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The relationship between air pollution emissions and income: US Data*

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ABSTRACT: Considerable interest has focused on the possible existence of an environmental Kuznets curve, whereby pollution first increases but later falls with increasing income. Empirical studies have concentrated on a wide spectrum of countries and run into inevitable problems of data comparability and quality. We avoid these problems by looking at seven types of air emissions across the 50 US states and find all seven pollutants decrease with increasing per capita income. We also find strong evidence of heteroscedasticity with respect to the income–emissions relationship: lower-income states display much greater variability in per capita emission levels than higher-income states. Additionally, we look at the best measured of these emissions, air toxics, for the period 1988–94. Using a simple sign test, we find support for the notion that an increase in income is associated with a decrease in per capita emissions. However, the change in emissions appears to be unrelated to the magnitude of the change in income. We do find, though, that the reduction in per capita emissions is increasing both in terms of the 1988 level of per capita emissions and income. Possible implications of these results for the development process are discussed.

1. Introduction

Policymakers have recently shown considerable interest in the relationship between per capita income and per capita pollution.[1] Indeed the shape of this relationship played a substantial role in the debate over ratifying the NAFTA treaty between the North American countries with attention being

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[1] 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 US states with more stringent environmental regulation have tended to have higher income growth (e.g., Meyer, 1992; Bezdek, 1993; Goetz, *et al.*, 1996).

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focused, in particular, on an analysis by Grossman and Krueger (1993). That analysis showed ambient levels of both sulphur 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 $5,000 (in 1985 US$). Selden and Song (1994) and Grossman and Krueger (1995) later produced more refined estimates for these and other pollutants using higher-quality data. Both of these analyses also suggested the presence of an inverted U-shaped relationship between per capita GDP and pollution, with pollution first increasing with income but later decreasing. The turning point generally comes by the time a country reaches a per capita income of $12,000.[2] 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 fall with income can be loosely classified into two groups. The first is that the richer countries tend to use different technology to produce goods that is 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. The second is that consumers will demand better environmental quality as they become wealthier. This factor can be manifested in a variety of different ways, such as shifts in output consumption toward less polluting products, moving to cleaner areas, or demanding that their government agencies more strictly regulate the output of various types of pollution. These different factors are likely to interact with each other (e.g., stricter regulation can induce technological change) making their respective influences difficult to sort out. Further, there are likely to be other factors that play an important role in determining pollution output. Among them are population density, the location of natural resource deposits such as coal, industrial composition and the efficiency of a country's regulatory structure. The presence of these other factors does not undermine policy interest in whether an environmental Kuznets curve exists, but does present the possibility that any relationship found between income and pollution is a spurious one.

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

[2] 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.

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pollution is a causal one. With respect to data comparability and quality, Stern *et al.* (1996, p. 1156) note that 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.'[3] 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.[4]

A possible alternative data source, which we use in this paper, is data from the 50 US states. We use state-level emissions for seven major air pollutants: greenhouse gases, air toxics, carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), volatile organic carbon (VOC), and particulate matter less than ten microns in diameter (PM_{10}).[5] US air emissions 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 US 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 may seem strange to look at data from the US 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 50 US states are being used with increasing frequency to explore various aspects of the

[3] The US Environmental Protection Agency (1995a, p. 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.'

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

[5] 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 (US Environmental Protection Agency, 1996b, p. 4). We use 'point' source emissions for CO, NO_x, SO_2, VOC and particulates. The US 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 (US Environmental Protection Agency, 1996a, p. 4) area emission sources 'are too small, too numerous, and too dispersed to catalog individually.'

