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# The environmental Kuznets curve: an empirical analysis*

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ABSTRACT. This paper examines the relationship between per capita income and a wide range of environmental indicators using cross-country panel data sets. The manner in which this has been done overcomes several of the weaknesses associated with the estimation of environmental Kuznets curves (EKCs) outlined by Stern *et al.* (1996). Results suggest that meaningful EKCs exist only for local air pollutants whilst indicators with a more global, or indirect, impact either increase monotonically with income or else have predicted turning points at high per capita income levels with large standard errors—unless they have been subjected to a multilateral policy initiative. Two other findings are also made: that concentrations of local pollutants in urban areas peak at a lower per capita income level than total emissions per capita; and that transport-generated local air pollutants peak at a higher per capita income level than total emissions per capita. Given these findings, suggestions are made regarding the necessary future direction of environmental policy.

## 1. Introduction

The environmental Kuznets curve (EKC) hypothesis is that there is an inverted-U relationship between economic growth and environmental damage (Stern *et al.*, 1996). Factors such as changes in the composition of output, the introduction of cleaner production technology and greater public demand for stricter controls on emissions (Grossman and Krueger, 1996) can lead to a declining, and eventually a negative, marginal change in pollution being associated with rising per capita incomes. A number of studies have estimated EKCs from cross-country panel data sets relating emissions per capita (Selden and Song, 1994; Holtz-Eakin and Selden, 1992) or concentrations of pollutants (Grossman and Krueger, 1993, 1995; Shafik, 1994) to per capita income for certain air and water pollutants. As emphasized by Grossman and Krueger (1996), Arrow *et al*. (1995) and Stern *et al*. (1996), these estimated regressions are reduced-form relationships; they reflect correlation rather than a causal mechanism by which the growth process affects the environment. Nevertheless, these studies provide evidence that, for at least those pollutants involving local short-term health hazards, market and institutional mechanisms have eventually

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brought about a reduction in environmental damage during the course of economic growth.

This paper extends the previous empirical analysis of EKCs in a number of ways. First, it is more extensive in that it investigates a wider range of environmental indicators and employs more recent data, thereby serving as a check on earlier results. The environmental indicators used in this analysis are: carbon dioxide, CFCs and halons, methane, nitrogen dioxide, sulphur dioxide, suspended particulate matter, carbon monoxide, nitrates, municipal waste, energy consumption and traffic volumes. In addition, emissions of nitrogen dioxide, sulphur dioxide and suspended particulate matter from the transport sector and energy use by the transport sector, are considered separately. Second, it utilizes a generalized least squares (GLS) estimation procedure to correct for heteroscedasticity and autocorrelation, so giving more efficient estimations in contrast to many earlier studies, which rely on ordinary least squares (OLS). Third, standard errors at the estimated turning point level of income are calculated to indicate the accuracy of the estimates. Of the other studies, only Grossman and Krueger (1993, 1995) also do this. Fourth, the possibility of contemporaneous feedback from environmental degradation to economic growth, which would lead to simultaneity bias in the estimation of EKCs, has been examined by testing the null of exogeneity of the income variables. Results indicate that simultaneity is not present. These refinements of earlier studies go some way towards meeting the strictures of Stern *et al.* (1996) regarding the problems surrounding the estimation of EKCs.

The employment of a reasonably comprehensive data set permits the examination of a number of hypotheses relating to the association between economic growth and the environment. First, that pollutants with a local short-term impact (e.g., suspended particulate matter) will have estimated turning points at lower per capita income levels than those environmental indicators whose impact is more global in nature (e.g., carbon dioxide).[1] Indeed, Arrow *et al.* (1995) suggest that the latter may even increase monotonically with income. Thus, a subsidiary hypothesis is that a global pollutant will only have an estimated turning point within the observed income range if it has been subjected to a multilateral policy initiative. Second, for local air borne pollutants, turning points for concentrations in urban areas will be at lower per capita income levels than for total emissions per capita.[2] Third, that emissions per capita of transport-generated local air pollutants will have turning points at higher levels of per capita income than total emissions per capita of the same local air pollutants.[3]

[1] Grossman (1994) suggested that this distinction is due to the fact that individuals demand that governments address *local* pollutants, because of their obvious antisocial effects. In contrast, governments have little incentive to unilaterally reduce *global* pollutants.

[2] Selden and Song (1994) provide several reasons why this may be the case, including the point that it is more difficult to reduce total emissions than urban concentrations, since the latter could be reduced by simply building taller chimneys.

[3] The rapid growth of the transport sector in recent years, together with the reluctance of many governments to regulate its environmental impact, suggests that air pollution from transport will prove more stubborn to control than in other sectors.



