Title

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Publication Date
2009-09-21

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Draft
September 21, 2009

Abstract

In the early 1990's the attention of economists was captured by empirical evidence suggesting rising income levels in developing countries could be good rather than bad for the environment. This evidence drove a stake into the heart of those opposing growth on environmental grounds. Ultimately, the view that income growth *by itself* eventually will be good for the environment also appears to be wrong because a causal relationship between income and environmental quality cannot be demonstrated. The original empirical estimates appear fragile at best compared to the use of more representative datasets, higher quality data, and more appropriate econometric techniques. More plausible stories revolve around good government, effective regulation and diffusion of technological change. These factors tend to be related in a diffuse manner with higher income and suggest it is likely, but not inevitable, that a society will chose to reduce pollution levels as it becomes wealthier.

Key Words: pollution control, environment and trade, growth and income

JEL Codes: O13, Q52, Q56

Introduction

Long before the environmental Kuznets curve (EKC, see Figure 1), under which pollution at first increases and then decreases as income increases, became enshrined in standard "principles" texts (*e.g.,* Frank and Bernanke, 2005), a very different view was set out by Ehrlich and Holden (1971) to which much of the science and policy community still subscribes. Their famous IPAT equation, I=PAT, relates **I**mpact (*e.g.,* pollution or nature resource use), to **P**opulation, **A**ffluence (often proxied for by per capita income), and **T**echnology.[1] It generated considerable controversy and lay behind Ehrlich's best selling popular book *The Population Bomb* (1968) and the Club of Rome's *Limit's to Growth* (Meadows, *et al.,* 1972). These books saw the primary force lying behind adverse impacts to be population growth coupled with growing affluence. They viewed technology as a neutral or even mildly beneficial factor, although some environmentalists such as Commoner (1972) saw it as the main destructive force.

Economists engaged this debate on three fronts (*e.g.,* Kneese and Ridker, 1972; Nordhaus, 1973; Solow, 1973). The first was to see technological progress as a large positive influence that was resource conserving, pollution reducing, and growing at a rate large enough to offset the other two factors. This view was diametrically opposed to the Club of Rome approach where exponential growth in the use of resources but not technological progress drove adverse impact estimates. The second pointed out that the IPAT equation effectively lacked any behavioral response to the increasingly adverse impact being modeled. In the Club of Rome's world, people choked to death on pollution, froze, or starved in enormous numbers without the explicit and implicit prices

[1] IPAT in a slightly different form known as the Kaya Identity plays a central role in the Intergovernmental Panel on Climate Change estimates of future CO_2 emissions. In it, total CO_2 emissions are a product of population, per capita GDP, energy use per capita, and CO_2 emissions per unit of energy consumed.

of the economic system changing in any way. Groundbreaking passage of environmental laws across the developed world (starting in the late 1960s) is the best indication that the bleak world the Club of Rome foresaw would not be allowed to manifest in the wealthiest countries. The final point of contention was to note substantial problems with both the quantity and quality of the underlying data.

There is some irony that the initial and highly influential forays into looking at the environmental Kuznets curve (Grossman and Krueger, 1991; Shafik and Bandyopadhay, 1992) never referenced the IPAT/Club of Rome debate. Perhaps this was not surprising as the concept of an EKC was originally advanced by trade/development economists in the context of an international trade agreement and not by environmental/resource economists in a pollution control context.[2] But the question at the heart of the debate was almost identical: does economic growth need to be slowed, if not stopped, in order to avoid increasing harm to the environment? Grossman and Krueger (1991; 1995) provided an answer that seemed to turn arguments (Daly, 1993) against joining the North American Free Trade Agreement (NAFTA) on the grounds of increasing environmental degradation, particularly in Mexico, on their head. Shafik and Bandyopadhyay's (1992) work provided a justification for the World Bank's (1992) position that increasing income would likely help improve a wide array of environmental indicators. Ultimately both studies would fall victim to the same criticisms brought against the IPAT/Limits to Growth framework: the underlying model is misspecified, a behavioral response mechanism is missing, and poor quality data underlay the estimates.

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[2] The tie was quickly noted by environmental economists such as Stern, Common and Barbier (1996) who pointed out: "If the EKC hypothesis held generally, it could imply that instead of being a threat to the environment as argued in, for example, *The Limits to Growth* (Meadows, *et al.*, 1972), economic growth is the means to environmental improvement."

The lasting contribution of the EKC literature, however, has been to shift the conventional wisdom of rank and file economists and many policymakers toward a belief that economic growth is good for the environment. Beckerman (1992) represents an early influential statement in *World Development*. Official U.S. recognition of the EKC in its standard sense of an income-driven U-shaped pollution function across political jurisdictions came in the 1999 *Economic Report of the President*.[3] The title of the opinion piece "Growth is the Key to Protecting the Environment, Not Its Enemy" in the *Sydney Morning Herald* (M. Robinson, 9 September 2008, p. 10) sums up the popular view of growth advocates. Many, perhaps even most, of those currently working in the area, however, have come to believe this popular view is wrong (*e.g.,* Arrow, *et al.*, 1995; Stern, 2004).

The push back against the EKC, however, was not in the direction of the IPAT model, but rather to a belief that both are fatally flawed. This should not be surprising. It is easy to show the IPAT model is simply a restricted version of the EKC. The casual empiricism characterizing much of the early EKC literature established the stylized fact that environmental quality tends to be positively not negatively correlated with income in wealthier countries. This suggests the EKC specification is a distinct improvement over the IPAT model. The problem lies with the causal role of income growth and the inadequacy of reduced form specifications that presumed that a common process, conditional on fixed effects, income and a few observable covariates, adequately describes the generation of the pollutant of interest.

[3] This formulation is also a staple in environmental economics textbooks. See Russell (2001) for a clear statement of the standard version of the EKC model and its interpretation "as [empirical] evidence for the notion that, eventually, income growth will, one way or another, tend to 'fix' environmental problems," and an easily digestible discussion of the conceptual and empirical problems with this view.

My intent in this paper is not to comprehensively review the sprawling EKC literature as several reviews are available.[4] Rather it is to look at how the current state of play concerning the EKC came about and to then ask what can and should be salvaged.

The organization of the paper is as follows. First, I look at establishing the basic empirical regularities. Next, I turn to Mexico, the focus of Grossman and Krueger's initial work (1991) and examine what actually happened since the implementation of NAFTA. I then look at the theoretical literature that developed to provide an explanation for a stylized EKC empirical result. Coupled with the early empirical evidence, these theoretical results were often taken as supporting of the basic EKC finding, although a variety of other interpretations are possible. With these results in mind, I turn to the initial questions asked about the econometric structure of the EKC models and nature of the data used to estimate them. Ironically, that moves the focus to the United States, of all places, which provides key insights to unraveling the EKC puzzle. Over time, econometric issues with the EKC have been raised, particularly with respect to data quality and inferring a causal relationship. These provide much of the impetus for a revisionist view that little substance lies behind the EKC and a more nuanced viewed of a relationship in which income helps by working through other factors. I conclude by discussing what can be learned from our twenty year fascination with the EKC.