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development process where issues of data comparability have been raised.[6] For instance, Leichenko and Erickson (1997) look at the role of foreign direct investment on exports at the US state level and Barro and Sala-i-Martin (1991) use US state-level data to look at the income convergence hypothesis. Blanchard (1991, p. 159) in a comment on the Barro and Sala-i-Martin paper argues that 'Comparisons of regions [within a country] offer much better controlled experiments than comparisons of countries.' For the data from the US 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 50 US states, we find income in the richest state, Connecticut ($18,774 in 1982 dollars) is over 100 per cent 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, fall within the income range covered by the data from the 50 US 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.[7] If the turning points found previously are to be believed, we would expect to see per capita air emissions 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. Finding a relationship between the two variables in cross-sectional analyses is clearly not a demonstration of any simple causal relationship and it is obvious that income *per se* cannot directly determine the level of pollution emissions. The approach to dealing with this second concern thus far has been to estimate a dynamically specified model using a panel data set 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, owing 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 (1994) use data from 30 countries and three different time periods.

[6] 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.

[7] A much larger group of countries falls within the range of income found in the US counties (less than 6 thousand dollars to over 42 thousand dollars) which we look at with respect to PM_{10}.

To help address concerns over the nature of the income–pollution relationship, we do two things. First, we examine whether environmental Kuznets curves for the different pollutants exist when various factors such as population density and industrial composition are controlled for. We also note that some of the factors thought to underlie an environmental Kuznets curve are probably weaker in our data set than in other studies. In particular, access to technology across the United States is likely to be very similar, although there may be substantial differences between states with respect to cost and the knowledge base as well as clear differences in 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 US Environmental Protection Agency. Thus differences in the regulatory structure across the 50 US states are likely to be smaller than the differences in regulatory structure that would be present across any equally large set of countries.[8] Second, we look at changes in one class of pollutants, air toxic emissions, over the seven-year time period 1988 to 1994. Air toxic emissions tend to be a fairly 'local' problem in contrast to, say, sulphur 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 because of large legal penalties for false reporting.

2. Cross-sectional analysis

In our initial analysis, we examine 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 considers county-level PM_{10} emissions. All pollution data are taken from US Environmental Protection Agency sources, while income data come from the US Census Bureau.[9] Greenhouse gases are considered in terms of thousands of pounds per capita while the rest of the emissions are in pounds per capita. Income throughout the paper is

[8] 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. California had stricter regulations than those originally embodied in the US Clean Air Act as was allowed by that Act to continue to maintain stricter standards that those issued by the US EPA. We will look at the possibility of different behaviour by California relative to other states later in our empirical analysis.

[9] The original source of the greenhouse emissions data is the US EPA, *National- and State-Level Emissions Estimates of Radiatively Important Trace Gases (RITGs) from Anthropogenic Sources*, October 1990. The conversion factors used to estimate CO_2-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 US EPA (US Environmental Protection Agency, 1996b). The other air pollutants at the state and county level come from US EPA's computerized database (US Environmental Protection Agency, 1995b). Per capita income for 1985 and 1990 was taken from the US Bureau of the Census (1996).

Table 1. *Income and pollution summary statistics (1990)*

Variable	*No. obs.*	*Sample mean*	*Standard deviation*	*Min.*	*Max.*
Income					
State[1] (1985)	48	11.93	1.79	8.48	16.39
State[1]	50	13.08	2.08	9.28	18.77
County[1]	1748	11.36	2.63	5.99	42.18
Greenhouse gases (1985)[2]	48	50.22	32.99	23.52	228.80
Air toxics[3]	50	10.91	10.48	0.61	61.70
CO[3]	50	62.28	83.97	0.31	371.86
NO_x[3]	50	112.58	135.26	1.84	848.76
SO_2[3]	50	193.96	216.26	3.32	1203.29
VOC[3]	50	25.55	25.03	0.04	118.97
PM_{10}					
State[3]	50	11.34	8.64	0.21	35.49
County[3]	1748	35.61	103.55	<0.01	2166.92

Notes: [1] Thousands of 1982 US dollars per capita. [2] Thousands of pounds per capita.
[3] Pounds per capita.

expressed in terms of thousands of 1982 dollars. Table 1 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 carboxyhaemoglobin 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.[10]