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In order to throw further light on the relationship between economic growth and environmental quality, this paper examines several indicators which have only an *indirect* impact on the environment, namely per capita values of total energy use, energy use from transport, municipal waste and traffic volumes. Even though these indicators may be responsible for serious environmental problems, it is hypothesized that they will exhibit a relationship with per capita income similar to that of the global air pollutants—as a result of the lack of incentive for government action.

The remainder of the paper is organized as follows; Section 2 sets out the framework which has been adopted to examine the relationship between economic growth and environmental quality; Section 3 provides results and Section 4 concludes the paper.

## 2. Framework

The existence of a path of environmental quality implies that there is systematic variation in the indicator of environmental quality associated with a rising level of per capita income, and that this relationship is common to all countries. This reduced form relationship is postulated to have an inverted-U functional form (either quadratic in levels or quadratic in logs) and is estimated for each indicator of environmental quality from cross-country/region panel data. Exogenous shift variables are also included in the analysis: in particular, country/region-specific intercept dummy variables to allow for the differential impact of natural endowments on environmental quality; a linear time trend to allow for the possibility of technological change; and a trade intensity variable to represent trade openness. It has been suggested that the latter variable may result in environmental degradation for several reasons—one of which being the possibility of environmental standards falling to a lowest common denominator as a consequence of trade liberalization (Esty, 1994).

The basic model is:

$$E_{it} = f(Y_{it}, F_i, X_{it}) \tag{1}$$

where $E_{it}$ denotes the environmental indicator in per capita form[4] in country/region $i$, year $t$, $Y_{it}$ denotes per capita income in country/region $i$, year $t$, $F_i$ denotes effects specific to country/region $I$, $i = 1, \ldots, n$ countries, $t = 1, \ldots, T$ years, and $X_{it}$ represents exogenous factors, such as trade intensity and the level of technology in country/region $i$, year $t$.

The environmental indicators used in this paper are listed in Table 1. The income, population and trade intensity data originate from the Penn. World Tables Mark 5.6, in Summers and Heston (1991). Further information regarding the variables used can be found in Appendix A.

Two alternative functional forms are employed for estimating equation (1) from a cross-country/regional panel set: quadratic in levels and quadratic in logarithms. These are written as:

[4] All environmental indicators are in per capita form with the exception of nitrate concentrations in river water, which are given in terms of mg N/litre and are not appropriate to conversion to per capita values.



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Table 1. *Data information*

| *Environmental indicator* | *Time period* | *No. countries/ regions* | *Unit* | *Source*[1] |
|---|---|---|---|---|
| Nitrogen dioxide | 1970–92 | 10 OECD countries | tonnes | OECD (1993, 1995) |
| Sulphur dioxide | 1970–92 | 11 OECD countries | tonnes | OECD (1993, 1995) |
| Suspended particulate matter | 1970–92 | 7 OECD countries | tonnes | OECD (1993, 1995) |
| Carbon monoxide | 1970–92 | 7 OECD countries | tonnes | OECD (1993, 1995) |
| Nitrogen dioxide from transport[2] | 1970–92 | 9 OECD countries | tonnes | OECD (1993, 1995) |
| Sulphur dioxide from transport | 1970–92 | 9 OECD countries | tonnes | OECD (1993, 1995) |
| SPM from transport | 1970–92 | 7 OECD countries | tonnes | OECD (1993, 1995) |
| Nitrate concentrations | 1975–90 | 30 rivers in 15 OECD countries | mgN/litre | OECD (1993, 1995) |
| Carbon dioxide | 1960–91 | 7 regions | tonnes of carbon | Marland, Andres and Boden (1994) |
| Total energy use | 1980–92 | 22 OECD countries | MTOE[3] | OECD (1993, 1995) |
| CFCs and halons | 1986, 1990 | 38 countries (1986) 39 countries (1990) | tonnes | UNEP[4] (1993) |
| Methane | Late 1980s | 88 countries | tonnes | UNEP[4] (1993) |
| Municipal waste | 1975–90 | 13 OECD countries | tonnes | OECD (1993, 1995) |
| Energy use from transport | 1970–90 | 24 OECD countries | MTOE | OECD (1993, 1995) |
| Traffic volumes | 1970–92 | 22 OECD countries | kilometres | OECD (1993, 1995) |

*Notes*: [1] For the OECD data sets, the minimum and maximum levels of per capita income are $2,202 and $18,095, respectively, with the exceptions of sulphur dioxide and suspended particulate matter which range from $5,105 to $18,095.
[2] Faiz *et al.* (1992) estimate that the transport sector is responsible for 29–32 per cent of world-wide anthropogenic emissions of nitrogen dioxide, 10–20 per cent of suspended particulate matter and 2–6 per cent of sulphur dioxide. Note that carbon monoxide from the transport sector has not been considered separately from total carbon dioxide since there is very little difference between the two.
[3] MTOE = million tonnes of oil equivalent.
[4] UNEP = United Nations Environment Programme



