Does the Environmental Kuznets Curve Describe How Individual Countries Behave?

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Abstract

The environmental Kuznets curve (EKC), an inverted-U relationship between pollution and income, is an influential generalization about the way environmental quality changes as a country makes the transition from poverty to relative affluence. The EKC predicts that pollution will first increase, but subsequently decline if income growth proceeds far enough. We examine within-country time series data on air pollution and income for a sample of individual countries to see if this generalized prediction is commonly borne out. The empirical approach employs robust, nonparametric methods and a recently available data set on SO_2, smoke, and particulate air pollution. In most cases examined, the within-country income-pollution patterns we observe do not differ significantly from what would be expected to occur by chance. Where income-pollution relationships are consistent with EKC predictions, the patterns involved are also consistent with a much simpler hypothesis.

1 Introduction

The environmental Kuznets curve (EKC) hypothesis postulates that, as income grows, levels of pollution will initially rise, but subsequently decline if growth proceeds far enough. If true this is a powerful and attractive policy message,

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suggesting that the pursuit of economic growth and a cleaner environment in the same time frame need not work against one another. Instead, growth will eventually lead to greening over time, even if it does not appear to do so immediately. It also establishes the EKC ‘turning point,’ the income level beyond which additional growth causes pollution to decline, as a key policy parameter. Early evidence on the EKC led the World Bank to conclude “economic growth is essential for environmental stewardship” and induced one observer to declare that “the surest way to improve your environment is to become rich.”[1] The EKC phenomenon also seems to agree well with the experience of environmental progress in some of the world’s wealthier nations over the last 50 years. Casual empiricism indicates that environmental quality initially worsened in these countries as their economies grew following World War II, but then improved when environmental cleanup began in earnest in during the 1970s.

The initial literature on the EKC was empirical. Although empirical results vary for different pollutants and specifications, the inverted-U relationship between pollution and income has come to be widely accepted. As the environmental Kuznets curve gained credence as a stylized fact, an increasingly complex theoretical literature emerged to explain the mechanisms that might cause income and environmental quality to be linked in this fashion. Since both are clearly endogenous, attention was eventually drawn toward the mechanisms that determine growth and environmental quality and how they relate to one another, particularly in developing countries.

Loosely speaking, the EKC hypothesis predicts that pollution increases with income in low income countries, decreases with income in high income countries, and follows an inverted-U path in middle income countries. In what follows we examine whether or not countries actually behave this way. While our objective is empirical, our approach differs in two respects from the empirical approach most commonly found in the literature. First, we focus attention on *within-country* relationships between pollution and income. We do this because the EKC purports to answer a within-country question: How will a nation’s environmental quality evolve if it makes the transition from poverty to wealth? Despite its focus on within-country predictions, existing empirical support for the inverted-U is based primarily on cross-country variations in income and pollution. Within-country analysis clearly is possible, however, as available pollution data cover periods of substantial economic growth. If the EKC is a strong enough empirical regularity to be used for making policy, it should not be difficult to find examples of countries following its predictions.

Another advantage of the within-country approach is that it minimizes the influence of unobserved factors. The standard fix for dealing with unobserved

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[1] The quotes are from World Bank (1992) and Beckerman (1992), respectively. Bartlett (1994) drew a seemingly perverse conclusion, that environmental protection policy might actually hamper efforts to improve environmental quality if it hinders growth.

heterogeneity is to include fixed effects for countries. This does not allow the parameters in the relationships examined to be country-specific, however. With country fixed-effects the shape of the pollution-income curve will, aside from a shift of the intercept, be invariant to whether a country is a dictatorship or a democracy, or whether it relies on coal vs. hydropower for energy. Indeed, the peak of an inverted-U income-pollution curve occurs at the same income level for all countries under this specification.[2] By contrast, focusing on within-country data allows the shape of the pollution-income relationship to be country-specific. With this approach, one need only control for country attributes that change during the sample period.

The second difference in our empirical approach is that we take care to use income and air pollution data that are matched to one another. The dependent variable in an EKC model is a measure of pollution, e.g., the ambient concentration of airborne SO_2. In the data set relied upon most heavily in the EKC literature, which we examine empirically later, readings on pollution are collected from hundreds of individual monitoring sites in scores of countries. Data from different sites in the same country clearly show that some sites are in dirtier locations than others. Given that pollution varies within countries, is not obvious how income should be measured. Income clearly is the most important *independent* variable in an EKC model and errors in measuring it will lead to biased estimates of an inverted-U curve and its turning point.

Considering the centrally important role of income in the EKC story, the empirical literature has been surprisingly casual about measuring it. The most commonly used income variable is per capita GDP, measured *nationally,* a choice that clearly seems motivated by data availability.[3] A *local income* measure is arguably more closely matched to the pollution data, however. The left-most portion of the EKC is thought to slope up because increased production causes more pollution to be generated—a production scale effect. Because air pollution tends to be concentrated near its source, local output (income) is the appropriate measure of scale. The factors that cause the EKC to bend downward are changes in the composition of output and pollution abatement effort, the ‘composition’ and ‘technique’ effects.[4] Both national and local income levels are arguably important determinants of these effects. National level income is relevant if national governments set air pollution control policy. It is common for affluent communities in a given country to have better air quality than poor communities, however, presumably because local governments can control pollution by

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[2] The natural generalization, interacting income terms with the fixed effects or specific country attributes, has not been the practice in existing empirical work.

[3] Two studies on income-pollution relationships within U.S. jurisdictions have used pollution and income data at the county and census tract level. See, respectively, Carson et al (1997) and Khanna (2002).

[4] Antwiler, Copeland, and Taylor (2000).

controlling land use and local economic activity. In short, both local and national level income belong in the model.

Unfortunately, local income or production measures are generally not available with sufficient coverage to allow consistent econometric analysis across a wide range of countries and income levels. We are thus forced to rely on national level income data. The use of national level income dictates that we examine pollution measures that are also national in scope, i.e., series that capture the national level time pattern of pollution for each country. The method used to derive these national pollution series is explained later.

With time series data on both national income and pollution for a broad set of individual countries, the procedure we use to see if individual countries follow the EKC's predictions is very simple: we plot air pollution against income in as many countries as possible to see if the EKC emerges as a stylized fact. More formally, we test to see if the shapes of within-country pollution-income plots conform to EKC predictions more often than would occur by chance.

We examine three measures of air pollution reported in the GEMS/AIRS (Global Environment Monitoring System/Aerometric Information Retrieval System) data set.[6] This source is a corrected and extended version of the GEMS data set that featured prominently in early work on the EKC. It includes data from 1971-1992, a time frame sufficiently long for significant economic growth and environmental change to occur. This time frame also spans the period in which many governments began to initiate major environmental policies. If the EKC hypothesis describes how individual countries behave, we would expect to find evidence of it in these data.

2 Empirical and Theoretical Work on the EKC

The EKC first emerged in Shafik and Bandyopadhyay's (1992) cross-country analysis of the relationship between income and air and water pollution, deforestation and waste output. They concluded that airborne SO_2 and smoke concentrations began to diminish after an income level of \$3-4,000 per capita was reached. The EKC was also prominent in Grossman and Krueger's (1993) analysis of the environmental implications of NAFTA, which concluded, counter-intuitively, that industrial growth in loosely-regulated Mexico might actually lead to improved environmental quality. In an expanded analysis, Grossman and Krueger (1995) concluded that, for SO_2 and smoke, economic growth first caused

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[5] This procedure largely avoids the potential problem of cross-country heterogeneity. Only those attributes that changed within countries during the sample period are a concern.

[6] Thanks are due to Arik Levinson for making these data available to us. Harbaugh, Levinson, and Wilson (2002) (HLW) explain differences between the GEMS/AIRS data and the earlier GEMS data set. Many observations that were missing in the original GEMS data set have been filled in, duplicate entries have been eliminated, and some original entries have been amended.

environmental degradation, but led to improvements once income reached the \$4,000-\$6,000 range.[7]

Extensions of this purely empirical approach sought to better isolate the income effect by controlling for variables that covary with income and pollution. Panayotou (1997) controlled for industrial structure, to allow for the possibility that production shifts toward cleaner products as income grows. Toras and Boyce (1998) and Barrett and Graddy (2000), seeking to control for determinants of the environmental policy response, included measures of literacy, economic inequality, and civil and political freedoms. In each case, the inverted-U was confirmed using the GEMS data set.[8]

Relatively few empirical studies have sought evidence of the EKC by looking within countries, and fewer still have focused on their behavior over time rather than across regions. De Bruyn (1997) estimated income-pollution relationships for emissions in four OECD nations separately, highlighting the importance of structural changes within countries. The relationships he found took a variety of shapes, including Us and Ns, in addition to the famous inverted-U. Carson *et al* (1997) estimated EKCs for air quality using state level panel data from the United States. They found that most measures of air quality improved monotonically with income over the sample range. Vincent (1997) tested predictions from the EKC literature on a panel of detailed data from Malaysian states. He found that parameters from published empirical models failed to predict the pattern of changes in Malaysian air and water pollution; moreover, none of the Malaysian pollution measures exhibited an EKC at all. Perman and Stern (2003) found that after accounting for the time series properties of sulfur emissions data there was no statistical support for the EKC hypothesis either in the panel or in within-

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[7] Grossman and Krueger (1995) found the same general pattern for additional environmental measures, however the income level at which further growth induced environmental improvements was somewhat higher and some measures behaved differently. They cautioned that this did not imply an automatic reduction in pollution as income rose, but required a policy response, driven by income growth, that eventually outweighed the pollution generation effect of increased output.