The Initial Reaction and Questions About the EKC

[4] A broad ranging general review is Dinda (2004). Focusing on the empirical literature, Dasgupta, *et al.* (2002) and Yandle, Bhattarai, and Vijayaraghavan (2004) put forth an optimistic picture while de Bruyn, van den Bergh and Opschoor (1998) and Stern (2004) puts forth bleak pictures. Cavlovic, *et al.* (2000) provide a meta-analysis of the early empirical results. Copeland and Taylor (2003) and Brock and Taylor (2005) provide extensive discussions of the theoretical models. Closest in spirit to this paper is a review article by Levinson (2002) that deserves much more attention than it has received.

The initial reaction to Grossman and Krueger was a flurry of work both empirical and theoretical. Empirical confirmation of their provocative findings soon came from World Bank researchers. Shafik and Bandyopadhyay (1992) and Shafik (1994), using additional environmental indicators and more countries, found either an EKC relationship or monotonically improving environmental quality with income (with the exception of dissolved oxygen in rivers and CO_2). They also started to use other variables as predictors, such as trade indicators and political freedom. Panayoutou (1993) used a larger set of purely cross-sectional data and found support for a number of EKC relationships. Selden and Song (1994), using the same GEMS database as Grossman and Krueger, improved upon the econometric techniques and still found empirical support for an EKC.[5] Grossman and Krueger (1995) expanded their initial analysis to include additional pollutants available from the GEMS project.

Another important result was that of Holtz-Eakin and Selden (1995) who found CO_2 emissions were increasing over any plausible income range for the broad set of countries they examined. This result seemed to nicely limit the range of the EKC prediction by making the obvious distinction between local and global externalities and, of course, pointed for the need for global action (*e.g.*, Kyoto) to deal with the problem.[6]

In commentary in the more public part of the policy arena (*e.g.*, Bartlett, 1994) economic growth *per se* began to be touted as the answer to environmental problems. This was never quite what Grossman and Krueger (1991) had said. They had been clear about the nature of their assumptions and put in all the usual caveats typical of careful

[5] Selden and Song (1994) argued the immediacy of health problems in cities would drive clean-up efforts.
[6] The Montreal Protocol represents a successful example of developed countries helping to subsidize the phase out of a global externality, CFCs, in developing countries by the diffusion of clean technology.

researchers. They were particularly forthcoming about the reduced form nature of their model limiting policy interpretations of their results. Still Grossman and Krueger (1996) felt compelled to reiterate these points again in a policy forum piece in *Environment and Development Economics* and to emphasize that "there is nothing inevitable about the relationship between growth and environment that has been observed in the past." Taking on their most prominent critics, Grossman and Krueger note:

> "Arrow, *et al.* [1995] conclude, 'economic liberalization and other policies that promote GNP growth are not substitutes for environmental policy'. We would agree. But we would go further and state that neither is the suppression of economic growth or of economic policies conducive to it a suitable substitute for environmental policy."

Interestingly this statement is consistent with either repudiating the IPAT view that growth in income is detrimental for environmental quality or the position that there is no relationship between income growth and environmental quality.

Theoretical Issues

The major theoretical advance concerning the possibility of an EKC relationship was made quite early when Grossman and Krueger (1991) pointed out three possible impacts of an increase in economic activity due to a trade agreement.[7] The first was an increase in the *scale* of current production, the second a change in the *composition* of current production, and the third a shift in production *techniques*. The first factor naturally leads to more pollution in the face of economic growth predicted by freer trade. The second had ambiguous effects in any particular country but could not result in a reduction in pollution everywhere. This leads to the possibility of pollution havens and a

[7] Note these arguments are cast in terms of total emissions. The theoretical literature alternatively uses production (emission) when the driving force is technology and utility (ambient quality measures) when the tradeoff is between consumption and pollution. Changes in population size are rarely considered.

race to the bottom that lay behind the debate on NAFTA. Only the third factor points to the possibility of lower pollution levels being associated with economic growth.

Grossman and Krueger were not the first to address the influence of trade on pollution, and the more general over-arching theoretical result (*e.g.*, Pethig, 1976) that differences in pollution control costs across countries could give the country with lax standards a comparative advantage in producing “dirty” goods was well known. In the late 1980’s, a related literature (*e.g.*, Sutton, 1988) started to spring up focused largely on agriculture, the environment and trade using a computable general equilibrium (CGE) framework. The difficulty with CGE models of the day was that they embodied a constant-returns-to-scale assumption to make them tractable that effectively guaranteed the prediction of an adverse environmental outcome. With environmental concerns a flash point for opposing free trade agreements and empirical evidence suggesting trade was good for the environment; it is not surprising theoretical work started to fill the void.

López (1994) was one of the first such papers out the gate and into print. He looks at stock externalities (*e.g.*, soil erosion) and shows a key issue was whether producers internalize the externality. If so, the growth in income/trade would be reflected in improved environmental quality. López is careful to note this internalization could happen via voluntary cooperative agreements, but for the usual reasons might require corrective government action. Assuming constant returns to scale, non-stock externalities and non-homothetic preferences, he shows as the substitution elasticity between conventional output and pollution falls and relative curvature of income in the utility function (the relative risk aversion coefficient) falls, an inverse U-shape income-pollution relationship emerges. The López article, which had first appeared as a widely-circulated

World Bank working paper, was highly influential. Aimed squarely at environmental economists, it invoked both the production and utility sides of the picture as an explanation for the emergence of empirical EKC under plausible parameter values without removing any of the need for the usual tools to deal with pollution.[8]

The theoretical literature also took a more abstract direction tied to macroeconomic work on optimal growth. Using an overlapping generations approach, John and Pecchenino (1994) "provide a theoretical explanation of the observed correlation between environmental quality and income." They note the possibility of multiple equilibria and over-provision of environmental quality as well as the potential importance of increasing returns to scale, which gained greater emphasis later. Presciently they conclude: "The relationship between growth and the quality of the environment is complex."

