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THE SIMPLE ANALYTICS OF THE ENVIRONMENTAL KUZNETS CURVE

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ABSTRACT

Evidence suggests that some pollutants follow an inverse-U-shaped pattern relative to countries' incomes. This relationship has been called the "environmental Kuznets curve." This paper lays out a simple and straight-forward static model of the microfoundations of the pollution-income relationship. We show that the environmental Kuznets curve can be derived directly from the technological link between consumption of a desired good and abatement of its undesirable byproduct. The inverse-U shape does not depend on the dynamics of growth, political institutions, or even externalities, and can be consistent with a decentralized economy as well as a Pareto efficient policy.

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The Simple Analytics of the Environmental Kuznets Curve

by James Andreoni and Arik Levinson

I. Introduction.

Evidence suggests that some pollutants follow an inverse-U-shaped pattern relative to countries' incomes.[1] Due to its similarity to the time-series pattern of income inequality described by Kuznets (1955), the environmental pattern has been called the "environmental Kuznets curve." Because the empirical evidence relies on reduced-form regressions of environmental quality on income and other covariates, most researchers avoid interpreting those results structurally, leaving open the question of why pollution follows this inverse-U pattern. Nonetheless, a number of people have appealed to this empirical relationship to argue that economic growth by itself is a panacea for environmental degradation. Beckerman (1992), for instance, writes that "in the end the best – and probably the only – way to attain a decent environment in most countries is to become rich," while Bartlett (1994) claims that "existing environmental regulation, by reducing economic growth, may actually be reducing environmental quality." It is important, therefore, to understand the nature and causes of the environmental Kuznets curve before adopting such far reaching, and to many quite alarming, implications for policy.

A number of plausible explanations exist for the observed inverse-U relationship. First, it could be that the pattern reflects the natural progression of economic development, from clean agrarian economies to polluting industrial economies to clean service economies (Arrow, *et al.*, 1995). This mechanism may be facilitated by advanced economies exporting their pollution-

[1] See, for example, Grossman and Krueger (1995), Holtz-Eakin and Selden (1995), Selden and Song (1994), Shafik and Bandyopadhyay (1992), World Bank (1992), Hilton and Levinson (1998), Kahn (1998), and Chaudhuri and Pfaff (1998).

intensive production processes to less-developed countries (Suri and Chapman, 1998). If the downward sloping portion of the pollution-income relationship is due to this type of pollution exporting, then the process of environmental improvement will not be indefinitely replicable, as the world's poorest countries will never have even poorer countries to which they can export their pollution.

An alternative explanation for the inverse-U notes that pollution involves externalities, and that appropriately internalizing those externalities requires relatively advanced institutions for collective decision-making that may only be implementable in developed economies. Jones and Manuelli (1995), for example, posit an overlapping generations model in which economic growth is determined by market interactions and pollution regulations are set through collective decision-making by the younger generation. Depending on the decision-making institution, the pollution-income relationship can be an inverted-U, monotonically increasing, or even a "sideways-mirrored-S."

Still others have suggested that pollution stops increasing and begins decreasing with income because, with economic growth, some constraint becomes non-binding. Stokey (1998), for example, describes a static model with a choice of production technologies with varying degrees of pollution. Her critical assumption is that below a threshold level of economic activity, only the dirtiest technology can be used. With economic growth, pollution increases linearly with income until the threshold is passed and cleaner technologies can be used. The resulting pollution-income path is therefore inverse-V-shaped, with a sharp peak at the point where a continuum of cleaner technologies becomes available. Similarly, Jaeger (1998) rests on the assumption that at low levels of pollution consumers' taste for clean air is satiated, and that the marginal benefit of additional environmental quality is zero. Consequently, with few firms and few individuals, the environmental resource constraint is non-binding. More pollution does not result in lower utility. With economic growth represented by a growing population of individuals and polluting firms, once the satiation threshhold of consumers' preferences is passed, depending on the parameters, growth may be accompanied by improved environmental quality. Like Stokey (1998), therefore, Jaeger's pollution-income relationship is inverse-V-shaped, peaking when the optimum moves from a corner solution to an interior solution.