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$$E_{it} = (\alpha + \mu_i F_i) + \beta Y_{it} + \gamma Y_{it}^2 + X_{it} + e_{it} \quad (2)$$

and

$$\ln E_{it} = (\lambda + \kappa_i F_i) + \eta \ln Y_{it} + \theta(\ln Y_{it})^2 + X_{it} + \epsilon_{it}. \quad (3)$$

In both equations (2) and (3) fixed effects are represented by country-specific dummy variables, denoted by $F_i$, for $i = 2, \ldots, n$ with country/region 1 used as the base.

A cubic function was also considered, but the fact that every cubic relationship necessarily extends to plus or minus infinity was deemed to be unrealistic. The study therefore concentrates on quadratic relationships, although linear and log-linear relationships are also considered for CFCs and halons 1986. Note also that for CFCs and halons and methane a panel analysis was not possible owing to data constraints. These indicators have instead been subjected to a cross-section OLS analysis.

An environmental quality path exists if there is a statistically significant relationship between an environmental indicator and income. A path displays a turning point if $\beta > 0$ and $\gamma < 0$ in equation (2) and $\eta > 0$ and $\theta < 0$ in equation (3). Income at the turning point, denoted by $Y^*$ is $Y^* = (-\beta/2\gamma)$ in equation (2) and $Y^* = \exp(-\eta/2\theta)$ in equation (3).

*A priori*, the quadratic logs function would seem to provide a more realistic income–environmental quality path than the quadratic levels function because of the symmetrical nature of the latter. If, for example, pollution is considered, this symmetry implies, first, that pollution levels will fall at the same rate as they increased and, second, that these pollution levels will become negative, probably in a short space of time. This is in contrast to the quadratic logs function which falls away only gradually, once it passes the turning point, as the curve asymptotically approaches zero. Generalized least squares is used to estimate the functions, following Kmenta (1986). This method uses the estimated autocorrelation coefficient to transform the observations and then divides the transformed equation by the standard error of the residuals, to remove autocorrelation and heteroscedasticity, respectively. Both conditions were found to exist when the residuals from ordinary least-squares estimation were analysed. Note that for all estimations, Box–Pierce and Durbin–Watson tests were used to test for autocorrelation, whilst Breusch–Pagan–Godfrey, Harvey and Glejser tests were used to test for heteroscedasticity.

A Hausman specification test was employed to test the null of exogeneity of current income in the EKC. Lagged income was used as the instrumental variable. The test statistic is a Wald statistic, which is then referred to a chi-squared distribution, with appropriate degrees of freedom (Greene, 1993). The null of exogeneity was accepted in all cases.[5]

A random-effects specification was also used, even though it was felt that this specification is more appropriate for studies that use site-specific

[5] Further information regarding test results can be obtained from the authors. Note that this test is similar to the Holtz-Eakin, Newey and Rosen test used by Holtz-Eakin and Selden (1992). Note also that the Holtz-Eakin, Newey and Rosen test and the test used in this paper have low power to reject the null.



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data, such as Grossman and Krueger (1993, 1995). A Hausman test was used to ascertain whether fixed- or random-effects estimation was preferred. In all instances the test statistics indicate that the random effects are correlated with the income variables, and hence the fixed-effects estimation is favoured.[6]

## 3. Results

Appendix B presents estimates of equations (2) and (3) using GLS for regressions including fixed effects, together with OLS results for CFCs and halons and methane. Note that the trade intensity and time trend variables are omitted. Although the trade intensity variable had a negative coefficient in all preliminary regressions, the variable was not statistically significant for any of the environmental indicators, perhaps because country/region-specific differences in trade intensity were captured by the fixed effects. Similar results have also been found by Grossman and Krueger (1993); namely a negative but generally non-significant impact. The time trend was statistically significant for only seven of the environmental indicators considered, and its inclusion did little to affect estimated turning points.[7] Consequently, the reported regressions are those for which statistically significant variables are common to all environmental indicators.

In Tables 2 and 3 we report estimates of the turning point levels of income (in 1985 US dollars) derived from the regression results and compare these estimates with those of other studies (where available). As a point of reference, in 1992, per capita income (in 1985 US dollars) was $17,945 in the USA, $12,724 in the UK, $1,282 in India and a mere $408 in Chad (Summers and Heston, 1991). The standard errors for these turning points are reported in parentheses and were calculated using the Delta method following Greene (1993). The bold letter **F** denotes estimated turning points that are higher than the maximum observed income in the data set; for the environmental indicators with these projected turning points, per capita emissions/environmental damage are increasing, at a declining rate, throughout the observed income range. Note that no turning points are estimated to be below the minimum income level in each sample.

