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Factoring the Environmental Kuznets Curve: Evidence from Automotive Lead Emissions

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This article describes the relationship between automotive lead emissions and national income for 48 countries over 20 years. It draws three principal conclusions. First, lead emissions can be shown to follow an inverse-U or an "environmental Kuznets curve" with respect to income. Second, the peak of this curve is sensitive to both the functional form estimated and the time period considered. Third, automotive lead pollution is the product of two separate factors, lead per gallon of gasoline (pollution intensity) and gasoline consumption (polluting activity), and the declining portion of the curve depends critically on reducing gasoline lead content, not gasoline use.

Key Words: environmental Kuznets curve; automobile emissions; leaded gasoline.

INTRODUCTION

Substantial empirical evidence now suggests that the relationships between many forms of pollution and national income follow an inverse-U-shaped pattern, rising initially, peaking, and then declining.[1] Because this pattern resembles the time series of income inequality described by Kuznets [10], the environmental pattern has been labeled the "environmental Kuznets curve" (Selden and Song [17]). To date, the literature on environmental Kuznets curves has not addressed the case of automotive lead emissions, a problem the World Bank [23] describes as "the greatest environmental danger in a number of the large cities in the developing world."

This article provides new evidence of the existence of an environmental Kuznets curve for the case of airborne lead pollution, using a data set of 48 countries over a 20-year period. The article has three main findings. First, it adds automotive lead emissions to the list of pollutants shown to follow an inverse-U with respect to national income. Second, it shows that the location of the peak of this curve is sensitive to both the functional form and the time period chosen to estimate the curve. Third, automotive lead pollution is the product of two separate factors: lead per gallon of gasoline (pollution intensity), and gasoline consumption (polluting

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[1] See, for example, Grossman and Krueger [8], Holtz-Eakin and Selden [9], Selden and Song [17], and Shafik and Bandyopadhyay [18].

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activity). By separately estimating the relationship of these two factors to national income, the article takes one step beyond the typical aggregate estimates of environmental Kuznets curves and shows that the declining portion of the curve depends critically on reductions in gasoline lead content, not gasoline consumption. In other words, the improvement in environmental quality that accompanies income growth depends on the types of regulations and developments that reduce pollution intensity rather than reducing polluting activity.

BACKGROUND

The strongest evidence for the U-shaped pollution-income relationship comes from panels of data on environmental quality across countries over time, and regresses environmental quality on a polynomial function of income per capita and other covariates. Table I summarizes four such studies. The first two studies examine ambient environmental quality, while the latter two studies examine emissions. They use a variety of functional forms: cubic and quadratic, levels and logs, with and without lagged income terms, fixed and random effects, and with and without other covariates such as time trends, population density, and trade openness. With the exception of Holtz-Eakin and Selden [9], each study finds evidence of an inverse-U-shaped relationship between pollution and income for some subset of pollutants studied.

Grossman and Krueger [8] regress the level of ambient concentrations of urban air and water pollution on a cubic in gross domestic product (GDP), lagged values of the GDP polynomial, a time trend, population density, and indicators for the nature of the surrounding area (coastal, residential, etc.). Of the 14 pollutants studied, 13 have peaks between $1887 and $11,632 GDP per capita, and the other (large airborne particulates) declines monotonically. Grossman and Krueger conclude that the turning points for most of the environmental problems they study occur before per capita income reaches $8000 (in 1985 dollars). Above $8000, pollution declines with income. Similarly, Shafik and Bandyopadhyay [18] regress the level of various pollutants on a polynomial in the logarithm of GDP. They find evidence of U-shaped relationships for deforestation and urban air pollution, but not for drinking water quality, urban sanitation, or river water quality.

Selden and Song [17] focus on emissions of common local air pollutants. Their quadratic in levels of GDP peaks somewhere below $10,000 of GDP per capita for particulate and sulfur emissions, above that for nitrogen and carbon emissions. Importantly, they note that both peaks are high enough above the per capita incomes of most countries that global emissions of these pollutants will continue to increase for the foreseeable future. Finally, Holtz-Eakin and Selden [9] examine carbon monoxide emissions using quadratic equations in levels and logs of GDP. Unlike the other environmental problems listed in Table I, carbon emissions constitute an international externality. Each country's emissions affect the entire planet, and emissions reduction has the nature of a global public good. Countries are unlikely to impose unilateral carbon regulations, given the incentives to free ride on other countries' efforts. Perhaps for this reason, Holtz-Eakin and Selden find that carbon emissions increase monotonically, only peaking far out of sample at GDP per capita above $8 million.

