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Income and the demand for environmental quality

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ABSTRACT: The environmental Kuznets curve (EKC) is an empirical regularity showing how some pollutants increase and then decrease with rising per capita incomes. Popular discussions and models of the EKC emphasize the role of the income elasticity of demand for environmental quality as a driving force for the inverted U-shaped relationship between income and pollutants. This paper explores the role of the income elasticity of demand for environmental quality by decomposing the reduced-form effect of income on pollution, showing that preferences consistent with a positive income elasticity of demand for environmental quality are neither necessary nor sufficient for the EKC. Increasing pollution may occur with increasing income but preferences that would imply a high income elasticity of demand for environmental quality, and decreasing pollution may occur simultaneous with preferences that put lower values on pollution reduction as incomes rise.

Introduction

Three broad forces could give rise to the empirical regularities known as the environmental Kuznets curve (EKC). One possibility is that pollution declines as incomes grow because of the change in the product mix. At higher incomes households just happen to demand goods which pollute less, for example, services. A second possibility is trade. When incomes increase, countries increase their imports of pollution-intensive goods, in essence exporting pollution. The third is that as incomes grow, households choose more environmental quality and the various production and consumption processes comply through public action. In the two latter cases, the demand for environmental quality plays a crucial role.

Models of the EKC, both empirical and theoretical, are macroeconomic. Empirical studies use aggregate data, while theoretical models use variants of the standard aggregate growth models. An important engine in the aggregate models is the demand for environmental quality. Yet our greatest source of knowledge of this demand comes from the microeconomic literature on non-market valuation. The purpose of this paper is to clarify the role of the demand for environmental quality in the EKC and to assess the non-market valuation literature as evidence of the EKC.

The connection between the aggregate EKC and individual valuations is confounded by simultaneity of pollution and output. On the supply side, at least for low incomes, pollution reduces output through various means,

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especially health effects. On the demand side, increases in income may increase the demand for environmental quality, not simply because households have greater control over resources, but because higher incomes encourage more effective public sectors to solve pollution problems. Further, higher incomes are accompanied by higher education, increasing the awareness of pollution and its harmful effects. The net effect of income on the demand for environmental quality includes the effects of more government and better education, as well as a bigger budget.

While the income elasticity of demand plays a prominent role in discussions of the EKC, there are several reasons to doubt its effect. First, environmental quality is a set of heterogeneous goods, only some of which may be valued more highly at higher incomes. Second, the income elasticity of demand for some environmental qualities may be negative. Third, the role of the income elasticity of demand is attenuated by various simultaneous pollution–income relations. Linking the microeconomic evidence with conceptual and empirical EKC models demonstrates the weak connection between preferences and the path of pollution.

Empirical results on growth and the environment

The main evidence on the EKC appears in Hettige *et al*. (1992), Grossman and Krueger (1993), Selden and Song (1994), and Shafik and Bandyopadhyay (1992).[1] The basic approach of these studies is similar. Measures of pollution (air quality, water quality, urban sanitation) are gathered from a variety of sources. Population and national income data are used to compute per capita GDP. Since pollution for the most part is a local phenomenon, and must be measured locally, estimated equations typically include characteristics of the locale of measurement, whether near desert, mountain or oceans. The data on pollution come from two types of sources, implying two types of measurement. Some urban air pollutants (SO_2, NO_x, suspended particulates) are calculated for cities within countries. Measures of water quality (dissolved oxygen, faecal coliform) are measured for some rivers. These are measures of ambient quality. Emissions are also used as proxies for pollution in the case of toxic substances and CO_2. Emissions are typically calculated by means of emissions intensity coefficients that show the relationship between sectoral output and the emission. The pollution and emissions data and the explanatory variables comprise a panel of approximately 50 countries from the 1970s to the 1990s. The panels tend to exclude the poorest countries, where the data on environmental pollution are not readily available.

The EKC is typically estimated in the following form:

[1] These papers concentrate on pollutants. There are also results showing how deforestation may follow an inverted U shape. See, for example, Cropper and Griffith (1994). Shafik and Bandyopadhyay failed to find an inverted U. Whatever the finding, the reasoning behind the transformation of forests seems quite different from pollution. While forests can be cropped for timber trade, they are also intensively cut for firewood. Pollution is typically linked to production, consumption or capital stock. The conceptual models discussed below deal with pollution, not deforestation. These linkages do not hold for deforestation.

