An empirical test of the environmental Kuznets curve:
The effects of industry and trade

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The last quarter of the 20th century saw a growing awareness of the need for environmental protection. Indeed, modern environmentalism has developed largely in response to the perceived threat that economic growth has on the Earth's natural systems. One of the first publications to bring attention to the sustainability problem was the 1972 book *The Limits to Growth* (and subsequent updates in 1992 and 2004). In it, the authors claim that

> if the present growth trends in world population, industrialization, pollution, food production and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next 100 years. The most probable result will be a sudden and uncontrollable decline in both population and industrial capacity.
>
> Meadows *et al.* (1992), p. xiii

There was particular concern that many of the world's rapidly industrializing nations – especially China and India, which together account for about one third of the global population – would not be able to reap the benefits of sustained economic growth without causing severe environmental destruction. It was widely believed that an increase in a nation's per capita income would have a positive effect on per capita environmental degradation.

However, by the early 1990s this assumption that continued economic growth would cause ever increasing environmental decay came under question. The *World Development Report 1992* noted that "The view that greater economic activity inevitably hurts the environment is based on static assumptions about technology, tastes and environmental investments" (World Bank, 1992, p. 38). It was suggested by some economists that the relationship between economic growth and environmental damage followed an inverted U shape. With respect to air and water pollution the idea was that an increase in per capita income would result in higher emissions per capita until per capita income reaches a turning point, after which a continued rise in income would actually reduce emissions per capita (Perman *et al.*, 2011). This relationship came to be known as the environmental Kuznets curve (EKC).

General overview of the EKC

The basic shape of the environmental Kuznets curve (EKC) is illustrated by the following figure.

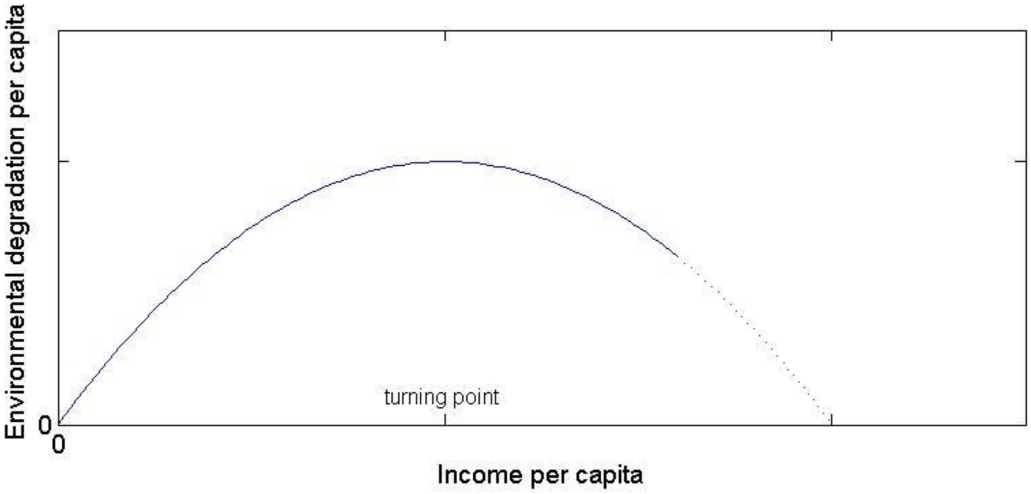


Figure 1. Theoretical relationship between degradation per capita and income per capita in the EKC

The graph of the EKC shows that in the early stages of economic development, an increase in individual income contributes to greater degradation per capita. This increasing relationship continues until a certain level of development is reached (the turning point). Continued economic growth after this point leads to a reduction in per capita environmental degradation. The dotted portion of the curve indicates uncertainty over whether or not degradation per capita eventually falls back down to 0 for high enough income. The EKC hypothesis is explained as follows:

> At low levels of development both the quantity and intensity of environmental degradation is limited to the impacts of subsistence economic activity on the resource base and to limited quantities of biodegradable wastes. As economic development accelerates with the intensification of agriculture and other resource extraction and the takeoff of industrialisation, the rates of resource depletion begin to exceed the rates of resource regeneration, and waste generation increases in quantity and toxicity. At higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental regulations, better technology and higher environmental expenditures, result in levelling off and gradual decline of environmental degradation.
>
> Panayotou (1993)

As a result, many economists have argued that if the EKC relationship were to hold true, then economic growth provides a solution (and not a threat) for improving environmental quality. As Beckerman (1992) notes, “the best – and probably the only – way to attain a decent environment in most countries is to become rich.”

Indicators of environmental quality and income:

Before we continue our discussion of the EKC, it is necessary to describe various indicators of *environmental degradation*. The most common are pollutants that are by-products of economic production and consumption. Examples include air pollutants such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), sulphur dioxide (SO_2), fluorinated gases, volatile organic compounds, as well as suspended particulates like black carbon smoke. Water pollutants, such as nitrates and phosphorous, are also often used.

Other common indicators of water quality are biological oxygen demand and levels of dissolved oxygen. Some studies have also used lack of clean water, lack of urban sanitation, annual deforestation rates, agricultural land fertility, municipal waste, and levels of bacteria in water.

With respect to air and water pollutants, it is important to note that the indicators may be taken as either *emissions* (typically measured in tonnes) or *ambient concentrations* (typically measured in micrograms per cubic metre, or in parts per million). All levels are usually taken as annual measurements, and all are reduced to per capita terms.

Finally, the other variable in the EKC relationship is *income*. It is usually measured by gross domestic product (GDP). It may be adjusted across countries according to either *purchasing power parity* or *market exchange rates* (usually in terms of US dollars for a chosen base year).

Causes and Effects:

We now turn our attention to discuss the economic factors that may be responsible for the EKC relationship between income and environmental degradation. Much of the discussion follows the analysis from David Stern's (2004) paper "The Rise and Fall of the Environmental Kuznets Curve".

Stern (2004) identifies both scale effects and time effects. The *scale effect* describes the growth in pollution and other environmental impacts that would be caused by pure growth in the scale of the economy if we assumed no structural or technological changes in the economy. The *time effects* are independent of income and describe the reduction in environmental impacts observed in countries at all levels of income as time progresses. One possible explanation for the EKC effect, as Stern (2004) suggests, is that middle-income countries experience rapid growth such that the scale effect, with its accompanying increases in environmental degradation, overwhelms the time effect. Conversely, wealthy countries experience slower growth such that the time effect (associated with pollution reduction efforts and improved technologies) overcomes the scale effect.

Stern also identifies both proximate causes and underlying causes that may explain the EKC. The *underlying causes* are those such as environmental regulation, awareness, and education, which influence the EKC only through proximate variables. The *proximate causes* are listed as follows:

- *Scale of production* refers to industrial input-output flow for given factor-input ratios, output mix, and state of technology. Every 1% increase in scale is assumed to increase emissions by 1%, *ceteris paribus*.
- *Pollution intensities* refers to the different output mixes characteristic of different industries. As industries change over the course of economic development – for example, from agriculture to manufacturing to services – the output mix (and emissions per unit of output) changes accordingly. A service industry typically pollutes less than a heavy manufacturing one.
- *Changes in input mix* refers to substitution of inputs that are more environmentally damaging for inputs that are less damaging, and vice versa. Other things equal, this change holds output constant.
- *State of technology*. As technology improves, industries benefit from the increased productivity of existing processes. More output can be produced with fewer inputs.

