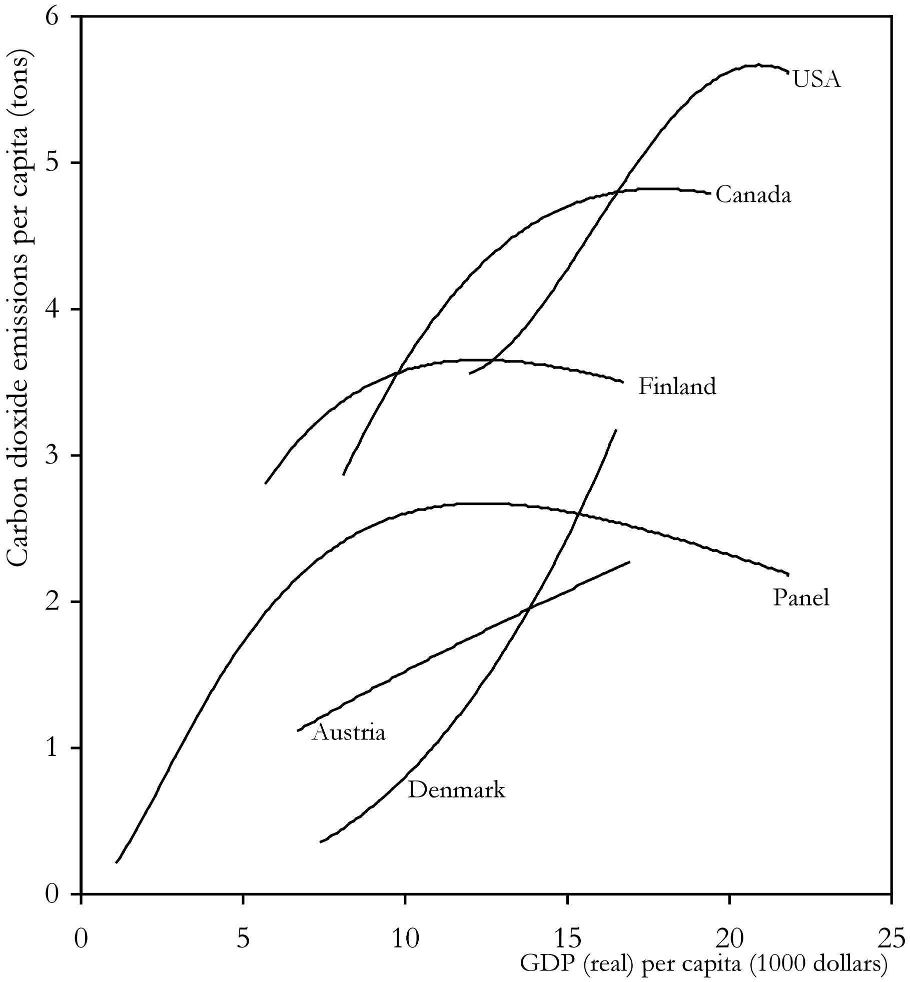

Figure 6. Fitted IER for some selected countries based on their GDP sample between 1960-1991 (based on time series estimation, see table 5).

TABLES

Table 1. Summary Kuznets studies

Study	Database	Dependent variable(s)	Fixed effects tested	Random effects tested	Curvature	Turning point (in $)
Shafik and Bandyopadhyay (1992)(See also Shafik (1994))	Pooled (153 countries, 1960-1989)	Lack of safe water, lack of urban sanitation, annual deforestation, total deforestation, dissolved oxygen in rivers, fecal coliform in rivers, ambient SPM, ambient SO_2, municipal waste per capita and carbon emissions per capita	Yes (country)	No	Varies per indicator	Varies per indicator
Hettige *et all.* (1992)	Pooled (80 countries, 1960-1988)	Toxic intensity manufacturing	?	?	Linear	No
Grossman and Krueger (1993)	Pooled (19 to 42 countries, 1977, 1982, 1988)	SO_2, suspended particles, dark matter	Yes (site specific)	Yes (site specific)	EKC	4,000 - 5,000
Selden and Song (1994)	Pooled (20 countries, period averages of 1973-1975, 1979-1981, 1982-1984)	SO_2, NO_x, CO, suspended particles	Yes (country)	Yes (country)	EKC	8,000 - 11,000
Cropper and Griffiths (1994)	Pooled (64 countries, 1961-1991)	Deforestation	Yes (country)	No	EKC	5,000

Study	Database	Dependent variable(s)	Fixed effects tested	Random effects tested	Curvature	Turning point (in $)
Grossman and Krueger (1995)	Pooled (19 to 42 countries, 1977, 1982, 1988)	Urban air pollution and oxygen regime, fecal contamination and heavy metals in river basins	No	Yes (site specific)	EKC	< 8,000
Holtz-Eaking and Selden (1995)	Pooled (130 countries, 1951-1986)	CO_2	Yes (country and year)	No	EKC	35,428 (levels), > 8,000,000 (logs)
Roberts and Grimes (1997)	Cross-section per year (144 countr., 1962-1991)	CO_2	No	No	< 1972: Linear> 1971: EKC	?