### *3.1 Indicators with a **direct** local environmental impact*

Turning points for per capita emissions of total nitrogen dioxide, sulphur dioxide, suspended particulate matter and carbon monoxide can be seen to be well within the observed income range, indicating that per capita emissions of these pollutants are now falling in many developed countries. It is likely that the turning points for total nitrogen dioxide emissions per capita are higher than those estimated for total emissions per capita of the other local air pollutants because of the large contribution of the ever-growing transport sector to total nitrogen dioxide emissions. The turning

[6] For reasons of space, neither the random effects results, nor the Hausman test results are reported. Both are available from the authors.

[7] Further details of the results of regressions containing time trends can be found in Cole, Rayner and Bates (1997).



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Table 2. *Estimated turning points (1985 US$)*

| | *This study* | | *Other studies*[1] | | |
|---|---|---|---|---|---|
| | *Emissions per capita* | | *Urban concentrations* | | *Emissions per capita* |
| *Environmental indicator* | *Quadratic logs* | *Quadratic levels* | *G&K*[2] | *Shafik*[3] | *S&S*[4] |
| Sulphur dioxide | $6,900 (563) | $5,700 (1,386) | $4,053 | $3,670 | $8,916 |
| Sulphur dioxide —transport | $9,800 (586) | $9,400 (908) | | | |
| Suspended particulate matter | $7,300 (264) | $8,100 (630) | $6,151 | $3,280 | $9,811 |
| Suspended particulate matter —transport | $18,000 (2,709) | $15,000 (1,114) | | | |
| Carbon monoxide | $9,900 (353) | $10,100 (319) | | | $6,241 |
| Nitrogen dioxide | $14,700 (587) | $15,100 (758) | | | $12,041 |
| Nitrogen dioxide —transport | $17,600 (1,579) | $15,100 (498) | | | |
| Nitrates | $25,000 **F** (6,779) | $15,600 (385) | $10,524 | | |

*Notes*: [1] G&K refers to Grossman and Krueger (1995), Shafik refers to Shafik (1994) and S&S refers to Selden and Song (1994). All estimated turning points are in 1985 US dollars.
[2] Grossman and Krueger's estimates result from a quadratic levels functional form. Suspended particulate matter data were split into smoke and heavy particles. This turning point is for smoke. The relationship between heavy particles and income was estimated to be monotonically decreasing.
[3] Shafik's estimates are from a logged quadratic functional form.
[4] Selden and Song's estimates are from their fixed-effects quadratic levels functional from, without population density.

points for carbon monoxide emissions, a significant proportion of which also stem from the transport sector, are perhaps lower than those for nitrogen dioxide emissions because even the earliest form of catalytic converter tackled carbon monoxide, whilst only more recent versions are able to reduce nitrogen dioxide emissions. The low turning points for sulphur dioxide and suspended particulate matter reflect the change, in the developed world, from domestic coal burning to electricity and natural gas for cooking and heating. Furthermore, in 1985, the Convention on Long-Range Transboundary Air Pollution was formed, which contained the Sulphur Protocol committing signatories to reduce emissions by 30 per cent from 1980 levels by 1993. Most nations achieved this goal and even non-signatories have reduced their emissions.

Turning points for the above pollutants can be seen to have small standard errors, indicating that the results are reliable—with the possible exception of the quadratic logs turning point for nitrate concentrations.



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Table 3. *Estimated turning points (1985 US$)*

| | *This study* | | *Other studies* |
|---|---|---|---|
| *Environmental indicator* | *Quadratic logs* | *Quadratic levels* | *Holtz-Eakin and Selden*[1] |
| Carbon dioxide | $62,700 **F** (27,247) | $25,100 **F** (5,640) | $35,428 and $8 million |
| Total energy use | $34,700 **F** (9,719) | $22,500 **F** (2,617) | |
| CFCs and halons 1990 | $12,600 (3,686) | $15,400 (3,405) | |
| Transport energy use | $4 million **F** (1.5 million) | $400,000 **F** (327,658) | |
| Traffic volumes | $65,300 **F** (19,412) | $108,200 **F** (123,297) | |
| Municipal waste and methane | No estimated turning points | | |

*Note*: [1] Holtz-Eakin and Selden's turning point of $35,428 resulted from a quadratic levels functional form, whilst the turning point of over $8 million was estimated by a quadratic logs function.

The turning point income for nitrate pollution can be seen to be reasonably high, indicating that concentrations of nitrates are still rising, even in many developed nations.