> Lower emissions per unit of output can also be achieved. Alternatively, new technologies may change production processes altogether so that they use less inputs per unit of output and less emissions per unit of output. In the case of deforestation, for example, better scientific knowledge and technology may suggest more replanting, selective cutting, and wood recovery such that less deforestation is required per unit of wood produced.

As mentioned, any observed changes in the level of pollution must be caused by changes in the proximate variables. However, it must be noted that those changes in proximate variables may be driven by corresponding changes in underlying variables. For example, over the course of economic development, preferences and cultural changes may induce corresponding changes in proximate variables that result in reduced emissions.

Econometric structure:

As the EKC is essentially an empirical phenomenon, an econometric approach is necessary to describe and test the relationship using our observations. The most basic EKC regression equation is given by

$$\ln E_{it} = \gamma + F_i + K_t + \delta \ln Y_{it} + \phi (\ln Y_{it})^2 + \varepsilon_{it} \qquad (1)$$

where E is emissions per capita; Y is income per capita; F represents country-specific effects; K represents time-specific effects; ε is the random error; γ, δ, and ϕ, are regression parameters; and i and t are country and time indicators, respectively. The logarithm of Y is used to model the relationship in order to impose the restriction that the indicators be positive, i.e. $Y > 0$ and $E > 0$. Since the logarithm is a strictly monotone increasing function, the value of Y at which E is maximized is the same value at which ln E is maximized. Thus, the value of income Y at which the indicator for environmental degradation E is at a maximum is given by

$$Y^* = \exp(-\delta/(2\phi))$$

This is the so-called ‘turning point’ of the environmental Kuznets curve – the income level up to which emissions are increasing and beyond which emissions decline. Implicit in the EKC equation is the assumption that the income elasticity is constant across countries at a given income level, even though emissions per capita may vary across countries at any particular income level.

The above model is usually estimated using panel data, i.e. pooled cross-sectional time-series data. The cross-sectional units, indicated by the subscript i, are typically countries or regions. The subscript t indicates the time period, usually the calendar year. The term K_t in equation (1) above is used to account for possible time-varying omitted variables and stochastic shocks that are experienced by all countries. The model itself is most often estimated using either fixed-effects or random-effects. In the *fixed-effects* model, the terms F_i and K_t are treated as regression parameters. The *random-effects* model, on the other hand, considers F_i and K_t as components of the random disturbance ε_{it}. As Stern (2004) points out, in general, the fixed-effects model can be estimated consistently. We can use a Hausman test to compare the slope parameters calculated by both the fixed-effects and random-effects models. If the difference is statistically significant, then the random-effects model is estimated inconsistently because of the correlation between the explanatory variables and the error ε_{it}.

Even though the fixed-effects model can be estimated consistently, an important point to keep in mind is that the parameters estimated are conditional on the country and year in the data sample. Consequently, it would be inappropriate to use our estimated model to extrapolate to other samples of data. In particular, if only developed country data are used to estimate our fixed-effects model, then it may not be of much use to describe the future behaviour of developing countries (Stern, 2004).

Although many environmental economists take the EKC as a stylized fact, the question of whether the relationship can be generalized for all classes of pollutants and measurements is a matter to be tested. According to Stern (2004), the EKC may be valid for local *concentrations* of certain pollutants. However, recent evidence suggests that the relationship for *emissions* may well be monotonic. In such a case, the inverted U-shaped curve would not be a desirable property for the econometric model.

Findings from previous studies:

Many early studies indicate that the inverted U-shape of the EKC is a property more characteristic of local pollutants rather than global ones (Stern, 2004). As theory suggests, local impacts affect individual regions internally and will likely encourage environmental policies to correct for them before they are applied to global problems.

With respect to the measures of environmental degradation and income, Stern *et al.* (1996) found higher turning points for the EKC when purchasing power parity adjusted income was used instead of market exchange rates and when emissions of pollutants were used instead of ambient concentrations in urban areas. In other words, using ambient concentrations of pollutants will likely produce an EKC relationship with a more evident and narrower inverted U-shape. One possible explanation for why ambient concentrations may increase and decrease more quickly with income is that in the early stages of economic development industrial activity is usually concentrated in small areas with high population densities. With further economic development, industries tend to spread outward and cities' high population densities gradually decrease through the process of suburbanization (Stern, 2004). These observations are consistent with Selden and Song's (1994) study in which they used panel data from developed countries to estimate EKCs for four different air pollutants. They found that the turning point in the EKC for emissions was higher than that for ambient concentrations. Furthermore, as Stern (2004) points out, "it is possible for peak ambient pollution concentrations to fall as income rises even if total national emissions are rising."

Another influential EKC study is Grossman and Krueger's (1991) study on the potential effects of NAFTA. They used a panel data set of ambient concentrations from several cities around the world. The pollutants measured were SO_2, dark matter, and suspended particles. For each one, the per capita concentrations were regressed as a cubic function of purchasing power parity GDP per capita together with various site-related variables, a time trend, and a trade intensity variable. What they found was an N-shaped curve for SO_2 and dark matter with concentrations increasing, decreasing, and then increasing again. The first turning point occurred at around \$4000 – 5000. For income levels over \$10,000 – 15,000, the concentrations of pollutants appeared to increase once again.

Shafik and Bandyopadhyay's (1992) study used a similar analysis to estimate EKCs for different indicators of environmental quality. They concluded that lack of clean water and lack of urban sanitation decrease monotonically with rising income. On the other hand, river quality deteriorated with income. Two of the air pollutants measured seemed to support the EKC hypothesis with both having turning points at income levels in the \$3000 – 4000 range.

However, municipal waste and carbon emissions were found to increase monotonically with increasing income.

Emissions based estimates such as those of Selden and Song's (1994) study used data that is primarily from OECD countries. As a result, the values of income per capita in the sample are fairly high and with relatively small variability among them. According to Stern (2004), using a larger sample that includes data from more low-income countries might result in an EKC turning point that is higher. In fact, Stern and Common (2001) used emissions of sulphur data from the US Department of Energy that covered a large range of income per capita and found the estimated turning point at over $100,000! Stern (2004) claims that more recent studies using larger representative samples show that both sulphur and carbon dioxide emissions increase monotonically with rising income.

Altogether, Stern (2004) suggests that the particular choice of sample used is at least partly responsible for the differences in turning points seen for different pollutants. Comparing various studies, the overall impression is that concentrations of pollutants may exhibit the inverted U-shape, rising and then falling, with the peak (turning point) corresponding to middle-income countries. By contrast, emissions tend to increase monotonically with income.

Weaknesses in the EKC theory:

One of the main criticisms of the EKC theory strikes at the heart of the model itself in that it takes income as the independent variable and environmental degradation as the dependent one. According to Arrow *et al.* (1995) and Stern (2004), the model assumes that "environmental damage does not reduce economic activity sufficiently to stop the growth process and that any irreversibility is not so severe that it reduces the level of income in the future" (Stern, 2004). In other words, income is taken as exogenous and there is assumed to be no feedback from environmental damage to economic production. In short, the EKC model assumes that the economy is sustainable. However, if environmental damage erodes the productivity of an economy, then persistent growth – particularly in the early stages of development – may turn out to be 'uneconomic'.

Another common weakness of most early EKC literature is its failure to consider the relationships between different pollutants and the possible substitution of one for the other. Over the course of economic development, new technologies often alter industrial processes by changing the composition of inputs and outputs. Therefore, it is possible for one pollutant to be gradually replaced by another. While the former may possess the inverted U characteristic over the course of economic growth, the latter may not. As a result, the efforts to reduce some impacts may worsen others (Stern, 2004).