Jones and Manuelli (1995) and Stokey (1998) provide more satisfying variants from the macro-growth perspective. Jones and Manuelli focus on the interaction between growth, the environment and collective decision making. In their model, the young can choose to tax pollution which will exist when they are older. The nature of collective decision making influences the income-pollution path chosen, and, hence, societal utility. In doing so, they helped move the debate away from the autonomous correction of pollution by getting wealthier. López and Mitra (2000) provide a more concrete version of this story with stronger assumptions focusing on corruption, and show corruption does not preclude and EKC but the turning point will be higher than without it. Stokey (1998)

[8] Selden and Song (1995) soon followed advancing the idea that pollution abatement expenditures followed a J-curve increasing rapidly at some point as a country became richer and that this produced the inverted U in pollution. They showed that this concept was implicit in some earlier models of optimal growth incorporating environmental considerations.

takes dead aim at the growth-is-bad crowd with her provocative title: "Are There Limits to Growth?" Using a simpler Ramsey framework with infinitely lived agents, she shows the key to inducing the EKC relationship is being on the right capital accumulation path with respect to pollution control.[9] A pollution tax of the right magnitude can help ensure this happens, whereas the usual command and control approach has difficulties.

Many nuances that have since been developed which are covered in detail by Brock and Taylor (2005). One of these stands out (Andreoni and Levinson, 2001) as an instant classic for graduate reading lists due to its theoretical simplicity, the compelling underlying intuition, and easy to explain empirical evidence. Andreoni and Levinson first illustrate their model using a familiar Cobb-Douglas framework. Utility is defined on consumption and pollution, with pollution in turn dependent on both consumption levels and pollution control efforts (which reduces consumption). An inverted U-shaped EKC relationship occurs if there are increasing returns to scale in terms of the pollution control effort. One gets a linear relationship if there are constant returns to scale and a U-shaped relationship if there are decreasing returns to scale. Andreoni and Levinson ask how much longer it takes to sweep a floor covered with two centimeters of dust rather than one centimeters of dust. If the answer is less than twice as long, there are increasing returns. They go on to cite relevant empirical evidence from coal fired power plants and results from large government surveys on U.S. pollution control expenditures by industry, suggesting increasing returns to scale may be the norm. Their theoretical framework is generic enough to encompass a variety of underlying forces that might give rise to increasing returns. This includes from Jones and Manuelli's (1995) better institutions

[9] The strong cautionary note is the Arrow, *et al.* (1995) critique which points out that feedbacks between ecosystem services and traditional industrial capital stock accumulation are not well understood, and thus, there may not be clear signals of problems until thresholds have been exceeded.

story since institutions look like a classic fixed cost and Stokey's (1998) story in which better technology becomes more possible as the scale of production increases. Clearly, increasing returns to scale in pollution control is possible and likely in many cases. Income growth, however, need not be the driving force behind increasing returns to scale for pollution control. Population growth, technological change, or shifts in consumption/trade patterns all work equally well as the source.

Empirical Issues

Back to Mexico

The immediate purpose of Grossman and Krueger's work was to argue that their empirical estimates suggested Mexico was either close to the turning point where an increase in income would result in a decrease in pollution rather than an increase. It is probably worth a trip to Mexico to see what transpired.

Let's look at a simple graph (Figure 2) of the average annual PM_{10} concentration in the Tijuana area taken as a weighted average of the available monitors starting in 1997. The monitors are part of a joint effort with Mexico, the State of California, and USEPA and part of USEPA's standard air quality database.[10] The 1997-2007 period covers most of the relevant history of the NAFTA agreement. Tijuana is one of the wealthiest parts of Mexico with income steadily rising over this time period and the area most closely linked to the NAFTA agreement.[11] Here a clear picture emerges. For over a decade, there has

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[10] http://www.epa.gov/ttncatc1/cica/sites_sd_e.html. Particulates are generally thought to be the pollutant with the most severe health effects, with smaller particles doing the most harm. The PM_{10} measure (ten microns) is better than the total suspend particulates (TSP) measure used in early EKC studies but not as good as the $PM_{2.5}$ measure which is not available for Tijuana over this time period. Fernandez and Carson (2002) provide an overview of NAFTA related environmental activities in border areas.

[11] NAFTA started in 1994 and was fully implemented by the end of 2007. At the beginning of 1994, Mexico was hit with the Peso Crisis which lasted roughly two years, so the initial years of the agreement are confounded by that event. While income trended up over this time period, there were some ups and downs. Other than a drop in 2000, these don't map very well onto changes in the PM_{10} concentrations.

been virtually no change in the ambient PM_{10} concentrations. A casual reading of Grossman and Krueger suggests particulates should have fallen substantially, as roughly a 20% increase in income occurred over this time frame.

The other wealthy area is Mexico City. Here too there is a mixed picture. Mexico City has long had some of the worst air pollution the world. A few air pollutants, most notably lead, which was phased out in gasoline, have declined but most others show little post-NAFTA change. The current struggle to control Mexico City's air pollution is well documented in the volume by Molina and Molina (2002) and specific policies have been the subject of investigation by economists (*e.g.,* World Bank, 2002; Davis, 2008).

It is also possible to look at total emissions of major air pollutants from Mexico where the 1990 to 1995 period can be thought of as pre-NAFTA and the 1995-2000 post-NAFTA period. Table 1 shows fairly slow growth in the pre-NAFTA period. In contrast, the post-NAFTA period shows fairly rapid growth for all of the major air pollutants, the opposite of what might have been hoped for if a strong EKC relationship held.

Table 1: Emissions of Major Air Pollutants in Mexico 1990-2000

	1990	1995	2000
CO	12,297	13,268	20,595
CO2	308,806	329,886	386,100
NOX	1448	1584	2257
SO2	2106	2251	2934
VOC	3242	3356	4286

Source: WRI (Earthtrends Website, 20 September 2008), Thousands of Metric Tons

But this is not the whole story. There are, of course, other confounding variables. Population increased over the time period, albeit at a slower rate than it had been, producing a flatter but still increasing per capita growth in the major air pollutants.

Gallagher (2004) and Stern (2007) provide comprehensive looks at the environmental impacts of NAFTA and reach similar conclusions that much of what transpired was the continuation of long term trends and the convergence over time of Canada, Mexico, and the United States in a technological sense, which to a large degree cannot be clearly tied to NAFTA. Surprisingly, Gallagher finds that that increased income in Mexico did not result in more government spending on environmental policies. Stern notes: "that regarding air pollution and energy efficiency none of the more extreme predictions [good or bad] of the outcomes of NAFTA have come to fruition to date."