[8] Several empirical researchers proceeded down a parallel path, examining pollution *emissions* rather than concentrations. Hilton and Levinson (1998) successfully separated the policy response (pollution per unit output) from the scale effect for lead emissions. They found an EKC with a turning point in the normal range, but it was sensitive to specification and sample period. Selden and Song (1994) examined airborne emissions of SO_2 and particulates in a panel of mostly OECD nations. They found the EKC pattern, but with turning points in the \$8,000-10,000 income range. Selden and Holtz-Eakin (1995) examined CO_2 emissions, an unregulated pollutant at the time, and found no point at which emissions declined with total income. Stern and Common (2001) examined SO_2 emissions and found that the ‘turning point’ exceeds \$100,000, far outside the observed range of per capita income. Stern et al (1996) argued that running a single regression on countries at different stages of development might run afoul of specification bias. Coondoo and Dinda (2002) suggested that the direction and pattern of causality between pollution and income might differ from one group of countries to another. De Bruyn (1997) noted that only 13% of the variation in SO_2 emission targets can be explained by variation in income, suggesting that the focus on income might be misplaced.

country analysis. Overall, within-country empirical analysis has generally failed to find inverted-U relationships for individual countries.[9]

A recent empirical paper by Harbaugh, Levinson and Wilson (2002) (HLW) is particularly important to our analysis for two reasons. First, HLW introduced EKC researchers to the EPA's AIRS data set and showed that its predecessor, the original GEMS data that served as the cornerstone of much EKC empirical work, was fairly inaccurate. Second, HLW's empirical results on EKC relationships were highly sensitive to slight changes in the sample, specification, and estimation method. Overall, HLW found no clear support for the inverted-U relationship in the GEMS/AIRS data.

Given the early popularity of the EKC as a stylized fact, a substantial theoretical literature arose to explain why the relationship between pollution and income might follow an inverted-U.[10] Because our own aims are entirely empirical, we summarize this literature only briefly. Stokey (1998) showed that the inverted-U could emerge from a model in which pollution control effort is not expended until a pollution threshold is crossed. Andreoni and Levinson (2001) demonstrated that an EKC could result from sufficiently strong increasing returns to scale in pollution abatement. Lopez and Mitra (1997) showed how corruption in government, by reducing abatement effort, could affect the shape of the EKC.[11] Copeland and Taylor (2003, Chapter 3) examine four mechanisms that can generate an inverted-U in the context of a single consistent modeling framework, effectively summarizing much of this theoretical work.

A few observations on this received literature will motivate the empirical strategy that follows. First, the most influential empirical work on the EKC hypothesis has been based on the GEMS and GEMS/AIRS datasets, due primarily to their extensive coverage of countries, time periods, and pollutants. Accordingly, we base our empirical analysis on this data set. Second, although the EKC hypothesis is fundamentally a *within-country* story, i.e., a prediction of how a country's pollution will change as it experiences economic growth, empirical support for the inverted-U has come entirely from cross-country data. While pollution readings in the GEMS/AIRS panel data set do vary within-countries over time, this time series variation is small relative to the variation in mean annual pollution readings across countries (or within countries across sites.) The most credible evidence in favor of the EKC as a policy relevant generalization

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[9] In another study Lantz (2002) found a U-shaped relationship between forest clear-cutting and per capita income when looking across Canadian provinces.

[10] Thompson and Strohm (1996) and Stern (1998) among others criticized the purely empirical nature of early work on the EKC hypothesis, arguing that more emphasis on theory was needed to inform the techniques used and the conclusions drawn.

[11] Antweiler, Copeland and Taylor (2001) present a carefully crafted model of pollution generation that separates scale, technique, and output composition effects, and test it using the expanded GEMS data on SO_2. They do not examine the EKC hypothesis directly, however.

would be a demonstration that it describes the experiences of individual countries as they grow. This observation motivates us to look within countries, over time.

3 Pollution and Income Data

We require annual time series observations on income and pollution for individual countries. Because the only reliable income series with sufficient coverage are measured at the national level, our income measure is national—per capita real GDP (1985 dollars) taken from the Penn World Tables. Data on air pollution are median annual concentrations of SO_2, suspended particulates, and smoke (fine particulates) taken from the GEMS/AIRS data set. The GEMS/AIRS data set reports pollution readings for hundreds of individual monitoring sites, often with multiple sites in a country. Within countries, pollution varies across sites with variations in local weather, geography, and economic activity. This source reports data for at least some monitoring sites for each year between 1970 and 1992, which we refer to as the sample period.

Because our income variable is measured nationally, we seek a pollution measure that captures the nationwide time path of pollution in each country. If all monitoring sites in a given country reported data in all years, within-country averages of observations from each site would provide a suitable index of pollution in that country over time. Monitoring sites do not operate continuously, however; some start up part way through the sample period, others cease operation before it ends, and still others operate sporadically.[12] To extract national level pollution series from this data set, we postulate that the pollution reading from site i, in country j, in year t equals a country-specific constant, a_j, plus a country-specific year effect g_{jt}, plus a site-specific term b_{ij} determined by site i's topographic, meteorological, and economic conditions, plus a mean zero error term e_{ijt}. The appropriate nationwide time series for pollution in country j is j's constant (a_j), plus the mean of j's site-specific terms (b_{ij}), plus the national year effects for country j in year t (g_{jt}). These terms can be estimated from the following model:

$$P_{ijt} = a_j + \mathring{a}_i b_{ij} D_{ij} + \mathring{a}_t g_{jt} T_t + e_{ijt},$$

where P_{ijt} is the pollution reading in country j, at monitoring site i, for year t, the D_{ij} are dummy variables for monitoring sites in country j, the T_t are dummy

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[12] For example, Brussels, Belgium reported particulate observations from one monitoring site in 1976-1986 and from another site in 1985 and 1986, and the second site was about 25 percent dirtier than the first. Simply splicing these observations together to get a series for Belgium would give a spurious indication of increasing pollution. For estimation of a parametric model with panel data, a common method of dealing with this composition problem is the inclusion of site-specific fixed effects.

variables for years, and e_{ijt} is a homoskedastic mean zero error term.[13] We also estimate this equation using logs of pollution as the dependent variable, which allows site-specific effects to be proportional rather than additive.

Examining individual countries over time requires data over a span of years long enough for pollution generation and environmental policy responses to occur as income increases. Accordingly, we excluded from further analysis any pollutant-country case that did not have data for at least 10 years. This criterion was met by 25 individual countries for SO_2 pollution, by 14 for particulates, and by 13 for smoke. These within-country pollution series contain 744 observations in total, 379 for SO_2, 183 for particulates, and 182 for smoke. The data cover 28 separate countries and, on average, provide 15.2 annual observations per country for SO_2, 13.1 for particulates, and 14.0 for smoke.

4 Within-country Relationships Between Pollution and GDP

We use a simple, non-parametric approach to examine the relationship between income and air quality in each country. It involves plotting pollution against income and inspecting the shape of the plot to see if it agrees qualitatively with EKC predictions. For each country, observations on per capita GDP and pollution are ordered by per capita GDP and formed into tritiles. There are three tritiles for each country-pollutant combination: they contain the lowest, middle and highest third of income observations, respectively, for the country in question. The mean income and pollution level within each tritile are then computed, yielding three income-pollution points for each country-pollutant combination. We examine the plot of these points to determine if it is consistent or inconsistent with EKC predictions. The income data are three-year lagged averages of per capita GDP, which is intended to allow time for a gradual policy response and which should have the additional effect of smoothing income changes and moderating the effects of short-term business cycle fluctuations.[14]

Grouping the data into income categories and taking means obviously suppresses much of the information in the original series. It has the advantage, however, of allowing clear, robust conclusions to be drawn regarding the shape of the pollution-income relationship. This point is elaborated shortly. Tritiles were chosen rather than, for example, quartiles or quintiles, in part to correspond with the three proposed stages in the income-pollution relationship set out by the EKC hypothesis. More importantly, collapsing the data to three points limits the number of shapes the income-pollution relationship can take and makes minimal

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[13] An alternative approach would be to drop observations from sites that do not report pollution over the entire sample period, and form within-country averages. This has the disadvantage of throwing away information.

[14] The tritile data are reported in Appendix Table A1. The analysis was also performed using log pollution levels and using contemporaneous income. Results were not qualitatively different and are available upon request.

demands on the data to conform to the EKC hypothesis. If a larger number of groups were used, the number of possible patterns for the income-pollution relationship would increase and the fraction of those that are necessarily inconsistent with EKC behavior also would increase.[15] Thus, even if the relationship between pollution and income were random, grouping the data into a smaller set of points will increase the fraction of shapes that are deemed to be EKC-consistent. A minimum of three points is required to trace out an EKC curve and so we use three groups. As we quantify momentarily, the pattern taken by three data points will be judged (potentially) EKC-consistent in a large proportion of cases even if the underlying data are random.

The Predictive Power of the EKC: Descriptive Statistics

The EKC hypothesis predicts that the relationship between pollution and income depends on a country's income level. One must therefore consider the country's income when judging whether or not its behavior is EKC-consistent. We take up this question in some detail in the section on hypothesis testing and derive precise criteria for defining appropriate income categories. This level of detail is not necessary for discussing descriptive statistics, however, so we simply describe countries (somewhat loosely) as having high, low, and middle income in the remainder of this subsection. With this understanding, the EKC hypothesis predicts that pollution will increase monotonically with income in a low-income country, decrease monotonically with income in a high-income country, and exhibit the archetypical inverted-U shape in a 'middle-income' country. We regard each of these three patterns as clearly *consistent* with the EKC hypothesis. We regard the following five patterns as *inconsistent* with the EKC: a monotone decreasing relationship for a poor country, a monotone increasing relationship for a rich country, and a trough, or U-shaped relationship, for a country of any income level. There are four other possibilities: a rich country or a poor country that exhibits a single peak and a middle-income country that displays a monotone increasing or monotone decreasing relationship. Because the position of the EKC peak might be uncertain, these final four patterns may be consistent or

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[15] With three data points, there are four patterns the data can exhibit: monotone increasing, monotone decreasing, a single peak, and a single trough. Considering monotone increasing and monotone decreasing shapes to be single-peaked (with the peak at an end point,) any of these three single peaked curves could be EKC-consistent, depending on a country's income level. Only one shape out of four, the trough which has two peaks, is necessarily inconsistent. With four data points, eight shapes are possible. The four that are single peaked (one monotone increasing, one monotone decreasing, and two with single interior peaks) are potentially EKC-consistent, depending on the income level. Four of the eight shapes have multiple peaks and are necessarily inconsistent with EKC. More generally, the number of distinct shapes that can be observed when the data are summarized by n data points equals 2^{n-1}. The fraction of possible shapes that is necessarily inconsistent with EKC equals $1-n/2^{n-1}$, which increases rapidly as n increases.

inconsistent. This point is considered in some detail in the section on hypothesis testing.