The results of this paper would appear to support the hypothesis proposed by Selden and Song (1994) that estimated turning points for total emissions per capita will tend to be higher than those estimated for urban air concentrations. However, the turning points estimated in this paper, whilst still being notably *higher* than those of Grossman and Krueger and Shafik (urban air concentrations), are also notably *lower* than the estimates of Selden and Song (total emissions per capita), thereby weakening their argument. Thus, this paper would suggest that the difference between turning points for total emissions per capita and urban air concentrations is not as large as Selden and Song believed. Compared to Selden and Song, this paper uses far longer time series for each country,[8] resulting in a greater number of observations and hence degrees of freedom. However, although this paper's observations for both sulphur dioxide and suspended particulate matter do fall on both the upward and downward sloping portions of the estimated curves, Selden and Song include more low-income countries in their sample, and have a wider spread of income and better representation on the upward sloping portion. It is therefore difficult to say which results are preferable.

With regard to transport-generated emissions per capita of local air pollutants, Table 2 indicates that estimated turning points are noticeably higher than those estimated for total emissions per capita of the same pollutants, with the exception of the quadratic-levels turning points for nitrogen dioxide, where the turning points for total emissions per capita

[8] Selden and Song's time series consists of averages for the periods 1973–75, 1979–81 and 1982–84.



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and transport-generated emissions per capita are identical. This fact illustrates that local air pollution in the transport sector has proven more difficult to control than in other sectors, largely because traffic volumes are increasing steadily, negating any minor fuel efficiency achievements. The introduction of the three-way catalytic converter, which occurred in most OECD countries towards the end of the time period under consideration, should see a marked drop in nitrogen dioxide emissions (as well as carbon monoxide and hydrocarbons). Unfortunately, however, the three-way catalyst is not without its drawbacks since it cannot be used on diesel vehicles, whilst it also increases fuel use and emissions of nitrous oxide (a greenhouse gas). Suspended particulate matter from the transport sector is released largely by diesel-fuelled vehicles. Therefore, as a result of the wider use of catalytic trap oxidizers, which are primarily designed to reduce particulate emissions from diesel engines, particulate emissions from transport will at least begin to stabilize, unless goods-vehicle traffic volumes increase significantly.

### *3.2 Indicators with **no direct** local environmental impact*

Turning points for per capita carbon dioxide emissions and total energy use per capita clearly fall well outside the observed income range, and the quadratic logs turning points for both environmental indicators possess relatively large standard errors. Thus, carbon dioxide emissions monotonically increase within the observed income range and little confidence can be had in the estimated turning points. These results illustrate that the global nature of carbon dioxide's impact has provided little incentive for nations to take unilateral action to reduce emissions, and multilateral action has been slow to develop. Cole, Rayner and Bates (1996) provide a global projection of total carbon dioxide emissions for the period 1992–2025 and show total emissions increasing steadily throughout the period. On a more positive note however, the 1992 Earth Summit in Rio de Janeiro at least heralded the start of joint action to prevent climate change. Although many nations look unlikely to meet their agreed targets, the very existence of the targets at least indicates that the issue of climate change is slowly entering the political agenda. Closely related to the issue of carbon dioxide emissions is that of energy use. Since the latter has increased throughout the observed income range, despite regular advances in energy efficiency, it is no surprise that so too have carbon dioxide emissions. It would appear that the effect of the growth of GDP has exceeded the extent of any energy efficiency gains.

Figure 1 illustrates the cross-section relationship between per capita income and the per capita consumption of CFCs and halons for 1986 and 1990.

Estimates for both 1986 and 1990 display heteroscedastic errors, seemingly due to the extreme variability of the data. As a result, t-statistics should be treated with caution. For 1990, the quadratic functions provided a good fit, although for 1986 the income-squared terms were not significant, resulting in the use of linear functions. Figure 1, therefore, shows the log-quadratic function for 1990 and the log-linear function for 1986. The Montreal Protocol would appear to be a major factor in explaining the



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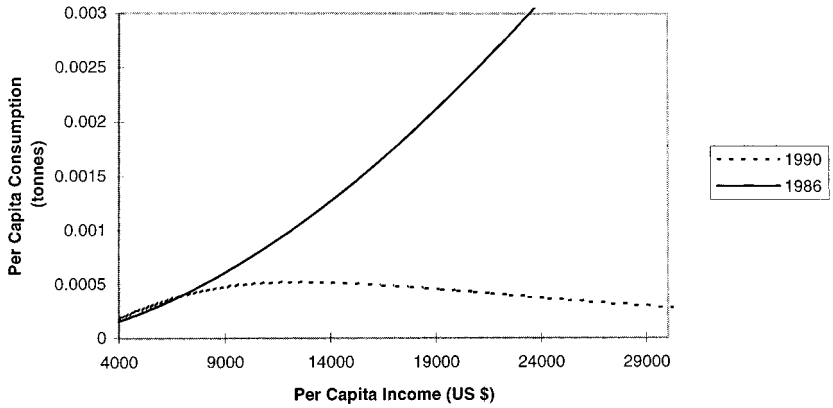