Grossman and Krueger did not explicitly study Mexico City's air pollution because it was not included in the GEMS (global environmental monitoring) database of pollutants and cities. In retrospect, it would have been possible to put together some type of dataset. There have long been efforts to monitor and deal with the air pollution situation in Mexico City (*e.g.,* Alvarez, 1987) and along the U.S.-Mexican border (*e.g.,* Applegate and Bath, 1974). Grossman and Krueger's big assumption was that something could be learned about the impact of NAFTA increasing income in Mexico on pollution from a reduced form equation with data with no direct connection with Mexico and it was this assumption that gave the EKC its broad policy relevance.[12]

A Detour to the United States and Side Trips to Malaysia and China

Much of the initial empirical critique of the EKC view of the world revolved around the fact that relatively few developing countries were used in the sample. Selden

[12] Grossman and Krueger did perform a different analysis using the U.S. input-out tables and associated pollution to ask what would happen if particular sectors of the U.S. economy shifted to Mexico as a result of NAFTA. While not directly part of the EKC literature, it was seen as supportive of the general EKC result. Herriges, Lucas and Wheeler (1992) extend this type of analysis to a set of 80 countries and found an inverted U-shaped curve with respect to output per unit of GDP, although they found that the pollution intensity of manufacturing steadily rose with income. Birdsell and Wheeler (1992) found that the mix of industries in Latin American countries with more open economies was associated with being cleaner from an environmental perspective than those in countries with less open economies.

and Song's (1994) analysis, for instance [Table 1], showed that there were 22 high, 6 middle, and only 2 low income countries. Obviously, not a lot of data from which to identify a non-linear relationship with respect to income. Further, it became clear that in spite of best efforts, the data was not as comparable across countries as one might hope. Stern *et al.* (1996) in an early influential critique note: the pollution data used in environmental Kuznets curve studies are "notoriously patchy in coverage and/or poor in quality." The World Resource Institute (WRI) guides (1994; 1996) that served as a source of air pollution data for some EKC studies contained the warning: "These data on anthropogenic sources should be used carefully. Because different methods and procedures may have been used in each country, the best comparative data may be time trends within a country." Even this warning was probably insufficient. Comparing the estimates in the 1994–95 and 1996-97 WRI guides shows large differences in some instances for the same pollutant in the same country and year.

One way out of this dilemma was pointed out by Carson, Jeon and McCubbin (1997) who look at only one side of the inverted U by using data from the 50 U.S. states. This substantially increased the sample size and resolved data comparability questions since USEPA measured pollution the same way in every state. Further, there was reasonable income range with per capita income in Connecticut, the richest state, over twice that of Mississippi, the poorest state. The U.S. was on the down side of any turning points that had been found for air pollutants other than CO_2 so there was a strong prediction that air pollution should monotonically decline with income.

Carson, Jeon and McCubbin (1997) showed per capita emissions in a 1990 cross-section of state level point-source emissions for air toxics, CO, NOx, SO_2, VOC, and

PM_{10} all monotonically decline as income increased. Similar results were shown for carbon dioxide emissions for point and mobile sources combined at the state level and for PM_{10} emissions from a sample of 1748 counties where data was available. The results were shown to be robust to the use of different statistical techniques and functional forms, although the specific treatment of outliers could have a large impact on significance levels and the shape of the curve fit. The most striking finding across all of the air pollutants was that the high income states uniformly had low per capita emissions while the per capita emissions from lower income states were highly variable.

Though the Carson, Jeon and McCubbin cross-sectional results provide support for the EKC hypothesis, their analysis of a panel data set of air toxics emissions over a six year period from 1989 to 1994 showed no relationship between changes in income and per capita emissions. On the other hand, states with high initial incomes were associated with larger reductions in per capita emissions over the time period. The same was true of states that had high initial per capita emissions levels. Put simply, the wealthy states continued to reduce emissions, irrespective of changes in income levels, as did dirty states. These results are consistent with a strong regulatory structure built up by higher income states and a technology story whereby it is cheaper to reduce pollution if there is lots of it. Changes in income which lie at the heart of thinking about the EKC as having policy relevance thus seemed misleading, at least in this case where comparison across political jurisdictions was least likely to be an issue.

Vincent (1997) looked at an interesting panel data set of 17 Malaysian states and six pollution measures (TSP and five water pollutants) from the late 1970’s through 1991, which is arguably of higher quality than data available from most developing countries.

In no case does he find evidence of an inverted U-shape pattern even though the change in income should have encompassed typically estimated turning points. Malaysia's experience cannot be easily reconciled with the predictions concerning income-pollution relationships that come from models of Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992), and Selden and Song (1994). Some pollutants predicted to increase actually decreased, while pollutants predicted to decrease increased. Even when the direction of change is correctly predicted the magnitude of the change was substantially off. However, various policy measures taken by the Malaysian government do seem to provide an explanation for the observed patterns. Vincent succinctly summarizes his conclusion from this effort by saying:

> "The lack of evidence of EKCs in Malaysia does not prove that EKCs do not exist anywhere. It does indicate, however, that policymakers in developing countries should not assume that economic growth will automatically solve air and water pollution problems."

I now turn back to the United States to look at a study by List and Gallet (1999) that uses a unique data set put together by the USEPA of per capita SO_2 and NO_x emissions at the state level from 1929-1994, with data before 1985 based on estimates of production activities at the state level. Having a much longer time series plus real income levels that range from just over $1000 to over $20,000, List and Gallet are able to estimate individual EKC models for each state for the two pollutants and find EKC-like turning points. These appear driven by substantially different processes across states. This simultaneously provides empirical support that an EKC process is at work but rejects a core concept that lies behind much of the EKC work such as Grossman and Krueger's, that a common process drives the income-pollution relationship after taking account of state fixed-effects terms. This negates the usefulness of empirical estimates of the income-pollution relationship derived from other political jurisdictions. In List and Gallet's work turning points between states often differ by a factor of two or three, and in some instances, an order of magnitude. Any attempt to force the different states into a single underlying process can be statistically rejected and *a priori* one would expect different U.S. states to be much more alike than different countries. This casts doubt on what is really being learned from the "average" parameter estimates in the typical cross-country panel dataset and whether those parameters have any relevance for what is likely to happen in an individual country. Given List and Gallet's result, it should be no surprise that statistical tests of whether OECD and non-OECD countries can be pooled, as is typical in the standard EKC regression, are easy to reject (Cole, 2005). In retrospect, a clear distinction should have been drawn between a weak conceptual version of the EKC a particular political jurisdiction is likely to have income related turning point which is supported by U.S. state-level evidence and the much stronger, empirically actionable version with a common income-pollution relationship across political jurisdictions after controlling for a small number of relevant factors which is not supported that evidence.

Completing our tour of the United States is Aldy (2005) who looks at CO_2 emissions across the 48 continental U.S. states. Aldy constructs annual estimates for each state from 1960 to 1999 using the same basic approach of extrapolating from fossil fuel use that underlie the quasi-official IPCC estimates maintained by Oak Ridge National Laboratory. Consistent with Carson, Jeon and McCubbin's cross-sectional result, Aldy finds evidence supporting an EKC relationship for the United States, and now with a much wider income range can estimate reasonably precise turning points. Like List and Gallet, Aldy finds evidence that different states follow substantially different income-pollution processes. He adds additional explanatory power, in this case, energy endowments and climate variables that influence the results. Aldy examines the dynamic properties of the time series and finds them problematic (an issue examined later) and quite different across the states. Perhaps the paper's most interesting result is that a consumption-based per capita emissions relationship has a turning point about 40% higher than a production-based estimate.[13] Higher income states are effectively importing their energy consumption from lower income states. This raises questions about what is the EKC relationship of interest that will be examined later.