We present descriptive statistics on the shape of within-country pollution-income relationships for each pollutant and each country examined. The countries following each pattern are identified and summary income statistics are provided for each group. Table 1 shows results on sulfur dioxide pollution for the 25 countries reporting SO_2 data. A trough appears in four of the 25 cases, exactly as often as the inverted-U. In 15 of 25 countries SO_2 concentrations decline as income rises. This group as a whole has above average income, which weakly agrees with the EKC hypothesis. However, the decreasing group anomalously includes two poor countries, Egypt and Thailand, and (less anomalously) two middle-income countries, Brazil and Iran. Neither of the two countries for which pollution increases with income is poor, contrary to the EKC prediction; indeed, Japan is one of the world's wealthiest countries.

Some of the countries in Table 1 experienced little economic growth over the sample period, and one might argue that the pollution income relationships displayed by these countries should be given little weight when assessing the predictive power of the EKC hypothesis. To see if this materially affects the results in Table 1, we note that the following nine countries grew less than 20% between bottom and top tritiles: Australia, Brazil, Denmark, India, Ireland, Israel, New Zealand, the Netherlands, and the U.K.[16] If these countries were dropped from Table 1, those that remain would display essentially the same pattern. There would still be equal numbers of countries exhibiting peaks and troughs, three for each. The two countries with anomalously increasing pollution-income relationships, Japan and Venezuela, would remain. The 15 countries that display decreasing pollution with economic growth, which the EKC predicts should be relatively well off, would be reduced by six, but five of the six dropped actually are well off and the sixth is of middle income. If anything, dropping countries with relatively modest economic growth worsens the correspondence between EKC predictions and actual behavior.[17]

Table 2 shows results for 14 countries for total suspended particulates. The most common pattern is a trough, which is never consistent with EKC behavior; it appears three times as often as the inverted-U. The two countries exhibiting an inverted-U, China and Finland, are quite poor and quite wealthy, respectively,

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[16] More detailed income statistics for countries in the sample are presented in Appendix Table A2.

[17] We also examined income-pollution plots for the fastest growing countries, the five countries that grew more than 50% between bottom and top tritiles: Egypt, Hong Kong, Iran, Japan, and Thailand. Considering only these countries, one exhibits a peak (Hong Kong) and none exhibit troughs. However, one rich country (Japan) still displays an increasing pollution-income relationship and the three countries for which pollution decreases as income grows are either poor (Egypt and Thailand) or of middle income (Iran). Restricting attention to only these fast growers, the tally would be three EKC disagreements (Japan, Egypt, and Thailand) and two ambiguous cases (Hong Kong and Iran.)

rather than of middle income as the EKC hypothesis predicts. The one country that exhibits an increasing income-pollution relationship, Denmark, is quite rich; the EKC hypothesis predicts that it should be poor. The group with a decreasing relationship between pollution and income has higher than average income, which agrees with the EKC hypothesis, but it includes two relatively low-income states, Brazil and Thailand. On balance, the correspondence to EKC predictions is poor at best and restricting attention to countries that experienced substantial growth does nothing to improve matters.[18]

Results for smoke, presented in Table 3, also show no obvious agreement with the EKC hypothesis. As with SO_2, we see just as many troughs as peaks. As with particulates, the group for which pollution increases with output is relatively wealthy, not poor as the EKC hypothesis predicts. On the positive side, four of the five countries showing a monotone decrease in pollution as income rises are rich and the remaining nation is of middle income. Overall, the EKC does a poor job of predicting the qualitative response of smoke pollution to economic growth. Dropping countries that grew less than 20% would eliminate roughly equal numbers of anomalies and EKC-consistent cases.[19]

The Potential Impact of European Union (EU) Policy

By the end of the sample period 10 of the 28 countries represented in Tables 1-3 were EU members, and three countries joined during the period studied. This is significant because European Union environmental policies affected the abatement behavior of these countries. In 1980 the EU adopted Directive 80/779/EEC, a requirement that member states harmonize air quality standards for SO_2 and *particulates* in urban areas. It directed EU members to uphold domestic laws consistent with the 'environmental acquis,' the body of laws and standards agreed by the union. The compliance date, 1983, falls roughly in the middle of the sample period; the regulation was revised by Directives 89/427/EEC and 91/692/EEC, which also fall within the sample period.[20] Contrary to the EKC hypothesis, this directive required a single policy response of all EU members

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[18] Dropping countries for which GDP growth is less than 20% would reduce the number of anomalies in Table 2 by two, the trough for India and the increasing pollution-income relationship for Denmark. One instance of agreement and one ambiguous case, the decreasing pollution-income relationships for Australia and Brazil, respectively, would also be dropped. Overall, this reduced set of comparisons still exhibits little agreement with EKC predictions: troughs outnumber peaks by five to two and the countries with decreasing pollution-income relationships are a mixture of rich and poor.

[19] This would remove the two 'increasing' anomalies in Table 3, Denmark and Ireland. It would also remove two cases of agreement, however, the 'decreasing' cases of New Zealand and the U.K. (plus one inconclusive case, Brazil.) The reduced set of comparisons would still show equal numbers of peaks and troughs, however two of the three decreasing cases, Hong Kong and Spain, would be consistent with the EKC.

[20] Information on EU policy was taken from Kraus (1997).

regardless of income. Several of the EKC-consistent cases in Tables 1 and 2, specifically the relatively rich European countries that experienced 'decreasing' pollution-income responses, may be attributable to this policy rather than the EKC mechanism.

Two details of EU environmental policy are arguably even more important for the interpretation of results in Tables 1 and 2. First, the environmental acquis applied to *prospective* member states as well as existing members, and Spain and Portugal both joined after the initial directive was established. This raises the possibility that pollution control effort in these two countries reflected a desire for EU membership rather than a preference for cleaner air *per se.* Second, the EU subsidized pollution control in some of its poorer member states when they were unable to comply with the acquis as agreed.[21] In our sample, the nations receiving subsidies are Ireland, Portugal, and Spain. Overall, EU policy affected environmental outcomes in all three countries by enhancing pollution control benefits (EU membership) and by reducing pollution control costs (EU subsidies,) processes that play no role in the EKC story.

It is instructive to reconsider the descriptive results for Ireland, Spain, and Portugal in this light. Consider Ireland, for which we have data on smoke and SO_2 over the period 1977-1989. Smoke, which was not covered by EU regulations, rose steadily with income, nearly doubling between first and third tritiles. Sulfur dioxide, which was covered by EU policy, exhibits an inverted-U relationship, declining sharply in the final tritile. (In Ireland the third tritile takes in the years 1986-1989.) Spain, which was a prospective member in the early 1980s, experienced sharp reductions in smoke and SO_2 between the first and third tritiles of observations. Because Spain is relatively rich this is consistent with the EKC hypothesis. Spain's most dramatic reductions were for SO_2, however, which was covered by the EU directive and for which Spain received EU subsidies. Furthermore, Spain's SO_2 reductions were deepest after 1983, when the EU policy went into effect. Portugal reports data for SO_2 and particulates, both of which were regulated by the EU. Portugal's plot for both pollutants is a trough, which reached bottom the mid-1980s and jumped sharply in 1989-1992. It is plausible that Portugal strove for better air quality to improve its case for EU membership and in response to EU subsidies received after accession, but then relaxed after gaining admission.

Whether or not EU policies were partially responsible for the patterns shown in Tables 1 and 2 is unclear. What is clear, and what these cases illustrate, is the difficulty of separating the air quality effects of EU policies, which are not part of the EKC story, from the effects of processes that the EKC hypothesis emphasizes, such as the influence of economic growth on the demand for air quality.

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[21] Subsidies were administered through the EU Structural Fund and the EU Cohesion Fund (Hansen and Rasmussen 2001).

The Predictive Power of the EKC: Hypothesis Tests

Three preliminary steps must be completed before we can test formally for consistency with the EKC hypothesis. First, we need precise criteria for dividing countries into income groups and a precise specification of EKC-consistent and inconsistent behavior for each group. Second, to apply the criterion we need to specify EKC turning points for individual pollutants. Third, because we use 'random assignment' as an alternative to EKC-consistency in statistical testing, it is necessary to specify what is meant by random assignment.

If one could precisely identify a single EKC turning point, TP, the first step would be simple: count a country as 'low-income' if its observed income range is less than TP, as 'high income' if its income range exceeds TP, and as 'middle-income' if its income range includes TP. Each of the following cases would then be judged as EKC-consistent: an increasing income-pollution plot for a low-income country, a decreasing plot for a high-income country, and a single-peaked plot for a middle-income country. The EKC literature is rather ambiguous about the exact location of the turning point, however. Rather than impose consensus where none exists, and risk stacking the cards against EKC-consistency in the process, we acknowledge this imprecision and adopt a relaxed requirement for EKC-consistent behavior.

The criterion we use requires the identification of upper and lower bounds for the EKC turning point, income levels denoted TP_L and TP_H, respectively. Let I_{iL} and I_{iH} be country i's lower and upper income tritile values, respectively. Then country i is designated as low-income if $I_{iH}<TP_L$; here, consistency with the EKC hypothesis requires an increasing relationship between income and pollution. Similarly, i has high income if $I_{iL}>TP_H$, and EKC-consistency requires a decreasing relationship between income and pollution. If i's income range crosses only TP_L, we regard either an increasing or single-peaked income-pollution curve as EKC-consistent. Likewise, we regard either a decreasing relationship or a single peak as EKC consistent if i's income range crosses only TP_H. If i's income range lies entirely between TP_L and TP_H, we regard increasing, decreasing, and single-peaked relationships as EKC-consistent. Finally, if i's income range crosses both TP_L and TP_H, only a single peak is consistent with EKC. Figure 1 summarizes these income ranges and the criteria used for judging consistency with the EKC hypothesis. In effect, an individual country's income-pollution plot is judged to be EKC-consistent if it could have been generated by an EKC with a turning point *anywhere* in the range of uncertainty.