Finally, another argument suggests that if there is an apparent EKC relationship between income and pollution, it may be due to the effects of trade on the distribution of polluting industries around the world (Stern, 2004). There are at least two possible explanations for this phenomenon:

- First, as trade theory suggests, countries tend to specialize "in the production of goods that are intensive in the factors that they are endowed with in relative abundance" (Stern, 2004). Consequently, developing countries would specialize in activities such as harvesting, processing raw materials, and heavy manufacturing that are intensive in labour and natural resources. Meanwhile, the developed countries would specialize in services and lighter manufacturing which are intensive in human capital and physical capital already in place. The low levels of environmental degradation experienced by high-income countries and the corresponding higher levels in middle-income countries may result from such specializations (Stern, 2004).

- Second, environmental regulations in developed countries may encourage polluting industries to relocate their activities to developing countries (Stern, 2004). This redistribution of polluting activities may explain the apparent shape of the EKC. Since we live in a finite world with a limited number of countries and regions, as poor countries become wealthy they will eventually be "unable to find further countries from which to import resource intensive products" (Stern, 2004). As a result, if these countries wish to introduce similar environmental regulations as the developed countries, they would have no choice but to abate polluting activities rather than outsource them (Arrow *et al*., 1995).

We will look at the effects of trade more closely in the next section.

Trade and the Pollution Haven Hypothesis

We now turn to examine the extent to which trade and industry may explain the relationship between per capita income and pollution in the environmental Kuznets curve. In principle, it is possible for high income economies to specialize in the production of 'clean' goods and services while low (or middle) income economies specialize in the production of 'dirty' ones. The result would be that high income economies would experience a reduction in per capita pollution even though they are relying and depending on products originating in lower income economies. This effect is known as the *pollution haven hypothesis (PHH)*. The most important consequence of this phenomenon is that the EKC would imply not an overall reduction in pollution but rather a transfer of pollution from high income countries to lower income ones.

The relationship between trade and the environment may be described by three independent effects (Grossman and Krueger, 1991; Cole, 2004).

- The *scale effect* describes the likely increase in pollution caused by economic growth resulting from increased market access due to trade.
- The *technique effect* refers to a change in the production process that may result from free trade. These may be induced by a demand for greater environmental regulations and the adoption of more environmentally-friendly production technologies.
- The *composition effect* refers to changes in the composition of an economy that may result from trade as countries increasingly specialize in production for which they have a comparative advantage.

The composition effect is the one that is most relevant to the environmental Kuznets curve and serves as the mechanism through which the PHH would affect pollution.

Historically, as industrial economies have developed, there has been a change in composition from heavy industry towards lighter manufacturing and services. Developing economies, on the other hand, have become more specialized in the heavy industrial sectors (Cole, 2004). These structural changes may be captured by including the ratio of manufactured exports to domestic manufacturing production as an independent variable in the EKC. Similarly, this ratio may be calculated using imports instead of exports. If we find that the export ratio has a positive relationship with pollution, or that the import one has a negative relationship, then it may count as evidence in support of the PHH, in which case some countries specialize in the production of ‘dirty’ goods while others specialize in ‘clean’ goods (Stern, 2004). Furthermore, if these structural changes also coincide with the middle-income countries taking on dirty production and high-income countries specializing in clean products, then it may explain the inverted U relationship of the EKC. Thus, the claim that economic growth provides a ‘cure’ for environmental problems would be seriously undermined because as income increases, developed countries would simply export their ‘dirty’ industries to middle-income developing countries. If this is indeed the case, then there will come a time when developing countries have no one on whom to pass their pollution-intensive industries. It would be impossible for them to follow the same pollution-income path that today’s developed economies have been able to experience.

If it is true that countries specialize according to their relative abundance of factors of production, then we would expect the developed (high-income) countries to increase its specialization in capital intensive industries while the developing (low and middle-income) countries specialize in labour intensive ones. Capital intensive sectors are usually more pollution-intensive than the labour intensive ones. Nevertheless, previous studies have suggested that the capital intensive sectors tend to be dirtier than the labour intensive ones (Cole, 2004). Under this line of reasoning, it would not be at all obvious that factor abundance explains the shape of the EKC.

One explanation of why pollution havens may exist in the first place is the possible difference in environmental regulations between developed (high income) and developing (low to middle income) countries. As the developed world implements more stringent environmental regulations and the costs of complying with them increases, industrial activities that are pollution-intensive may relocate to developing countries that have fewer regulations. In other words, “developing countries may have a comparative advantage in pollution-intensive production.” (Cole 2004)

However, the evidence for low-regulation pollution havens is somewhat mixed. Some studies find no evidence, whereas others find evidence for temporary pollution havens. Mani and Wheeler (1998) support this last theory with their analysis of dirty industries’ import-export ratios. Also, Lucas et al. (1992), and Birdsall and Wheeler (1993) suggest that an increase in pollution intensity in developing countries corresponds to periods of tougher OECD environmental regulations. Other studies, such as Antweiler et al. (2001), analyzed how the concentration of sulfur dioxide at city level was impacted by trade liberalization, as evidence of “pollution haven pressures.” Adding to the mixed findings, contradicting studies show, at one end, evidence that trade patterns are influenced by regulations (Van Beers and Van den Bergh, 1997) and at the other end, that this evidence is not accurate when the studies include fixed effects (Harris et. al, 2002). Furthermore, some analysts–such as Ederington and Minier (2003), and Levinson and Taylor (2002)—focus on endogeneity arguments, stating that the environmental regulations influence trade patterns in the US, only when they are considered an endogenous variable, and therefore they are only “secondary barriers.”

The search for an interpretation of the lack of substantial evidence of pollution havens, in spite of the theoretical expectations, include arguments related to the real cost of environmental compliance. Indeed, even though significant in absolute values, these costs amount to a small percentage (2% or less) of the total costs of the industry, reducing the disadvantaged competitiveness in highly regulated countries to an insignificant factor (Walter, 1973, 1982; Tobey, 1990; Dean, 1991). Other approaches to explain the small evidence in favour of the pollution havens theory and the relocation of industries include the dependence of heavy industries on home markets, and the factors of unreliable regulations that deter foreign investment. Besides, the pollution intensive production has not seen a reduction in absolute terms, even though its share of GDP shows a decrease.

Thus, in the context of PHH, it is important to evaluate the role of consumption in the specialization patterns of net exports. Then, the increase of net exports in pollution intensive sectors in developing countries could be the result of an increase in their domestic consumption of ‘dirty’ products. Therefore, net exports need to be analyzed as a proportion of consumption, for trade of ‘dirty’ output for a developed country with a developing one (Cole 2004). This evaluation would show a reduction in specialization in relation to consumption in a developed country, and the consequent assumption that the developing countries are supplying the demand for pollution-intensive products. When the specialization patterns for ‘dirty’ products are compared between developed and developing regions over time, there is indication of falling NETXC during specific periods and between particular trading countries, supporting the PHH theory. However, this decrease in NETXC was also seen in many ‘clean’ industries, when observing their specialization patterns comparing developed and developing trading regions. Consequently, these findings imply that the different environmental regulations and compliance between developed and developing countries are not the only factors to be considered.

Estimating EKCs

In order to include all the considerations studied in the previous analyses of EKC, and overcome many of their contradicting arguments, Cole (2004) estimates the following EKC model:

$$\ln E_{it} = \gamma + F_i + K_t + \delta (\ln Y_{it}) + \phi (\ln Y_{it})^2 + \psi (\ln Y_{it})^3 + \sigma (\ln M_{it}) + \lambda (\ln DX_{it}) + \theta (\ln DM_{it}) + \eta (\ln T_{it}) + \varepsilon_{it} \qquad (2)$$

where E is the pollutant, F is the country specific effects, K is the year specific effects, Y is the per capita income, M is the share of manufacturing in GNP, DX is the share of ‘dirty’ exports to non OECD countries in total exports, DM is the share of ‘dirty’ imports from non-OECD countries in total imports, T is the trade intensity; i is the country, and t is the year.