John and Pecchenino (1994) present an overlapping generations model in which environmental quality is a stock resource that degrades over time unless maintained by investment in the environment. An economy that begins at the corner solution of zero environmental investment will see its environmental quality decline with time and with economic growth until the point at which positive environmental investment is desired, when environmental quality will begin improving with economic growth. Like Stokey (1988) and Jaeger (1988) therefore, John and Pecchenino's pollution-income relationship exhibits an inverse-V shape, peaking when the dynamic equilibrium switches from a corner solution of zero environmental investment to an interior optimum with positive investment.

By contrast to these prior explanations, this paper lays out a simple and straight-forward static model of the microfoundations of the pollution-income relationship. We show that the observed inverse-U pattern does not require dynamics, predetermined patterns of economic growth, multiple equilibria, released constraints, political institutions, or even externalities. Rather, an environmental Kuznets curve can be derived directly from the technological link between consumption of a desired good and abatement of its undesirable byproduct.

Furthermore, it can be consistent with either a Pareto efficient policy or a decentralized market economy.

II. A model of the pollution-income relationship.

We begin our model with the simplifying assumption of an economy with only one person. The one-person model is useful for two reasons. The first is its simplicity. More importantly, however, in a one-person model there are no externalities, so any solution can be interpreted as Pareto efficient. We generalize our analysis to an economy with many individuals in section V below.

Suppose the single agent gets utility from consumption of one private good, denoted C, and from a bad called pollution, P. Then preferences can be written

$$U = U(C,P) \tag{1}$$

where $U_C>0$ and $U_P<0$, and U is quasiconcave in C and $-P$. With only one person, the distinction between P as a public or private bad is irrelevant.

Next we must discuss the technology that generates C and P. It seems natural to assume that pollution is a byproduct of consumption. Suppose further that our consumer has a means by which he can alleviate pollution by expending resources to clean it up or, equivalently, to prevent it from happening at all. Call those resources E, for environmental effort. Pollution is then a positive function of consumption and a negative function of environmental effort:

$$P = P(C,E) \tag{2}$$

where $P_C > 0$ and $P_E < 0$. Finally, suppose that a limited endowment, M, of resources can be spent on C and E. For simplicity, normalize the relative costs of C and E to be 1. The resource constraint is therefore simply $C+E=M$.

Consider a simple example:

$$U = C - zP \tag{3}$$

$$P = C - C^{\alpha}E^{\beta} \tag{4}$$

Utility in **(3)** is linear and additive in C and P, and $z>0$ is the constant marginal disutility of pollution. Pollution in **(4)** has two components. The first, C, is gross pollution before abatement and is directly proportional to consumption. The second term of **(4)**, $C^{\alpha}E^{\beta}$, represents "abatement." Equation **(4)** indicates that consumption causes pollution one-for-one, but that resources spent on environmental effort abate that pollution with a standard concave production function.[2]

Begin with the case where $z=1$. Substituting **(4)** into **(3)** implies the individual is maximizing $C^{\alpha}E^{\beta}$ subject to $C+E=M$, hence consumption and effort have standard Cobb-Douglas solutions

$$C^* = \frac{\alpha}{\alpha+\beta}M \quad \text{and} \quad E^* = \frac{\beta}{\alpha+\beta}M \quad . \tag{5}$$

The optimal quantity of pollution is then

$$P^*(M) = \frac{\alpha}{\alpha+\beta}M - \left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\right)^{\beta}M^{\alpha+\beta} \quad . \tag{6}$$

[2]Note that it is possible, in this framework, for $\partial P/\partial C<0$. However, equation **(4)** is a resource constraint, and in the optimum, the resource constraint will be tangent to an indifference curve with a positive slope in (P,C) space. Therefore, it will never be optimal for the agent or a social planner to choose levels of consumption and pollution such that $\partial P/\partial C<0$.