Two patterns are notable from the articles in Table I. First, none of the pollutants with U-shaped income curves involve international externalities. The

TABLE I

Existing Evidence on the Income-Pollution Relationship

	Dependent variable						
	Pollutants	Units	Countries	Years	Specifications	Turning point ($1985)	Other independent variables
Grossman and Krueger [8]	SPM, SO_2, water quality	Ambient concentrations	42 (SO_2) 29 (SPM)	1977–1988	Cubic in levels	< $8000	Time trend, population density, geography
Shafik and Bandyopadhyay [18]	SPM, SO_2, water quality, CO emissions	Ambient concentrations for SPM SO_2	149	1972–1988 for SMP SO_2	Quadratic in logs	$3670 (SO) $3280 (SPM)	Investment, growth, energy subsidies, trade openness, debt, civil and political liberties
Selden and Song [17]	SPM, SO_2, NO_X, CO	Emissions	30	1973–84	Quadratic in levels	$9000–$10,000 (SPM, SO_2) $12,000–22,000 ($NO_X$, CO)	none
Holtz-Eakin and Selden [9]	CO	Emissions	130	1951–1986	Quadratic in levels and logs	> $8 million	none

Note: SPM = suspended particulate matter; SO_2 = sulfur dioxide; NO_x = nitrogen oxides; CO = carbon.

jurisdiction that emits the pollutant suffers the damage and therefore has the incentive to reduce emissions. When the pollutant crosses borders, there is no Kuznets peak at reasonable levels of income. Second, while the different functional forms hinder comparisons of the various studies, the pollutants that consistently exhibit inverse-Us (including this study) typically involve local air pollution.

All four studies in Table I carefully avoid making structural interpretations of their results. With no theory to explain the observed pattern of environmental quality, the door is left open for divergent conclusions. Particularly worrisome are suggestions that environmental improvement is a naturally occurring process, and that economic growth by itself will be a panacea for environmental degradation. Beckerman [2] writes that "in the longer run, the surest way to improve your environment is to become rich." Even more disturbing are claims that "existing environmental regulation, by reducing economic growth, may actually be reducing environmental quality" (Bartlett [1]).

Two alternative theories may explain the observed inverse-U relationship between many pollutants and income. It could be that the natural pattern of economic development involves a transition from subsistence agriculture, which is not pollution intensive, to the more polluting early stages of manufacturing, to less polluting service industries. This is sometimes called the "composition effect." In part, the transition away from polluting industries could be the result of wealthy countries shifting pollution-intensive manufacturing processes to less developed countries. If so, then it will not be possible for all nations to experience improving environmental quality, as the poorest nations will never have poorer ones on which they can dump polluting processes.

Alternatively, it may be that the environmental Kuznets curve is based on two entirely separate relationships. First, many economic activities pollute the environment, and wealthy countries (with more polluting activity) generate more pollution. This has sometimes been called the "scale effect." Second, environmental quality is a normal good, and wealthier countries' citizens demand more of it in the form of regulations requiring reductions in the amount of pollution per unit of activity (pollution intensity). This has sometimes been called the "technique effect." Overall pollution is the product of polluting activity and pollution intensity, and consequently the pollution-income relationship has a theoretically ambiguous shape.

The existing literature estimates only the relationship between income and overall pollution. By estimating separately the relationship between income and these two factors of pollution (intensity and activity), this article provides support for this last interpretation of the environmental Kuznets curve: Polluting activity increases with income, pollution intensity decreases with income, and the product of the two happens to follow an inverse-U. The primary obstacle to exploring this hypothesis has been the lack of separate time-series data on pollution emissions per unit of economic activity. This study focuses on lead emissions from gasoline in part because of the availability of international data on both gallons of gasoline consumed and the amount of lead per gallon of gasoline.

Lead was first added to automotive gasoline in the 1920s for its ability to increase engine efficiency and to reduce unwanted engine "knock." Until the 1960s, health concerns about lead exposure focused on *acute* lead poisoning, and it was generally believed that automotive lead emissions were not sufficient to be harmful. Gradually, however, the recognized threshold of dangerous blood-level concentrations of lead dropped from 60 μg dl before 1970 to 10 in 1991 (Center for Disease Control [3]). Epidemiological and experimental evidence suggests that automotive lead accounts for the majority of blood lead. In the United States, during a period when gasoline lead additives dropped by 50%, average blood lead levels dropped by 30% (Pirkle *et al.* [15]). In Turin, Italy, scientists altered the isotopic composition of gasoline lead so that it would not be confused with lead from other sources. They then showed that gasoline lead additives were the major contributor to blood lead (Faschetti and Geiss [7]).

In 1971, the U.S. EPA administrator announced his intention to regulate gasoline lead additives for two reasons: to reduce lead poisoning from breathing air contaminated by lead emissions, and to protect lead-intolerant catalytic converters that would be required on all automobiles manufactured after 1975 (Weimer and Vining [22]). Both concerns involve local air pollutants generated by consumption activity, and both concerns were evident from the beginning of the U.S. regulatory process (Schwartz *et al.* [16]). Perhaps not surprisingly, these regulations encountered industry opposition. Octel, for example, waged an international campaign claiming that the use of unleaded gasoline in cars without catalytic converters may increase exposure to benzene, a carcinogen. However, benzene exposure has little to do with the presence of catalysts, and the benzene content of gasoline is limited in the United States and Europe and is not necessarily higher than that of leaded gasoline (Thomas [21]). While the phaseout of leaded gasoline may have some hidden costs, they are almost certainly dwarfed by the health benefits of reduced lead poisoning (Schwartz *et al.* [16]).