This equation is estimated for a group of ten air and water pollutants for selected OECD countries, between 1980 and 1997, including the share of manufacturing in GNP, as well as the share of pollution intensive exports and imports, from and to, non-OECD countries (in total exports and imports) to test for pollution haven effects. The PHH theory would indicate a decline in the share of ‘dirty’ exports (in total exports), and an increase in the share of ‘dirty’ imports (in total imports) in developed countries. Trade intensity (the ratio of the sum of imports and exports to GNP) may show a positive or negative relation to pollution emissions.

The many complexities of the PHH are explained by this equation: (1) it clarifies the importance of trade and PHH in the EKC relationship; (2) it tests the “null of exogeneity” of current income, agreeing that there is no simultaneity bias; (3) it verifies the presence of heteroscedasticity and autocorrelation using a “generalised least squares” procedure; (4) to allow the possibility of an N-shape curve, it includes a “cubic income term” (or a quadratic equation when the cubic term is not significant); (5) by estimating the equation in logs, it prevents the dependent variable becoming zero; (6) by estimating EKC for numerous indicators, it tests its weaknesses.

When analysing the estimated results for the air pollutants and the water quality indicators, the World Bank data of various per capita incomes was used to observe the turning points in context (Cole 2004). For almost all the indicators at significant levels, there is an inverted U-shape relationship with per capita income, and there is no indication of an N-shape relationship between per capita income and emissions. In other words, when incomes rise at high levels, emissions are not increased. Also, the manufacturing share of GNP shows a positive relationship with environmental quality, indicating that there is a correlation between structural changes within the economies and the reduction in ‘dirty’ emissions at high levels of income.

Most of the observations of PHH show mixed evidence when considering the share of ‘dirty’ exports in total exports, and the share of ‘dirty’ goods in total imports. Indeed, while there are indications that the imports from the developing world replace the domestic manufacturing of intensive-pollution products, the share of ‘dirty’ exports to the developing countries has a positive impact on environmental quality.

Therefore, these findings cannot fully support the statement that the transfer of ‘dirty’ industry to developing countries has an impact on pollution, and the economic significance is low.

Some interesting points are drawn from the analysis of the variables of the equation: (1) the basic EKC may indicate pollution haven effects that contribute to the reduction in emissions at higher income levels; (2) there is a positive relationship between trade openness and environmental quality for OECD countries; (3) there is an improvement in environmental quality over time due to various factors, such as regulations, technology, efficiency, and education.

The study of the effect of trade through pollution haven effects and structural change on the EKC relationship carried by Cole (2004) sheds some light on the following issues: although pollution havens form temporarily and limitedly in some specific regions and sectors, they may have an effect on pollution emissions. By analyzing the significance played by income, trade openness, structural changes and ‘dirty’ trade between developed and developing regions on air and water pollutants, there is indication that there is a relationship between each pollutant and the per capita income. Also, environmental quality and emissions are partially connected to the share of pollution intensive imports and exports between OECD and non-OECD countries, albeit not for all pollutants nor with a significant economic impact.

The study of EKC shows two important conclusions. First, the share of manufacturing output in GDP has an importantly positive relationship with pollution. Second, trade openness indicates a negative relationship with pollution, when controlling structural change, income and PPH effects. Thus, the reduction in emissions at high levels of income could be attributed to more rigorous environmental regulations, trade openness, structural change to reduce the share of manufacturing output, increase in imports of pollution-intensive goods. (Cole 2004)

It is still not clear which will be the future behaviour in the demand in the developing world for manufactured products as a share of GDP. Therefore, unless the income elasticity of demand for manufactured products drops with income, the decrease in manufacturing share of GDP in the developed world can only be explained so far by the transferring of manufacture to the developing world, which will have no escape from this pollution-intensive activity.

Estimating an EKC

We now turn to estimating an environmental Kuznets curve in a similar fashion to Cole (2004). Using the World Bank's "DataBank: World Development Indicators," we obtain information for 214 countries (from Afghanistan to Zimbabwe) for each year from 1960 to 2013 and organize it in a cross-sectional time-series (panel data) array. We consider the following variables:

E is carbon dioxide (CO_2) emissions (metric tons per capita); Y is GDP per capita (2013 US dollars); M is manufacturing product as a percentage of GDP; MI is manufacturing imports as a percentage of total imports; MX is manufacturing exports as a percentage of total exports; T is trade as a percentage of GDP. We then transform each of these variables by taking the logarithm of each, denoting the new variables with lower case letters:

$e = \log E$

$y = \log Y$

$m = \log M$

$mi = \log MI$

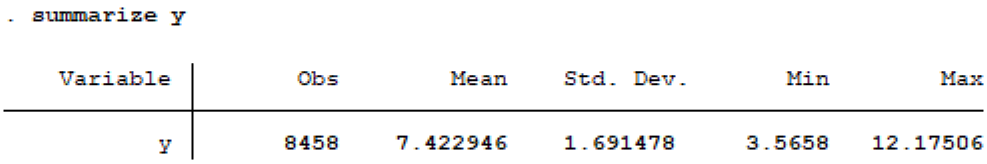
$mx = \log MX$

$t = \log T$

We will estimate four models in total: a simple quadratic, an expanded quadratic, a simple cubic, and an expanded cubic. (The models are quadratic or cubic in income.) The indices i and n will indicate country and time (year), respectively. (Note that the variable t has been reserved for trade.) The fixed effects models are estimated in Stata using ordinary least squares (OLS) linear regression with panel corrected standard errors to account for heteroskedasticity and contemporaneous correlation of errors across countries. The variables F_i are the country specific effects, K_n the year specific effects, and ε_{in} the errors. Parameters $\gamma, \delta, \phi, \psi, \sigma, \lambda, \theta,$ and η are those calculated from the data.

The purpose of the quadratic models is to explore the hypothesis that the relationship between *e* and *y* is that of an inverted U-shape. In other words, that increasing income causes an increase in emissions up to a point, past which further increases in income bring a decrease in emissions. This is the premise of the environmental Kuznets curve (EKC). The cubic model allows for the possibility that emissions may begin to increase again at high income levels (i.e. that the EKC may actually be an N-shaped curve). In each case, a simple and expanded version of the model is considered in order to observe any differences in the turning point (income level at which emissions begin to decrease). The variables *m*, *mi*, *mx,* and *t* are included in each expanded model to indicate the extent to which manufacturing and trade may affect pollution.

We first note the summary statistics for the variable *y*.