The derivative of **(6)** represents the slope of the environmental Kuznets curve,

$$\frac{\partial P^*}{\partial M} = \alpha - (\alpha+\beta)\left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\right)^{\beta} M^{\alpha+\beta-1} \quad , \qquad \textbf{(7)}$$

the sign of which depends on the parameters α and β.

When $\alpha+\beta=1$, effort spent abating pollution has constant returns to scale, and $\partial P^*/\partial M$ is constant. Given $0 \le \alpha,\beta \le 1$, then P^* rises with M and there is no downward sloping portion of the pollution-income curve, as depicted in Figure 1(a).

When $\alpha+\beta\neq 1$, the second derivative of **(6)** is

$$\frac{\partial^2 P^*}{\partial M^2} = -(\alpha+\beta-1)(\alpha+\beta)\left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\right)^{\beta} M^{\alpha+\beta-2} \quad . \qquad \textbf{(8)}$$

Thus, if $\alpha+\beta<1$, so that abatement technology exhibits diminishing returns to scale, $P^*(M)$ is convex, as in Figure 1(b). Likewise, if $\alpha+\beta>1$, so that abatement technology exhibits increasing returns to scale, then $P^*(M)$ is concave as in Figure 1(c). This is what has been described as the environmental Kuznets curve.

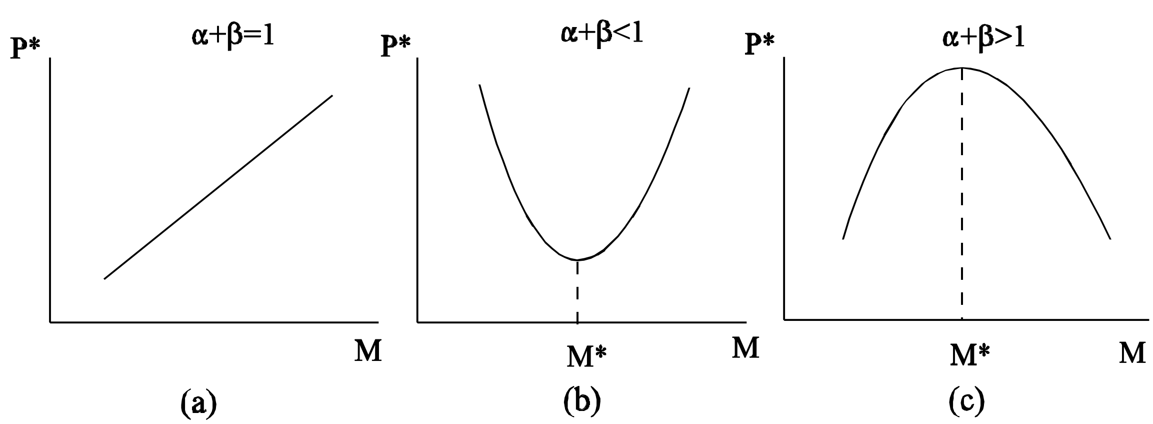

Figure 1

Next consider what happens when $z \neq 1$. The algebra becomes slightly more complex, but the basic result remains: the optimal pollution-income curve is inverse-U shaped if and only if the abatement technology has increasing returns to scale, α+β>1 in this example. Solving for the first order condition and rearranging its terms yields

$$\begin{aligned} C* &= \frac{\alpha}{\alpha+\beta}M + \frac{1-z}{z(\alpha+\beta)C^{\alpha-1}(M-C)^{\beta-1}} \\ &= \frac{\alpha}{\alpha+\beta}M + B\frac{(1-z)}{z} \quad , \end{aligned} \qquad \textbf{(9)}$$

where $B > 0$. If $z<1$ then C^* is larger than in **(5)** and pollution is also correspondingly larger at every level of income. If $z>1$, people have a higher disutility from pollution, and thus C^* and P^* are smaller. Though the absolute values of C^* and P^* change in response to changes in z, the implications for the inverse-U-shaped pollution-income path remain the same.

