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EMISSIONS AND DEVELOPMENT IN THE UNITED STATES: INTERNATIONAL IMPLICATIONS

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Introduction

Concerns about the sustainability of resource use have no doubt been raised since civilization began. The most famous proponent of these concerns is Thomas Malthus (1976), who, in 1798, predicted that population growth would outstrip the ability of agriculture to supply food, and mass starvation would ensue. More recently, the widely read *Limits to Growth* report, by Meadows et al. (1974), presented a model of resource use and development that predicted humans would face unprecedented pollution and starvation, *if* current resource use patterns continued into the future. Of course, both reports' most dire predictions have not come true for several reasons. They failed to account for improvements in technology, the power of market prices to ration scarce resources, and the public's demand for environmental preservation when confronted with a perceived scarcity of environmental goods.[1] Although the dire predictions failed to materialize, many believe that environmental quality will deteriorate as the world's economies grow, unless there are significant changes in human behavior. In this paper we make a modest attempt, using air pollution data, to examine the linkage between economic growth, human behavior, and environmental quality.

A debate has arisen that centers on the question, what happens to pollution emissions and environmental quality as low-income nations get richer? An oft-stated concern is that low-income countries, which often have large and rapidly growing populations, will contribute large amounts of air greenhouse and ozone-depleting gases and other pollutants as they gain income. This has prompted considerable interest from policymakers in the relationship between per capita income and environmental quality.[2] Indeed the shape of this relationship

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[1] Criticisms of the Limits to Growth are reported in Boyd (1972), Nordhaus (1973), and more recently in Nordhaus (1992).

[2] Much of this interest has been sparked by World Bank studies (e.g., World Bank, 1992, and Shafik, 1994). Pearce et al. (1995) provide a general discussion of the role of a country's financial situation in its development process. For recent theoretical discussions concerning the income-pollution relationship, see Selden and Song (1995) and Jones and Manuelli (1995). For a discussion of empirical issues, see the recent 1996 symposium in Environment and Development Economics. A different, but related, line of work looks at the effects of environmental regulation on income growth and finds that states with more stringent environmental regulation have tended to have higher income growth (e.g., Meyer, 19992; Bezdek, 1993; Goetz et al., 1996).

Table 1: 1995 Per Capita Income and Composition of GDP

		Distribution of GDP (%)		
Country Groups	Per Capita GNP (1990 $)	Agriculture Value Added	Industry Value Added	Service Sector Value Added
Low income (without China and India)	290	33	25	41
Low income	430	25	38	35
Lower-middle income	1670	13	36	49
Middle income	2,390	11	35	52
Upper-middle income	4,260	9	37	53
High income	24,930	2	32	66

Source: World Bank (1997, tab. 1, 12).

played a substantial role in the debate over ratifying the NAFTA treaty between the North American countries, with attention being focused, in particular, on an analysis by Grossman and Krueger (1993). Grossman and Krueger (1993) showed that ambient levels of both sulfur dioxide and suspended particulates first rose with a country's per capita GDP but later fell as income increased further, with the turning point falling between $4,000 and $5,000 (in 1985 U.S.$). Grossman and Krueger (1995) later produced estimates, using urban air quality and water quality, that suggested the presence of an inverted U-shaped relationship between per capita GDP and pollution, with pollution first increasing with income but later decreasing. This inverted U-shaped relationship is now often referred to as an environmental Kuznets curve.

The environmental Kuznets curve challenges the frequently advanced argument that increases in income lead inevitably to more pollution, because more income implies more consumption, which in turn implies more pollution. Conceptually, an environmental Kuznets curve admits the possibility that there may be factors having the opposite effect of decreasing, rather than increasing pollution. The combination of the two effects can thereby lead to pollution first increasing and then decreasing with increases in income.

The set of factors leading pollution to rise and then fall with income can be loosely classified into three groups: scale of production, industrial composition, and production technique (Grossman, 1995, 19). The scale of production simply refers to how much output is produced. If we assume that industrial composition and production technique stay constant, then as output (scale) rises, emissions rise and ambient environmental quality declines. Industrial composition refers to the types of goods that are produced. Historically, as GDP per capita rises, there has been a movement away from agriculture and towards service goods. Interestingly, we see that the contribution of industry (an important source of emissions) rises and then falls with country income (Table 1). The third factor, production technique, refers to how firms decide to produce their output. Richer countries tend to use production processes that are less polluting per unit of output. Technology can be less polluting because it is explicitly designed for that purpose or simply because richer countries tend to use later vintage technology which is often more efficient, particularly with respect to energy consumption.

These three processes driving an environmental Kuznets curve are, in turn, affected by a number of underlying factors. Population density, the location of natural resource deposits such as coal, topography, and the efficiency of a country's regulatory structure, all may be important and interact in complex ways. Consumer demand, driven by these and other factors may affect pollution. Richer consumers may demand that their government agencies more strictly regulate output emissions (which may induce technological changes), consumers may become more actively involved in public action leading to informal regulation, or they may simply decide to move and live in a cleaner area.