The modelling approach we adopt is straightforward. Using OLS, 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. The results are likely to be strongly influenced by outliers, so we also provide robust regression estimates 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). It is also possible that the functional relationship between the two variables is not linear, so we plot curves in Figures 1 to 4, based upon LOWESS (Cleveland, 1979), a locally

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

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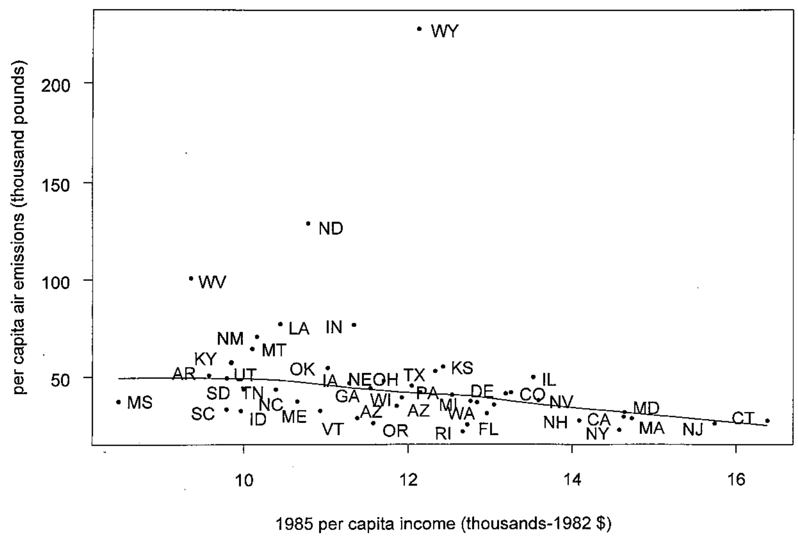