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$$P_{it} = \beta_{0i}(t) + \beta_1 y_{it} + \beta_2 y_{it}^2 + \beta_3 y_{it}^3. \quad (1)$$

P_{it} is pollution in the ith country for year t, $\beta_{0i}(t)$ a set of country-specific, or site-specific random, and time-dependent covariates, and y_{it} is per capita GDP for the ith country. Not all empirical work includes the cubic term and on occasion y_{it} is replaced by its natural logarithm. There are often several observations per country, reflecting the pollutants in different cities. Results differ by pollutant. Findings of an inverted U shape for ambient quality seem to be robust in the sense that the inverted U is found for different pollutants (air and water pollutants in Table 1), with different econometric approaches (fixed versus random effects) and distinct sets of countries.

The reduced-form effects of per capita income reflect the fact that income growth is accompanied by many changes in the economy and its institutions. More important changes which represent society's willingness and ability to abate pollution, are the establishment of governmental agencies responsible for pollution control, increases in education and the concomitant increase in awareness of the effects of pollutants, change in the product mix of GDP from agriculture to industry to services, reductions in the inequality of income distribution and expenditures on research. Per capita growth in GDP is a proxy for all of these changes, as well as for an increase in household budgets.

Basic results for selected studies are summarized in Table 1. These results are only roughly comparable, varying by econometric approach and by level of aggregation, number of countries and years of data available. Most models are estimated for total pollutants, except for SS for all results and SB in the case of CO_2. The latter estimate results in terms of per capita emissions or ambient levels. Further, SS use country-wide emissions, rather than emissions for urban areas only. SS suggest that total emissions

Table 1. *Summary of results on pollutants as a function of per capita GDP*

Pollutant	*Inverted U*	*Increasing*	*Decreasing*
SO_2 (ambient)	SB, GK[1], SS[4]		
SPM (ambient)	SB, SS		GK
NO_x (ambient)	SS		
Faecal coliform (ambient)	SB, G		
Dissolved oxygen (ambient)		G	SB
Dark matter (ambient)	GK		
CO (ambient)	SS		
CO_2 (emissions)	SB[2]	HS[3]	
Heavy metals (emissions)	R[5]		

Notes: [1] Random effects model; [2] In per capita CO_2. [3] Decreases gradually to \$8,500, then increases. [4] All of SS results are in per capita ambient levels. [5] Cross section only.
Key: SB = Shafik and Bandyopadhyay (1992); GK = Grossman and Krueger (1993); SS = Selden and Song (1994); HS = Holtz-Eakin and Selden (1992); G = Grossman (1994); R = Rock (1996).
Sources: SB: Table 1. GK: Tables 2, 3 and 4 for 50th percentile. SS: Tables II–V. HS: Text and tables. R: Table 1.

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at the country level would be less responsive to changes in per capita income than urban emissions. The two differences, measuring dependent variable as per capita emissions rather than total pollutants make it difficult to determine what causes the SS model to be less responsive to per capita income than GK.[2] Note that dissolved oxygen is a desirable attribute of water bodies, but the other entries in the table are pollutants or emissions that induce pollution.

The results support the idea of the EKC in that pollution tends to increase and then decline for a number of pollutants. Especially for the major urban air pollutants, ambient pollution seems to increase and then eventually decline. The results for CO_2 are naturally different. These gases are more expensive to abate and do not inflict local damage; the ambient level is not dependent on local emissions because the local level of CO_2 depends on global emissions. (For a discussion of many aspects of global warming, see Cline, 1992.) Individual preferences do not typically include CO_2 directly or even amenities which are adversely affected by CO_2. The relation between CO_2 and income stems from the connection between global energy consumption and income. An EKC curve for CO_2 could not reasonable be attributed to social choice for the atmospheric levels of CO_2. While governments may trade increases in income for better air and water quality, control of CO_2 has probably not been a conscious policy of many governments. It has been argued that the monotonic decline in suspended particulate matter is a consequence of high health benefits from the particulates, compared with reasonable abatement costs.