Emissions Versus Ambient Pollution

Researchers have examined the environmental Kuznets curve using both ambient measures of pollution (e.g., Grossman and Krueger, 1995) as well as emissions per capita (e.g., Selden and Song, 1994). Both types of studies have reported finding an inverted-U, with emissions first increasing with income and later decreasing; not surprisingly, the turning points occurred at different incomes.[3]

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[3] There are some exceptions to this finding. For instance, Holtz-Eakin and Selden (1995) find a very high or non-existent turning point for greenhouse gas emissions, and one of Selden and Song's models suggest a turning point of slightly over $20,000. In addition, as discussed by Selden and Song (1994, 148), there may be

Using several types of pollution emissions, Selden and Song (1994) found a turning point for per capita emissions generally comes by the time a country reaches a per capita income of $12,000, whereas work by Grossman and Krueger (1995) found a lower turning point for ambient air quality of around $4,000 to $5,000. Selden and Song explained their higher turning point as a result of a shift in emissions from urban to rural areas due to increased urban regulation and rising urban land rents. Future work might profitably examine whether emission sources have indeed moved into rural areas or whether there are other factors that need to be considered.[4]

The choice to use emissions *per capita*, rather than *total* emissions, is a natural one since it normalizes emissions, so that measures are comparable across countries. However, measures of emissions of pollution per capita and measures of ambient environmental quality are not perfect substitutes. If emissions per capita decline, due to, say, better production techniques, then ambient air quality should improve if population remains constant. Alternatively, if emissions per capita decline, but emission sources are more concentrated due to urbanization and population growth, then ambient air quality may worsen. Similarly, if we look at total emissions, we may either see a rise or a decline in environmental quality due to the location of emission sources, since different locations have different assimilative capacities. The point is that there is not a fixed relationship between either total emissions or emissions per capita and ambient quality.

Nevertheless, ambient measures of pollution and emissions per capita are both useful to exploring the relationship between environment and development, although they tend to conflate the effects of scale, composition, and technology.[5] Alternatively, it may be helpful to use emissions data that are normalized, not by population, but by a measure of output. Emissions per unit of output—particularly if one looks at the same industry (and thus controls for industry composition)—allows one to examine the effect of income on production technique. Unfortunately, such data are rare.[6] However, in this paper, in addition to state-level emissions data for a variety of pollutants, we include a panel analysis of industry-level toxics emissions data that allow us to control for both industry composition and the scale of production. We discuss our choice of data further below.

Concerns with Empirical Estimates

There are two main sources of concerns with empirical estimates of environmental Kuznets curves: the comparability and quality of available environmental data, and whether the relationship between income and pollution is a causal one.

With respect to data comparability and quality, Stern et al. (1996, 1156) note the pollution data used in environmental Kuznets curve studies are "notoriously patchy in coverage and/or poor in quality." To some degree this is an unavoidable problem if one is working with data from a number of different countries, and in particular, developing countries. *World Resources: A Guide to the Global Environment* (1994, 1996), editions of which have been used as a source of air pollution data by some of the existing studies, contains 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."[7] Even this warning may be insufficient. Simply comparing the estimates in the 1994–95 World Resources to the estimates in the 1996–97 World Resources reveals some large differences for the same pollutant in the same country and year.[8]

A possible alternative data source, which we use in this paper, is data from the fifty states. We use state-level emissions for seven major air pollutants: greenhouse gases, air toxics, carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), volatile organic carbon (VOC), and particulate matter less than ten microns in diameter (PM_{10}).[9] U.S. air emis-

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important differences between using ambient pollution data and emissions data. However, Grossman (1995, 28) does not rule out that any differences "may be an artifact of the way in which the data on estimated emissions are constructed."

[4] Grossman (1995, 28), questioning the quality of the data used to obtain this result, noted that "we cannot rule out the possibility that the result may be an artifact of the way in which the data on estimated emissions are constructed."

[5] Of course, both measures have weaknesses. Ambient measures may be confounded by the movement of pollution between regions (Grossman et al., 1994, 17). Emissions per capita do not control well for regional differences in urbanization, topography, industrial location, and so on; a comparison of regions with similar emissions may show quite different ambient pollution levels due to these factors.

[6] The U.S. Environmental Protection Agency (1995b) has detailed data over the period 1985-1995, but as we discuss below it is not based on actual measurements, and thus may be problematical for time-series analysis.

[7] The EPA (1995a, 7-1) report on pollution across countries contains a similar warning: "It is also important to note that to the extent that emission methodologies differ across countries, intercountry comparisons may be misleading."

[8] For instance, the 1990 estimate of NOx emissions (thousands of tons) for Greece increased from 150 to 388 while the estimate for Belgium decreased from 300 to 172.

[9] The greenhouse gas emissions estimates are based on emissions from the principal anthropogenic sources; and the air toxics emissions estimates are based on reports from manufacturing facilities that meet the EPA's reporting requirements (EPA, 1996b, 4). We use "point" source emissions for CO, NOx, SO2, VOC and particu-

sions data, while still having measurement problems, are generally agreed to be among those of the best quality in the world. There is considerable variation in the per capita emission levels between the states, ranging from an order of magnitude difference between the highest and lowest state for greenhouse gases and air toxics to over three orders of magnitude difference for CO, SO_2, and VOC.

It might seem strange to look at data from the United States to learn something about the pollution-income relationship in less developed countries. However, nothing underlying the concept of an environmental Kuznets curve is specific to less developed countries; and data from the United States are being used with increasing frequency to explore various aspects of the development process where issues of data comparability have been raised.[10] For instance, Leichenko and Erickson (1997) looked at the role of foreign direct investment on exports at the U.S. state level, and Barro and Sala-i-Martin (1991) used U.S. state-level data to look at the income convergence hypothesis. Blanchard (1991, 159) in a comment on the Barro and Sala-i-Martin paper argued that "Comparisons of regions [within countries] offer much better controlled experiments than comparisons of countries."