Turn now to China, Auffhammer and Carson (2008) look at forecasting CO_2 emissions, a critical feature in any discussion of climate policy. They use provincial-level per capita emissions with the national estimate obtained by aggregating across provinces from 1985-2004. Here, there is considerable income variation across the Chinese provinces both temporally and spatially making China an ideal case to look at. Given past estimates of turning points for CO_2, all of the observations should be on the upside of any inverted U. Auffhammer and Carson find there is a highly significant EKC relationship in their panel data estimated in the traditional quadratic fashion. However, the effect while still important is diminished considerably when lagged emissions are included as a predictor. Using a flexible smoothing spline for income along the lines of Schmalensee, Stoker, and Judson (1998) suggests a flattening out of per capita emissions with respect to income. No downturn is evident in the income range observed. Auffhammer and Carson argue that using lagged emissions is consistent with emissions being driven to a

[13] Aldy, by having data both on where U.S. consumption and production took place, was able to incorporate into the dependent variable the spirit of analysis run by Suri and Chapman (1998), who looked at per capita energy consumption for 33 countries over 20 years as a function of income and trade variables to determine the extent to which energy embodied in the form of goods was being imported and exported.

large degree by the technological efficiency of long lived capital stock (*e.g.*, coal fired power plants) and show the size of the provincial specific lag has very substantial implications for the path of a province's CO_2 emissions. Further, the lag structure eliminates some of the time series issues discussed below. The Auffhammer and Carson paper moves away from the association/causality framework inherent in most EKC papers to an out-of-sample forecasting performance perspective. Inclusion of a quadratic income term clearly helps over a model with only a linear term.

Will the Real EKC Please Stand Up?

The discussion in the previous subsections raise a subtle question: what is the dependent variable on which the EKC is defined? Aldy's (2005) work uses two distinct definitions of the EKC relationship that operationalize the concern that all richer areas have done is to offload dirtier production to poorer areas. Other definitions of what was meant by an EKC have been implicitly introduced without making any distinctions between them. This plethora of EKC definitions has implications for both the theoretical and econometric discussions below. The original Grossman and Krueger (1991) work used ambient quality measures in defining an EKC relationship. Later papers, however, often worked with per capita emissions and, in still other cases, with total measures like the quantity of land deforested. It is possible to make a reasonable case for, and against, any of these.

Ambient quality measures have the closest tie to social welfare but are inherently impacted by population and physical conditions such as the presence of mountains and climate.[14] Per capita measures are easily interpreted in terms of how a resource is being

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[14] Most of these effects are proxied for using fixed effects. Cropper and Griffiths (1994), who look at deforestation, is one of the few papers that tries to separate out the independent effect of population growth.

used or how much pollution is being created on average by each person. Such measures are popular because they are easily compared across countries and can often be estimated from production data. The difficulty, of course, is that they don't necessarily bear any relationship to individual utility. The concept, like the popular environmental footprint statistics, ignores the ability of the environment to cope with the imposed externality. Two cities with the same per capita SO_2 emissions may have radically different exposure levels. Per capita measures have weak ties to most theoretical EKC models which assume that at some point it is likely to be advantageous to tradeoff some income for better environmental quality.[15] Aldy's production versus consumption per capita measures only drive this point home further as it is possible once trade is allowed to consume goods without experiencing externalities associated with their production (Suri and Chapman, 1998).

For things like deforestation, which is not the result of widely shared industrial processes, it is natural to think of the total amount of forested land, and hence the tie to population is much more tenuous. It may be useful to distinguish between stocks, such as the percent of the land forested, and flows, such as the rate of deforestation in a particular year (Shafik and Bandyopadhyay, 1992).

Econometric Issues

The econometric foundations of EKC models have long been both suspect and fragile. Stern (2004) provides a detailed and highly critical overview of many of the specific econometric issues related to the EKC heavily drawn upon in this section. A prime example of the problems with the EKC is illustrated by Harbaugh, Levinson and

[15] While this tradeoff typically requires government action, Pfaff, Chaudhuri and Nye (2004) using a household production function show Pakistani households switch to cleaner fuels as their income increases.

Wilson (2002) who look at an extended version of the GEMS dataset air pollution variables originally used by Grossman and Krueger. Their analysis added several more years on each end of the GEMS dataset, corrected data values and filled in a considerable amount of missing data. They conclude:

> "The evidence for an inverted U is much less robust than previously thought. We find the location of the turning points, as well as their very existence, are sensitive to both slight variation in the data and to reasonable permutations of the econometric specification."

Part of the Larger Cross-Country Growth Equation Debate

From a larger perspective, the EKC debate can be seen as a subplot in the much larger cross-country growth equation play that took center stage in economics in the late 1980's and early 1990's (*e.g.*, Barro, 1991; Mankiw, Romer and Weil, 1992) with the availability of the Summers and Heston (1988) Penn World Table data underlying both. The possibility that economists could predict economic growth as a function of a few key input variables clearly captured the imagination and attention of the profession. However, the cracks soon became evident. As Levine and Revelt (1992) in an early systematic and highly cited review of the evidence from an econometric perspective put it:

> "A vast literature uses cross-country regressions to search for empirical linkages between long-run growth rates and a variety of economic policy, political, and institutional indicators. This paper examines whether the conclusions from existing studies are robust or fragile to small changes in the conditioning information set. We find that almost all results are fragile."

Note the striking the similarity between Harbaugh, Levinson and Wilson (2002) and Levine and Revelt's (1992) conclusions.

The major issue that dominates the early EKC discussions was the representativeness of samples used and the comparability of the pollution measure used.

At heart of this issue is what can really be learned from the regression models estimated. The most glaring problem was the relative lack of developing countries in GEMS data that underlay much of the early EKC work. But as Stern (2004) points out the deeper problem is that statistical tests usually reject random effects specifications due to the correlation between the random effects and the included covariates. The implication of this finding is that while the fixed effect model may be consistent for the sample on which it is estimated, the parameter estimates of interest cannot be generalized to another sample. This makes any EKC model missing the countries of interest suspect. Ironically, the fixed effects models estimated on U.S. state level data or their equivalent in other countries are fine because all of the political units of interest are all included.

The major reason for the set of countries used in most EKC studies has been the availability of an indicator of interest measured in a reasonably comparable way. As Grossman and Krueger put it in their 1995 *Quarterly Journal of Economics* article:

> The main contribution of the present paper is that it employs reliable data and a common methodology to investigate the relationship between the scale of economic activity and environmental quality for a broad set of environmental indicators. We attempt to include in our study all of the dimensions of environmental quality for which actual measurements have been taken by comparable methods in a variety of countries.