Figure 1. *1985 greenhouse gas emissions*

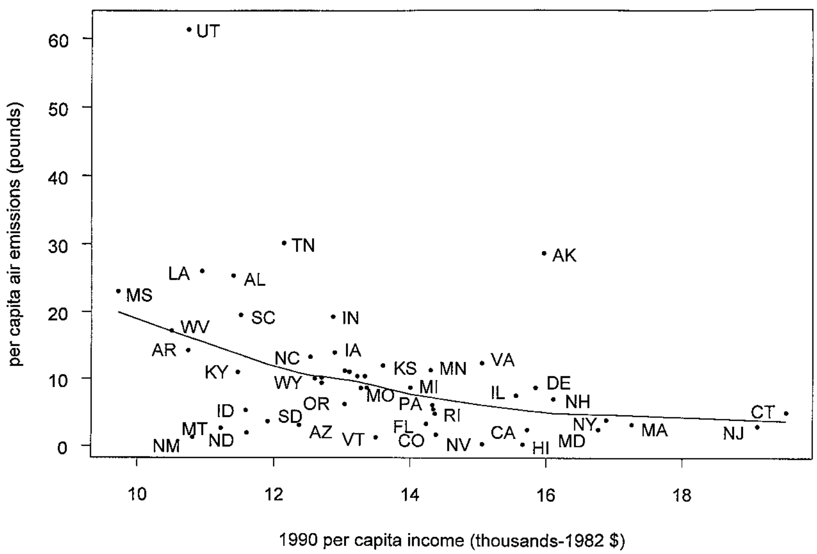

Figure 2. *1990 air toxic emissions*

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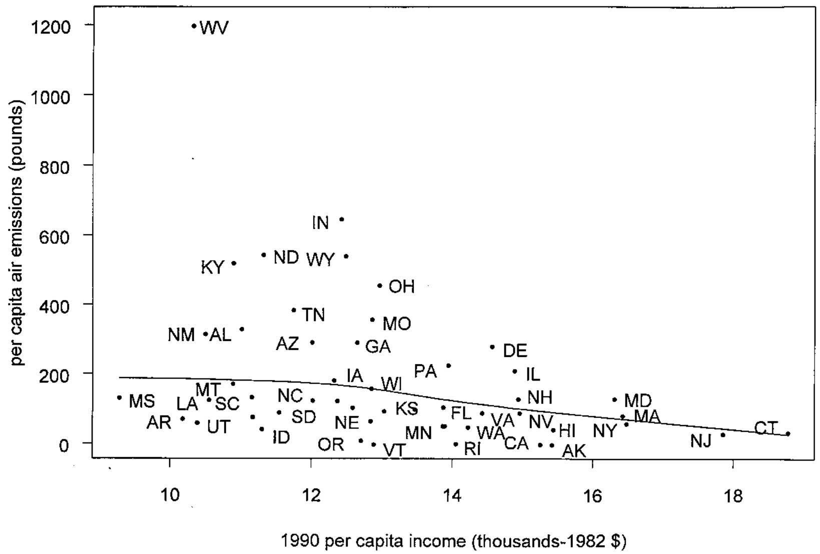

Figure 3. *1990 sulphur dioxide emissions*

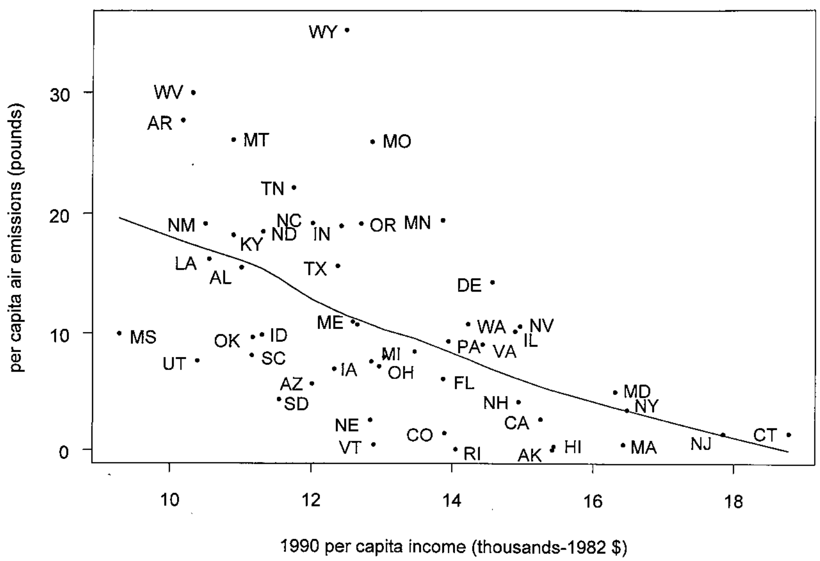

Figure 4. *1990 PM_{10} emissions*

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weighted robust scatterplot smoother based on Tukey's biweight function. LOWESS allows the curvature of the income–emission relationship to differ in different parts of the income space and heavily downweights observations that are outliers in each part of the income space.

Table 2 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.[11] The coefficients on GNP per capita are all negative, suggesting that air emissions per capita in the USA 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 environmental Kuznets curves found for the seven different air pollutants represent spurious relationships, by looking at a small number of other possible predictors of per capita pollution. The first set of variables we looked at take account of the industrial mix including employment shares at the one-digit SIC (industry category employment) codes. 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

Table 2. *Cross-sectional regression analyses (t-values in parentheses)*

	OLS with White standard errors			*Robust regression*	
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)
County	100.55	−5.71	0.02	17.83	−0.77
	(8.67)	(−6.64)		(50.14)	(−87.63)

[11] 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 favour the linear specification since they tend to downweight the outliers that are responsible for the curvature in the log-log models.

of people exposed to the class of air pollutant, population density and percentage urban. 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 per cent level for NO_x, SO_2 and PM_{10}, and was significant at the 10 per cent level for VOC and suggestive (15 per cent) for CO.[12] When we included population density and percentage urban variables, the signs on these coefficients were never significant, although 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. Of course, this should not be surprising given the high correlation (0.66) and (0.59), respectively, of these two variables with per capita income.[13] 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

Figures 1 through 4 display the negative relationship between state per capita income and emissions of greenhouse gases, air toxics, SO_2, and PM_{10}; the figures for CO, NO_x and VOC were similar and have been omitted to save space. 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 2. In those equations the estimated variance for all pollutants decreased as income increased. The LOWESS curves in Figures 1 to 4 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, large coal-producing states, are consistent outliers. Among middle-income states, Rhode Island and Vermont usually have emissions substantially below the

[12] 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 toxics.