For the data from the United States to be useful in looking at the relationship between income and air pollution, there must be substantial variation in income. Looking at 1990 per capita income across the fifty states, we find income in the richest state, Connecticut ($18,774 in 1982 dollars) is over 100 percent larger than the income in the poorest state, Mississippi ($9,281). This span of income levels is roughly half the income range examined in previous papers and lies on the right side of most of the turning points that have been found. Most of the OECD countries, which form the bulk of the observations in some environmental Kuznets curve studies like Selden and Song's (1994), fall within the income range covered by the data from the fifty states. There are also a number of rapidly developing countries whose per capita income levels are beginning to approach the lower end of this range.[11] If the turning points found previously are to be believed, we would expect to see per capita air emissions to fall as income rises across our data set.

The second concern raised by studies of an environmental Kuznets curve has to do with whether there is any underlying causal nature in the relationship between income and pollution. The approach to dealing with this thus far has been to use panel data consisting of different countries across time (e.g., Grossman and Krueger, 1995; Selden and Song, 1994). The models are, however, still largely of a reduced form nature. Further, due to data limitations, one faces the problem of having to use a panel data set which is on the "short" side of what would be desirable with respect to either the number of countries or the number of years available. For instance, Selden and Song used data from thirty countries and three different time periods.

To help address concerns over the nature of the income-pollution relationship we do two things. First, we look at changes in one class of pollutants, air toxic emissions, over the seven-year time period 1988–94. Air toxic emissions tend to be a fairly "local" problem in contrast to, say, sulfur dioxide which may be transported hundreds of miles from its source. The air toxics data over this time period are thought to be of high quality due to large legal penalties for false reporting. Table 2: Income and Pollution Summary Statistics, 1990

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lates. The EPA divides emissions into three classes: point, mobile and area emissions. An analysis of mobile (i.e., highway vehicle) emissions produces results similar to that of point emissions. The estimated coefficients based for area emissions are often insignificant; perhaps because area sources (e.g., road dust, construction, off-road vehicles) are generally measured with greater uncertainty. Further, as noted by the EPA (1996a, 4) area emission sources "are too small, too numerous, and too dispersed to catalog individually."

[10] When good data are available, looking across the regions of a single developing country can help control for extraneous factors when looking at hypotheses related to the development process. For instance, Mallick and Caraynnis (1994) look at the role of transportation infrastructure in the convergence of different regions of Mexico, while Cardenas and Ponton (1995) look at the often studied cross-country relationship between per capita income growth and educational expenditure using different regions of Columbia.

[11] A much larger group of countries falls within the range of income found in the U.S. counties (less than 6 thousand dollars to over 42 thousand dollars) which we look at with respect to PM10.

Second, we examine whether environmental Kuznets curves for the different pollutants exist when various factors such as population density and industrial composition are explicitly controlled. We also note that other factors thought to underlie an environmental Kuznets curve are probably weaker in our data set than in other studies. Differences in the regulatory structure and in technology across the fifty states are likely to be smaller than the differences in regulatory structure that would be present across any equally large set of countries. Access to technology across the United States is likely to be very similar, although there may be differences between states with respect to cost, human capital, and technology vintages. Further, while there are some differences in state-based pollution control regulations and enforcement, air pollution control regulations are put forth on a national basis by the U.S. Environmental Protection Agency (EPA). Nevertheless, there is still room for variation (Ringquist, 1993a, 3). State governments have a limited ability to adopt stricter regulation but do have substantial ability to engage in stricter enforcement of existing regulations. State and local governments also have considerable regulatory authority over granting siting permits necessary for the operation of many types of facilities.

Cross-Sectional Analysis

In our initial analysis, we examined the 1990 state-level per capita emissions for greenhouse gases converted to pounds of equivalent carbon dioxide (CO_2), air toxics, and point-source emissions of CO, NO_x, SO_2, VOC, and PM_{10}; a further analysis considered county-level PM_{10} emissions. All pollution data were taken from EPA sources, and income data from the U.S. Census Bureau.[12] Greenhouse gases were considered in terms of thousands of pounds per capita, the rest of the emissions are in pounds per capita. Income is expressed in terms of thousands of 1982 dollars. Table 2 reports the summary statistics.

The different classes of air pollution emissions considered contribute to a number of serious adverse effects and comprise a reasonably comprehensive set of the major air pollutants. A rising level of greenhouses gas emissions is associated with increased risk of global warming. Many air toxics are thought to pose significant acute and chronic health risks. CO exposure can lead to high levels of carboxyhemoglobin in the blood and to angina attacks; recent evidence (Schwartz and Morris, 1995) links CO to hospital admissions for congestive heart failure. NO_x and SO_2 both contribute to acid rain; and they help form particulates, which are linked to a wide range of adverse health effects, including asthma attacks, bronchitis and cardiopulmonary mortality (Pope et al., 1995). VOC emissions also contribute to particulate formation, and VOCs and NO_x are the main contributors to tropospheric ozone pollution, which is linked to acute and chronic respiratory problems.[13]

Variable	No. of obs.	Sample Mean	Standard Deviation	Min.	Max.
Income - State[a] (1985)	48	11.93	1.79	8.48	16.39
State[a]	50	13.08	2.08	9.28	18.77
County[a]	1,748	11.36	2.63	5.99	42.18
Greenhouse gases (1985)[b]	48	50.22	32.99	23.52	228.80
Air toxics[c]	50	10.91	10.48	0.61	61.70
CO[c]	50	62.28	83.97	0.31	371.86
NO_x[c]	50	112.58	135.26	1.84	848.76
SO_2[c]	50	193.96	216.26	3.32	1,203.29
VOC[c]	50	25.55	25.03	0.04	118.97
PM_{10} - State[c]	50	11.34	8.64	0.21	35.49
County[c]	1,748	35.61	103.55	<0.01	2,166.92

[a] Thousands of 1982 U.S. dollars per capita.