Table 2. Emissions factors CO_2

Fuel	Ton carbon per toe
Gas	0.64
Oil	0.84
Coal, Europe	1.11
Coal, USA, Canada	1.08
Coal, Pacific	1.10
Other solid fuels	0.89

Source: IEA, 1991

Table 3. Estimations IER pooled dataset

	Model (specification see below table)			
Variables	1	2	3	4
GDP	0.930 (1.65)	1.605 (10.43)	2.211 (9.15)	2.130 (8.85)
GDP^2	0.278 (0.86)	-0.123 (-3.05)	-0.252 (-1.99)	-0.237 (-1.87)
GDP^3	-0.072 (-1.25)		-0.048 (-2.05)	-0.051 (-2.19)
T_{6072}	0.178 (1.71)	0.184 (1.77)	0.216 (6.62)	
T_{7375}	0.163 (2.08)	0.172 (2.19)	0.217 (8.40)	
T_{7678}	0.146 (2.14)	0.153 (2.25)	0.183 (8.33)	
T_{7981}	0.103 (1.73)	0.109 (1.83)	0.134 (7.16)	
Trend	-0.002 (-0.30)	-0.002 (-0.35)	0.019 (7.20)	
C	-2.095 (-6.48)	-2.423 (-12.82)		
R^2	0.70	0.70	0.97	0.97
DW	0.02^B	0.02^B	0.29^B	0.20^B
Turning point^A	185	3,096	57	54

Model 1. Identical country coefficients for countries, GDP, GDP^2, GDP^3
Model 2. Identical country coefficients, GDP, GDP^2
Model 3. Identical country coefficients, GDP, GDP^2, GDP^3, fixed country effects.
Model 4. Identical country coefficients, GDP, GDP^2, GDP^3, fixed country and year effects.

Below coefficients are T-statistics.
R^2 is adjusted for degrees of freedom.
[A.] Turning point in percentage of maximum GDP panel.
[B.] Autocorrelation hypothesis not rejected (Durbin-Watson below lower bound).

Table 4. Durbin-Watson statistics pooled estimation (fixed country effects)

Country	Durbin-Watson	Country	Durbin-Watson
Great-Britain	0.08	New-Zealand	0.57
Italy	0.10	Australia	0.59
Greece	0.11	Germany	0.71
Belgium	0.16	Netherlands	0.76
Ireland	0.17	Denmark	0.78
Spain	0.17	Norway	0.84
France	0.18	Japan	0.95
Sweden	0.19	Austria	1.02
Switzerland	0.21	Finland	1.10
Portugal	0.22	Turkey	1.11
Canada	0.23		
USA	0.48	Pooled	0.29

Durbin-Watson lower bound at 5 % significant points is 0.88, upper bound is 2.12.