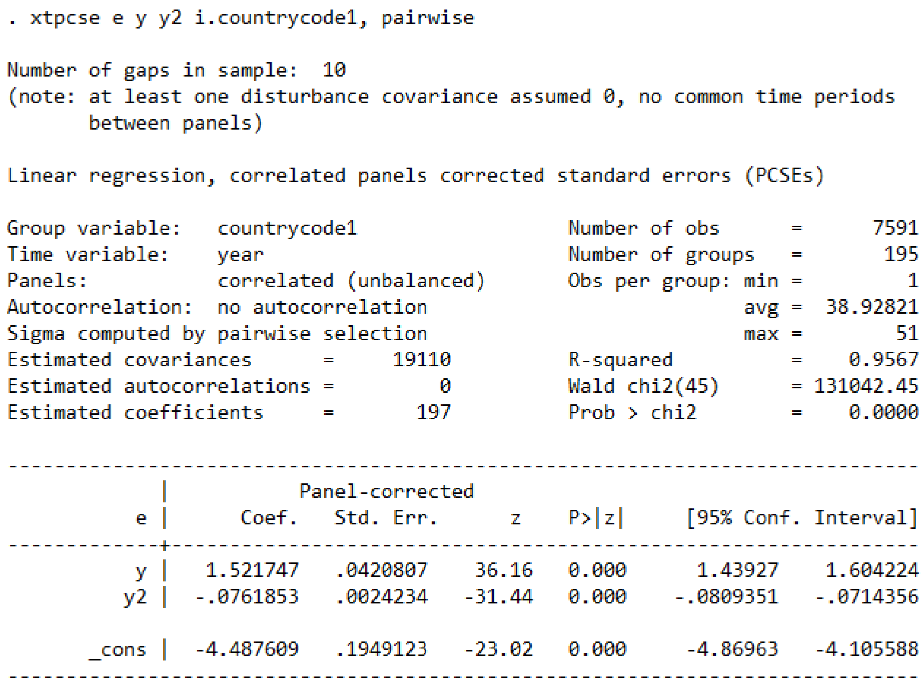
```
. summarize y

    Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
           y |      8458    7.422946    1.691478     3.5658   12.17506
```

Table 1. Summary statistics for *y*

Now we estimate the simple quadratic EKC model given by the equation

$$e_{in} = \gamma + F_i + K_n + \delta\,(y_{in}) + \phi\,(y_{in})^2 + \varepsilon_{in} \qquad \text{(A1)}$$

The output in Stata is as follows.



```
. xtpcse e y y2 i.countrycode1, pairwise

Number of gaps in sample:  10
(note: at least one disturbance covariance assumed 0, no common time periods
       between panels)

Linear regression, correlated panels corrected standard errors (PCSEs)

Group variable:   countrycode1                  Number of obs      =      7591
Time variable:    year                          Number of groups   =       195
Panels:           correlated (unbalanced)       Obs per group: min =         1
Autocorrelation:  no autocorrelation                           avg =  38.92821
Sigma computed by pairwise selection                           max =        51
Estimated covariances      =     19110          R-squared          =    0.9567
Estimated autocorrelations =         0          Wald chi2(45)      = 131042.45
Estimated coefficients     =       197          Prob > chi2        =    0.0000

------------------------------------------------------------------------------
             |           Panel-corrected
           e |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           y |   1.521747   .0420807    36.16   0.000      1.43927    1.604224
          y2 |  -.0761853   .0024234   -31.44   0.000    -.0809351   -.0714356

       _cons |  -4.487609   .1949123   -23.02   0.000     -4.86963   -4.105588
------------------------------------------------------------------------------
```

Table A1

The parameters calculated for equation (A1), including the constant term, are

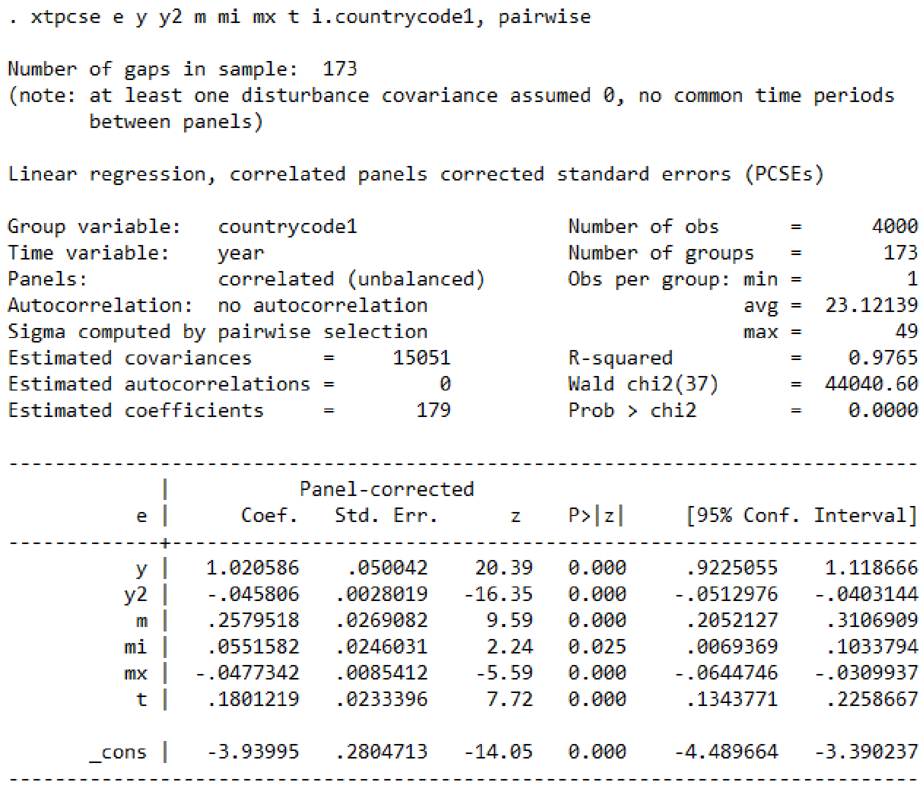
$$\hat{\gamma} = -4.487609, \ \hat{\delta} = 1.521747, \ \hat{\phi} = -0.0761853$$

The individual *p*-values of these parameters together with the Wald test suggest the coefficients are statistically significant.

Next, we test an expanded quadratic model that incorporates manufacturing production, imports and exports of manufacturing, and trade. Our equation is

$$e_{in} = \gamma + F_i + K_n + \delta\,(y_{in}) + \phi\,(y_{in})^2 + \sigma(m)_{in} + \lambda(mi)_{in} + \theta(mx)_{in} + \eta(t)_{in} + \varepsilon_{in} \qquad \text{(A2)}$$

We obtain the following output from Stata.



```
. xtpcse e y y2 m mi mx t i.countrycode1, pairwise

Number of gaps in sample:  173
(note: at least one disturbance covariance assumed 0, no common time periods
       between panels)

Linear regression, correlated panels corrected standard errors (PCSEs)

Group variable:    countrycode1                 Number of obs      =      4000
Time variable:     year                         Number of groups   =       173
Panels:            correlated (unbalanced)      Obs per group: min =         1
Autocorrelation:   no autocorrelation                          avg =  23.12139
Sigma computed by pairwise selection                           max =        49
Estimated covariances      =     15051          R-squared          =    0.9765
Estimated autocorrelations =         0          Wald chi2(37)      =  44040.60
Estimated coefficients     =       179          Prob > chi2        =    0.0000

------------------------------------------------------------------------------
             |           Panel-corrected
           e |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           y |   1.020586    .050042    20.39   0.000     .9225055    1.118666
          y2 |   -.045806   .0028019   -16.35   0.000    -.0512976   -.0403144
           m |   .2579518   .0269082     9.59   0.000     .2052127    .3106909
          mi |   .0551582   .0246031     2.24   0.025     .0069369    .1033794
          mx |  -.0477342   .0085412    -5.59   0.000    -.0644746   -.0309937
           t |   .1801219   .0233396     7.72   0.000     .1343771    .2258667

       _cons |   -3.93995   .2804713   -14.05   0.000    -4.489664   -3.390237
------------------------------------------------------------------------------
```