Although the United States eventually imposed an outright ban on leaded gasoline (effective December 31, 1995), the nations of Western Europe have relied more on financial incentives. In Germany, one of Europe's least leaded nations, drivers have paid up to 15% less for super unleaded than for super leaded (Earth Summit Watch [6]). Officials in Sweden attribute much of their phaseout success to the 16% price differential between leaded and unleaded gasoline (Lovei [11]).

Automotive lead emissions constitute an excellent subject for a Kuznets-curve analysis for several reasons. First, the earlier literature suggests that local air pollution follows an inverted-U curve. Because automotive lead emissions generate local air pollution, one can expect that they will also follow an inverse-U pattern with respect to income. Second, because it is generated by a consumption activity, declines in airborne lead cannot be the consequence of shifting production to less developed countries. Finally, and most important, data are available on both the quantity of gasoline consumed and its lead content for a large panel of countries, enabling separate analyses of polluting activity and pollution intensity with respect to income.

DATA AND PRELIMINARY EVIDENCE

The data for this project come from Octel's *Worldwide Gasoline Survey* [12], which reports the average lead content of gasoline biannually for over 150 countries. The Octel data are acquired from loosely described ‘‘contacts’’ in various countries. Some provide unofficial estimates of lead content. All of the contacts are anonymous. The data sometimes make discrete jumps, are missing for extended periods, or are otherwise inconsistent or suspect. To try to limit misreporting and inconsistencies, we focus on the 48 countries with 1990 populations over 10 million and for which Octel data were continuously reported, using data every other year from 1972 to 1992. Data on total gasoline consumption are compiled from various OECD publications. Income and population data are from the Penn World Tables (Mark 5.6) documented in Summers and Heston [20].

Figure 1 presents three cross-sections of total lead per capita against GDP per capita in 1992, 1982, and 1972. The top panel, containing the 1992 data, depicts the environmental Kuznets curve: Low-income countries and high-income countries have low lead exposure, while middle-income countries have the highest lead exposure. However, this pattern has only emerged in recent years. In 1982 evidence for the downward-sloping portion of the curve is sketchy, and in 1972 nonexistent. One explanation for the gradual appearance of the inverse-U-shaped cross-section is that even the wealthiest countries in 1972 had not reached income levels at which Kuznets curves for lead emissions would peak. Alternatively, decreases in lead content may have been prompted by advances in medical understanding of the dangers of low-level lead poisoning or by advances in the technology of lead substitutes in gasoline. Either way, Fig. 1 illustrates the danger of drawing historical inferences from cross-section data.

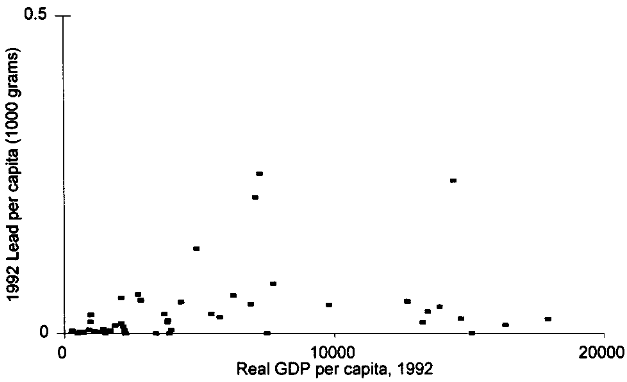
The basic premise of this article is that gasoline use is a measure of polluting activity, and that ambient lead levels are a direct function of the amount of gasoline used multiplied by its lead content.[2] Figure 2 describes the relationships underlying the environmental Kuznets curve: lead per gallon of gasoline (pollution intensity), and gasoline consumption (polluting activity). Figure 2(a) plots grams of lead per gallon against per capita GDP for the same countries in 1992, and it is clear that lead per gallon declines with income. Countries with the highest average lead per gallon are those with the lowest incomes. On the other hand, Fig. 2b shows that gasoline use rises with income. The product of these two series generates the U-shaped pattern in the top panel of Fig. 1.

Regardless of the underlying causes, several preliminary conclusions can be drawn from the scatter plots in Figs. 1 and 2. First, lead emissions per capita apparently follow an inverse-U-shaped environmental Kuznets curve, rising and then falling with income. Second, this pattern results from the combination of falling amounts of lead per gallon (pollution intensity) and increasing gasoline usage (polluting activity). These conclusions, however, are based on visual examinations of the cross-section data. In order to control for other country characteristics and to distinguish cross-country differences from within-country differences over time, the next section presents several econometric specifications of lead emissions and its components using the entire panel of data.