The bounds we identify for EKC turning points (GDP per capita in 1988 dollars) are:

Pollutant	*Lower bound*	*Upper bound*
SO_2	$3,012	$6,188
Particulates	$4,140	$7,140
Smoke	$4,855	$8,140

These choices are based on our review of the EKC empirical literature, the results of which are summarized in Table 4.[22] For SO_2 and smoke we set the upper and lower bounds for turning points at the mean of estimates from the literature on concentrations plus and minus one standard deviation. For particulates, the standard deviation is so large that applying the same procedure would cause the upper and lower bounds to differ by a factor of nearly four, a range so broad it renders the EKC hypothesis virtually meaningless. For this pollutant, we set the upper and lower bounds for the turning point at the mean plus and minus $1,500. It is worth emphasizing the degree to which our procedure gives the EKC hypothesis the benefit of the doubt—we judge a country's qualitative behavior to be EKC-consistent if it could be predicted by *any* inverted-U shaped curve with a peak in the range specified above.

The alternative to EKC-consistency we examine is 'random assignment,' and two different specifications of randomness are considered. The first postulates that a country's income level tells one nothing about the direction in which its pollution will *change* in response to a *change* in income. Specifically, for rich and poor alike, increasing a country's income will cause its pollution to increase or decrease with equal probability. (We rule out the possibility of no change in pollution.) With three data points, this process implies a one-fourth probability for each of the four possible shapes, and it is accordingly termed the *changes independent* assignment.

The second version postulates that a country's income level tells one nothing about its pollution *level*.[23] In this case, our tritile observations for a given country can be regarded as three pollution draws from the same distribution, albeit with different income levels. Label the pollution levels in these draws X, Y, and Z, and assume X<Y<Z. If we happen to draw X when income is low, Z when income is middle, and Y when income is high, the resulting income-pollution shape is an inverted-U. The shape is also an inverted-U, however, if we draw Y when income is low, Z when income is middle, and X when income is high. In total there are

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[22] None of the studies examined interacts income with other variables, hence the turning point estimates are meant to apply uniformly to all countries.

[23] Thanks are due to Chris Costello for the following argument.

six different orderings for X, Y, and Z, so the probability of drawing an inverted-U is one-third. A symmetric argument demonstrates that the probability of drawing a trough under this set of assumptions is also one-third. It is then clear that the probabilities of monotone increasing or monotone decreasing pollution-income relationships are one-sixth each with this process. This is termed the *levels independent* version of random assignment.

We begin by testing the simple null hypothesis that the frequency of EKC-consistent plots we observe is no different than what random assignment would produce. To do this we compute the frequencies of EKC-consistent and EKC-inconsistent plots under random assignment as well as the proportions of EKC-consistent and inconsistent cases observed in the data for each income range. The sum of squared deviations between the observed frequencies and the frequencies under random assignment follows a $C^{2}(1)$ distribution under the null hypothesis. In computing the number of EKC-consistent plots under random assignment, we know the proportion of observations in each of the income categories (Low, High, and Middle A, B, C and D) and impose these proportions in computing the frequencies that would occur under random assignment. Thus, for example, under changes independent randomness we specify that one-fourth of the observations for Low Income countries take on each of the four possible shapes.

The results obtained under the changes independent null hypothesis are:

H_O: 'Changes independent' random assignment.

H_A: H_O is false.

	Percent Consistent:			
Pollutant	Actual	Random	$C^{2}(1)$	Prob.
SO_2	60%	37%	5.67	1.7%
Particulates	21%	32%	0.74	39%
Smoke	46%	38%	0.32	57%

The first two columns of figures show the percent of EKC-consistent observations in the data and under random assignment. Thus, the percent that is observed to be EKC-consistent ranges from 21% for particulates to 60% for SO_2. The last column of figures shows the probability of the observed pattern under random assignment.

Results for the levels independent random assignment are:

H_O: 'Levels independent' random assignment.
H_A: H_O is false.

	Percent Consistent:			
Pollutant	Actual	Random	$C^{2}(1)$	Prob.
SO_2	60%	29%	11.34	<0.01%
Particulates	21%	26%	0.16	69%
Smoke	46%	32%	1.19	28%

As these results show, the level of agreement with EKC predictions for particulates and smoke could easily have occurred by chance. For particulates, EKC matches actually occur *less often* in the data than either form of random assignment would produce. The pollution-income patterns observed for SO_2 clearly agree with the EKC more often than would be expected with random assignment. This agreement is, however, of a very specialized form. We elaborate on this shortly.[24]

The preceding tests consider only the 'overall' predictive power the EKC hypothesis: Is the proportion of cells found to be EKC-consistent greater than would occur by chance? One might also wonder how well the EKC hypothesis predicts the shapes of income-pollution relationships for individual income categories. This question can be addressed by classifying observations as either consistent or inconsistent with EKC for each of the six income categories defined in Figure 1. With six income categories and two possible classifications (consistent or inconsistent,) there are at most 12 frequencies to consider when comparing observed frequencies to random assignment. In some cases an income category has no observations, which reduces the number of comparisons to be made. Accordingly, degrees of freedom differ from one pollutant to another. As before, we know the proportion of observations in each of the income categories and impose these proportions when computing the random assignment frequencies.

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[24] One might naturally consider a different procedure: test the null of random assignment against the alternative of EKC-consistency using a likelihood ratio test. This strategy would not be informative, however. EKC theory, strictly interpreted, predicts that certain patterns actually observed in the data are not possible, e.g., troughs, so the sample would have zero likelihood under the EKC hypothesis. Specifying a stochastic variant of the EKC theory is not something we have attempted.

The null hypothesis of random assignment (two versions) produced the following test results:

H_O: 'Changes independent' random assignment.

H_A: H_O is false.

Pollutant	C^2(d.f.)[25]	Prob.
SO_2	28.03	<0.01%
Particulates	7.33	40%
Smoke	6.33	71%

H_O: 'Levels independent' random assignment.

H_A: H_O is false.

Pollutant	C^2(d.f.)	Prob.
SO_2	43.03	<0.01%
Particulates	9.60	21%
Smoke	8.00	53%

Again, the SO_2 results are highly consistent with the EKC hypothesis. The patterns for particulates and smoke, however, could easily have arisen by chance.

We end this subsection by considering whether the plots and income categories we observe exhibit any non-randomness at all. That is, we ignore the question of consistency or inconsistency with the EKC hypothesis, and simply test the null hypothesis of (both versions of) random assignment. While we already know that the SO_2 patterns are non-random, it is still of interest to check for non-randomness for the other two pollutants. Also, it is of interest to identify more precisely the form that non-randomness takes for SO_2 and (possibly) other pollutants. Considering the four possible pollution-income shapes and all six of the income categories defined in Figure 1, would allow 24 possibilities, which seems excessively detailed in light of the data available.

To simplify, we reduce the number of income groups to three by combining the four middle-income groups into a single middle-income group. The 12 possibilities that remain are illustrated in Figure 2. Rejecting the null of random assignment in this set of possibilities would not indicate that the EKC has any predictive power, of course, because there are many non-random assignments and

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[25] Degrees of freedom for these tests are as follows: 7 for SO_2, 7 for particulates, and 9 for smoke.

EKC-consistent assignments are only a subset of these. This null is still of interest, nevertheless, because it is the least demanding test that seems sensible to examine. As always, the known proportions of observations in each income category are applied.

The test statistics obtained for each of the three pollutants are:[26]

H_O: 'Changes independent' random assignment.

H_A: H_O is false.

Pollutant	$C^2(11)$	Prob.
SO_2	26.71	<0.01%
Particulates	10.00	53%
Smoke	4.60	95%

H_O: 'Levels independent' random assignment.

H_A: H_O is false.

Pollutant	$C^2(11)$	Prob.
SO_2	45.29	<0.01%
Particulates	10.50	49%
Smoke	7.70	74%

Only sulfur dioxide can be regarded as non-random assignment with any degree of confidence, and the form of this non-randomness is examined shortly. The income-pollution relationships observed for particulates and smoke are not significantly different than what one would get by rolling a 12 sided, appropriately weighted die.[27]

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[26] Results using log pollution were not materially different.

[27] We tested the sensitivity of the last set of results to alternative ways of defining income groups based on 1983 income levels. In one test, countries with income below $3,500 were designated low income, countries with incomes above $7,000 were designated high income, and countries between these limits were called middle income. The results were essentially the same as those shown in the text. These sensitivity tests were extended to two other cutoff pairs: one with a narrower middle range, $4,000 and $6,500, and one with a broader middle range, $3,000 and $7,500. For the former categories, smoke and SO_2 patterns exhibited lower $C^2(11)$ values than those reported in the text; particulates yielded a higher, though still insignificant, value. In each

The pattern of EKC-consistent relationships within the GEMS/AIRS data set

A few summary observations on the patterns observed are illuminating. Looking across all three pollutants and considering the detailed income categories and EKC-consistency criteria in Figure 1, we observe 24 cases of EKC-consistent behavior and 28 cases of EKC-inconsistent behavior. The classic inverted-U appears in only nine of the 52 cases, which is less often than a U-shaped curve appears, 13 of the 52. A positive relationship between pollution and income occurs in five country-pollutant pairs and *none* of these are low-income countries as the EKC predicts.

By far the most common example of EKC-consistent behavior in the GEMS/AIRS data is that of the wealthy country that reduces pollution as income grows. Eleven of the 14 EKC-consistent observations for SO_2 (73%) are of this type. Looking across all three pollutants combined, high-income countries that cleaned up their pollution account for two-thirds of *all* EKC-consistent observations.