The inverted U shape implies a level of income at which the pollutant reaches a maximum with respect to per capita GDP, after which it begins to decline. These turning points have become important in debates over regional and global pollutants. They are informative both for individual countries and for global pollution. For poor countries, a high turning point implies a long wait for better environmental quality. For global pollutants, the turning points determine the future path of pollution. Economic growth with high turning points implies periods of growth when pollution is increasing and future increases of global pollutants. Table 2 shows the turning points computed by various authors or implicit in the estimated equations. The turning points estimated by Selden and Song are considerably higher than others, because their results use measured emissions for the country as a whole rather than for urban air quality as in Grossman

[2] SS estimate a model where the dependent variable is per capita pollution: $P(y)/N(y)$ where P is pollution, N is population and y is per capita income. Define z as the effect of income on per capita pollutants: $z = d[P(y)/N(y)]/dy = (P'(y)N - N'(y)P)/N^2$, where the primes denote the derivatives of the variable with respect to per capita income. The usual EKC is $P'(y)$. Estimating at the per capita level scales down the total effect by $1/N$ and subtracts the term $N'(y)P/N^2$. Suppose that $N'(y) > 0$. Then $P'(y)$ may be inverted U-shaped and z could be negative everywhere. If $N'(y) < 0$ an inverted U-shaped $P'(y)$ might lead to an everywhere-positive relationship between per capita pollution and income.

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Table 2. *Selected turning points (in 1985 US dollars)*

	Pollutant						
Study	*SO_2*	*SPM*	*NO_x*	*Dark matter*	*CO*	*Faecal coliform*	*Heavy metals*
SS[1]	10,600	9,600	21,700		19,000		
SB	3,670	3,280				1,220	
GK[2]	4,200			5,000			
R[3]							10,800

Notes: [1] There are results for the random effects model of Selden and Song (1994). They are turning points for per capita emissions. [2] Approximate. Read off Figures 2 and 3, Grossman and Krueger (1993). [3] From Rock (1996), Table 1, equation 6.
Key and Sources: See Table 1.

and Krueger.[3] As Selden and Song argue, urban air quality would respond to public policies for abatement at lower levels of income because the damage is more evident. In fact, urban air quality could improve while a country's emissions increased if the emissions were more dispersed, or even spread efficiently across seasons.

In most cases, specification of models such as $P_{it} = \beta_{0i}(t) + \beta_1 y_{it} + \beta_2 y_{it}^2 + \beta_3 y_{it}^3$ implies turning points that are the same for different countries and different time periods. Yet countries could have systematically different abilities to assimilate pollution, different willingnesses to pay to avoid pollution and hence different turning points. Further, international diffusion of pollution control technologies as well as the perception and health costs of pollution could change the timing of the turning points for different countries.

Stern *et al.* (1996) discuss some of the econometric problems of the EKC. There are additional reasons for cautious interpretation of these empirical models. First, the models imply that increases in per capita income would eventually lead to improvements in environmental quality. This could follow when social choice is made by comparing the aggregate benefits with the social costs. Social choices could also be made consistent with the median-voter model. All households expecting to experience an increase in net benefits from the environmental improvements would vote for the environmental regulation. Majority rule will lead to environmental regulations consistent with the preferences of the median voter. With marginal values for environmental quality that change with income, different distributions of income would imply different median-voter preferences. A high degree of inequality would imply a low marginal value for the median voter when the income effect is positive.

A second reason for caution stems from the distinction between ambient

[3] However, subject to the previous footnote, it may be that if population responds to per capita income, the turning points calculated for per capita emissions are the points where the rate of increase in population with respect to income equals the rate of increase in emissions with respect to income. If population declines with increases in per capita income, then the turning point for total emissions will occur at lower incomes than the turning point for per capita emissions. The reverse holds if population increases with per capita incomes.

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air quality and emissions. Countries can only control domestic emissions[4] (although it would be consistent with the increasing value of the environment for countries to be more willing to negotiate internationally for pollution controls as incomes rise).