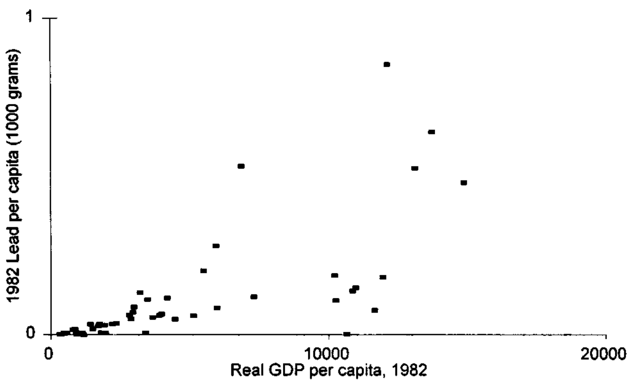
FACTORING THE ENVIRONMENTAL KUZNETS CURVE FOR LEAD EMISSIONS

Earlier analyses use a variety of specifications to estimate the relationship between income and pollution. This article presents two of the most common: (1) polynomials in the levels of GDP per capita, and (2) a quadratic in the logs of GDP

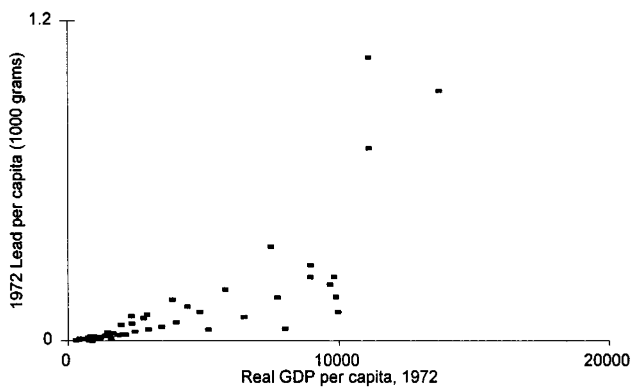
[2] Gasoline consumption is itself the product of two factors: miles driven, and miles per gallon. Outside of a few industrialized countries, however, there are insufficient data to break down this relationship further. Among industrialized countries, miles driven grows steadily with income, while miles per gallon does not exhibit a consistent pattern with income over time.



(a)



(b)



(c)

FIG. 1. The environmental Kuznets curve for lead: three cross-sections; (a) grams of lead per capita in 1992, (b) grams of lead per capita in 1982, (c) grams of lead per capita in 1972.

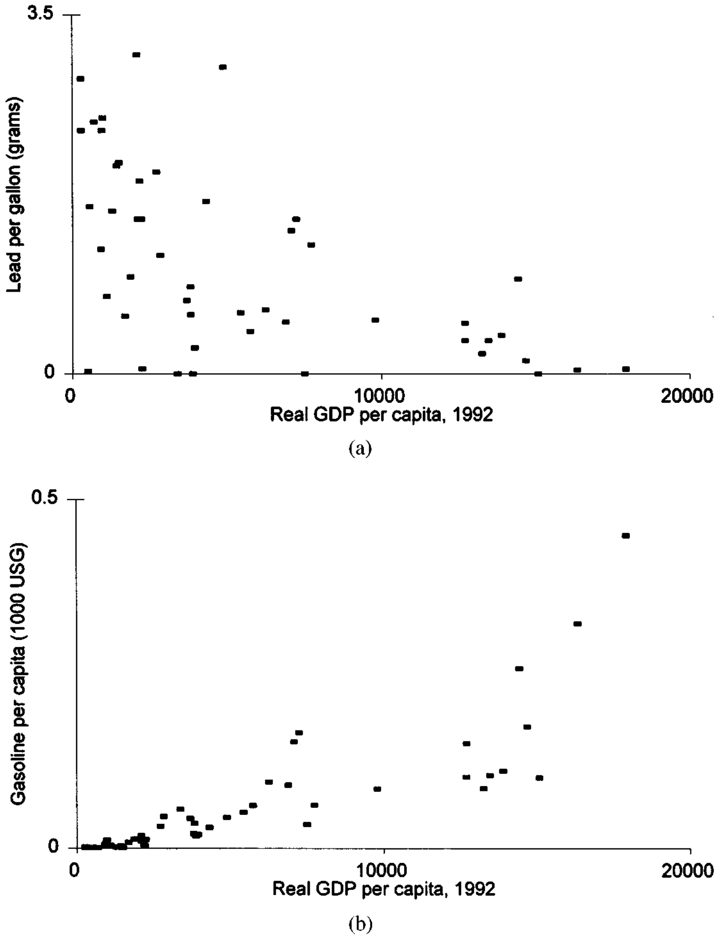


FIG. 2. Factoring the environmental Kuznets curve: 1992 cross-sections; (a) grams of lead per gallon in 1992, (b) gasoline use per capita in 1992.