This simple behavioral pattern, rich countries cleaning up pollution, has been given undue weight in EKC research due to the fact that high-income countries are overrepresented in the GEMS/AIRS dataset. Countries with 1983 per capita GDP greater than $7,000 represent exactly half of all the country-pollutant cases in the data we examine. In contrast, only 22% of the 144 countries in the Penn World Tables would qualify as high income using this criterion. Low-income countries are correspondingly underrepresented in GEMS/AIRS; countries with incomes below $3,500 represent 21% of the country-pollution pairs in our sample but 58% of observations in the Penn World Tables.

Recognizing that low-income countries are underrepresented in EKC empirical work is important for two reasons. First, one aim of EKC analysis is to predict the environmental protection behavior of precisely this underrepresented group. Second, the corresponding overrepresentation of high income countries, together with the fact that EKC-consistent responses are concentrated among this group, may have played a key role in the emergence of the inverted-U as a stylized fact. The EKC story attributes the marked trend toward environmental cleanup in many parts of the world to an income effect on the demand for environmental quality and an ensuing policy response. Part of the increase in public support for environmental protection may have resulted from increased knowledge of the health effects of air pollution and from better technology for pollution control, however. Both factors arguably caused the desired level of air quality to rise independent of income effects, particularly in the U.S. and other wealthy nations. We only note this possibility here—that the apparent ability of the EKC to explain

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case, patterns for all three pollutants combined differed less from random assignment than with the $3,500 and $7,000 cutoffs.

changes in pollution may really reflect a shift in demand based on environmental education and control technology—and pursue it in more detail later.

Allowing for trends in tastes, technology and other factors

Many EKC researchers implicitly allow for the possibility that better information on pollution-related risks, environmental education, and emissions control technology contributed to long run improvements in air and water quality. Empirically, they have incorporated the pollution impacts of these factors in the time trends or time dummies typically found on the right-hand side of estimated EKC equations. Under this interpretation, the EKC hypothesis postulates that pollution is determined by trend-related factors common to all countries, such as pollution control technology, by country-specific factors that are constant over time, and by an inverted-U relationship with income. Accordingly, this interpretation implies that the EKC's predicted income response applies only to the portion of pollution that remains after trend-related effects are removed. Given this, it is natural to wonder if the shapes of within-country pollution-income relationships and results of hypothesis tests we reported earlier would have been more favorable to the EKC hypothesis had this factor been taken into account.

To examine this possibility, we estimated year-specific terms for each pollutant and year in the sample, controlling for the effect of income, country fixed effects, and systems of governance.[28] Specifically, we used our three cross-country panels on individual pollutants to estimate panel data models that include fixed effects for countries, year-specific dummy variables, and third order polynomials in income using the same per capita GDP variable used throughout.[29] The predicted year-specific terms were then subtracted from each of the three pollution series to get 'detrended' series on pollution within each country. These series portray the within-country behavior of each pollutant, after accounting for common worldwide pollution trends. These series also have the advantage that results are not driven by a common global business cycle affecting income and/or pollution.

As it turns out, these detrended pollution data provide less support for the EKC hypothesis as a predictor of within-country behavior than the data examined originally. We present only brief descriptions of the detrended results and make the revised data and detailed results available on request. Looking across all three pollutants, 17 of the 52 pollution-country cases considered change when the detrended data are used. For smoke, with 13 cases to examine, the number classified as EKC-consistent shrinks from six to only four, or 31%. For SO_2, with 25 cases to consider, the number agreeing with the EKC hypothesis falls from 15

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[28] The rationale for including governance as a determinant of pollution is discussed shortly. See, also, Barrett and Graddy (2000) and Torras and Boyce (1998).

[29] We also included the 'Polity score' for each observation, which indicates a country's political system. This measure is explained in the next section.

to 14, or 56%. For particulates, with 14 available cases, the number agreeing with the EKC declines from three to two, or 14%.

Clearly, this is abysmal predictive performance. Re-performing the formal hypothesis tests on the detrended data confirms this point. For smoke, the probability that the observed agreement with EKC predictions could have occurred by chance was above 57% in all tests conducted and in most cases it was above 70%. For particulates, the agreement with EKC predictions is markedly *worse* than chance would produce.[30] The SO_2 results generally agree with the EKC, but the match is weaker. For SO_2 the $C^{2}(1)$ tests for simple agreement yielded probabilities less than 5% for both versions of random assignment. The $C^{2}(7)$ tests of more detailed agreement yielded a probability level of 6% for the *levels independent* version of randomness. For the *changes independent* version, however, random assignment would produce the observed level of agreement with 46% probability. Overall, this represents a worsening of the EKC's predictive performance relative to what the original data indicated.

Political change and the shape of pollution-income relationships

We earlier claimed that the within-country approach is advantageous because it minimizes the influence of unobserved heterogeneity and thereby allows one to isolate the effect of income on pollution more precisely. This advantage would be illusory, however, if a country's attributes change during the sample period. A country's system of government is a potentially important attribute because democratic governments arguably will provide pollution control and other public goods at greater levels than non-democratic governments.[32] Failure to control for political change might yield misleading results.

Figure 3 illustrates how political change might skew the interpretation of observed income-pollution relationships. It shows a single country's income-pollution curve under dictatorship and democracy, with pollution lower under democracy as hypothesized. For illustrative purposes, increased production is assumed to cause increased pollution under both systems of governance. Y_0, Y_1, and Y_2 are income levels in three periods, e.g., the periods corresponding to our tritiles. Suppose the country starts out as a dictatorship at point '**a**' and ends up as a democracy at point '**c**'. If the political change occurred between periods 1 and 2 the observed income-pollution curve would be an inverted-U, **abc**. If the shift took place between periods 0 and 1, however, the observed income-pollution

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[30] For the $C^{2}(1)$ tests for simple agreement, the probability of getting a match as poor as what is observed in the data is 15% and 31% for the two versions of randomness.

[32] See Deacon (2003).

curve would be a trough, **ab'c**. Clearly, failure to control for political change could bias the estimated income-pollution relationship.[33]

To circumvent this problem we identify countries that experienced substantial political change during the sample period and exclude them from EKC consistency tests. We then look at the EKC's predictive power separately for democracies and autocracies. The political or governance measure used is a country's 'polity' score, as reported by Marshall and Jaggers (2003.) The polity score is computed from information on the degree to which a country's system of government displays democratic attributes, e.g., constraints on the chief executive, competition for political office, and relative openness to political participation, versus autocratic attributes, which largely amount to an absence of democratic characteristics. The polity score ranges from 0, indicating autocracy, to 1, indicating democracy.

'Political changers' were defined to be countries whose polity scores changed by at least 0.3 during the sample period.[34] These countries are: Brazil, Poland, Spain and Thailand. We comment later on the nature of the political and environmental change these four countries experienced. Countries not experiencing change were classified as 'autocracies' if their mean polity scores were .35 or below. Five countries met this criterion: China, Chile, Egypt, Indonesia and Iran. Non-changers with polity scores averaging 0.9 or above were classified as 'democracies.' Seventeen countries met this criterion: Australia, Belgium, Canada, Denmark, Finland, India, Ireland, Israel, Italy, Japan, New Zealand, Netherlands, Portugal, U.K., U.S., Venezuela, and West Germany.[35]

We test separately for agreement with the EKC hypothesis (versus random assignment) in autocracies and democracies. Because the results are similar to those reported earlier, we simply summarize them here and make the details available on request. For both democracies and autocracies, the shapes of income-pollution plots for particulates and smoke could have been generated by random assignment with relatively high probability. The C^2 tests that compare outcomes to EKC predictions for individual income categories yielded probability levels for the null hypothesis of random assignment that always exceeded 0.60 for autocracies and 0.24 for democracies.

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[33] While various authors have included political indicators among the independent variables in reduced form EKC models, they have not interacted these terms with income. In effect, pollution was allowed to be higher or lower under dictatorship than democracy, but the shape of the income-pollution curve is the same for both.

[34] This cutoff resulted in a fairly sharp distinction. Of countries classified as non-changers, only two experienced a change in polity of as much as 0.2 and changes in the remaining non-changers were all 0.1 or less.

[35] Two countries were dropped from this part of the analysis: Hong Kong because no polity score is reported and Malaysia because its polity score fell between the bounds set for autocracy and democracy.Malaysia's polity score was constant over the sample period at 0.7.

The results for SO_2 are more interesting. For autocracies, agreement with EKC predictions is substantially *worse* than would occur by chance, so the EKC hypothesis clearly is not supported. For democracies, agreement with EKC predictions is very strong, but this agreement is dominated by one now-familiar pattern—wealthy countries that reduced pollution as their incomes increased. This pattern is even more dominant for democracies alone than for the entire sample; 10 of the 11 democracies displaying EKC-consistent behavior are of this type. The only EKC-consistent democracy showing different behavior is Ireland, a ‘Middle income C’ country displaying an inverted-U.

On balance, what we have accomplished by eliminating the influence of political change and by distinguishing among political systems is a further narrowing or the range of countries exhibiting EKC-consistent behavior; they are relatively rich democracies that reduced SO_2 pollution during the 1970s and 1980s.[36]

5 Reductions in SO_2: Declining Trend or Income Effect?

The only EKC-consistent behavior systematically observed within countries is a strong tendency for SO_2 pollution to decline in wealthy democracies as their incomes increase. Causation is unclear, however, because pollution and income both followed trends in these countries during the 1970s and 1980s, pollution downward and income upward. Any other characteristic following a time trend in wealthy countries during this period would be an equally valid explanation for the observed behavior.