[13] 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 (NO_x), both predictor variables are significant.

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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 3 for sulphur 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.[14] While this relationship is significant ($p < 0.001$) 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.

3. Air toxics 1988–94

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.[15] 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 per cent) in Utah and the largest increase was 1.3 pounds (7.3 per cent) in Mississippi. Likewise, there is a fairly large range of changes in real per capita income, with California losing over $700 (−4.6 per cent) and the North Dakota gaining $2,400 (24.6 per cent).

Using these data, we test the null hypothesis that emissions are positively correlated (or uncorrelated) to income. The standard non-parametric test of this hypothesis is the sign test (Conover, 1971). We partition observations into one of four cells: A [increased income, increased pollution], B [decreased income, decreased pollution], C [increased income, decreased

[14] A similar negative relationship was found using emissions of CO, NO_x, SO_2 and VOC.

[15] The EPA has a long series of emissions estimates for CO, NO_x, SO_2, VOC and PM_{10} stretching from 1900 to 1995, with the most detailed estimates for the period 1985–95. 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 1985–95. US EPA (US Environmental Protection Agency, 1995a, Chapter 6) discusses the development of these emission estimates. The toxics reporting program began in 1987, but, because of problems associated with reporting during this first year, the US Environmental Protection Agency 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 1988–94 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.

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 50 states (92 per cent) fail to conform to the null hypothesis. The value of the sign test statistic is 21 ($p < 0.001$), which clearly rejects the null hypothesis that pollution is positively correlated (or uncorrelated) with income.

Rejecting the hypothesis that income and toxic emissions do not move together in the manner expected under the environmental Kuznets curve hypothesis 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 US states is uniformly improving irrespective of changes in income. To look at this possibility, we need to consider in more detail how the two series move together. Table 3 reports a bivariate OLS regression of the change in per capita air toxics emissions occurring between 1988 and 1994 (PCTOXCHANGE) on the change in per capita income (PCICHANGE). 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 5 reinforces the OLS regression results in Table 3 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.[16]

Table 3. *Change in air toxics 1988–94 regression analysis (t-values in parentheses)*

Independent variables	*OLS with White standard errors*				*Robust regression*
CONSTANT	−4.9083	−7.7774	0.50249	8.1282	1.8856
	(−6.53)	(0.26)	(0.96)	(2.47)	(1.38)
PCICHANGE	0.6261			0.0018	0.2413
	(0.68)			(0.00)	(0.82)
PCI88		0.2648		−0.5659	−0.1649
		(0.62)		(−2.73)	(−2.01)
PCTOX88			−0.4815	−0.5209	−0.4499
			(−7.68)	(−9.47)	(−13.49)
R^2	0.00	0.01	0.82	0.87	

Notes: The dependent variable is PCTOXCHANGE = 1994 state per capita air toxics emissions minus 1988 state per capita air toxics emissions. PCICHANGE = 1994 state per capita income minus 1988 state per capita income. PCI88 = 1988 state per capita income. PCTOX88 = 1988 state per capita air toxics emissions.

[16] We dropped Utah from Figures 5 and 6 because its initial large level of emissions (71.2 lbs.) and its subsequent large drop in emissions (39.0 lbs.) forces most states into a fairly small portion of the figures.