per capita. Because the scatter plots in Fig. 1 exhibit different patterns for different years, we also interact the income polynomials with a dummy variable for the post-1983 period.[3] For example, the specification for the quadratic in levels is

$$\text{lead} = \alpha + \beta_1 G + \beta_2 G^2 + \beta_3 D_{83} + D_{83}\left[\beta_4 G + \beta_5 G^2\right] + \beta_6(\text{population density}) + \beta_7(\text{year}), \tag{1}$$

where G is per capita real GDP, D_{83} is an indicator equal to one for the post-1983 observations, and country and time subscripts are suppressed. In the estimations

[3] We also explored interaction terms between a time trend (rather than a post-1983 indicator) and the GDP polynomials. These regressions had extremely similar implications and were somewhat more difficult to depict graphically. For clarity, we opted to present the regressions using the post-1983 indicators rather than the time trends.

that follow, we also present a version of Eq. (1) that includes cubic terms in GDP per capita. For the quadratic in logs, the specification is

$$\ln(\text{lead}) = \alpha + \beta_1 \ln G + \beta_2 (\ln G)^2 + \beta_3 D_{83} + D_{83}\left[\beta_4 \ln G + \beta_5 \ln G^2\right] + \beta_6(\text{population density}) + \beta_7(\text{year}). \quad (2)$$

Both specifications also contain 48 country fixed effects.[4]

Table II presents estimates of Eqs. (1) and (2). The first two columns present the polynomial regression (1) with and without the cubic terms. The third column presents Eq. (2). The time trend is negative in all three regressions, and statistically significant in both polynomials, suggesting that there may be a secular downward trend in lead emissions that is independent of income. Lead emissions declined for these countries more than would be predicted by income growth alone. This may

[4] Specifications with time dummies rather than a time trend, or random rather than fixed effects had nearly identical results.

TABLE II

Estimating the Environmental Kuznets Curve for Automotive Lead Emissions

	Quadratic in levels of income: dependent variable = total automotive lead [millions of grams] (1)	Cubic in levels of income: dependent variable = total automotive lead [millions of grams] (2)	Quadratic in logs of income: dependent variable = ln(total automotive lead) [millions of grams] (3)
GDP per capita[a]	−1.58	4.12	7.83*
	(2.89)	(8.64)	(2.02)
GDP per capita squared[a]	0.0003	-0.0010	-0.49*
	(0.0002)	(0.0016)	(0.13)
GDP per capita cubed	—	6.49×10^{-8}	—
		(8.12×10^{-8})	
Dummy = 1 if year > 1983	−11,476*	13,453*	−14.8*
	(3,623)	(3,235)	(3.9)
(Year > 83) × (GDP/capita[a])	8.97*	−12.6*	4.02*
	(2.36)	(3.4)	(0.99)
(Year > 83) × (GDP/capita[a])^2	−0.0008*	0.0029*	−0.27*
	(0.0002)	(0.0008)	(0.06)
(Year > 83) × (GDP/capita)^3	—	-1.59×10^{-7}*	—
		(0.49×10^{-7})	
Population density	38.4*	22.9†	-4.9×10^{-5}
	(14.5)	(13.0)	(137.7×10^{-5})
Year	−308*	−240*	−0.0074
	(148)	(122)	(0.0090)
Constant (avg. fixed effect)	25,149*	18,835†	−23.5*
	(9,435)	(10,121)	(8.04)
n	528 (48 × 11)	528 (48 × 11)	528 (48 × 11)
R^2	0.68	0.73	0.90
F-test of hypothesis that all time-interaction coefficients = 0	5.14	5.32	14.05

[a] In column (3) the logarithms of these values are used as regressors.

* Statistically significant at 5%. † Statistically significant at 10%.

Heteroskedastic-consistent standard errors in parentheses. Models include 48 country fixed effects.

be due to advances in medical understanding of the effects of low-level lead poisoning, or to advances in or propagation of the lead substitute technology. Because the fixed effects hold country area constant, the population density coefficient picks up the effect of population growth, which seems to be insignificant.

The specifications in Table II tell starkly different stories about the shape of the lead-income curve. Although the existence of a Kuznets curve peak is robust to the specification chosen, the location of that peak is not. In columns (1) and (2), the polynomials in income are statistically significant only when interacted with the dummy variable for the post-1983 period. Furthermore, the post-1983 dummy reverses the signs of the polynomial coefficients, altering the shapes of the curves. In column (3), the quadratic in logs of income is statistically significant for both time periods, and the post-1983 dummy only exaggerates the shape of the curve. In all three cases, F-tests easily reject the hypothesis that the polynomial coefficients are the same before and after 1983. These differences can perhaps best be seen graphically.

Figure 3 plots the predicted values of total lead emissions from Table II as a function of GDP per capita, using the point estimates of the GDP coefficients and setting other country characteristics at their mean values. Panel (a) presents the quadratic in levels. The light line plots the predicted values of lead before 1983 (setting the post-1983 indicator at zero). The dark line plots the lead predictions after 1983 (setting the post-1983 indicator at one). Although the results must be interpreted cautiously because the pre-1983 coefficients are not statistically significant, panel (a) depicts the change in shape predicted by the point estimates in column (1) of Table II. Only after 1983 does the curve exhibit a statistically significant peak.