[b] Thousands of pounds per capita.

[c] Pounds per capita.

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[12] The original source of the greenhouse emissions data is the EPA, National- and State-Level Emissions Estimates of Radiatively Important Trace Gases (RITGs) from Anthropogenic Sources, October 1990. The conversion factors used to estimate CO2-equivalent emissions come from the World Resources Institute (1993). Greenhouse gas emissions estimates are for 1985; estimates were not reported for Alaska and Hawaii. The toxics data come from the EPA (1996b). The other air pollutants at the state and county level come from EPA's (1995b) computerized database. Per capita income for 1985 and 1990 was taken from the U.S. Bureau of the Census (1996).

[13] Bascom et al. (1996a; 1996b) review the evidence regarding the health effects of ozone, CO, NOx, particulates, and other outdoor pollutants.

Table 3: Cross-Sectional Regression Analyses

	OLS with White Standard Errors[a]			Robust Regression[a]	
Emission	Constant	Income	R^2	Constant	Income
Greenhouse gases	110.42	–5.05	0.07	88.88	–3.82
	(6.07)	(–3.65)		(8.96)	(–5.41)
Air toxics	38.78	–2.13	0.18	23.14	–1.11
	(3.62)	(–2.83)		(5.48)	(–4.01)
CO	258.41	–14.99	0.14	105.79	–5.74
	(3.29)	(–2.78)		(5.89)	(–5.14)
NO_x	424.38	–23.83	0.14	254.95	–13.10
	(5.02)	(–4.37)		(6.64)	(–5.24)
SO_2	714.32	–39.77	0.15	382.64	–18.77
	(3.34)	(–2.72)		(4.28)	(–3.38)
VOC	79.05	–4.09	0.12	55.30	–2.54
	(3.66)	(–2.76)		(3.53)	(–2.41)
PM_{10} - State	41.98	–2.34	0.32	38.20	–2.11
	(7.21)	(–5.81)		(4.86)	(–3.21)
PM_{10} - County	100.55	–5.71	0.02	17.83	–0.77
	(8.67)	(–6.64)		(50.14)	(–87.63)

[a] Numbers in parentheses are t-values.

The modeling approach we adopt is straightforward. Using ordinary least squares, we regress the per capita emissions for each emission class on per capita income. The error terms from the regression are likely to be heteroscedastic so the results displayed use White's (1980) approach to obtain consistent estimates of the standard errors. In addition, the results are likely to be strongly influenced by outliers, so we provide robust regression estimates.[14] Finally, it is possible that the functional relationship between the two variables is not linear. We plot curves in Figures 1–7 based upon LOWESS (Cleveland, 1979), which allows the curvature of the income-emission relationship to differ with different income levels and heavily downweights outlying observations.

Table 3 reports the cross-sectional regression results for each class of air emissions. In all cases, the linear terms were significant while second order terms were insignificant when included.[15] The coefficients on GNP per capita are all negative, suggesting that air emissions per capita in U.S. decrease as GNP per capita increases. The robust regression results put little weight on a small number of low-income high-per-capita emitters, and suggest a smaller, but still significant, income relationship.

We checked the possibility that we simply found a spurious relationship between income and emissions, by looking at other possible predictors of per capita pollution. We included employment shares (using one-digit SIC codes) to take account of the industrial mix. Use of this set of variables also controls to some degree for effects related to the location of high-polluting natural resources. We also looked at two variables that are likely to be related to the number of people exposed to the class of air pollutant: population density and the percentage of the state population living in urban areas. The argument here is that the government may be forced to adopt stricter pollution control regulations when more people are exposed. Since income levels generally rise with population density and urbanization in the United States, the income-pollution relationship may simply be a consequence of the population density/urbanization effect.

For the linear specification, controlling for one-digit-SIC employment shares reduces the significance of the income coefficient surprisingly little, given that nine regressors were added. The income coefficient remained significant at the 5 percent level for NO_x, SO_2, and PM_{10}, and was significant at the 10 percent level for VOC and suggestive (15 percent) for CO.[16] When we included population density and

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[14] The robust estimates are based on Tukey's biweight loss function and a robust correction for multiplicative heteroscedasticity (Subramanian and Carson, 1988); the reported standard errors are those proposed by Street et al. (1988).

[15] We also estimated log-log models. In many instances that functional form in the OLS regression framework resulted in substantially larger (absolute) t-values on income. However, non-nested J-tests based on the linear and log-log equations that include predicted values from the other equation in the estimated model suggest that neither specification dominates and that each has substantial independent predictive power. The robust regression models tend to favor the linear specification since they tend to downweight the outliers that are responsible for the curvature in the log-log models.