Table A2

The coefficients estimated are

$$\hat{\gamma} = -3.93995, \qquad \hat{\delta} = 1.020586, \qquad \hat{\phi} = -.045806, \qquad \hat{\sigma} = 0.2579518,$$

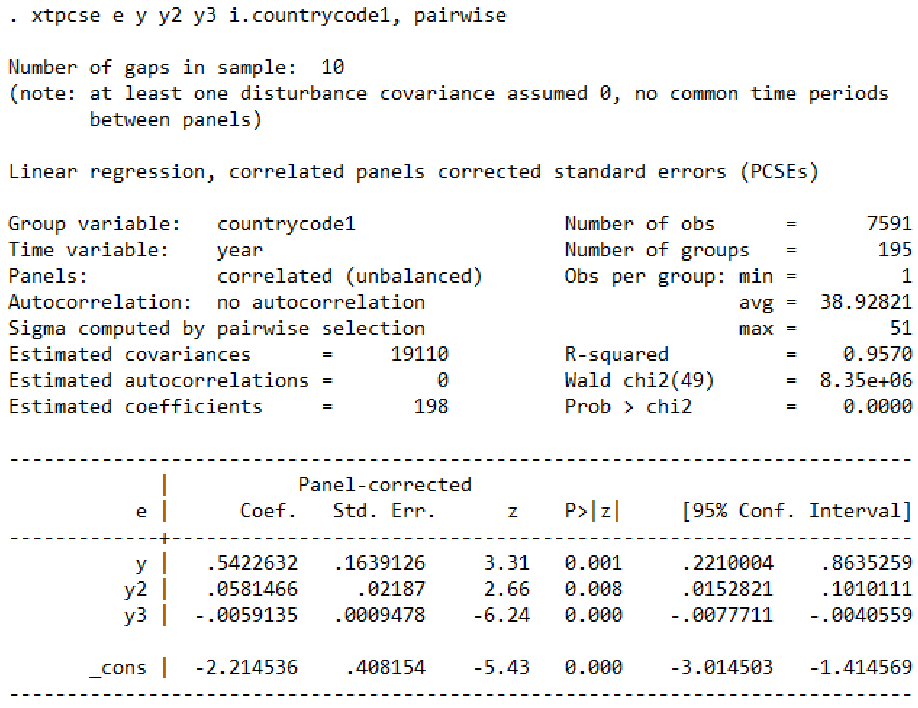
$$\hat{\lambda} = .0551582, \qquad \hat{\theta} = -0.0477342, \qquad \hat{\eta} = 0.1801219$$

The *p*-values and Wald statistic again suggest that these coefficients are significant.

We repeat the procedure, except this time we consider a cubic model of the EKC. We first estimate the simple cubic.

$$e_{in} = \gamma + F_i + K_n + \delta\,(y_{in}) + \phi\,(y_{in})^2 + \psi(y_{in})^3 + \varepsilon_{in} \qquad \text{(B1)}$$

The Stata output is given here:



```
. xtpcse e y y2 y3 i.countrycode1, pairwise

Number of gaps in sample:  10
(note: at least one disturbance covariance assumed 0, no common time periods
       between panels)

Linear regression, correlated panels corrected standard errors (PCSEs)

Group variable:   countrycode1                  Number of obs      =      7591
Time variable:    year                          Number of groups   =       195
Panels:           correlated (unbalanced)       Obs per group: min =         1
Autocorrelation:  no autocorrelation                           avg =  38.92821
Sigma computed by pairwise selection                           max =        51
Estimated covariances      =     19110          R-squared          =    0.9570
Estimated autocorrelations =         0          Wald chi2(49)      =  8.35e+06
Estimated coefficients     =       198          Prob > chi2        =    0.0000

------------------------------------------------------------------------------
             |           Panel-corrected
           e |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           y |   .5422632   .1639126     3.31   0.001     .2210004    .8635259
          y2 |   .0581466     .02187     2.66   0.008     .0152821    .1010111
          y3 |  -.0059135   .0009478    -6.24   0.000    -.0077711   -.0040559

       _cons |  -2.214536    .408154    -5.43   0.000    -3.014503   -1.414569
------------------------------------------------------------------------------
```

Table B1

The coefficients estimated are

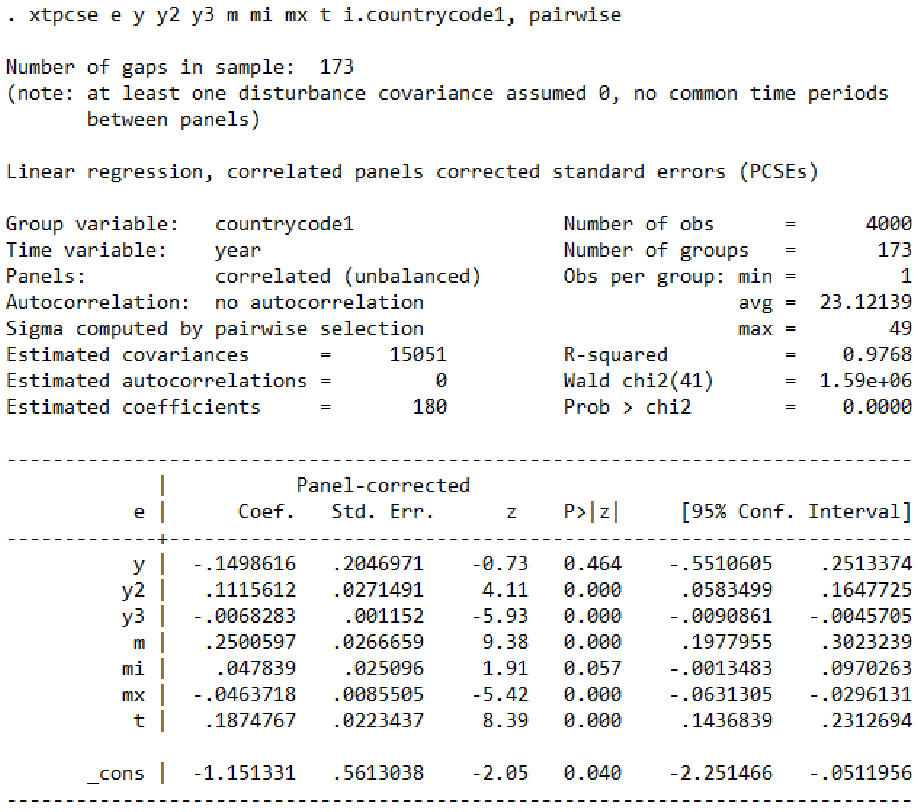
$$\hat{\gamma} = -2.214536, \qquad \hat{\delta} = 0.5422632, \qquad \hat{\phi} = 0.0581466, \qquad \hat{\psi} = -0.0059135$$

The *p*-values and Wald test suggest they are statistically significant.