So far, we have deliberately kept preferences simple in order to focus attention on the effects of technology. The inverse-U does not depend on either consumption or lack-of-pollution being inferior goods, nor does it depend on tastes changing as income changes. Rather, it depends on the technological link between a good (consumption) and a bad (pollution). The critical link is that consumption of the good generates pollution, and that expenditure of resources on abatement ameliorates that pollution. High-income individuals demand more consumption and less pollution. When abatement is possible with increasing returns, high-income individuals can more easily achieve both goals.

III. General sufficient conditions for an inverse-U-shaped pollution-income relationship.

Consider a general version of the model presented above:

$$\begin{aligned} U &= U(C,P) \\ P &= C - A(C,E) \\ &= C - A(C,M-C) \end{aligned} \qquad \textbf{(10)}$$

where $A()$ is the abatement production function, increasing in environmental effort E and in existing pollution C. In this general case, we can define relatively weak sufficient conditions for the optimal pollution-income relationship to be inverse-U-shaped.

> **Theorem:** Assume that the utility function $U(C,P)$ is quasiconcave in C and $-P$, and that C and $-P$ are both normal goods. Then if there exists a value θ such that
>
> $$\lim_{C \to M} R(C) \equiv \frac{\partial U(C,0)/\partial C}{\partial U(C,0)/\partial P} \geq \theta > -\infty \qquad \textbf{(11)}$$
>
> and a pollution abatement function $A(C,M-C)$ as in **(10)** that is concave and homogeneous of degree $k>1$, where $A(0,x)=A(x,0)=0$ for all x, then for any combination of utility and abatement technology that yields positive pollution for some level of income, optimal pollution will eventually decline back to zero for some sufficiently large income.

First note that this statement amounts to a description of an environmental Kuznets curve. When $M=0$, consumption and pollution are zero, by definition. The statement asserts that for some large M, optimal pollution will also be zero. For any parameterizition of utility and abatement technologies that lead to positive pollution for some level of income, the optimal pollution path must therefore increase from zero and then decrease back to zero, exactly the pattern observed empirically.

The proof works by describing the slope of the consumption-pollution possibility frontier – determined by abatement technology – and the slope of the consumption-pollution indifference curve – determined by preferences – at the point where pollution is equal to zero and as M

increases towards infinity. If the indifference curve crosses the possibility set at the point of zero pollution, then a corner solution of $P=0$ must be optimal at high values of M.

Since the intuition for goods is more natural than for bads, begin by defining $L=-P$, as the "lack" of pollution, a good. It will be important to remember that $L<0$ corresponds to pollution, $L=0$ corresponds to no pollution, and $L>0$, if possible, corresponds to an environment "cleaner than nature."

Next we can take advantage of the assumption that $A(C,E)$ is homogeneous of degree k by defining all variables relative to M. Let $c=C/M$ and $\lambda \equiv L/M$. Then $\lambda(c)=A(c,1-c)M^{k-1}-c$. For ease of notation, let $a(c)=A(c,1-c)$. Since $A(c,1-c)$ is assumed concave, $a(c)$ reaches a unique maximum for some $\bar{c}$. To make the model interesting, assume $0<\bar{c}<1$.

With these definitions, the consumption possibilities frontier is given by

$$\lambda(c;M) = a(c)M^{k-1} - c \ . \qquad \textbf{(12)}$$

The shape of this frontier is illustrated in Figure 2[3]. A critical value will be the slope of the frontier, $\partial\lambda/\partial c = \partial a/\partial c \ M^{k-1} - 1$. Note also that $\partial L/\partial C$ is the same as $\partial\lambda/\partial c$.