[16] The air toxics data is only from manufacturing sources so controlling for one-digit codes is not very informative. In the next section, we control for SIC code at the two-digit level for air

percent urban variables, the signs on these coefficients were never significant, however the significance of the income variable was usually reduced. We see this particularly in the greenhouse gas and NO_X equations when population density is added and, in the SO_2 and VOC equations, when percentage urban is added. [17] Of course, this should not be surprising given the high correlation (.66) and (.59) , respectively, of these two variables with per capita income.[18]

Figures 1–7 display the negative relationship between state per capita income and emissions of green house gases, air toxics, CO, NO_x, SO_2, VOC, and PM_{10}. Visually, the dominant feature across the set of figures is the greater variability of emission levels at low-income levels. This result was also seen in performing the heteroscedasticity corrections for the robust regression equations reported in Table 3. In those equations the estimated variance for all pollutants decreased as income increased. The LOWESS curves in Figures 1–7 generally indicate a linear relationship between per capita emissions for the different classes of pollutants and per capita income, with a small number of high emitting outliers among the low-income states. The LOWESS fit is similar, in most cases, to the corresponding robust regression estimate and reflects a flatter slope than the OLS estimate. West Virginia and Wyoming, relatively poor, coal-producing states, are consistent outliers. Among middle-income states, Rhode Island and Vermont usually have emissions substantially below the LOWESS curve. California, which has the strictest regulations on air pollution, is consistently a low per capita polluter for the pollutants considered; but given California's per capita income, emission levels are not much below what would be otherwise predicted. Not surprisingly, Figure 1 for greenhouse gases, which are not directly regulated, has a strong resemblance to Figure 5 for sulfur dioxide, which is regulated, since burning coal is the major source of both pollutants.

Turning now to the county level PM_{10} data, we see that the regression estimates in Table 2 also suggest that emission levels are negatively related to increases in income.[19] While this relationship is significant ($p < .001$) and almost twice the size in absolute value terms, the R^2 for the equation is dramatically smaller. The robust regression equation suggests a much smaller effect, but one that is nonetheless highly significant. Figure 8 displays the entire range of data. Figure 9 displays a much smaller range of income and PM_{10} emissions which corresponds to the state level data displayed in Figure 7. The key distinction between the two figures is that Figure 8 is dominated by a small number of counties with very large per capita emission levels; these counties generally have small populations—most have fewer than 25,000 people.

Air Toxics, 1988–94

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toxics.

[17] In the log-log models, the log of income is still significant after the inclusion of the log of population density in all equations; the log of population density is significant only in the greenhouse gas, air toxics, and VOC equations. The inclusion of the log of the percentage urban along with the log of per capita income offers a different result. In equations for five of the seven air pollutants, the log of per capita income is significant and the log of percentage urban insignificant. In one of the other two cases (VOC), both predictor variables were insignificant, while in the other case (NOx), both predictor variables are significant.

[18] Surprisingly, the correlation between population density and percentage urban is only 0.49. This is due to the fact that there are some states, such as California, New York, and Texas, which encompass fairly large geographic areas but have most of their population living in urban areas.

[19] A similar negative relationship was found using emissions of CO, NOx, SO2 and VOC.

Of the different air pollutants examined above, only air toxics emissions are available at the state level in a consistent form over time, and then only for the seven year period 1988–94.[20] Nevertheless, there is a still a fair amount of variation between states over this time period. The largest reduction over 1988 levels for per capita air toxic emissions was 39 pounds (–54.8 percent) in Utah and the largest increase was 1.3 pounds (7.3 percent) in Mississippi. Likewise, there is a fairly large range of changes in real per capita income, with California losing over $700 (–4.6 percent) and North Dakota gaining $2400 (24.6 percent).

Table 4: Change in Air Toxics 1988–94 , Regression Analysis

Independent Variable	OLS with White Standard Errors[a]				Robust Regression[a]
Constant	–4.9083	–7.7774	0.50249	8.1282	1.8856
	(–6.53)	(0.26)	(0.96)	(2.47)	(1.38)
Change in per capita income	0.6261			.0018	0.2413
	(0.68)			(0.00)	(0.82)
1988 per capita income		0.2648		–0.5659	–0.1649
		(0.62)		(–2.73)	(–2.01)
1988 per capita toxics			–0.4815	–0.5209	–0.4499
			(–7.68)	(–9.47)	(–13.49)
R^2	0.00	0.01	0.82	0.87	

Note: The dependent variable is the 1994 state per capita air toxics emissions minus 1988 state per capita air toxics emissions. The change in per capita income is the 1994 state per capita income minus 1988 state per capita income.

Using these data, we tested whether or not emissions are correlated to income. The standard nonparametric test of this hypothesis is the sign test (Conover, 1971).[21] The value of the sign test statistic is 21 ($p < .001$), which suggests emissions are negatively correlated with income.