An alternative explanation for observed SO_2 reductions rests on a shift in preferences toward environmental protection. The end of the 1960s was

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[36] Commenting briefly on the four countries experiencing political change during the sample period, we note that three switched from relatively autocratic rule toward democracy. Brazil’s change took place in the mid-1980s when the military ceded control of the country and a new constitution was adopted. All three measures of air pollution fell in Brazil over the sample period and the declines were most dramatic after political reform. Spain’s polity score moved toward democracy shortly after the death of Franco, early in the sample period, and both SO_2 and smoke pollution (the two measures Spain reports) fell dramatically during the sample period. The patterns in both countries thus agree with the hypothesis that a shift toward democracy fosters environmental protection, although they might also have resulted from growth in income or trend-related factors. Poland moved toward democracy during the 1980s as the Soviet Union lost power, however identifying the response of pollution to political change is confused by the fact that income did not rise monotonically in Poland. Indeed, the highest income tritile includes the first four years observed, and the last three years of income data are each in a different tritile. In Thailand the political change that occurred during the sample period was more modest—the polity score fluctuated in the higher end of the range, but didn’t move monotonically. Because there was no clear pattern to political change in Thailand, there is no basis for interpreting its pollution trends (decreasing for both SO_2 and particulates) as having political determinants.

punctuated by environmental events such as Earth Day, highly publicized oil spills, and disturbing claims about the environmental effects of pesticides. Stricter air and water pollution control laws, protections for endangered species, and requirements for comprehensive environmental review of land use changes followed rapidly in the early 1970s.[37] The abruptness of these events suggests a shift in public preferences favoring permanently lower levels of pollution. This shift was brought about in part by better information on environmental risks, the introduction of environmental education in public schools, and the rise of environmental advocacy. Lower pollution was not achieved instantly, however, but was phased in gradually as control technology developed, heavily polluting capital wore out, and political hurdles were overcome. The downward trend in SO_2 and other pollutants that occurred during the observed period might simply have been movement along a transition path, from an old 1960s equilibrium where environmental health risks were not widely publicized, environmental education was largely non-existent, and pollution control technologies were primitive, to a new equilibrium where each of these gaps has been filled to a substantial degree.[38]

This alternative story does not highlight income growth as the primary force driving pollution downward. Income may well matter in this process, of course; it is plausible that wealthy nations made the transition to a new equilibrium relatively quickly and adopted more ambitious pollution control targets. There is no presumption, however, that *income growth* in wealthy countries caused the *downward trend* in pollution or that income's effect followed an inverted-U shape. In what follows we test a simple 'trends' hypothesis—pollution trended downward after 1970, with the most rapid declines coming in wealthy countries—against the power of the EKC's all important income effect. The first step is to estimate within-country trends in SO_2 pollution for individual countries and to test whether reductions were more rapid in wealthier countries. Because the trends explanation is simpler than the EKC story, the principle of Occam's razor suggests adopting it as the null hypothesis and then including income only if it adds explanatory power. Estimating models with two potentially trended series, income and pollution, raises econometric issues which we address as they arise.

Table 5 lists the 25 countries for which we have SO_2 pollution data. Column (1) reports pollution trends estimated from a regression of $\log(SO_2)$ on a trend

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[37] See Portney (1990,) for a review of pre- and post-1970 air pollution policy in the U.S. According to Portney (1990, pp. 48-51,) U.S. emissions of particulates dropped rapidly after 1970 and sulfur dioxide emissions, which had peaked in 1970, fell steadily thereafter.

[38] The elimination of lead in gasoline provides an stark illustration. Between 1970 and 1992 the lead content of gasoline declined from roughly 2.5 grams per gallon to essentially zero in wealthy countries, while incomes in these countries increased only x%. For lead elimination to result from the ordinary effect of income growth on the demand for pollution control, the implied income elasticity of pollution control would necessarily be enormous. A more plausible explanation, in our view, is that lead reductions were driven primarily by the emergence of new information on the health effects of lead.

variable.[39] All of the significant trends are negative and all but one of these occur in wealthy countries. To test whether cleanup was more rapid in higher income countries, the within-country trends were correlated with average income for each country. The simple correlation coefficient is -0.4849, which is significant at the 1% level; pollution reduction therefore was more rapid in wealthier countries. Additionally, the simple correlation coefficient of the trends and mean polity scores (for countries not designated as political changers) is -.4282, indicating that cleanup was faster in more democratic countries, consistent with our earlier finding.

To see if income enhances explanatory power, third degree polynomials in income were added and tested for significance as a group using a standard F test.[40] Test results are reported in column (2) and indicate that income is significant at 5% in 10 of the 25 cases.[41] Income rose fairly steadily over the sample period in most of the countries we observe, so the time trend may partially capture the effect of income growth leaving income terms to explain only deviations around that trend. While this makes it difficult to separate the effect of income from a pure trend effect, our approach is consistent with empirical models for which inverted-U shaped relationships have been estimated. These models invariably include trend variables along with income terms, and our approach conforms to that practice.

Before commenting further on estimated income effects, it is appropriate to examine the time series properties of within-country income and pollution data. If a regressor follows a unit root process its coefficient is not normally distributed, even in large samples, and the normal critical values for hypothesis tests do not apply. Many economists believe income follows a unit root process generically, so this issue cannot be ignored. A more troubling concern is that a significant estimated relationship between income and pollution may be spurious if both variables follow stochastic trends. This concern is moot, of course, if income terms are statistically insignificant. Given this reasoning, we performed augmented Dickey-Fuller tests on income and pollution for the 10 countries where income terms are significant.[42] The hypothesis of a unit root in income could not be rejected (at 5%) for any country and a unit root in pollution could be rejected only for China.

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[39] Pollution was expressed in logs rather than levels to ease comparisons of trend coefficients across countries.

[40] The lagged three-year moving average income variable described earlier was used. Adding income terms naturally changes the estimated trends. The trend coefficients reported in column (1) are those estimated from a model without income terms.

[41] Income terms were jointly significant at 10% in four other countries: Belgium, Canada, Finland, and Italy.

[42] Dickey-Fuller tests were performed on income levels only, and not separately on income squared and income cubed. Perman and Stern (2003) note that low order polynomials retain the unit root property when the untransformed variable follows a unit root.

Having unit root series on both sides of a model is not a problem if the two are cointegrated, i.e., if they follow the same stochastic trend. The hypothesis of cointegration could not be rejected for any of the 9 countries displaying unit roots in both pollution and income.[43] For these countries, Durbin-Watson tests were then performed for positive first-order serial correlation in the residuals of the OLS model. Here, the statistics either indicated rejection at 5% or fell into the indeterminate range. Accordingly, for these 9 countries we report OLS income coefficients in columns (3)-(5) and interpret the coefficients as usual. The remaining case is China, which exhibited a unit root in income but not in pollution.[44] For China, first differencing income and pollution twice yielded series that both have unit roots in both variables. The hypothesis of cointegration cannot be rejected for the double-differenced data and residuals from the model with double-differenced data do not display positive first-order serial correlation. Consequently, for China we report OLS results from the model estimated on double-differenced data.[45]

Income coefficients for countries with significant income terms are shown in columns (3)-(5). Because the model has a third-order polynomial in income, each country generally exhibits two turning points. The income values of left (lower) and right (upper) turning points are reported in columns (6) and (7), along with an indication of whether a given turning point is a max (peak) or a min (trough). To judge whether or not a given shape for the income function is EKC-consistent, it is necessary to know the income range for the actual data.[46] Each country's maximum and minimum income are shown in columns (8) and (9). Column (10) reports the general 'shape' of each country's income function over the range of data actually observed. Finally, as explained shortly, column (12) indicates whether or not a country's estimated income function is consistent with the EKC hypothesis.

Consider first the one clear case of EKC-consistent behavior, Brazil. Brazil's income range lies entirely within the range of SO_2 turning points reported in the literature, hence increasing, decreasing, or peaked functions would be EKC-consistent for Brazil. (The upper and lower bounds for SO_2 turning points are reported in the title to Table 5.) Brazil's estimated income function is peaked, and hence is EKC-consistent. With a bit of generosity, Iran's income function can also be regarded as EKC-consistent. Iran's income range also lies within the range of

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[43] The null hypothesis is that the residuals follow a unit root. In all cases the unit root hypothesis could be rejected at 1% or better.

[44] It is not possible for an independent variable to follow a unit root process while the dependent variable does not. However, given the short time series we observe and the relatively low power of unit root tests, we are not inclined to regard this as compelling evidence of a specification problem.

[45] Income coefficients for China when double-differenced data were used were very similar to coefficients obtained from estimating the model with undifferenced data.

[46] For example, an estimated trough for a high-income country would be EKC-consistent if all of the data observed for that country lies on the downward sloping (left-hand) portion of the trough.

EKC turning points in the literature, so increasing, decreasing, and peaked shapes are EKC-consistent. Iran's plot actually shows a trough at $4,242 and a peak at $4886, but there is only one data point in the upward sloping range between these values and the difference between predicted trough and peak pollution levels is very slight. With this minor exception, then, Iran's pollution-income function is downward sloping, which is consistent with the EKC hypothesis.

Eight of the 10 estimated pollution-income relationships are judged EKC-inconsistent. China, a low-income country, has a peak followed by a trough and both are at income levels well below consensus turning points in the EKC literature.[47] Thailand, also a low income country, has a trough shaped plot throughout its observed income range; 13 of its 15 data points are in a region where predicted pollution declines as income increases, contrary to the EKC hypothesis. Hong Kong's income range crosses the upper bound for SO_2 turning points (it is classed as a 'middle income C' country in Figure 2) so a peaked or decreasing pollution income curve would be EKC-consistent, however the predicted plot for Hong Kong actually increases monotonically over the data range observed.

The 5 remaining cases are all high-income countries. Japan and Venezuela both have peaked pollution-income plots over ranges of observed data, with peaks occurring at income levels well above levels reported in the literature, $12,738 for Japan and $8,153 for Venezuela. Moreover, most of the data points actually observed (18 out of 21 for Japan and 15 out of 16 for Venezuela) are in a range where pollution increases as income increases, which is contrary to EKC predictions for a rich country. Israel is similar; predicted pollution increases as income increases. The Netherlands exhibits a distinct trough over the data range. This would not be troubling if most of the data were on the downward sloping region, where pollution decreases as income rises. In actuality, 12 of the 15 observations for the Netherlands are in a range where income growth leads to higher pollution. The remaining country, New Zealand, exhibits a trough followed by a peak, with both occurring at income levels well above peaks reported in the EKC literature.[48]

The results of this section can be summarized as follows. If one allows both income and purely trend driven factors to explain within-country pollution patterns during the 1970s and 1980s, the separable role of income is typically insignificant and, where significant, its effect is not consistent with predictions of the EKC hypothesis.[49]

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[47] The predicted pollution-income plot for China is relatively flat, however, so income's role in determining pollution is very minor.