We next need to find the slope of the consumption possibilities frontier when $\lambda=L=0$. For any $c>\bar{c}$, we can pick an M such that $\lambda=L=0$. Call this level of income $\bar{M}(c)$, defined implicitly by $0 \equiv c - a(c)\bar{M}^{k-1}$, or $\bar{M}(c)=[c/a(c)]^{1/(k-1)}$. So at $M=\bar{M}$, $L=0$ by definition, and when $M > \bar{M}$, the consumption possibility frontier in Figure 2 shifts up, and $L \geq 0$ at the originally chosen level of c.

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[3]Figure 2 makes clear why no optimum will have the feature that $\partial P/\partial C<0$, a concern raised in footnote 2. Pollution decreases with consumption at the very left portion of consumption possibilities frontier, where it is upward sloping, and where it can never be tangent to any indifference curve.

That is, the environment is "cleaner than nature." Let S be the slope of the consumption possibility frontier where it intersects L=0 for our given $c>\bar{c}$. Then

$$S(c) \equiv \left.\frac{\partial\lambda}{\partial c}\right|_{\bar{M}(c)} = \left.\frac{\partial L}{\partial C}\right|_{\bar{M}(c)}$$

$$= a'(c)\left[\bar{M}(c)\right]^{k-1} - 1 \tag{13}$$

$$= a'(c)\frac{c}{a(c)} - 1 < 0 \quad .$$

Because $\bar{c}$ is defined so that $a'(c)<0$ for $c>\bar{c}$, the slope of this consumption possibility set, S, must be negative when $c>\bar{c}$.

Next, we show what happens to this slope as c increases. Differentiating **(13)** we see

$$\frac{\partial S}{\partial c} = a''(c)\frac{c}{a} + a'(c)\left[\frac{a(c) - a'(c)\cdot c}{\left(a(c)\right)^2}\right] < 0 \ . \tag{14}$$

By concavity of $a(c)$, and the fact that $c>\bar{c}$, $\partial S/\partial c<0$. Then as c goes to 1, we know $a(c)$ goes to 0. Hence, for finite a', a'',

$$\lim_{c\to 1} \frac{\partial S}{\partial c} = -\infty \tag{15}$$

As we increase c from $\bar{c}$ to 1, in each case choosing a corresponding $\bar{M}(c)$ such that $\lambda=L=0$, along the thickly shaded line segment in Figure 2, the slope of the consumption possibility constraint at (c,λ)=(1,0) becomes arbitrarily steep. All we need do is show that the indifference curve does not also become arbitrarily steep, and the optimal outcome will be a corner solution with zero pollution, L=0.

Turning, then, to the preferences side of the problem, we need to show the MRS at (c,λ)=(1,0) does not have an asymptote of minus infinity as M increases. First, define

$V(c,\lambda;M) \equiv U(cM,-\lambda M)$, a representation of utility in (c,λ) space, holding income constant, as in Figure 2. Then define

$$R(c) \equiv -\frac{\partial V(c,0)/\partial c}{\partial V(c,0)/\partial \lambda} \tag{16}$$

as the marginal rate of substitution evaluated along the thickly shaded line segment in Figure 2. $R(c)$ can be interpreted as the marginal willingness to pay for c in terms of less pollution when $\lambda=0$. Normality of C and $-P$ ensures that $dR/dc \leq 0$.[4] The only way we would not have the indifference curve cross the consumption possibilities frontier as M goes to infinity is if the MRS has an asymptote of minus infinity, just as the slope of the frontier does. Hence, we have now demonstrated the theorem – as long as $\lim_{c\to 1} R(c)$ is finite, which is true so long as equation **(11)** holds, then pollution must eventually return to zero as income increases.