Finding a negative correlation is clearly not the same as showing that changes in income result in changes in toxic emissions. It is possible, for instance, that real per capita income is simply trending upward on average while per capita toxic emissions are generally trending downward because technology in all States is uniformly improving irrespective of changes in income. To look at this possibility, we needed to consider in more detail how the two series move together. Table 4 reports a bivariate OLS regression of the change in per capita air toxics emissions occurring between 1988 and 1994 on the change in per capita income. The regression results show no relationship between the change in income and the change in the level of air toxics emitted per capita. This is inconsistent with a strict interpretation of an environmental Kuznets curve, which predicts a negative relationship. The LOWESS curve in Figure 10 reinforces the OLS regression results in Table 4 by showing that the relationship between the income change and the emission change is essentially flat, with the exception of two states, North and South Dakota. These two states have large increases in per capita income and very small decreases in per capita emissions.[22]

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[20] The EPA has a long series of emissions estimates for CO, NOx, SO2, VOC and PM10 stretching from 1900 to 1995, with the most detailed estimates for the period 1985-1995. These data give a reasonably good idea of the relative importance of different pollution sources; however, they are not useful for looking at changes over time. Much of the data—especially in the early years—rely on relatively crude extrapolations. The 1990 estimates are generally considered the best. They were derived from a comprehensive study of emissions and are used as the base to calculate (using various "growth factors" among other considerations) estimates for other years in the period 1985-1995. EPA (1995a, Chapter 6) discusses the development of these emission estimates. The toxics reporting program began in 1987, however, due to problems associated with reporting during this first year, the EPA uses 1988 as the initial year for comparative purposes. There were some changes in the set of chemicals for which reporting was required during the 1988-1994 time period; however, the data we use are based on the set of chemicals common to all years in that period. (The list of chemicals is available upon request from the authors.) In 1995, substantial changes were made in the toxic information report system with respect to both the particular chemical emissions that had to be reported and, more importantly, the types of firms that had to make reports.

[21] We partition observations into one of four cells: A [increased income, increased pollution], B [decreased income, decreased pollution], C [increased income, decreased pollution], and D [decreased income, increased pollution]. Income/emissions pairs are assigned a value of –1 if they fall into cells A or B (consistent with the null hypothesis of a positive (or zero) correlation), and a value of 1 if they fall into C or D (consistent with the environmental Kuznets curve). Forty-six of the fifty states (92 percent) fail to conform to the null hypothesis.

[22] We dropped Utah from Figures 10, 11, and 12 because its initial large level of emissions (71.2 lb) and its subsequent large drop in emissions (39.0 lb) forces most states into a fairly small portion of the figures.

It may be useful to consider the starting position of the different states with respect to their initial 1988 emission levels. One might expect that the higher the initial level of emissions the lower the cost of reducing them. The bivariate regression results show a very significant relationship, and the R^2 statistic suggests that over 80 percent of the variance in the change in emission levels is being explained by this variable. Figure 11 displays the relationship with the LOWESS curve being plotted.

We also looked at the initial 1988 per capita income level. The bivariate OLS regression for this relationship is also given in Table 4 and the relationship plotted in Figure 12. The OLS regression equation suggests no relationship between initial income and the change in emissions. The LOWESS curve suggests more structure with initial low-income states experiencing smaller reductions than middle and upper income states, which do not differ in the size of their reduction.

It is, of course, possible to estimate an OLS regression equation with all three predictor variables: the change in income, initial toxics emissions and initial income. While the change in income remains insignificant, the initial income is now significant with higher income states conditionally having larger reductions in emission levels.[23] Once we control for the initial emissions level, we see that income is linked to declining emissions, and that this is consistent with an environmental Kuznets curve. More complex models with nonlinear terms result in an improved fit, but suggest the same basic relationship.

Some high-income states, such as California, which are known to have fairly aggressive programs aimed at reducing air toxics, have experienced only small reductions in their air toxic reductions over the 1988–94 period. As seen though in Figure 11, these states already had quite low emissions in 1988. This suggests looking at the percentage change in emissions rather than the absolute level of emissions as the dependent variable. In Figure 13, we now observe a strong relationship between the percentage change in emissions and income at the start of the observation period; high-income states are much more likely to have achieved a large reduction in percentage terms of their 1988 emissions.

Panel Data

The reductions recorded for the richer states may be due to richer states: (1) having less polluting types of industries (composition effect), or (2) having cleaner technology (technology effect). If reductions are achieved by "dirty" industries moving out of a given state, then the emissions of toxics are simply being exported to other states or countries. Of course, using industry-level panel data, we cannot rule out that dirty industries simply moved, but we can rule out whether a given industry gets cleaner with rising per capita income.

Unfortunately, firm-level data are not available. While we have toxics emissions at the facility level, we do not have output and employment data at the facility level. Instead, we chose to use data aggregated at the two-digit SIC code level.[24] In turn we had to consider two imperfect choices for the dependent variable:

1. Average emissions at each facility in a given two-digit SIC codes, where the number of facilities is obtained from the TRI data.
2. Alternatively, we considered average emissions per dollar of payroll in each two-digit SIC code.

The second measure appears more desirable, but, unfortunately, potentially serious problems come with this measure. The employment data is derived from the U.S. Census Bureau's County Business Patterns, and includes many facilities that do not report any TRI emissions, further, some of the employment data has been censored to prevent disclosure of firm level data. This has the effect of biasing upwards estimated emissions per employee when the employment data is censored.

Tables 5 and 6 present the results using each of these dependent variables. As it turned out, both measures are highly correlated (r = 0.85) and give similar results.[25] A regression on income, income squared, and a time trend reveals a significant, negative income coefficient, and a positive coefficient on income squared. This relationship still holds, when we added variables that may be plausibly linked to emissions: the average number of employees per establishment in each SIC code, the total number of establishments per SIC code, and population den-

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[23] The R2 of the equation increased to 0.87 from the 0.82 achieved in the equation using initial toxics emissions alone. The robust regression suggests a smaller but still significant effect for initial income.

[24] There is a tradeoff between more precision with disaggregated data, and the loss of employment and payroll data that is not reported to prevent disclosure of individual firm data. This problem gets more severe as the data gets more disaggregated, so we chose to use the two-digit SIC level, as opposed to the three- or four-digit SIC level.