They go on to note that they are using all of the GEMS air and water quality data. At some level, the deficient developing country representation in GEMS dataset was symptomatic of the lack of interest in environmental issues in those countries at the time. A deeper problem was that even measures of ambient quality across cities taken using comparable equipment are suspect without a comprehensive monitoring network. This issue was recognized in early U.S. studies like Lave and Seskin (1977) and eventually led to monitoring schemes with spatial placement of monitors designed to gather comparable data based on population exposure (Auffhammer, Bento and Lowe, 2009).

Pollution Measurement Issues and the Focus on SO_2

Some measurement issues related to the GEMS data concerning both coverage and data quality are avoided with CO_2 and SO^2 emissions calculated from fuel consumption data using conversion ratios. CO_2, as noted earlier, had the readymade explanation for why it showed, at best, a weak EKC relationship, in that it was a global not a local externality. SO_2 became the poster child for the EKC relationship.

In retrospect, the emphasis on SO_2 may have been misplaced for a number of reasons, and it is unfortunate that some of the most sophisticated analysis (e.g., Copeland and Taylor, 2003) has been directed at this pollutant. SO_2's human health impacts relative to fine particulates or ozone are small. Stern's (2006) analysis using emissions data from a large number of countries shows SO_2 levels have fallen over time with advances in technology across the world and with greater rapidity in developed countries. His estimates still suggest an EKC relationship, but the turning point is now well outside the sample range above fifty thousand dollars–an order of magnitude higher than found in some of the earlier studies. Deacon and Norman (2006) look at within-country SO_2 data for 25 countries using 1970 to 1992 GEMS data and show there is an income-SO_2 relationship consistent with an EKC in more individual countries than would be expected by chance. (Surprisingly, even this very weak test is failed for the two other commonly used GEMS air pollutants, smoke and particulates.) However, this relationship appears to be driven almost entirely by increasing incomes and decreasing SO_2 concentrations in wealth democracies. Deacon and Norman conduct further analysis allowing income and purely trend driven factors to explain within-country pollution patterns during the 1970s and 1980s. When they do find a separable role of income it is generally insignificant and, "where significant, its effect is not consistent with predictions of the EKC hypothesis."

Problems with data quality and non-random/incomplete samples plague much of economics so there is nothing unique about the EKC experience. Most good papers are blunt and up front about the problem as Panyatou (1997) was: "Data on environmental problems are notoriously patchy in coverage and/or poor in quality. The only available data are not necessarily appropriate for testing the EKC hypothesis, estimating its parameters, and drawing inferences about future trends." Having made this acknowledgement, researchers then fixed as much of the problem as possible and proceeded to estimate the best model they can. Seeing a clear association between income and pollution that was strikingly different from the linear projection typically assumed it was natural to ask what lies behind the reduced form black box. This question was most prominently put forward in the early work employing cross-sectional data in the 1990's by Panayotou (1993; 1997) and pursued by a number of other authors (*e.g.,* Stern, Common and Barbier, 1996; Perman and Stern, 2003). Getting inside the black box implied one of two things: finding the policy levers that reduced pollution or showing causality from income to pollution. Panayotou followed the first course.

Role of Other Covariates

The earliest EKC research like Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992), and Selden and Song (1994) were all concerned with the influence of other variables like population density and trade indicators, either because they were possible alternative explanations to income or because they increased the precision of the estimates. To these Panayotou sought to add something more clearly exogenous and likely correlated with pollution control policy. His choice was one of now standard political variables on the quality of institutions related to the enforcement of contracts. (The quality of bureaucracy performed similarly which is expected given its high correlation with the contract variable.) The contracts variable is shown to shift the EKC relationship up and down by a considerable amount.

Other papers are supportive of some type of policy explanation. Grossman and Krueger's original work showed, controlling for other variables, communist countries were dirtier with respect to SO_2. Torras and Boyce (1998) show that in low income countries, improving political rights and civil liberties or the equality of the income distribution was typically associated with lower pollution levels in an EKC. They conclude: "The estimated effects of per capita income on pollution generally weaken once we account for inequality effects, but they do not disappear altogether." Barrett and Graddy (2000) use some of the same variables as Torras and Boyce but a broader range of GEMS pollutants and specifications. They start by demonstrating high correlations between various political/civil rights variables and income across countries. This is clearly problematic for showing separate effects for political variables and income, particularly given sizeable measurement error in both. Their empirical results, while similar in some ways to Torras and Boyce, are much more mixed, as some pollutants don't follow the same pattern as the commonly examined GEMS air pollutants. In puzzling over this they note that: "Research that links the inverted-U to actual policies would seem to be badly needed." Deacon and Saha (2006) provide a survey of the now fairly sizeable literature on public goods provision under different political conditions which suggests a robust association between the provision of environmental goods and more democratic systems. The major caveat with pushing this line too far is that many of the same issues with the EKC exist when looking at the role of political variables on the provision of environmental goods. Fundamentally, the political story is more satisfying as it is about how public preferences get translated into changes in environmental quality as income increases. However, as McConnell (1997) has shown from a theoretical vantage point, having positive income elasticity for environmental quality is neither necessary nor sufficient for an EKC relationship, making interpretation of empirical results difficult.

Difficulty of Showing Causality

A more fundamental problem is the need to show causality between income and the environmental variable of interest. This problem is not unique to looking at the underpinnings of a possible EKC relationship. It plagues most cross-country reduced form models looking at growth. A definition of causality frequently used by economists due to Granger (1980) is whether a change in one variable occurs before another variable and helps to predict that variable. While this is an intuitive definition, it is not a particularly strong one and there are a number of standard econometric issues involved including the role of conditioning variables and specification of the data generating process. Further issues are invoked if the variables of interest are not stationary from a time series perspective and panel data is used.

Recently tests using Granger causality (*e.g.*, Perman and Stern, 2003) have started to be performed. These results are disturbing. Key variables such as income can often be shown to be integrated (*i.e.*, non-stationary) suggesting that EKC regressions may result in spurious results. In some cases, Granger causality implies that variables must be cointegrated but there is little statistical support for the presence of cointegrated relationships consistent with an EKC. With few exceptions, early work on the EKC did not take the time series structure of the data seriously. Yet the whole conceptual notion behind the EKC was a long run equilibrium relationship in which increases in income would lead, after the EKC turning point, to less pollution being generated.

Further Issues: Functional Form for Income and Pollution Havens

One could take up any number of other econometric issues with the EKC or look at specific pollutants/amenities that have been examined but this would take up more space than available here. However, two issues should be briefly mentioned. The first is the common practice of fitting a cubic function to income as a generalization of the EKC's standard quadratic in income. Since the cubic term is sometimes significant, there has been the tendency to interpret this result as suggesting that environmental conditions eventually take a turn for the worse as income increases. More likely there is simply a flattening of the income-pollution relationship not approximated well by a quadratic function. This can be seen in papers that fit sufficiently flexible models.