Evaluating the sufficient condition on preferences, we see that it is quite weak. Equation **(11)** requires that the marginal willingness to pay for consumption in terms of pollution does not go to infinity. The converse of that is simply that the marginal willingness to pay to clean up the last speck of pollution does not go to zero as income goes to infinity. The standard notion that pollution clean-up is a normal good means that this assumption is natural and easily satisfied. The condition that the abatement technology exhibits increasing returns to scale is also reasonable, and we address that issue next.

[4]This follows from the fact that we are evaluating the MRS along a horizontal ray in consumption space. As we increase C holding P constant, normality implies that the marginal willingness to pay for C does not increase, and strict normality requires that the marginal willingness to pay decrease.

IV. Does pollution abatement exhibit increasing returns to scale?

As we saw above, the linchpin of this analysis is that the abatement technology $A(C,E)$ exhibits increasing returns to scale. Does increasing returns make intuitive sense? To answer this we must address this question: In a given setting, if we double both pollution and clean-up effort, will we get more than double the pollution abated? There are many reasons to think that this will, in fact, be the case. Consider the following simple examples.

Imagine the technology for sweeping a floor. The inputs to abatement are, first, a floor with a layer of dust one centimeter thick and, second, a person providing an hour of sweeping. Now consider two centimeters of dust and two hours of sweeping over the same floor. Assuming the person can sweep just as fast in both cases, then doubling these two "inputs" to abatement will clean up four times the dust, implying increasing returns to scale. As the dust gets thicker and heavier the sweeper may no longer be able to cover the same floor space in an hour, but his rate of sweeping would have to be cut in half before increasing returns switches over to decreasing returns.

This first example shows the relationship between the capacity for clean-up, the quantity of pollution, and clean-up effort. Given a certain capacity to clean – a broom and a person – then as the pollution quantity and effort increase in lock step, the amount cleaned up will increase with the square of the effort. If the capacity to clean is diminished as the density increases – such as slowing the rate of sweeping – then the amount cleaned will rise somewhat less than the square of effort. This still gives plenty of room for increasing returns.

Here is another more realistic example. Suppose the method of cleaning that has the cheapest marginal cost also requires the largest fixed cost, such as installing scrubbers on a smoke stack. A small economy may not be rich or polluted enough to get a good return on the fixed costs of the cleaning technology, and thus may rely on a technology with low fixed costs but high marginal costs. For larger economies, a greater share of manufacturing will be of sufficient scale that the low-marginal-cost/high-fixed-cost technology is cost-effective. Hence, for a larger economy the marginal cost of cleaning pollution may be beneath that of the smaller economy. If so, the abatement technology $A(C,E)$ will satisfy the sufficient condition of increasing returns to scale.

This second example illustrates the effect of lumpy inputs to abatement technologies. As an economy grows, more and more industries and manufacturing facilities become large enough to make the capital investment in abatement technologies worthwhile. As a result the marginal cost curve of larger economies will be beneath those of smaller economies. Although capital investment has not been modeled explicitly here, one could incorporate the lumpiness of capital investment into a clean-up cost function that would generate a result equivalent to assuming increasing returns in $A(C,E)$. Thus, this observation would satisfy the sufficient condition on technologies.

If either or both of these conditions, clean-up capacity or lumpy investment, characterize abatement technology, then the implied increasing returns will make the optimal pollution-income path inverse-U-shaped.

V. The case of many consumers.

By considering a model with a representative consumer, we have ignored the fact that most environmental problems involve externalities. Indeed, one of the fundamental points made thus far is that externalities are unnecessary for the optimal pollution-income relationship to be inverse-U-shaped. That said, the model can easily be generalized to incorporate externalities by increasing the population of consumers to N>1. To illustrate this, consider the following model:

$$\begin{aligned} U_i &= C_i - P, & i &= 1 \ldots N, \\ P &= C - C^{\alpha} E^{\beta}, & C &= \sum_i C_i,\ E = \sum_i E_i, \\ M_i &= C_i + E_i, & \alpha,\beta &\in (0,1). \end{aligned} \tag{17}$$