[25] Analyses using per capita emissions and average emissions per employee give essentially the same results. Likewise, analyses using a least absolute deviation estimator gives similar results. Interestingly, a biweight robust estimator using finds no significant relationship between income and emissions. It appears that observations heavily downweighted with this analysis are important in establishing the link income and emissions.

Table 5: Regression of Average Emissions per TRI Facility by Two-Digit Manufacturing SIC Code

	State Random Effects Excluded **		State Random Effects Included **		
Variable	#1	#2	#1	#2	#3
Constant	1,592,657	1,295,888	1,443,696	1,251,506	1,148,768
	(4.552)	(3.674)	(2.823)	(2.529)	(2.223)
State per capita income	–161.443	–148.304	–134.925	–123.743	–124.387
	(–4.373)	(–3.813)	(–1.790)	(–1.597)	(–1.550)
State per capita income squared	0.00515	0.00472	0.00428	0.00391	0.00394
	(4.187)	(3.531)	(1.700)	(1.463)	(1.427)
Year	–3,058.033	–2,512.843	–3,598.642	–2,960.328	–2,842.214
	(–1.392)	(–1.190)	(–2.867)	(–2.464)	(–2.273)
Avg employees per business in two-digit SIC		727.414		807.501	770.528
		(8.713)		(2.815)	(3.300)
Total # of businesses in two-digit SIC		0.928		–2.0459	–5.407
		(0.231)		(–0.434)	(–0.409)
State population density		4.521		17.541	4.096
		(0.215)		(0.514)	(0.123)
Two-digit SIC dummies		added			added
X^2 test for two-digit SIC dummies [prob>X^2]		47.16			236.95
		(0.000)			(0.000)
R^2	0.021	0.097	0.021	0.039	0.097
N	5,218	5,211	5,218	5,211	5,211

Note: Facilities that report emissions in the Toxics Release Inventory (TRI) were grouped by two-digit SIC (codes = 20–39). Facilities grouped under more than one two-digit SIC code were deleted.

[a] t-values in parentheses have been corrected for heteroscedasticity.

sity.[26] Controlling for the type of industry (by adding a dummy variable for two-digit SIC codes), there is still a clear negative relationship between annual per capita income and annual per capita air toxic emissions. However, when we control for the state in which the industry is located, using a random effects model, the relationship between income and air toxics becomes less significant. Although insignificant individually, in aggregate the coefficients are still significant. The results suggest that year to year changes in state income are relatively unimportant, but that there are important differences between states that appear to be related to the differences in the level of state income, most likely through the vintage of the industry, choice of production technique and regulatory effort.[27]

Discussion

Using data from the fifty states, we find that emissions per capita decrease with increasing per capita income for all seven major classes of air pollutants. In this respect, our results are consistent with country studies that find an environmental Kuznets curve.[28] As such, it is likely that those results, at least for higher income countries, are not an artifact of incompatible or poor quality data.

Questions still remain as to why this relationship exits. Cross-sectional regression equations are limited in this regard. It is worth noting, though, that the environmental Kuznets curve relationship, although a bit diminished, does not go away when industrial

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[26] Larger establishments, taking advantage of economies of scale, may use more efficient processing techniques that reduce toxics emissions per employee. On the other hand, the TRI data set includes only manufacturers with at least ten full-time employees and emissions of at least 25,000 pounds, so we might expect a positive coefficient on the average number of employees per establishment. In the event, we see that the latter dominates in both Tables 5 and 6, as there is a significant positive coefficient.

[27] Using ambient air quality measurements, Grossman et al. (1994) find support for the notion that improvements in technology occur with rising income levels.

[28] This result contrasts with Holtz-Eakin and Selden (1995), who looked solely at CO2 emissions. We included a broader set of greenhouse gases, and our initial suspicion was that this might lie behind the difference in the two results. However, we have now estimated an equation using only CO2 and found very similar results to those reported for greenhouse gases. Schmalensee et al. (forthcoming) find a similar result. Using an enlarged version of the country-level panel data set used by Holtz-Eakin and Selden and a more flexible functional form, Schmalensee et al. find a turning point substantial lower than Holtz-Eakin and Selden, and their projection of this result to the U.S. looks fairly similar to our Figure 1.

Table 6: Regression of Average Emissions per Dollar of Payroll by Two-Digit Manufacturing SIC Code

	State Random Effects Excluded **		State Random Effects Included **		
Variable	#1	#2	#1	#2	#3
constant	0.136	0.128	0.129	0.125	0.121
	(3.952)	(3.695)	(2.692)	(2.685)	(2.465)
state per capita income	-1.43 e-5	-1.49 e-5	-1.32 e-5	-1.24 e-5	-1.41 e-5
	(-4.565)	(-4.470)	(-1.922)	(-1.840)	(-1.850)
state per capita income squared	e-10	e-10	4.00 e-10	4.28 e-10	4.46 e-10
	(4.224)	(4.191)	(1.769)	(1.730)	(1.733)
year	e-4	-1.83 e-4	1.72 e-4	1.69 e-4	1.75 e-4
	(-0.744)	(-0.831)	(-1.955)	(-1.671)	(-1.943)
avg employees per business in two-digit SIC		2.01 e-5		e-5	2.51 e-5
		(3.064)		(1.317)	(1.131)
total # of businesses in two-digit SIC		e-7		-2.34 e-6	1.27 e-6
		(1.639)		(-2.970)	(1.470)
state population density		-4.16 e-6		-4.79 e-6	-4.98 e-6
		(-3.640)		(-2.001)	(-1.842)
two-digit SIC dummies		added			added
X^2 test for two-digit SIC dummies [prob>X^2]		61.62			287.98
		(0.000)			(0.000)
R^2	0.023	0.086	0.023	0.028	0.086
N	5,211	5,211	5,211	5,211	5,211

Note: Facilities that report emissions in the Toxics Release Inventory (TRI) were grouped by two-digit SIC (codes = 20–39). Facilities grouped under more than one two-digit SIC code were deleted.