The second is the concept of pollution havens that drove some of the original concerns over free trade agreements, since one obvious source of an EKC relationship was for a wealthy country to transfer its dirty industry to a poor country. Most influential was an early empirical paper by Tobey (1990) suggesting the stringency of environmental regulation had little impact on trade patterns. The usual rationale advanced is that pollution control costs are usually small relative to total cost and multinational firms who run similar operations across countries do not want to be seen as running a dirty operation in developing countries. Since then, a number of effects have been found, but these are usually small or temporary except for a pattern of transferring manufacturing from developed to developing countries, for which there are other potential causes. Cole (2004) provides a literature review and an empirical analysis consistent with this view. Levinson and Taylor (2008), however, have recently shown how unobserved heterogeneity, endogeneity and aggregation issues tend to bias the standard analysis against finding a pollution haven effect. Their empirical results using data from Canada, Mexico, and the United States suggest that pollution control expenditures have fairly sizeable and economically meaningful impacts on trade patterns.

Some Concluding Thoughts on the Interpretative Dance of the EKC

In the shadows of the EKC versus IPAT debate, the champions of growth and no growth dueled. The initial EKC literature clearly gave the edge to the growth side. The notion that growth was good for the environment struck fear deep into the souls of many with an ecological orientation and undermined their core beliefs. They wanted to counterattack but the weight of the empirical evidence was too strong. The simple graphs of concentration and emission levels for common pollutants told the tale: pollution tended to decline not increase after some point as income increased. Rich countries were generally cleaner than the major developing countries. No longer was it credible to claim that economic growth was axiomatically bad for the environment as the IPAT equation suggested. Eventually, even many of the proponents of that framework gave in and modified the equation to allow for the possibility that income could have a beneficial effect (Waggoner and Ausbel, 2002; York, Rosa and Dietz, 2003).

The other side was not without weapons. Some growth proponents overplayed their hand and many paid little, if any, attention to the careful caveats the early EKC researchers put forward. The major development banks, and indeed, any economist who had ever ventured outside of their office to look at the policy process at work knew that growth could never automatically make the environment better. Environmental externalities have proven remarkably hard to overcome. The necessity of having good institutions to deal with environmental externalities story put forward by Arrow, *et al.* (1995) resonated among more reasonable proponents of growth. Its emphasis on the importance of feedbacks between the economy and ecosystem services and possible thresholds had less impact even though that was the major focus of the paper. The belief that environmental conditions would get better with the right regulatory structure as countries got richer was seen by many as automatically addressing this issue. After all, it was clear that *all* wealthy democracies had solved the key environmental problems that plagued their earlier pasts and were devoting considerable attention and resources to ensuring that current problems were kept at a manageable level.

The difficulty with this view as Stern, Common and Barbier (1996) forcefully pointed out is that income levels in countries where much of the population lives are substantially below estimating turning points so that environmental conditions are going to get worse in most places for a long time before they improve, even if one believes the EKC story. More representative data and better econometric techniques have generally resulted in higher turning point estimates, if they exist at all, reinforcing this dismal view.

As we near the end of this almost two decade long search for the environmental Kuznets curve, it is useful to reflect back on what has been learned. Grossman and Krueger set out to demonstrate three things. First, increases in income were not automatically associated with increased pollution. Second, freer trade would not necessarily make pollution worse. Third, a free trade agreement with Mexico would make the pollution situation in Mexico and the United States better not worse. On the first two out of three, Grossman and Krueger have clearly succeeded in changing the views of most economists, and the bulk of the empirical evidence supports them. On the third point, the counterfactual is always hard to know. Our cursory examination of the evidence from Mexico suggests that Mexico is at best treading water with respect to pollution. However, this may not be as bad as it appears. With a large increase in economic output and population, it would have been easy to forecast the much worse path many critics contend was likely.

On the main message taken from Grossman and Krueger's work by the economics profession that trade and higher income levels would make for a better environment, the supporting evidence is scant, fleeting and fragile. Desperately sought, causality has yet to be conclusively found. Ultimately, dogged pursuit of ever better empirical estimates has shown the emperor has no clothes with respect to a causal income-pollution relationship, although as Auffhammer and Carson (2008) show there may be some short to medium term gain by using income in a forecasting equation. This, of course, cuts both ways. It is actually much more harmful to the IPAT view of the world where pollution is increasing monotonically in income on a per capita basis and growing affluence is still seen as the major cause of deteriorating environmental conditions. There is little evidence that stopping growth would improve pollution levels. Instead, there is robust evidence that pollution levels typically turn down at high income levels.

The difficulty is finding a common underlying process at work and linking specific changes in income to specific changes in pollution on the time scale of a few years. It may be possible to resurrect a much looser view of the reduced form EKC where different political jurisdictions can follow very different EKC paths for the same pollution indicator and that income impacts this indicator on a much longer time scale through a diffuse set of paths. Such a formulation, however, is not very useful for policy purposes and, for all practical purposes, is close to being empirically untestable from a causal perspective.

Dasgupta, *et al.* (2002) put forth a positive but realistic view of what remains of the original EKC story:

> "The environmental Kuznets curve posits an inverted-U relationship between pollution and economic development. Pessimistic critics of empirically estimated curves have argued that their declining portions are illusory, either because they are cross-sectional snapshots that mask a long-run "race to the bottom" in environmental standards, or because industrial societies will continually produce new pollutants as the old ones are controlled. However, recent evidence has fostered an optimistic view by suggesting that the curve is actually flattening and shifting to the left. The driving forces appear to be economic liberalization, clean technology diffusion, and new approaches to pollution regulation in developing countries."

This is, however, a far cry from a statement about an income-pollution relationship. Indeed, it could be recast as a statement about good government and technology feeding into an optimistic view of the IPAT equation. It subtly echoes the original economic critique that societal choice is missing from the mechanistic IPAT view of the world. Income can influence pollution levels, but it may do so in slow and subtle ways through its influence on other factors such as improving institutions. In practice it may be difficult to separate out growth and the diffusion of clean technology. One potential way out of this dilemma is to think of the EKC, not in terms of its typical reduced-form representation, but in terms of a structural model where income influences demand and supply factors that directly influence pollution (Kolstad, 2006).

A more pessimistic view of the situation is that the emphasis on the possibility of an EKC engendered an unfounded optimism that growth was helpful for the environment, resulting in a lost decade or more where environmental economists failed to focus on other potential driving forces behind changes in environmental quality within a country. As a group, we largely forgot the other two factors in the IPAT equation, population and technology. For every dozen EKC papers there might be one paper seriously looking at how the regulatory structures and incentive systems in place across different political jurisdictions can be used to improve environmental quality in a society where population is increasing, income is improving, and technology from around the world potentially available. What is needed is work on what factors result in translating some of the increased income from growth into improved environmental quality.