Panel (b) of Fig. 3 depicts the shapes predicted by the point estimates in column (2) of Table II, the cubic regression in levels of income. Again, only the post-1983 curve exhibits a statistically significant peak. Although the cubic term forces the predicted values to take on an S-shape, the post-1983 curve peaks at around $11,000 per capita, and declines thereafter.

Panel (c) of Fig. 3 plots the logarithmic specification from Table II. Again the light line represents predictions for before 1983, and the dark line represents predictions after 1983. Both curves are essentially the same, and peak early, at around $4000 per capita.[5] Thus although all three specifications generate inverse-U-shaped curves, they peak at different incomes and they have profoundly different implications. In 1972, 35% of the population sampled lived in countries with GDP per capita above $4000. Only 10% of the population lived in countries with GDP per capita above $11,000. Altering the functional form of the Kuznets curve estimate changed 25% of the population from a situation of improving environmental quality to one of declining environmental quality. Figure 3 thus summarizes two of the principal conclusions of this study: (1) automotive lead emissions follow an inverse-U-shaped path with respect to national income, but (2) the location of the peak of that path is highly sensitive to both functional form and time period.

[5] This is in apparent contrast with Fig. 1(a), the raw 1992 data, which peaked around $10,000. Recall, however, that Fig. 1(a) is a cross-section of countries in 1992, whereas Fig. 3 estimates the effect of changing GDP on lead emissions, holding country characteristics constant over time.

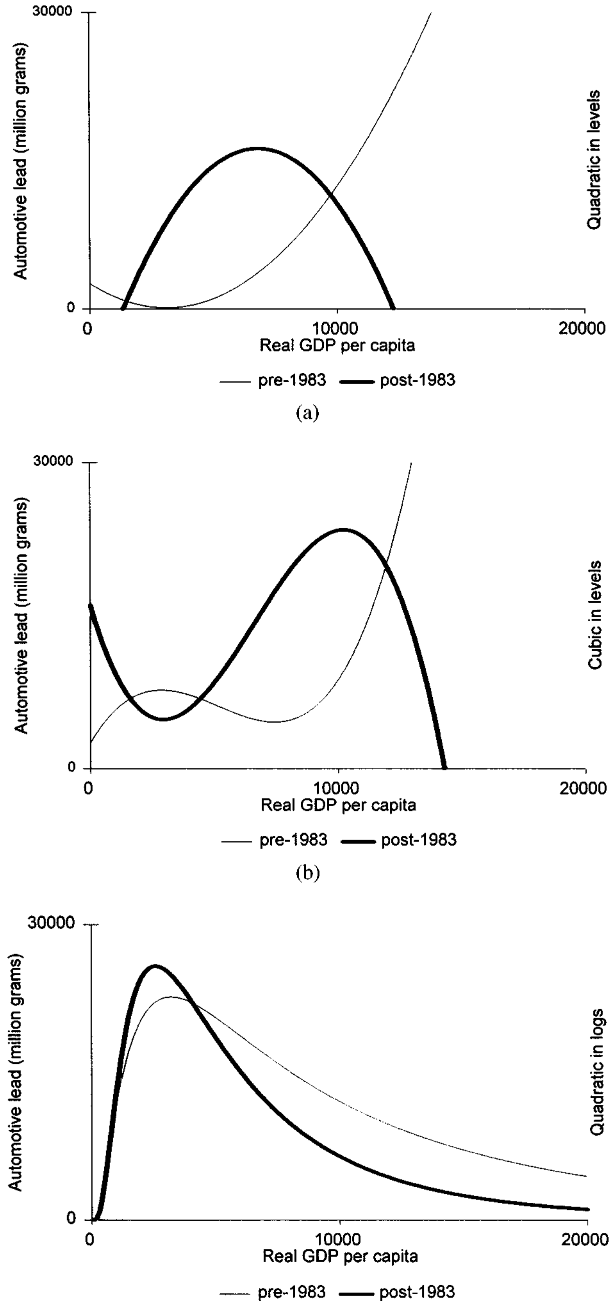


FIG. 3. Environmental Kuznets curves—various functional forms and years; (a) quadratic in levels, (b) cubic in levels, (c) quadratic in logs.

The specifications in Table II mimic the existing literature on environmental Kuznets curves by using polynomials in levels or logs of GDP per capita. These constrain the shape of the resulting income-pollution paths. The predicted peaks are the result of the functional form assumptions, and may be driven by relationships in income ranges far removed from the peaks.