[48] In New Zealand's case, the effect of income on predicted pollution is very slight

[49] Overall, our results are consistent with the findings of Perman and Stern (2003.)

6 Conclusions

Looking within individual countries, at their experiences over time with economic growth and changes in pollution, we find only a highly specialized form of agreement with EKC predictions. Relatively wealthy democracies controlled their SO_2 pollution (but not smoke and particulates) as their incomes increased, which is consistent with the EKC hypothesis. The remaining EKC predictions, i.e., pollution increasing monotonically with income in poor countries, middle income countries following an inverted-U path and rich countries reducing smoke and particulate pollution, are not observed with any greater frequency than chance would dictate.

The SO_2 reductions that occurred in rich countries, while consistent with the EKC story, are also consistent with any other force causing a secular decline in pollution during the 1970s and 1980s. One explanation was offered in the text, but there may be others. Once the effect of purely trended factors is accounted for, income growth has no consistent predictive power for the patterns of pollution experienced by individual countries.

Our aim was not to develop a framework for understanding why pollution behaves as it does in individual countries. This is obviously an important task, but one that is well outside the scope of the present analysis. Rather, our aim was to see if the EKC hypothesis gives reliable qualitative predictions about the way pollution behaves *within individual countries* that experience economic growth. Based on an examination of the data presently available, using robust empirical methods and a generous interpretation of what the EKC predicts, we find that most of the observed patterns could easily have occurred by chance. In the limited set of circumstances where the EKC's predictions are upheld, the behavior we observe also has a much simpler explanation.

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Table 1. The Shape of the Pollution-GDP Relationship: SO_2

Sulfur Dioxide	N	Countries
Peak (Inverted-U)	4	China, Ireland, Hong Kong, Italy
Mean GDP at peak	6,287	
Trough	4	Chile, India, Poland, Portugal
Mean GDP at trough	3,427	
Increasing	2	Japan, Venezuela
Center of GDP range	8,540	
Decreasing	15	Australia, Belgium, Brazil, Canada, UK Egypt, Finland, W. Germany, Iran, US Israel, Netherlands, NZ, Spain, Thailand
Center of GDP range	8,882	

Table 2. The Shape of the Pollution-GDP Relationship: Particulates

Particulates	N	Countries
Peak (Inverted-U)	2	China, Finland
Mean GDP at peak	6,231	
Trough	6	Belgium, India, Indonesia, Iran Malaysia, Portugal
Mean GDP at trough	4,320	
Increasing	1	Denmark
Center of GDP range	11,324	
Decreasing	5	Australia, Brazil, Canada, Japan, Thailand
Center of GDP range	8,805	

Table 3. The Shape of the Pollution-GDP Relationship: Smoke

Smoke	N	Countries
Peak (Inverted-U)	3	Egypt, Poland, Venezuela
Mean GDP at peak	4,408	
Trough	3	Belgium, Chile, Iran
Mean GDP at trough	5,798	
Increasing	2	Denmark, Ireland
Center of GDP range	9,135	
Decreasing	5	Brazil, Hong Kong, New Zealand, Spain, United Kingdom
Center of GDP range	7,861	

Table 4. Estimates of EKC Turning Points
(GDP per capita)

Author	SO_2	Partic.	Smoke
Panayotou (1997)	4,135		
Grossman and Kruger (1995)	4,053		6,151
Barrett and Graddy (2000)	4,202		8,097
	5,187		7,392
Torras and Boyce (1999)	3,890		4,350
	3,360		
Shafik and Bandyopatay (1992)	3,670	8,000	
	8,305	3,280	
Mean	4,600	5,640	6,498
Std. Dev.	1,588	3,338	1,642
Mean - 1 std. dev.	3,012	2,302	4,855
Mean + 1 std. dev.	6,188	8,978	8,140

Table 5. Within-Country SO2 Pollution Patterns: Trends vs. Income Effects
(Upper and lower bounds for the SO2 turning point are $3,012 and $6,188, respectively)

	Estimated	Income	--- Income coefficients ---			---- Turning points ----		-- Income range --		Shape	Income	EKC
Country	trend (1)	terms sig.? (2)	I (3)	I^2 (4)	I^3 (5)	left (6)	right (7)	min. (8)	max. (9)	(10)	category (11)	consistent? (12)
Australia	-0.1656*	no						11,350	12,730			
Belgium	-0.0980*	no						8,244	11,164			
Brazil	-0.0791*	yes	-131.06	35.62	-3.197	3,354 min	4,075 max	3,397	4,273	peak	Mid. B	yes
Canada	-0.0368*	no						10,233	17,318			
Chile	0.0092	no						3,044	3,904			
China	0.0051	yes	224.28	-193.2	55.167	1,080 max	1,254 min	891	1,334	peak/tr.	Low	no
Egypt	-0.0431	no						1,187	1,929			
Finland	-0.0810*	no						9,441	13,888			
Germany	-0.0879*	no						9,639	14,308			
Hong Kong	-0.0356	yes	13.96	-1.52	0.056	none	none	5,547	11,693	incr.	Mid. C	no
India	0.0216	no						779	977			
Iran	0.0186	yes	-23.93	5.27	-0.385	4,242 min	4,886 max	3,272	6,135	tr./peak	Mid. B	yes
Ireland	-0.0357	no						5,784	7,559			
Israel	-0.0659	yes	4.83	-1.33	0.103	2,607 max	6,018 min	6,529	8,356	incr.	High	no
Italy	-0.1363*	no						7,448	10,290			
Japan	0.0229	yes	-8.81	0.99	-0.034	6,872 min	12,738 max	7,163	14,324	peak	High	no
Netherlands	-0.0562*	yes	-101.96	9.49	-0.293	10,069 min	11,518 max	9,138	11,270	trough	High	no
New Zealand	-0.1213*	yes	-677.89	62.01	-1.889	10,566 min	11,323 max	10,141	11,650	tr./peak	High	no
Poland	-0.0258	no						3,807	5,021			
Portugal	0.0367	no						4,727	6,688			
Spain	-0.1064*	no						5,868	9,530			
Thailand	-0.0526	yes	-26.94	6.74	-0.53	3,228 max	5,244 min	1,790	3,528	trough	Low	no
United Kingdom	-0.1149*	no						8,721	10,578			
United States	-0.0411*	no						12,887	17,953			
Venezuela	-0.0055	yes	11.05	-1.17	0.04	8,152 max	11,240 min	6,246	8,173	peak	High	no

Notes:

* indicates significant at 5%.

Income was measured in thousands for estimation of income coefficients; income terms labeled significant if jointly significant at 5%.

Shape indicates the general shape of the income-pollution function over the income range observed for a given country.

Income categories refer to the categories defined in Figure 1.

Table A1. Mean Observations for Income Tritiles: Pollution Concentrations and GDP Per Capita

	Smoke	GDP per cap.		SO_2	GDP per cap.		Particulates	GDP per cap.
			Australia	46.3397	11,501	Australia	95.3790	11,501
			Australia	30.7791	12,058	Australia	82.3706	12,058
			Australia	16.5661	12,548	Australia	76.3537	12,548
Belgium	36.0286	8,827	Belgium	116.8195	8,994	Belgium	29.1400	9,956
Belgium	19.6936	10,054	Belgium	73.7542	10,272	Belgium	21.7733	10,691
Belgium	21.7324	10,882	Belgium	44.2985	11,001	Belgium	22.0650	11,033
Brazil	80.5677	3,709	Brazil	86.6564	3,709	Brazil	116.1000	3,892
Brazil	75.7069	4,015	Brazil	79.8099	4,015	Brazil	102.6335	4,092
Brazil	44.3609	4,192	Brazil	46.1519	4,192	Brazil	73.2767	4,230
			Canada	34.0893	11,597	Canada	80.4231	11,597
			Canada	22.9321	13,951	Canada	66.8190	13,951
			Canada	17.6316	16,368	Canada	52.3897	16,368
Chile	66.6257	3,132	Chile	62.8985	3,132			
Chile	61.2712	3,441	Chile	61.1786	3,441			
Chile	133.4660	3,799	Chile	65.8965	3,799			
			China	78.3637	946	China	334.6617	946
			China	88.2570	1,132	China	344.4906	1,132
			China	76.3880	1,294	China	338.9853	1,294

Table A1. Mean observations for income tritiles: Pollution concentrations and GDP per capita (continued)

	Smoke	GDP per cap.		SO_2	GDP per cap.		Particulates	GDP per cap.
Denmark	11.8829	10,766				Denmark	38.3133	10,766
Denmark	22.2176	11,303				Denmark	42.4050	11,303
Denmark	24.6385	11,944				Denmark	47.7733	11,944
Egypt, Arab Rep.	69.6962	1,260	Egypt, Arab Rep.	44.2098	1,260			
Egypt, Arab Rep.	72.8962	1,789	Egypt, Arab Rep.	40.4006	1,789			
Egypt, Arab Rep.	53.7488	1,917	Egypt, Arab Rep.	26.4219	1,917			
			Finland	25.7376	9,903	Finland	77.9465	9,710
			Finland	25.7115	11,360	Finland	80.7215	11,329
			Finland	14.4232	12,939	Finland	74.0048	13,169
			Germany (West)	73.0638	10,274			
			Germany (West)	43.0251	11,768			
			Germany (West)	13.1705	13,192			
Hong Kong	60.3428	5,702	Hong Kong	37.5560	6,095			
Hong Kong	53.3872	7,270	Hong Kong	45.8226	8,391			
Hong Kong	44.1136	9,149	Hong Kong	23.5749	10,521			
			India	37.7305	788	India	365.9112	788
			India	35.4374	827	India	328.2753	827
			India	48.7079	916	India	346.6284	916
						Indonesia	207.7535	1,087
						Indonesia	140.6697	1,450
						Indonesia	279.2413	1,662

Table A1. Mean observations for income tritiles: Pollution concentrations and GDP per capita (continued)