The initial EKC empirical results reinforced the Faustian bargain struck at the 1972 United Nations Conference on the Human Environment in Stockholm that developing countries should be able to ignore their environmental problems until they developed and became wealthier unless developed countries footed the bill. We now know that developing countries can take many actions (Dasgupta, *et al.*, 2002) to improve the environmental conditions for their people and that these actions can have enormously positive implications for societal welfare. The debate over the income-pollution relationship allowed us as a profession to take our eye off what really matters.

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Figure 1

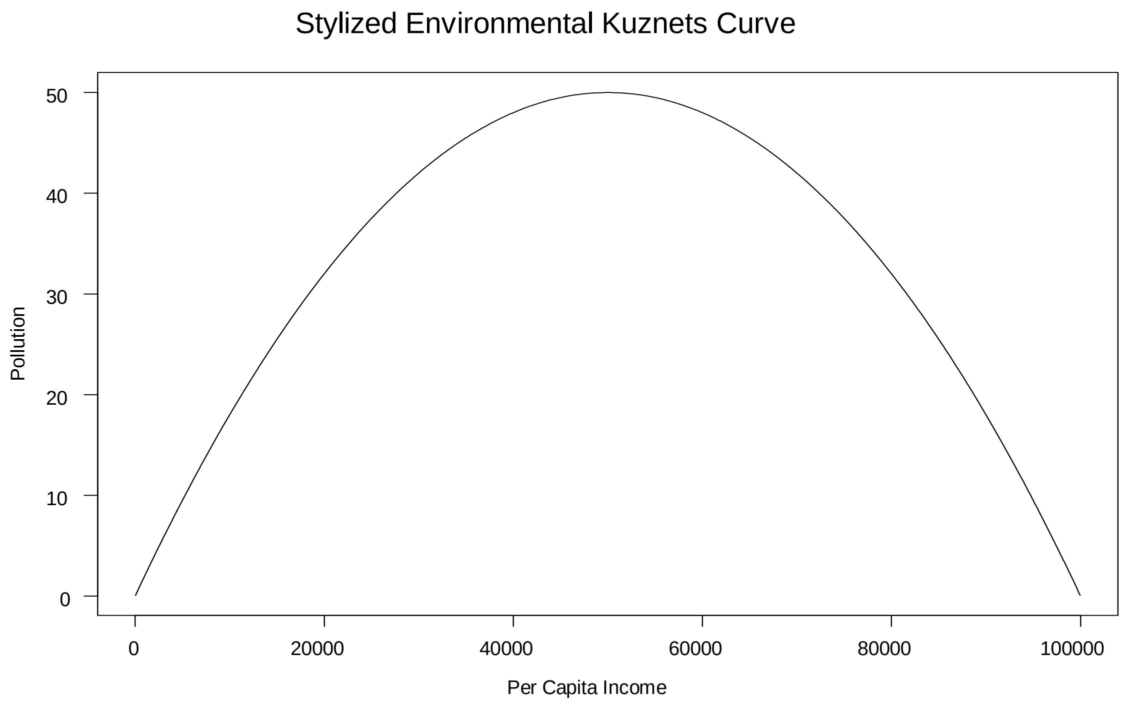
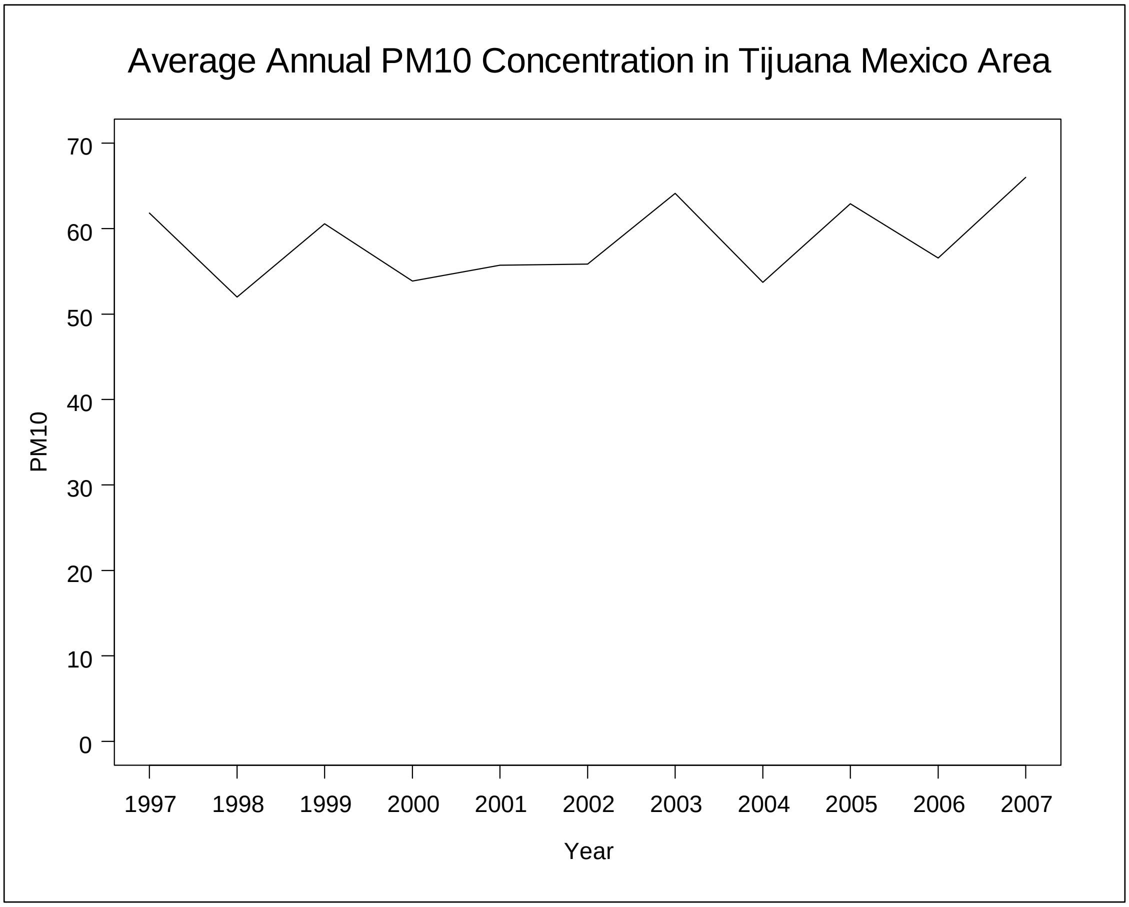

Stylized Environmental Kuznets Curve
Pollution
50
40
30
20
10
0
0
20000
40000
60000
80000
100000
Per Capita Income

Figure 2


Average Annual PM10 Concentration in Tijuana Mexico Area
70
60
50
40
30
20
10
0
PM10
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year