Figure 1. *Consumption of CFCs and halons pre and post Montreal Protocol*

difference between the two years. In 1986, countries may have been reluctant to unilaterally reduce their consumption of CFCs and halons because of the global impact associated with these pollutants.[9] However, in 1987 the Montreal Protocol was adopted which committed its signatories to a reduction in a number of substances, including CFCs and halons, by 50 per cent of their 1986 level by July 1999 (United Nations Environment Programme, 1993). This result would clearly seem to illustrate the potential effectiveness of a multilateral response to an environmental problem. The case of CFCs and halons may well prove to be idiosyncratic, however, not least because of the relative ease with which cleaner alternatives to CFCs and halons have been developed, and hence their relatively low abatement costs. This analysis of CFCs and halons does illustrate that a multilateral policy initiative targeted at a global air pollutant can provide an estimated turning point within the observed income range. Clearly, in this example, the effect of the Montreal Protocol was to 'tunnel through' the original 1986 curve, resulting in the vastly different curve for 1990.[10]

The final global air pollutant considered is methane. As Appendix B indicates, however, the relationship between per capita emissions of methane and per capita income levels is not statistically significant. The reason for this would appear to be the diverse nature of the sources of methane, which means that both developed and undeveloped economies can have relatively high methane emissions.

The final three environmental indicators—per capita values of municipal waste, energy use by transport and traffic volumes—all increase monotonically throughout the observed income range. The standard errors associated with turning points for per capita energy use from transport and per capita traffic volumes are very large, however, implying that these

[9] Barrett (1991), however, does point out that the severity of the potential impacts of ozone depletion seems to suggest that individual countries do have sufficient incentive to act unilaterally.

[10] Munasinghe (1995) introduced the concept of 'tunnelling through'.



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estimates are unreliable. There is little evidence that the inverted-U pollution–income curve exists for these indicators, probably as a result of the lack of a direct local environmental impact associated with each. Apart from perhaps causing a loss of amenity value when disposed of in landfill, municipal waste only indirectly harms the environment by representing an increased use of resources and by generating methane when disposed of in landfill sites. Furthermore, methane is a global air pollutant and, as such, there is little incentive to reduce emissions unilaterally. Finally, the environmental impact of municipal waste is further masked by the fact that the volume of municipal waste does not indicate just how much of that waste is recycled.[11] Similarly, both energy use by transport and traffic volumes may have only an indirect impact on the environment, although an increase in traffic volumes can directly affect the welfare of motorists. Nevertheless, the significant increase in traffic volumes is clearly tending to counteract improvements that have been made in terms of fuel efficiency and pollution levels. It would therefore appear that the already considerable impact of the transport sector on the environment looks unlikely to weaken, at least in the short term.

## 4. Summary and conclusions

By examining a wide range of environmental indicators, this paper has assessed whether EKCs exist for all such indicators, an issue raised by Arrow *et al*. (1995). The manner in which this has been done improves on many existing studies by correcting for autocorrelation and heteroscedasticity, calculating standard errors at the turning point level of income to indicate the reliability of estimates and testing for simultaneity to ensure that no bias was present in the estimates. These factors overcome at least some of the weaknesses associated with the estimation of EKCs outlined by Stern *et al*. (1996).

Results suggest that meaningful EKCs exist only for local air pollutants, whilst indicators with a more global, or indirect, environmental impact either increase monotonically with income or else have high turning points with large standard errors. Little confidence can be attached to such turning points. The results of this paper also support the hypothesis of Selden and Song (1994) that urban air concentrations will peak at lower income levels than per capita emissions. This implies that it is easier to improve urban air quality than it is to reduce national emissions. The difference between the two-turning point income levels would not appear to be as large as Selden and Song (1994) first suggested, however.

It is important that the EKCs estimated for local air pollutants are not misinterpreted, in terms of their global impact. As pointed out by Stern *et al*. (1996) and Selden and Song (1994), global income distribution is skewed, with median world income per capita far less than the mean, so that total emissions of a pollutant can still be increasing in the medium term, even though per capita emissions are estimated to peak at a

[11] Efforts to reduce the volume of municipal waste are beginning to be made, however. For example, on 1 October 1996 the British government introduced a tax of up to £7 per tonne of waste deposited at municipal collection sites.



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reasonably low per capita income level. Clearly, despite the existence of EKCs, the reduction of emissions of these local pollutants remains vital, particularly in the developing world.