Finally, we perform an estimate of the expanded cubic model given by the equation

$$e_{in} = \gamma + F_i + K_n + \delta\,(y_{in}) + \phi\,(y_{in})^2 + \psi(y_{in})^3 + \sigma(m)_{in} + \lambda(mi)_{in} + \theta(mx)_{in} + \eta(t)_{in} + \varepsilon_{in}$$

The results from Stata are given as follows.



```
. xtpcse e y y2 y3 m mi mx t i.countrycode1, pairwise

Number of gaps in sample:  173
(note: at least one disturbance covariance assumed 0, no common time periods
       between panels)

Linear regression, correlated panels corrected standard errors (PCSEs)

Group variable:   countrycode1                  Number of obs      =      4000
Time variable:    year                          Number of groups   =       173
Panels:           correlated (unbalanced)       Obs per group: min =         1
Autocorrelation:  no autocorrelation                           avg =  23.12139
Sigma computed by pairwise selection                           max =        49
Estimated covariances      =     15051          R-squared          =    0.9768
Estimated autocorrelations =         0          Wald chi2(41)      =  1.59e+06
Estimated coefficients     =       180          Prob > chi2        =    0.0000

------------------------------------------------------------------------------
             |           Panel-corrected
           e |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           y |  -.1498616   .2046971    -0.73   0.464    -.5510605    .2513374
          y2 |   .1115612   .0271491     4.11   0.000     .0583499    .1647725
          y3 |  -.0068283    .001152    -5.93   0.000    -.0090861   -.0045705
           m |   .2500597   .0266659     9.38   0.000     .1977955    .3023239
          mi |    .047839    .025096     1.91   0.057    -.0013483    .0970263
          mx |  -.0463718   .0085505    -5.42   0.000    -.0631305   -.0296131
           t |   .1874767   .0223437     8.39   0.000     .1436839    .2312694

       _cons |  -1.151331   .5613038    -2.05   0.040    -2.251466   -.0511956
------------------------------------------------------------------------------
```

Table B2

The parameters are given by

$$\hat{\gamma} = -1.151331\,, \qquad \hat{\delta} = -0.1498616, \qquad \hat{\phi} = 0.1115612\,, \qquad \hat{\psi} = -0.0068283,$$

$$\hat{\sigma} = 0.2500597\,, \qquad \hat{\lambda} = 0.047839, \qquad \hat{\theta} = -0.0463718\,,$$

$$\hat{\eta} = 0.1874767$$

We can see from the table that the *p*-value for the coefficient of the y term is quite large. However, since the coefficients for the y^2 and y^3 terms appear statistically significant, we keep all three in the following analysis. All the other coefficients, together with the Wald test, suggest that the model is robust.

Analysis

What we wish to examine next is how the turning point of the EKC in the *ye*-plane is affected by the additional explanatory variables *m*, *mi*, *mx*, and *t*.

We begin with the quadratic model. The turning point for both equations (A1) and (A2) is given by

$$y^* = -\frac{\delta}{2\phi}$$

Using the parameters calculated in Tables A1 and A2, we find that the turning points are

$$y^*_{\text{simple}} = 9.98714 \qquad \text{and} \qquad y^*_{\text{expanded}} = 11.14031$$

for models A1 and A2, respectively. We may see the differences between these two quadratic models in the following figure.

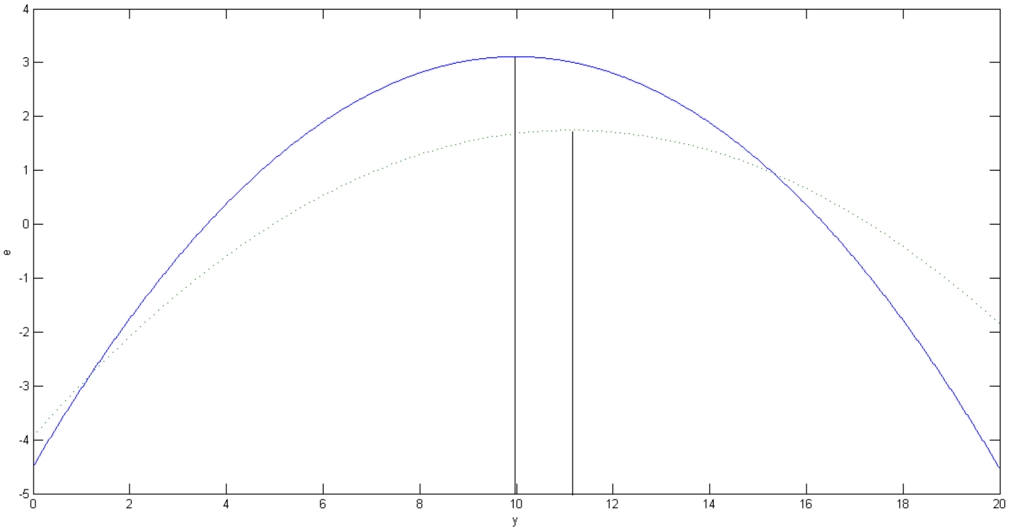


Figure 2. Quadratic models and their turning points. Simple model in solid line; expanded model in dotted line.

Recalling that $y = \ln Y$, we determine that these turning points correspond to per capita GDP of \$21,745 and \$68,893 (in 2013 US dollars), respectively for the simple and expanded models.

Similarly, for the cubic models (B1) and (B2), the turning points are given by

$$y^* = \frac{-2\phi - \sqrt{4\phi^2 - 12\delta\psi}}{6\psi}$$

Using the parameters calculated, the turning points are

$y^*_{\text{simple}} = 9.70484$ and $y^*_{\text{expanded}} = 10.17291$

for models (B1) and (B2), respectively. The following figure shows the fitted curves for the two models and their turning points. These values correspond to per capita GDP of \$16,397 and \$26,184.

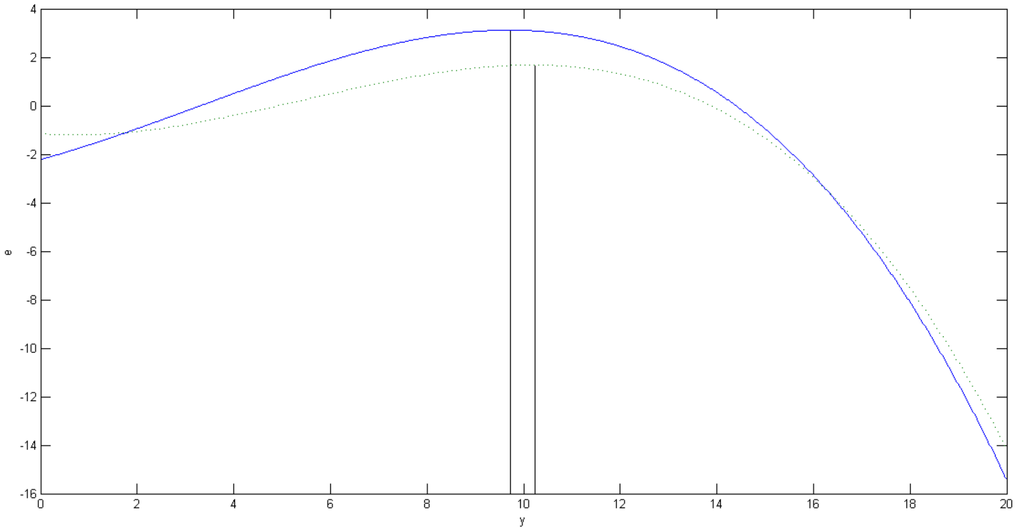


Figure 3. Cubic models and their turning points. Simple model in solid line; expanded model in dotted line.

Mathematically, each of these cubic models ought to have *two* turning points. Since the lower turning points occur for very small or even negative values of *y*, we ignore them as they are insignificant. We consider only the higher turning points. The results show no considerable evidence of an N-shaped relationship between *y* and *e*.

We do observe in both the quadratic and cubic models that $y^*_{\text{simple}} < y^*_{\text{expanded}}$. This observation lends some evidence to the hypothesis that as the EKC model is expanded by incorporating explanatory variables associated with a potentially “dirty” activity such as manufacturing and the trade of such products, the turning point at which emissions begin to decrease occurs at a higher level of income. As such, it remains *possible* that wealthy countries may simply be outsourcing pollution-intensive production of goods and services to lower income countries, thereby lending some validity to the pollution haven hypothesis (PHH).