Individuals, indexed i=1...N, are assumed to maximize utility as Nash players – they take others' consumption to be independent of their own. Solving the first order conditions yields the best response function

$$C_i^* = \frac{\alpha}{\alpha+\beta} M_i + \left[\frac{\alpha}{\alpha+\beta} \sum_{j \neq i} M_j - \sum_{j \neq i} C_j \right] . \tag{18}$$

If all individuals maximize utility in this manner, then the Nash equilibrium is

$$C_i^* = \frac{\alpha}{\alpha+\beta} M_i \quad \textit{for all } i. \tag{19}$$

In this decentralized case, pollution follows exactly the same path as in the one-person example in equation **(6)** – the pollution-income path is concave and peaked if and only if $\alpha+\beta>1$.

Notice that in the many-person example the solution is decentralized, and as a result is not Pareto efficient. To see this, assume a central planner maximizes the sum of utilities

$$\max \sum_i U_i = \sum_i C_i - NP. \tag{20}$$

Note that this aggregate utility function is identical to **(3)**, where C is replaced by $\sum C_i$ and z is replaced with N. Hence, all the solutions that follow will be identical, including the optimal consumption C^* obtained in **(9)**. Replacing z with N, we see that in the decentralized solution **(9)**, individuals consume too much and abate too little compared to the social optimum.[5]

Increasing the number of consumers does not change the implications regarding the shape of the pollution-income path. That shape depends on the technology of abatement, not the number of polluters or the relative marginal utilities of consumption and environmental quality. Increasing N merely lowers the optimal pollution-income path, as does increasing z, while retaining its inverse-U shape.

VI. Conclusions and further implications.

The model presented above, by its very simplicity, has several notable implications. First, it suggests that the observed income-environment relationship is perfectly reasonable. While some economists have created intricate political-economy models of collective decision making, externalities, and economic growth in order to explain inverse-U pollution patterns, our work suggests that those complications may be sufficient but unnecessary to explain the observed patterns. Instead, the environmental Kuznets curve may result from natural features of the abatement technology.

Second, the inverse-U-shaped pollution-income curve does not depend on externalities – it appears in both the single and many-person models. This is reassuring since several recent empirical studies (Chaudhuri and Pfaff, 1998; Kahn, 1998) find that household-level pollution also follows an inverse-U, consistent with our results.

[5]As before, similar results hold for more general preferences.

A third implication of these findings is that the environmental Kuznets curve may depend more on technology than on environmental externalities inherent in growth. The model merely has two commodities, one that people like and one that they do not like. Consumption of the good generates more of the bad, confronting consumers with a tradeoff. By spending some resources on abatement, consumers are able to ameliorate the ill effects of the undesirable good. Interestingly, pollution is simply one convenient such relationship. For example, in driving a motor vehicle the good (transportation) is accompanied by an associated bad (mortality risk) that can be ameliorated by resource expenditures (automotive safety equipment). We would not be surprised to find that both the poor, who drive very little, and the rich, who invest in safe cars, face lower mortality risk from driving than do middle-income people.

Finally, the model does not support the argument that observed inverse-U-shaped pollution paths justify laissez-faire attitudes towards pollution, or that economic growth alone will solve pollution problems. Rather, we show that, absent environmental regulations, the pollution-income path may well have an inverse-U shape, but the amount of pollution at every income will still be inefficiently high. Furthermore, while it may be reasonable to deduce that at sufficiently high incomes the optimal pollution will be zero, the model in this paper places no limit on the level of income necessary to generate that return. Neither this paper, nor any of its empirical or theoretical predecessors, supports claims that environmental regulations are unnecessary.

What do these results indicate about future thinking on the environmental Kuznets curve? Foremost they suggest that simple explanations regarding the technology of abatement could be central to understanding the phenomenon. Second, they suggest that, based the abatement technology, the pollution-income relationship can take on any shape, and we expect that for different pollutants, with different abatement technologies, the curves may or may not look like Kuznets curves. Finally, our results underscore the plea in the introduction – we need to understand the structure and causes of the pollution-income relationship before incorporating that relationship into environmental policy.