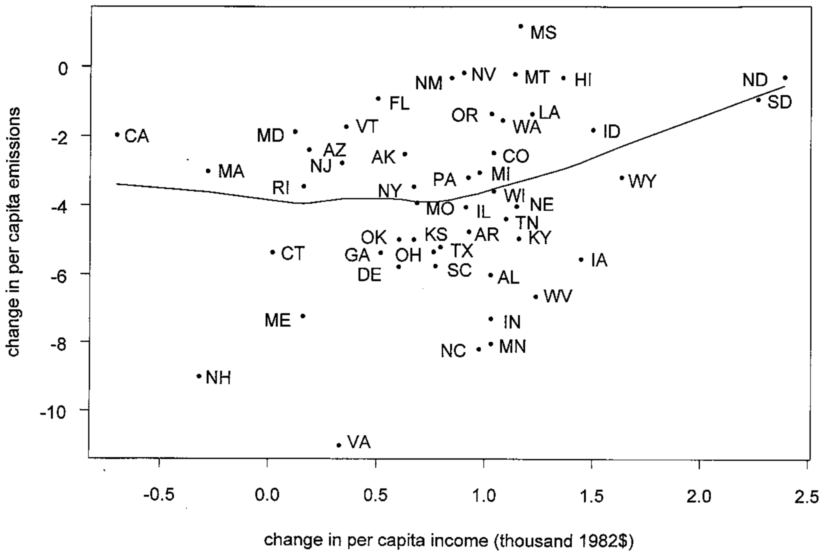

Figure 5. *Air toxics 1988–94*

It may be useful to consider the starting position of the different states with respect to their initial 1988 emission levels (PCTOX88); 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 per cent of the variance in the change in emission levels is being explained by this variable. Figure 6 displays the relationship with the LOWESS curve being plotted.

We can also look at the initial 1988 per capita income level (PCI88). The bivariate OLS regression for this relationship is also given in Table 3. The OLS regression equation suggests no relationship between 1988 per capita income and the change in emission level.

It is, of course, possible to estimate an OLS regression equation with all three predictor variables: PCICHANGE, PCTOX88, and PCI88. Note in the OLS equation that, while PCICHANGE remains completely insignificant, PCI88 is now significant with higher income states conditionally having larger reductions in emission levels, and the R^2 of the equation has increased to 0.87 from the 0.82 achieved in the equation using PCTOX88 alone. The robust regression suggests a smaller but still significant effect for PCI88. More complex models with non-linear terms result in an improved fit, but suggest the same basic relationship.

Our results are somewhat counterintuitive. They suggest that some high-income states, such as California, which are known to have fairly aggressive programmes aimed at reducing air toxics, have experienced only small reductions in their air toxic reductions over the 1988–94 period. However, as seen in Figure 6, 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 7,

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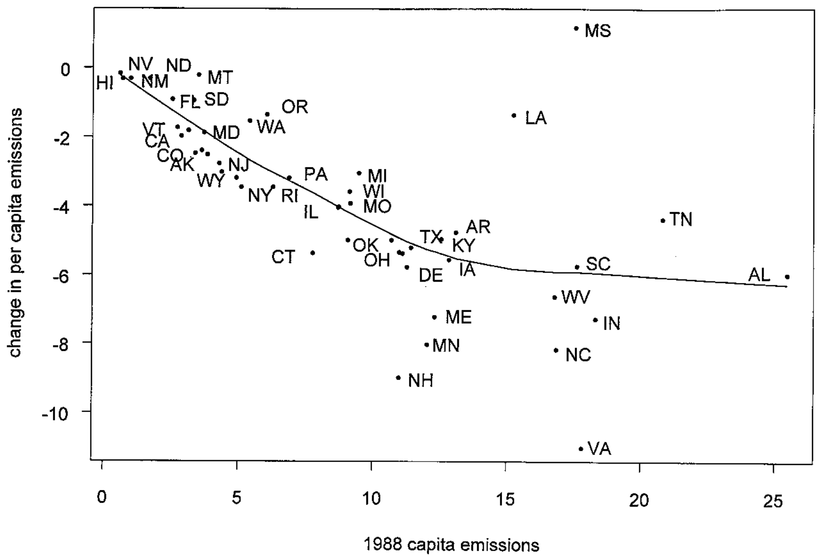