[b] t-values in parentheses have been corrected for heteroscedasticity.

composition and population density/urbanization are controlled for. The environmental Kuznets curve relationship is stronger when relatively low-income states such as West Virginia and Wyoming, that may be outliers simply due to location of large coal deposits are given equal weight with other states. However, it is still highly significant in the robust regressions and the LOWESS curves that place little weight on outliers. While there is a hint that the income-pollution relationship is weaker for pollutants like greenhouse gases and sulfur dioxide where there is long distance transport, the similarity between the income-pollution relationships for the seven air pollutant classes seems much strong than any differences. One might well expect the relationship to be more pronounced in a cross-country study, where there is clearly more variability with respect to access to technology and regulation than there is between the United States.

Without exception, the high-income states have low per capita emissions while emissions in the lower income states are highly variable. We believe that this may be the most interesting feature of the data to explore in future work. It suggests that it may be difficult to predict emission levels for countries just starting to enter the phase, where per capita emissions are decreasing with increases in income. Research on the reasons for greater variability in per capita emissions in lower-income political jurisdiction than in higher-income political jurisdictions may lead to a better understanding of what factors lie behind the cross-sectional environmental Kuznets curve relationship.

Our results suggest that with respect, at least, to air toxic emissions in the United States, either there is no relationship between changes in income and changes in toxic emissions or that the dynamic process is a very slow one. Our finding that the initial level of air toxic emissions matters, enriches the technology story in a way that accords with economic intuition: it is less expensive on a per unit of pollution basis to clean up dirty plants than clean ones. Our finding that a state's initial level of income matters provides some support for the possibility of a slow dynamic process.

With respect to that process, it is worth noting that it has been over twenty years since the U.S. Clean Air Act passed. Large differences in per capita emissions across the United States still exist. Some of this difference may be due to the limited ability of states and local areas to set differing standards (Portney, 1990). However, we believe this difference is more likely to be due to state differences in allowing particular types of point sources to be built in the first place, state differences in enforcing federal pollution laws, and most importantly, long-lived technology vintage effects.[29]

Our results suggest that the absolute income level in a political jurisdiction (rather than changes in income from year to year) may be more important in determining the zeal and effectiveness of its regulatory structure. In part, this is likely related to resources available to regulatory agencies, slowly changing public preferences, and the perceived danger of emissions. Ringquist (1993b), reports that the stringency of air pollution regulation, including enforcement, is strongly related to income. In part, it may be that rich states like California and Massachusetts that suffered real per capita income losses view those losses as transitory, as appears to have be the case, and regulate according to the higher expected income trajectory. In contrast, two relatively poor states (with low population densities), North and South Dakota, experienced large increases in real per capita income and only small percentage reductions in air toxic emissions.

Conclusion

The relationship between income and environmental quality is not an automatic one (Arrow et al., 1995). It is not necessarily the case that richer countries will have lower pollution levels, nor is it the case that poor countries must pass through high levels of pollution. Regulatory policy and technological choices have a large impact on the ultimate ambient pollution levels achieved in a region. Panayotou (forthcoming) found substantially lower ambient SO_2 levels in countries with more effective governments.

Most of the world's population is poor. If past trends hold, as the incomes of today's poor rise, pollution emissions will increase. New technologies, such as fuel-cell-powered cars, if widely adopted, would reduce the pollution that has historically accompanied development. Of course, such new technology may not be successfully adopted. Even in the United States, where technology is widely available, our results suggest that emissions per capita decline with income. This is not just a function of the composition of industry. Within a given industry class, we see some evidence that emissions are lower in richer states, due to more effective formal and informal regulation and, perhaps most importantly, better technology. The high variability in emissions that we found at low incomes suggests that there are a variety of development paths, some cleaner than others. If the long-term emissions of greenhouse gases are a concern, then work should be done to ensure that cleaner technologies are chosen today.

Year-to-year changes in income have little effect on emissions, while higher initial income is associated with lower emissions. This suggests that richer areas have chosen cleaner technologies and stricter regulation, and that these choices have long-lasting effects. Future research might examine development in the regions of Europe, where high-quality data could be assembled, to see if the results reported here are peculiar to the United States. At the plant level, this exercise could also be performed in some rapidly developing countries. The results thus far suggest that it is important to encourage the adoption of clean technology in the near-term, to avoid long-term problems such as global warming. The dire predictions of Malthus (1976) and Meadows et al. (1974) may never come true, but there are a range of choices that countries can take that have wide-ranging and lost-lasting effects.

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[29] The recent literature review by Jaffe et al. (1995), however, suggests that differences in state pollution regulations do not have large effects on firm-level decisions on where to locate plants. However, Becker and Henderson (1997) report that whether a county is in a nonattainment region (and thus subject to more regulation) has a significant effect on plant location.

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