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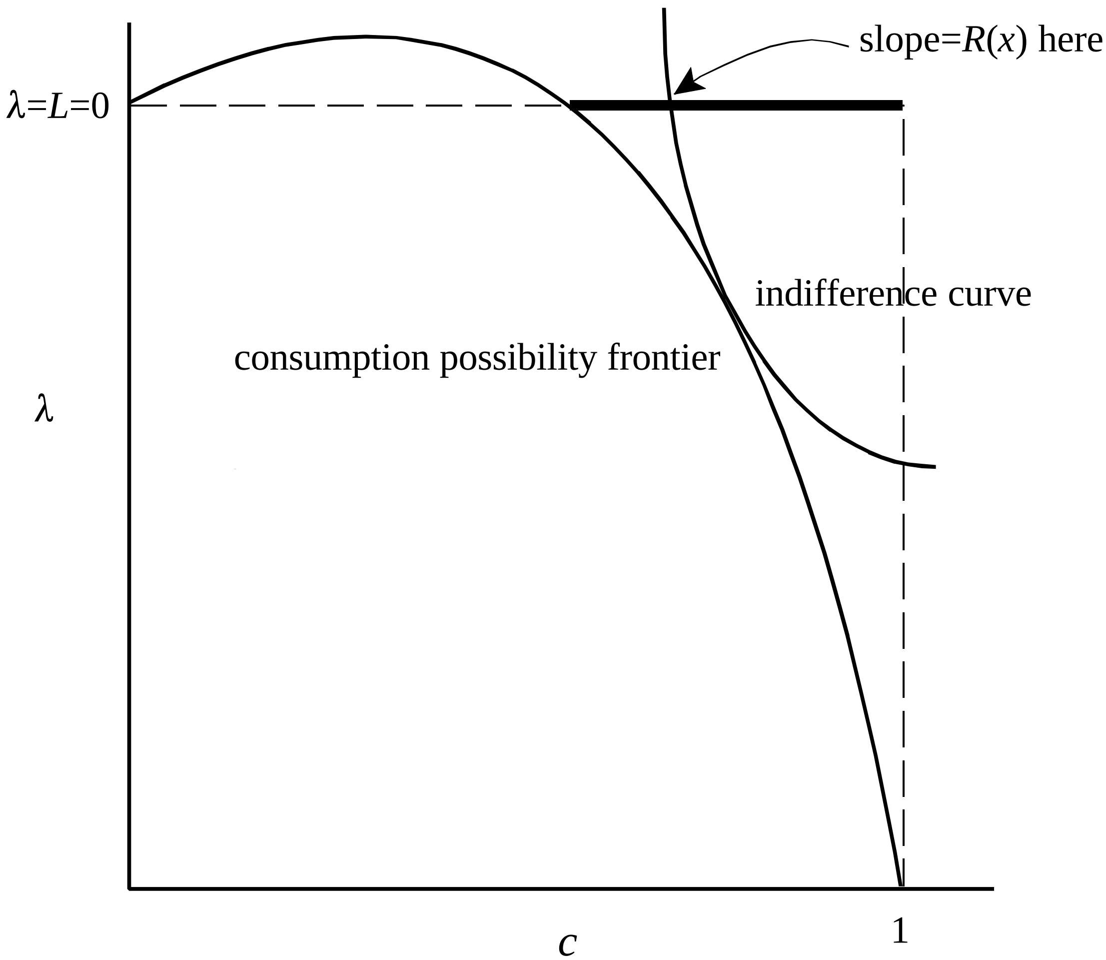
Figure 2


slope=$R(x)$ here
$\lambda=L=0$
indifference curve
consumption possibility frontier
λ
c
1