To estimate a less restrictive functional form, Table III presents a spline version of the equations. The data were divided into quartiles, at GDP-per-capita values of \$1500, \$3200, and \$7000.[6] Column (1) contains the spline regressions for total lead emissions. As with the polynomials from Table II, the GDP terms are statistically significant, indicating changes in the slope of the emissions-income path. More populous countries use more lead, and lead has been declining over time even holding income constant. Like the specifications in Table II, the spline shows that the shape of the lead-income curve changes dramatically over time. The post-1983

[6] Splines by income quintiles and thirds yielded largely similar results.

TABLE III

Factoring the Environmental Kuznets Curve.[a]

	Pollution: total lead emissions [millions of grams] (1)	Pollution intensity: lead per gallon [grams] (2)	Polluting activity: gasoline use [millions of gallons] (3)
GDP per capita	−0.43	0.00042	0.36*
	(1.12)	(0.00027)	(0.11)
GDP per capita > \$1500	5.35*	−0.00016	−0.36*
	(2.00)	(0.00032)	(0.17)
GDP per capita > \$3200	−9.86*	−0.00051*	0.004
	(2.70)	(0.00020)	(0.186)
GDP per capita > \$7000	11.22*	0.00024*	0.16
	(3.42)	(0.00009)	(0.24)
Dummy = 1 if year > 1983	3420†	−0.12	−635*
	(1983)	(0.26)	(164)
(Year > 83) × (GDP/capita)	1.58†	0.00039	0.15†
	(0.83)	(0.00026)	(0.09)
(Year > 83) × (GDP/capita > 1500)	−6.94*	−0.00086*	−0.16
	(1.96)	(0.00039)	(0.16)
(Year > 83) × (GDP/capita > 3200)	13.95*	0.00046*	0.11
	(3.55)	(0.00020)	(0.22)
(Year > 83) × (GDP/capita > 7000)	−19.40*	−0.00001	−0.005
	(5.03)	(0.00009)	(0.311)
Population density	21.94	0.0012	−2.97*
	(14.63)	(0.0020)	(1.14)
Year	−427*	−0.057*	60.5*
	(177)	(0.009)	(13.2)
Constant (avg. fixed effect)	34,226*	6.22*	−1364*
	(12,524)	(0.67)	(926)
n	528 (48 × 11)	528 (48 × 11)	528 (48 × 11)
R^2	0.66	0.64	0.99

[a] Spline by income quartiles with time trend and country fixed effects.
* Statistically significant at 5%.
† Statistically significant at 10%.
Heteroskedastic-consistent standard errors in parentheses. Models include 48 country fixed effects.

interaction changes the sign of every one of the spline coefficients. Again, these changes can best be seen graphically.

The top panel of Fig. 4 plots the predicted values from the spline regression of emissions in column (1) Table III. Like the cubic, the spline reverses shape after 1983. Only after 1983 does the spline exhibit a Kuznets-style peak. The spline for the post-1983 years supports the implication of the quadratic in levels that the peak occurs high in the distribution of national incomes, somewhere around $7000.[7]

Columns (2) and (3) of Table III explore the separate factors of lead pollution: lead per gallon (pollution intensity) and total gallons consumed (polluting activity). Column (2) contains the results for lead per gallon, and column (3) contains the results for total gasoline consumption. Especially noteworthy are the year coefficients. Lead per gallon declines over time, and gasoline use increases, even holding income constant.

Again the best way to understand the results is graphically. Figure 4 presents all three regressions from Table III. Total emissions in the top panel exhibit an inverse-U only after 1983, as previously discussed. Lead per gallon in the second panel appears to have its own Kuznets-style peak low in the income distribution, after which it exhibits a steady decline with income. The coefficients on these low break points are not statistically significant, so the low peak may be an aberration.[8] If it is a real phenomenon, it may be unique to this specific environmental problem. In particular, lead additives are not without benefit—they increase engine performance, reduce engine knock, and slow engine deterioration. Higher grades of leaded gasoline typically contain more lead. In countries where there were no changes in the lead content of the various grades of gasoline, people gradually switched to high-grade gasoline, perhaps as a result of increasing income. As a consequence, *average* lead per gallon consumed increases with income for some countries over short time periods.

Gasoline consumption, from column (3) of Table III, is plotted in the third panel of Fig. 4. It exhibits a steady rise throughout the distribution of national incomes. Clearly none of the decline in lead pollution has come from decreases in polluting activity.

Figure 4 thus makes the third key point of this study. The existence of the U-shaped pattern for total lead pollution is the product of decreasing average lead per gallon of gasoline and increasing gasoline consumption.[9] Despite increases in polluting activity, the curve declines at high incomes due to decreasing pollution intensity.