Discussion

We have examined evidence for the environmental Kuznets curve (EKC) and the pollution haven hypothesis (PPH). The idea of the EKC appears to be supported by both the quadratic (A1) and cubic (B1) simple models. Indeed, as countries' per capita GDP increases, their per capita emissions of CO_2 increase at first, reach a maximum, and then decrease. We then chose the additional explanatory variables of manufacturing, together with its imports, exports, and overall trade to see if it would capture some of the effects on emissions. We observed in the models (A2) and (B2) that the turning points occurred at higher per capita income levels, certainly not disproving the PHH.

We note that the models were only estimated using only data on emissions of one particular greenhouse gas (CO_2). Furthermore, gross domestic product (GDP) measured in 2013 US dollars was used as the measure of income. It would be interesting to conduct a subsequent investigation of the EKC and PHH using other measures of environmental degradation as well as other measures of GDP (such as purchasing power parity).

To grow or not to grow? That is certainly the underlying question motivating any discussion of the EKC. The significance of the EKC is in giving hope to enthusiasts of economic growth. It suggests that if all nations become wealthy (and therefore developed) enough, we may reap the fruits of high levels of consumption (implicit in the definition of "wealthy") and at the same time enjoy a relatively clean environment. The implication is that *insufficient development* is the cause of environmental degradation.

To further the discussion, we note the result when we consider *global* income per capita and *global* emissions of CO_2 per capita. The variables y and e here denote the logarithms of these two global measures, respectively.

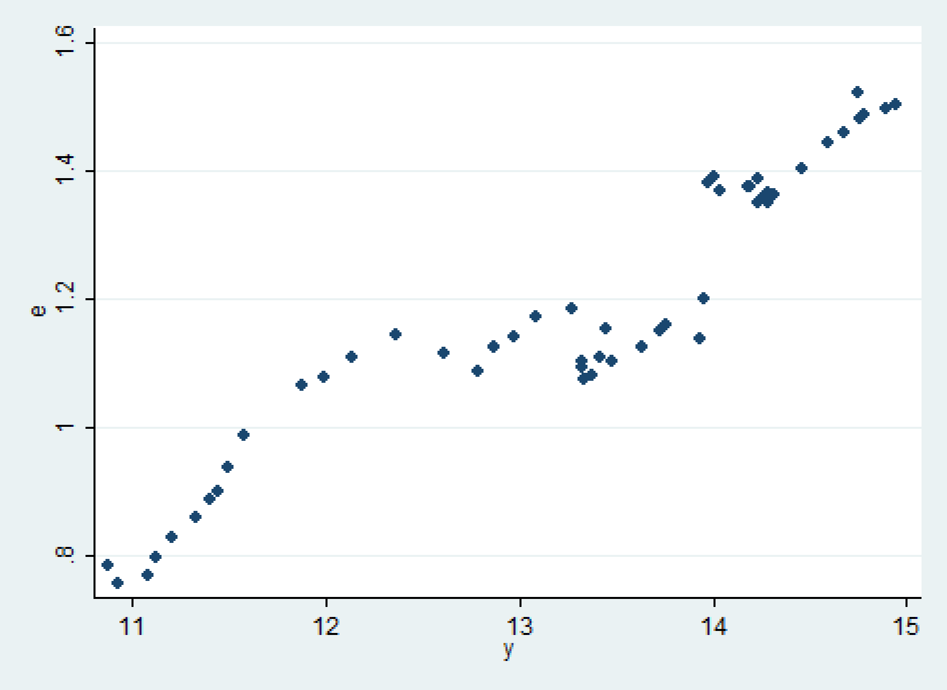


Figure 4. Scatter plot of global CO_2 emissions per capita and global income (GDP) per capita. (In logarithms)

We see from the figure that there is a fairly strong positive correlation between income per capita and emissions per capita when observed at the global level. It would appear that as the *world* gets wealthier, it also gets dirtier. So what is happening here? It has to be said that environmental degradation does not respect national boundaries. Whether we are considering the emissions of a particular greenhouse gas or some other measure, such as deforestation or loss of biodiversity, the degradation affects the *entire* biosphere. We may redraw political boundaries arbitrarily and consider one such region "clean" and another "dirty" but, to the planet, those distinctions are meaningless. If we consider the Earth to be *one system*, the effect of pollution is independent of which arbitrary region (i.e. "country") we associate it with. We may engage in as much environmental gerrymandering as we like, but the relevant measures ought to be *global*. There is nothing in Figure 4 to give hope to the belief that as we continue developing and getting wealthier globally, that we will become *cleaner*. The cross-sectional (country) unit of analysis in the EKC is a rather arbitrary measure. There is no reason to believe that there is any universality to the way societies have drawn their boundaries on a map, let alone that these boundaries are the ones to consider when examining the effect of human activities on a *natural* system like the planet. The EKC's attempt to study a *social* phenomenon (such as economic development and growth) alongside a *natural* phenomenon (such as environmental impact) is quite reductionist. As a result, it is very difficult to draw any meaningful conclusions from such an empirical analysis.

There is also the question of whether GDP is an appropriate measure of human progress and well-being, and whether indefinite economic growth is desirable. The decision to include these measures in defining the EKC is the product of an economic ideology that makes several presumptions – that more material consumption and transactions give us greater freedoms of "choice" and make us "better off" socially. There is a very utilitarian philosophy implicit in the EKC. If economic growth is what we are truly interested in, then the EKC does not really answer the question of whether it can be sustained indefinitely. Different analytic frameworks ought to be explored to consider the matter further. One such framework is considered in Victor's (2008) study, *Managing Without Growth: Slower by Design, Not Disaster*.

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Appendix

Stata commands for generating Tables A1, A2, B1, B2:

File used: master_stata_data_edit.csv

```
generate lco2=log(co2)

generate lgdppercap=log(gdppercap)

generate lgdppercap2=(log(gdppercap))^2

generate lgdppercap3=(log(gdppercap))^3

generate lmanufacturing_percgdp=log(manufacturing_percgdp)

generate
     manuf_imports_perc_total_imports=manuf_imports_perc_merch_i
     mports*merchandise_imports/imports

generate
     manuf_exports_perc_total_exports=manuf_exports_perc_merch_e
     xports*merchandise_exports/exports

generate
     lmanuf_imports_perc_total_imp=log(manuf_imports_perc_total_
     imports)

generate
     lmanuf_exports_perc_total_exp=log(manuf_exports_perc_total_
     exports)

generate ltrade_percgdp=log(trade_percgdp)


generate e=lco2

generate y=lgdppercap

generate y2=lgdppercap2
```

```
generate y3=lgdppercap3
generate m=lmanufacturing_percgdp
generate mi=lmanuf_imports_perc_total_imp
generate mx=lmanuf_exports_perc_total_exp
generate t=ltrade_percgdp
encode countrycode, gen(countrycode1)

xtset countrycode1 year

summarize y

xtpcse e y y2 i.countrycode1, pairwise
xtpcse e y y2 y3 i.countrycode1, pairwise
xtpcse e y y2 m mi mx t i.countrycode1, pairwise
xtpcse e y y2 y3 m mi mx t i.countrycode1, pairwise
```

Stata commands for generating Figure 4:

File used: time_series_aggregate2.csv

```
generate lgdp=log(gdp)
generate lgdppercap=log(gdppercap)
generate lco2=log(co2_total)
```

```
generate lco2_percap=log(co2_percapita)


generate e=lco2_percap

generate y=lgdppercap


scatter e y

twoway(scatter e y)(lfit e y)


reg e y
```