The fact that, for local air pollutants, estimated turning points for transport-generated emissions per capita are higher than those for total emissions per capita, indicates the importance of tackling pollution in the transport sector. In the developed world, emissions of local air pollutants are falling in many sectors, resulting in a reduction in total emissions. If increasing transport emissions could be reversed, however, total emissions would obviously fall more rapidly. Similarly, energy use in the transport sector would appear to be growing more quickly than total energy use. There is therefore a clear need for governments to address the impact of this ever-growing sector. More generally, the results also highlight the need to tackle indirect indicators, particularly energy use and traffic volumes. The steady increase of these indicators is clearly hindering attempts to control carbon dioxide emissions and transport generated emissions of local air pollutants.

With regard to CFCs and halons, the analysis illustrates the importance of multilateral action for a global air pollutant and tends to confirm that, without such a policy initiative, global air pollutants will increase monotonically with income—at least for the per capita income levels that are predicted in the medium term. Although the case of CFCs and halons may be encouraging, it does indicate that without multilateral action carbon dioxide emissions are unlikely to be controlled in the short term.

Finally, as Grossman and Krueger (1996) have observed, there is nothing inevitable about the relationship between per capita income and environmental quality, as encapsulated in the EKC fitted to historical data. Indeed, the analysis of CFCs and halons illustrates that appropriate policies can 'tunnel through' EKCs. Although there is evidence that developed countries have 'grown out of' some pollution problems, it is important to stress that this is by no means an automatic process. Pollution levels have fallen only in response to investment and policy initiatives.

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## APPENDIX A

### Data information

Data for the local air pollutants are constructed from estimates of fuel use, which are then applied to country- and year-specific estimates of emissions per unit of fuel used.

Carbon dioxide data include emissions from fossil-fuel consumption, cement manufacture and gas flaring. Cement emissions data stem from cement manufacturing data compiled by the US Bureau of Mines; the data on fossil-fuel emissions are created by applying carbon dioxide emissions coefficients to the United Nations fossil fuel consumption data series; gas flaring emissions stem from the United Nations and the US Department of Energy's Energy Information Association. Holtz-Eakin and Selden (1992) omitted carbon dioxide originating from gas flaring on the grounds that the few oil exporting nations would be outliers. Emissions from gas flaring are a very small proportion of total regional emissions and are included in this paper.

Data on the consumption of CFCs and halons are based on official reports submitted to the Ozone Secretariat, United Nations Environment Programme, under the terms of the Montreal Protocol. Note that the trade and consumption of black market CFCs are unlikely to be included in these data.

Methane emissions stem from solid waste, coal mining, oil and gas production, wet rice agriculture and livestock.

It should be noted that the municipal waste data simply record how much waste is collected, and provide no information concerning how much of that waste is then recycled. Recycling rates are rising steadily within the OECD, with the recycling of glass standing at 66 per cent in the Netherlands in 1990, for example. However, even for the Netherlands, recycled waste represented only 4 per cent of total waste collected in 1990. This compares with 3.6 per cent in France, 3.4 per cent in Japan and a relatively high 14 per cent in the USA. (OECD, 1993).

Nitrate data are given in terms of annual mean concentrations of nitrates, measured at the mouth or downstream frontiers of the rivers.

Total energy use data refer to the energy used 'by the different end-use sectors (i.e. industry, transport, agriculture, commerce, public services and residential uses, as well as non-energy uses of gas, coal, oil and oil products). It includes consumption of solid fuels (mainly coal), oil, gas, electricity and heat' (OECD, 1993, p. 204). Energy use by the transport sector refers to the energy used by air, road and rail transport.

Traffic volumes are estimated by multiplying the number of motor vehicles in use by the average number of kilometres travelled each year by road vehicles (excluding three-wheeled vehicles, caravans and trailers).

The income variable used is real per capita GDP, measured in purchasing power parity terms and in 1985 US dollars (variable RGDPCH). The measure of trade intensity is the trade openness variable which is the ratio of the sum of exports and imports to GDP.



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## APPENDIX B

### GLS (and OLS) results

The results are given in Table 4. T-statistics are in parentheses. Buse $R^2$ is a goodness of fit measure for GLS, which is calculated using weighted variables following Buse (1973). Note that estimated coefficients for country/region-specific dummy variables and the constant are not reported.