	Smoke	GDP per cap.		SO_2	GDP per cap.		Particulates	GDP per cap.
Iran, Islamic Rep.	122.5611	3,431	Iran, Islamic Rep.	113.0859	3,431	Iran, Isl. Rep.	264.1646	3,431
Iran, Islamic Rep.	113.7533	3,897	Iran, Islamic Rep.	92.9656	3,897	Iran, Isl. Rep.	243.0351	3,897
Iran, Islamic Rep.	173.3167	5,609	Iran, Islamic Rep.	90.5208	5,609	Iran, Isl. Rep.	322.9717	5,609
Ireland	25.1250	6,141	Ireland	38.4533	6,141			
Ireland	38.3933	6,913	Ireland	39.9740	6,913			
Ireland	48.8750	7,306	Ireland	33.0220	7,306			
			Israel	21.3144	6,985			
			Israel	15.4659	7,423			
			Israel	14.8409	8,110			
			Italy	151.7391	7,794			
			Italy	182.4800	8,775			
			Italy	115.1868	9,906			
			Japan	62.7886	8,089	Japan	90.0074	9,668
			Japan	86.7272	10,007	Japan	49.4272	11,481
			Japan	103.7951	12,671	Japan	49.0793	13,420
						Malaysia	143.7520	3,170
						Malaysia	102.5770	3,907
						Malaysia	121.9208	4,220
			Netherlands	47.1120	9,719			
			Netherlands	28.9733	10,798			
			Netherlands	27.9826	11,178			

Table A1. Mean observations for income tritiles: Pollution concentrations and GDP per capita (continued)

	Smoke	GDP per cap.		SO_2	GDP per cap.		Particulates	GDP per cap.
New Zealand	15.3682	10,351	New Zealand	20.6687	10,351			
New Zealand	13.9670	10,842	New Zealand	17.4754	10,842			
New Zealand	12.2619	11,552	New Zealand	10.1860	11,552			
Poland	64.5728	3,927	Poland	38.5018	3,927			
Poland	68.4654	4,315	Poland	33.7136	4,315			
Poland	57.2954	4,828	Poland	36.9028	4,828			
			Portugal	40.4475	4,889	Portugal	97.3816	4,968
			Portugal	22.6753	5,125	Portugal	97.2362	5,145
			Portugal	46.3658	6,141	Portugal	119.4131	6,141
Spain	160.4903	6,642	Spain	103.1478	6,736			
Spain	88.2269	7,378	Spain	64.2247	7,363			
Spain	72.8307	8,540	Spain	29.2386	8,381			
			Thailand	14.9120	2,005	Thailand	213.2565	1,909
			Thailand	12.0965	2,346	Thailand	209.4769	2,319
			Thailand	11.0363	3,010	Thailand	194.9811	3,010
United Kingdom	33.8157	9,138	United Kingdom	113.7764	9,138			
United Kingdom	27.7503	9,810	United Kingdom	71.4491	9,810			
United Kingdom	19.3935	10,329	United Kingdom	42.3709	10,329			
			United States	52.3358	13,596			
			United States	34.7110	15,161			
			United States	25.4385	17,178			

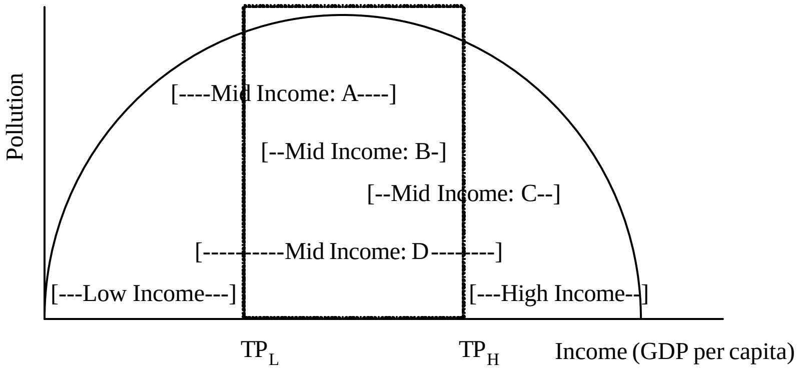
Table A1. Mean observations for income tritiles: Pollution concentrations and GDP per capita (continued)

	Smoke	GDP per cap.		SO_2	GDP per cap.		Particulates	GDP per cap.
Venezuela, RB	21.9850	6,340	Venezuela, RB	20.3607	6,340			
Venezuela, RB	26.2050	7,015	Venezuela, RB	22.3854	7,015			
Venezuela, RB	23.1050	7,905	Venezuela, RB	28.3902	7,905			

Table A2. Observed Ranges for Per Capita GDP

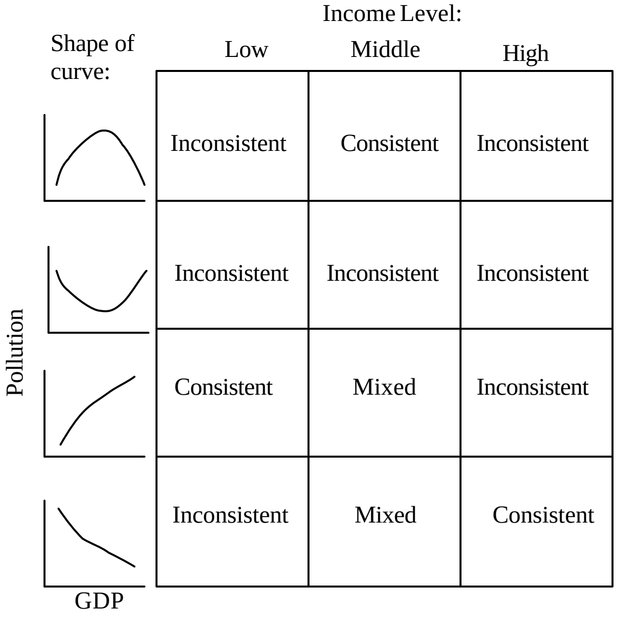
Country	Per cap. GDP peak/trough/median	Income category*	Years observed	Change in GDP percent	Change in GDP value	Low vs. hi tritile percent	Low vs. hi tritile value
Australia	$12,017	Rich	11	12%	$1,380	9%	$1,047
Belgium	$10,275	Rich	15	37%	$2,920	22%	$2,007
Brazil	$4,048	Middle	17	26%	$876	13%	$483
Canada	$14,133	Rich	21	70%	$7,086	41%	$4,771
Chile	$3,441	Poor	10	30%	$860	21%	$668
China	$1,142	Poor	11	44%	$443	37%	$348
Denmark	$11,324	Rich	10	18%	$1,877	11%	$1,178
Egypt	$1,894	Poor	18	58%	$742	52%	$657
Finland	$11,329	Rich	15	48%	$4,447	31%	$3,036
Hong Kong	$8,391	Rich	14	113%	$6,147	73%	$4,426
India	$827	Poor	14	25%	$198	16%	$128
Indonesia	$1,450	Poor	12	70%	$718	53%	$574
Iran	$3,897	Middle	17	85%	$2,862	64%	$2,179
Ireland	$6,947	Middle	13	31%	$1,775	19%	$1,165
Israel	$7,383	Rich	15	29%	$1,827	16%	$1,126
Italy	$8,702	Rich	12	39%	$2,842	27%	$2,112
Japan	$10,069	Rich	21	99%	$7,161	57%	$4,582
Malaysia	$3,907	Middle	11	48%	$1,431	33%	$1,050
New Zealand	$10,748	Rich	17	15%	$1,509	12%	$1,201
Netherlands	$10,903	Rich	15	24%	$2,132	15%	$1,458
Poland	$4,315	Middle	15	32%	$1,214	23%	$901
Portugal	$5,125	Middle	13	43%	$1,960	26%	$1,252
Spain	$7,383	Rich	21	61%	$3,662	29%	$1,898
Thailand	$2,310	Poor	16	106%	$1,827	58%	$1,101
U.K.	$9,817	Rich	13	22%	$1,857	13%	$1,192
U.S.	$15,267	Rich	22	40%	$5,066	26%	$3,582
Venezuela	$7,015	Middle	16	32%	$1,927	25%	$1,565
W. Germany	$11,803	Rich	20	49%	$4,669	28%	$2,919

* These income designations are intended only for discussions of descriptive statistics. Formal criteria for defining income categories are explained in the text in connection with hypothesis testing.



Shape consistent with EKC?	Peak	Trough	Increasing	Decreasing
Low Income:	No	No	Yes	No
High Income:	No	No	No	Yes
Mid Income A:	Yes	No	Yes	No
Mid Income B:	Yes	No	Yes	Yes
Mid Income C:	Yes	No	No	Yes
Mid Income D:	Yes	No	No	No

Figure 1. Income-Pollution Relationships Predicted by EKC.



Shape of curve:	Income Level: Low	Middle	High
Peak	Inconsistent	Consistent	Inconsistent
Trough	Inconsistent	Inconsistent	Inconsistent
Increasing	Consistent	Mixed	Inconsistent
Decreasing	Inconsistent	Mixed	Consistent

Figure 2. Expected Relationships Under the EKC Hypothesis

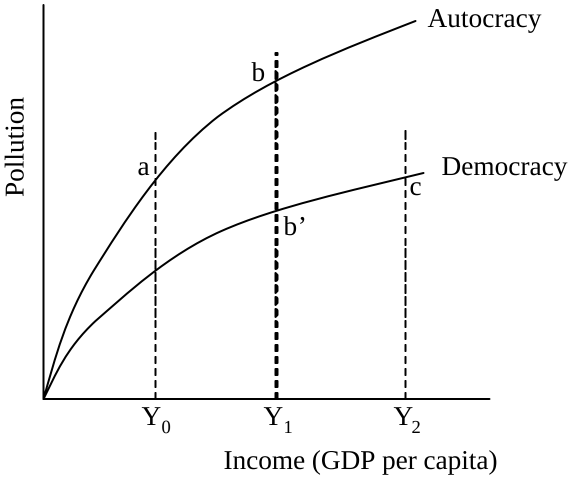


Figure 3. Political change and income-pollution relationships