Table 5. Estimations IER time-series dataset

Estimation^A	GDP	GDP^2	GDP^3	T_{6072}	T_{7375}	T_{7678}	T_{7981}	Trend	R^2	DW
Australia	2.526	-0.489		0.019	0.052	0.071	0.057	0.013	0.98	2.14
	(3.43)	(-2.71)		(0.40)	(1.22)	(2.11)	(2.21)	(1.76)		
Austria	0.748			0.135	0.116	0.067	0.065	-0.002	0.95	1.73
	(3.45)			(2.52)	(2.23)	(1.45)	(1.66)	(-0.22)		
Belgium	1.446			0.240	0.170	0.125	0.118	-0.031	0.91	1.82
	(6.86)			(4.07)	(2.91)	(2.53)	(2.99)	(-3.92)		
Canada	5.086	-0.878		0.103	0.089	0.116	0.111	0.004	0.98	2.29
	(9.16)	(-6.65)		(2.33)	(1.93)	(2.69)	(3.25)	(0.36)		
Switzerl.	14.469	-2.368		0.095	0.070	0.108	0.043	0.002	0.94	2.28
	(5.47)	(-4.71)		(0.87)	(0.74)	(1.84)	(0.88)	(0.15)		
Germany	1.985			-0.060	-0.053	-0.047	-0.035	-0.048	0.92	1.34*
	(9.15)			(-1.42)	(-1.40)	(-1.39)	(-1.20)	(-7.01)		
Denmark	2.804			0.073	-0.011	0.048	0.095	-0.051	0.91	2.25
	(8.54)			(0.79)	(-0.15)	(0.78)	(2.08)	(-4.67)		
Spain	-18.855	10.751	-1.900	-0.128	-0.064	-0.022	-0.047	0.001	0.99	1.36*
	(-4.76)	(5.18)	(-5.39)	(-1.12)	(-0.53)	(-0.22)	(0.82)	(0.07)		
Finland	2.394	-0.472		0.474	0.378	0.316	0.244	0.031	0.89	2.02
	(2.48)	(-2.03)		(4.59)	(3.73)	(4.27)	(3.91)	(1.58)		
France	2.186			-0.027	-0.005	0.030	0.050	-0.060	0.98	1.92
	(18.14)			(-0.71)	(-0.13)	(1.01)	(2.08)	(-13.06)		
UK	0.993			0.101	0.062	0.053	0.064	-0.021	0.88	2.04
	(4.89)			(2.88)	(2.14)	(2.29)	(3.57)	(-4.10)		
Greece	1.301			0.103	0.153	0.103	0.020	0.023	0.99	2.23
	(16.46)			(2.03)	(3.31)	(2.58)	(0.62)	(4.86)		
Ireland	2.107	-0.323		0.308	0.201	0.075	0.095	0.004	0.94	2.26
	(3.05)	(-2.31)		(3.82)	(2.77)	(1.19)	(1.81)	(0.31)		
Italy	5.105	-0.756		0.252	0.228	0.145	0.062	-0.010	0.99	1.72*
	(9.00)	(-4.35)		(5.32)	(5.50)	(4.15)	(1.77)	(-0.89)		

Table 5. Estimations IER time-series dataset

Estimation^A	GDP	GDP^2	GDP^3	T_{6072}	T_{7375}	T_{7678}	T_{7981}	Trend	R^2	DW
Japan	1.383			0.084	0.134	0.115	0.056	-0.033	0.99	2.01
	(19.24)			(1.61)	(3.01)	(3.36)	(2.09)	(-6.14)		
Netherlands	1.454			0.136	0.074	0.024	0.060	-0.013	0.95	1.56*
	(6.81)			(1.89)	(1.08)	(0.41)	(1.38)	(-1.83)		
Norway	5.388	-0.862		0.408	0.263	0.245	0.141	-0.008	0.94	1.98
	(5.46)	(-3.62)		(3.91)	(3.02)	(3.62)	(2.64)	(-0.51)		
New Zeal.	-13.240	2.849		0.186	0.161	0.219	0.036	0.017	0.95	2.54
	(-3.50)	(3.56)		(3.04)	(3.29)	(5.08)	(0.92)	(4.06)		
Portugal	0.290			0.030	0.008	-0.004	0.002	0.013	0.99	2.08
	(5.14)			(0.38)	(0.11)	(-0.08)	(0.04)	(1.42)		
Sweden	-70.18	30.22	-4.201	0.294	0.177	0.228	0.140	-0.026	0.93	2.27
	(-2.68)	(2.88)	(-3.00)	(3.10)	(2.09)	(4.00)	(3.13)	(-1.56)		
Turkey	1.636			-0.009	0.189	0.073	0.029	0.014	0.98	1.98
	(4.33)			(-0.08)	(1.76)	(0.67)	(0.41)	(1.19)		
USA	-111.47	40.72	-4.905	0.233	0.201	0.180	0.100	0.001	0.94	1.97
	(-2.94)	(3.02)	(-3.08)	(4.37)	(5.19)	(5.65)	(4.06)	(0.11)		

Below coefficients are T-statistics.

R^2 is adjusted for degrees of freedom

Possibly positive autocorrelation (Durbin-Watson in inconclusive region, between lower and upper bound)

A. For each estimation a constant is included but not reported due to space limitations

Table 6. Turning points countries for time-series dataset

	Turning point in percentage of	
Country	Maximum panel GDP	Maximum own GDP
Australia	60	82
Austria	No	No
Belgium	No	No
Canada	82	93
Switzerland	96	100
Germany	No	No
Denmark	No	No
Spain	49	93
Finland	57	75
France	No	No
UK	No	No
Greece	No	No
Ireland	118	232
Italy	133	183
Japan	No	No
Netherlands	No	No
Norway	103	142
New Zealand	No	No
Portugal	No	No
Sweden	76	99
Turkey	No	No
USA	96	96

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