Figure 6. *Air toxics 1988–94*

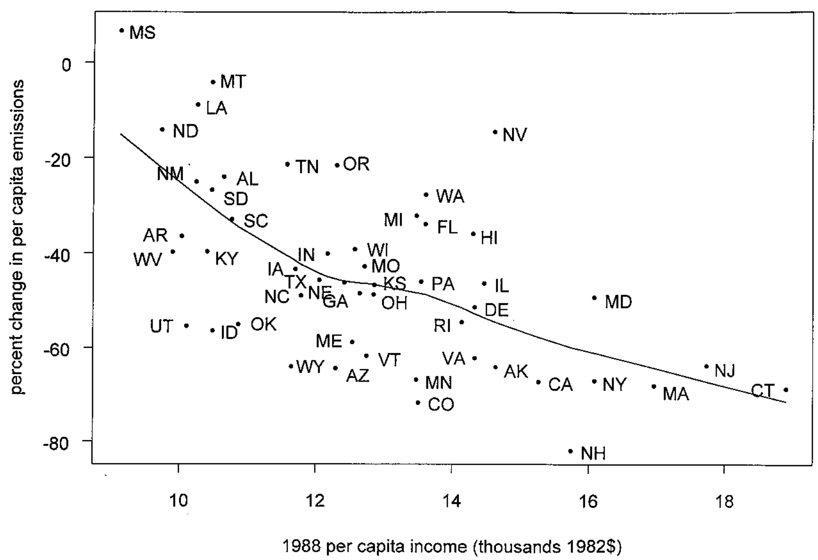

Figure 7. *Air toxics 1988–94*

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.

We also estimated a fixed-effects panel data model of air toxics

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emissions using several different specifications.[17] In general, the results of this exercise support the interpretation of the data found in the simpler time-difference model reported above. Without adding state-level fixed effects, there is a clear negative relationship between annual per capita income and annual per capita air toxic emissions. When the state-level fixed effects are added, the relationship between income and air toxics becomes insignificant. This is not surprising, since the state-level fixed effects are effectively incorporating both initial income and air toxic emission levels, as well as other factors we sought to difference out. Controlling for SIC codes at the two-digit level does not change this result.

4. Discussion

Using data from the 50 US 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.[18] 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 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, which may be outliers simply owing 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 sulphur dioxide where there is long-distance transport, the similarity between the income–pollution relationships for the seven air pollutant classes seems much stronger 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 US states.

Without exception, the high-income states have low per capita emissions while emissions in the lower-income states are highly variable. We believe

[17] The results are available from the authors upon request.

[18] This result contrasts with Holtz-Eakin and Selden (1995), who looked solely at CO_2 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 CO_2 and found very similar results to those reported for greenhouse gases. Schmalensee *et al.* (1997) 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 USA looks fairly similar to our Figure 1.

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 jurisdictions than in higher-income political jurisdictions may lead to a better understanding of what factors lie behind the cross-sectional environmental Kuznets curve relationship.

Clearly, there may be a relationship between income and pollution at any point in time. However, unless this relationship is dynamic in the sense of changes in per capita income being associated with changes in per capita emissions, then the relationship is of little policy interest. 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. A uniformly improving technology story is capable of explaining the general reduction in per capita emissions. 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 20 years since the US Clean Air Act was passed. Large differences in per capita emissions across the US 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, to state differences in enforcing federal pollution laws and, most importantly, long-lived technology vintage effects.[19] Our results suggest that the absolute income level in a political jurisdiction (rather than the change in income) 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 (1993) 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, which suffered real per capita income losses, view those losses as transitory, as appears to have been 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.

[19] Jaffe *et al.*'s (1995) recent literature review, however, suggests that differences in state pollution regulations do not have large effects on firm-level decisions on where to locate plants.

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