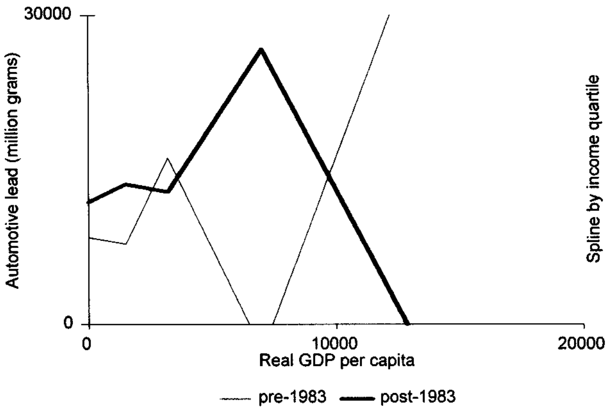
CONCLUSION AND IMPLICATIONS

This article makes three new points regarding the environment-income relationship. First, it adds automotive lead emissions to the list of pollutants that follow an

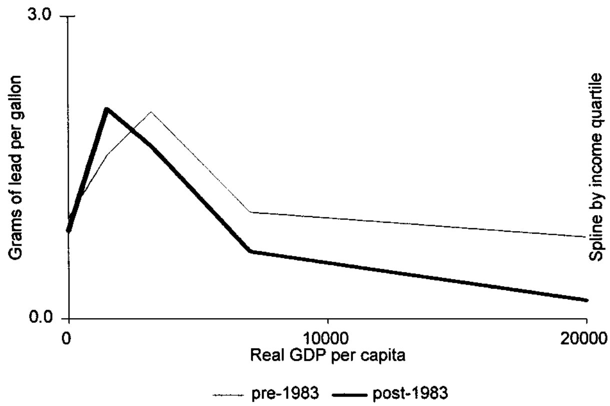
[7] Of course, the peak of the spline must occur at the selected break point. Therefore this specification predicts the peak to be at $7000. When $9000 or $10,000 are chosen as kinks in the spline, those exhibit the peak. It is notable, however, that the spline exhibits no Kuznets-style peak below $5000, where the logarithmic specification suggested it would occur. This is true despite there being two break points below $5000.

[8] This peak in lead per gallon with respect to income is also apparent in a logarithmic specification (not presented here).

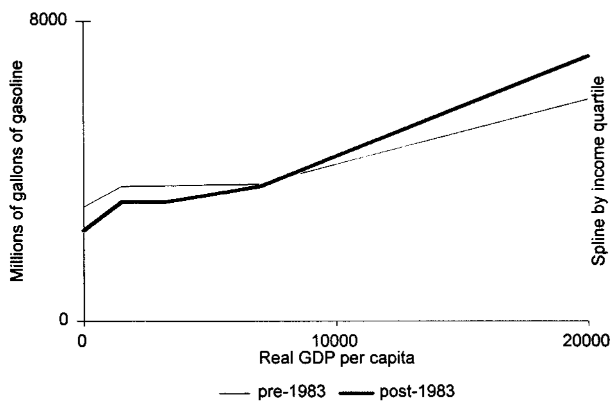
[9] This pattern also appears using quadratics or cubics in levels or quadratics in logs as in Table II.



(a)



(b)



(c)

FIG. 4. Factoring the curve; Spline regressions by income quartiles; (a) spline by income quartile, (b) lead per gallon, (c) total gas consumption.

inverse-U, or environmental Kuznets curve, relationship with income. Second, it describes how sensitive the location of the peak of that curve is with respect to the functional forms and time periods used to estimate the curve. Third, for the first time it estimates separately the two factors of the environmental Kuznets curve: pollution intensity and polluting activity. Although the paper focuses on automotive lead, it has several important implications for interpreting the environmental Kuznets curve literature to date.

The first implication stems from the fact that automotive lead emissions are the consequence of a consumption activity, driving. Polluting production in this case cannot be separated from consumption and exported to less developed countries. This eliminates one of the potential explanations for observed Kuznets curves. It is possible for the observed pattern of lead emissions to hold for *all* countries, not just those first to develop and export polluting production.

The second implication comes from the observation that the declining portion of the U-shaped pollution-income path depends critically on the decline in the pollution intensity of the polluting activity. Gasoline consumption, the polluting activity, increases steadily with income. Only by reducing the pollution intensity of that activity can overall pollution begin to decline. The lead content of gasoline (pollution intensity) is unlikely to be affected by individual behavior. Some government action such as taxes or bans on leaded gasoline appears to be behind much of the decline in automotive lead pollution. This undermines the claim that income growth is itself a panacea for environmental problems.

Third, the shape of the income-lead path appears sensitive to functional form and to the time period analyzed. Because the range of predicted peaks is so great, making long-term forecasts about global lead emissions would seem to be futile. If the shape of the curve changed in the last 20 years, it could certainly change again during the next 20 years.

A final implication can be drawn from the robust significance of the time trend variable in the total lead emissions and lead content regressions. Over time, lead emissions and lead content declined, even holding income constant. This suggests that there were some technological changes taking place not captured by the other regressors that caused lead pollution to fall even for countries on the upward sloping portion of the environmental Kuznets curve. In other words, environmental improvement does not depend exclusively on income growth, and poor countries need not wait passively to become wealthy before improving their environments.

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