Table 4. *GLS (and OLS) results*

| | | *Logs quadratic* | *Levels quadratic* |
|---|---|---|---|
| Sulphur dioxide, 165 obs. GLS | $Y$ | 28.43 | 8.19 |
| | | (5.39) | (2.13) |
| | $Y^2$ | −1.61 | −0.00071 |
| | | (−5.64) | (−4.32) |
| | Buse $R^2$ | 0.74 | 0.79 |
| Sulphur dioxide—transport, 135 obs. GLS | $Y$ | 23.82 | 0.42 |
| | | (4.29) | (2.62) |
| | $Y^2$ | −1.29 | −0.23e−4 |
| | | (−4.3) | (−3.154) |
| | Buse $R^2$ | 0.68 | 0.63 |
| Suspended particulate matter, 105 obs. GLS | $Y$ | 31.44 | 3.94 |
| | | (8.53) | (3.71) |
| | $Y^2$ | −1.76 | −0.00024 |
| | | (−8.70) | (−4.84) |
| | Buse $R^2$ | 0.89 | 0.87 |
| Suspended particulate matter—transport, 105 obs. GLS | $Y$ | 9.66 | 0.45 |
| | | (5.51) | (5.79) |
| | $Y^2$ | −0.49 | −0.15e−4 |
| | | (−5.15) | (−4.28) |
| | Buse $R^2$ | 0.94 | 0.91 |
| Carbon monoxide, 105 obs. GLS | $Y$ | 31.08 | 63.04 |
| | | (6.84) | (6.76) |
| | $Y^2$ | −1.68 | −0.0031 |
| | | (−6.97) | (−7.9) |
| | Buse $R^2$ | 0.87 | 0.92 |
| Nitrogen dioxide, 150 obs. GLS | $Y$ | 18.53 | 8.06 |
| | | (5.70) | (4.94) |
| | $Y^2$ | −0.96 | −0.00026 |
| | | (−5.61) | (−4.17) |
| | Buse $R^2$ | 0.91 | 0.89 |
| Nitrogen dioxide—transport, 135 obs. GLS | $Y$ | 20.48 | 8.19 |
| | | (5.13) | (9.20) |
| | $Y^2$ | −1.04 | −0.00027 |
| | | (−4.91) | (−7.26) |
| | Buse $R^2$ | 0.92 | 0.91 |
| Nitrates, 120 obs. GLS | $Y$ | 10.22 | 0.00063 |
| | | (3.84) | (7.04) |
| | $Y^2$ | −0.50 | −0.20e−7 |
| | | (−3.52) | (−6.45) |
| | Buse $R^2$ | 0.86 | 0.90 |



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Table 4. *GLS (and OLS) results (continued)*

| | | *Logs quadratic* | *Levels quadratic* |
|---|---|---|---|
| Carbon dioxide, 224 obs. GLS | $Y$ | 3.50 | 252.05 |
| | | (8.84) | (11.79) |
| | $Y^2$ | −0.15 | −0.0050 |
| | | (−6.63) | (−3.43) |
| | Buse $R^2$ | 0.96 | 0.95 |
| Total energy consumption, 286 obs. GLS | $Y$ | 4.28 | 0.00021 |
| | | (5.16) | (10.92) |
| | $Y^2$ | −0.20 | −0.46e−8 |
| | | (−4.56) | (−5.01) |
| | Buse $R^2$ | 0.98 | 0.99 |
| CFCs and halons 1986 (linear), 38 obs. OLS | $Y$ | 1.67 | 0.088 |
| | | (13.15) | (10.08) |
| | Buse $R^2$ | 0.85 | 0.86 |
| CFCs and halons 1990, 39 obs. OLS | $Y$ | 15.36 | 0.086 |
| | | (4.25) | (3.31) |
| | $Y^2$ | −0.81 | −0.28e−5 |
| | | (−3.80) | (−1.96) |
| | Buse $R^2$ | 0.73 | 0.74 |
| Methane, 88 obs. OLS | $Y$ | 0.50 | 2.84 |
| | | (0.51) | (0.74) |
| | $Y^2$ | −0.018 | −0.26e−5 |
| | | (−0.29) | (−0.011) |
| | Buse $R^2$ | 0.12 | 0.08 |
| Municipal waste, 52 obs. GLS | $Y$ | −17.46 | −35.04 |
| | | (−5.50) | (−5.40) |
| | $Y^2$ | 0.96 | 0.0022 |
| | | (5.69) | (8.89) |
| | Buse $R^2$ | 0.93 | 0.99 |
| Energy use by transport, 96 obs. GLS | $Y$ | 2.35 | 0.66e−4 |
| | | (4.24) | (7.67) |
| | $Y^2$ | −0.067 | −0.72e−10 |
| | | (−2.20) | (−0.18) |
| | Buse $R^2$ | 0.96 | 0.94 |
| Traffic volumes, 330 obs. GLS | $Y$ | 6.85 | 0.56 |
| | | (8.30) | (7.98) |
| | $Y^2$ | −0.30 | 0.26e−5 |
| | | (−6.8) | (−0.79) |
| | Buse $R^2$ | 0.96 | 0.90 |



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