Finally, one has to be careful about the precision of turning points. There may be large confidence intervals about these values induced by solving for per capita GDP as a non-linear function of the parameters.[5]

Models of the environmental Kuznets curve

This section presents a simple static model to show the role of the income elasticity of demand for environmental quality in the EKC. Three variants of the model are presented: the simplest model with an additive utility function when pollution reduces utility; the same model with non-additive preferences; and a model in which pollution reduces output. This model is essentially an amalgam of models from the literature.

A variety of models have sprung up to explain the empirical regularities of the EKC. These models differ in some important ways: how pollution is generated; the form of the utility function; whether the pollution externality is internalized; and how long the pollutant lasts. Despite the differences in the models, they all replicate the EKC. However, for some models, restrictions on preferences or technology are required for the inverted U shape of pollution. All models assume either homotheticity or additivity as restrictions on preferences.

Overlapping generations (OLG) models provide a framework for analysing the degree to which externalities are internalized. John and Pecchenino (1994), John *et al.* (1995) and Jones and Manuelli (1995) have developed OLG models which replicate the inverted U shape for pollution when the current generation considers the impact of pollution on its own welfare but not the welfare of future generations. Thus the externality is partly internalized. In contrast, optimal decisions by the infinitely lived representative household necessarily account for the full externality of pollution. Models of the infinitely lived household by Selden and Song (1995), Lopez (1994) and Stokey (1992) also capture the inverted U shape of pollution in empirical studies.

Pollution can be generated by consumption, production or the use of inputs. The chief distinction concerns differential effects on pollution among inputs. Jones and Manuelli construct a model of heterogeneous capital goods, in which the more productive capital is more polluting.

[4] For example, sulphur deposition in European countries can differ significantly from sulphur emitted.

[5] For example, in Selden and Song's results for SPM, their estimated turning point is about \$9,600 = $-\beta_2/\beta_1$. The distribution of the turning point can be simulated from means and the standard errors of these coefficients, assuming a correlation between the two coefficients and then drawing random normal variates with the distributions of the betas. In a typical sampling experiment, 50 per cent of the turning points are calculated to lie outside the range of 7,500 to 12,700. For SO_2, where the turning point is calculated to be \$10,600, a similar sampling experiment shows that 50 per cent of the calculated turning points lie outside a range of about 5,500 to 13,000. This range would be greater for a cubic curve.

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Consequently, controlling pollution influences growth in the long run by altering the mix of capital goods. John and Pecchenino model pollution as generated linearly by consumption but reduced by abatement. In the infinitely lived household models of Seldon and Song (1995), adopted from Forster (1973), pollution is generated by an aggregate capital good and abated by expenditures on abatement. Lopez models the environment as an input to production by allowing the exploitation of the environment to increase output. Stokey develops a model in which pollution depends on the output, conditional on abatement technology.

The choice of model is essentially a matter of analytical convenience when there is only one input. Models in which pollution influences output, output influences pollution, consumption produces pollution and abatement reduces pollution can all be used to replicate the EKC.

To demonstrate the role of the elasticity of demand for environmental quality, I adapt a static model of income and the environment. This will be equivalent to an infinitely lived household model in which pollution is optimal. Pollution is generated by consumption but reduced by abatement.[6] Let P be pollution, C consumption and A abatement expenditure in units of consumption. Then $P = P(C, A)$ where $P_C(C) > 0, P_A(A) < 0, P_{CC} > 0, P_{AA} > 0$ and for simplicity $P_{AC} = 0$. Let utility be an additive function of consumption C and pollution P, given by $U = U(C, P)$ so that $U_{CP} = 0$. The utility function has the standard curvature assumptions: $U_C > 0$ and $U_{CC} < 0, U_P \leq 0, U_{PP} \leq 0$.[7] Output is divided between abatement and consumption: $Y = C + A$.

In this model, the level of abatement expenditures, the quantity of resources used to reduce pollution, is explicit, as in Selden and Song and John and Pecchenino. In other models, it is implicit. In the most transparent of these models, Stokey constructs an index of pollution reduction, i.e., $C = zY$ and $P = \Phi(z)Y$ where z $(1 \geq z \geq 0)$ is an index of technique of pollution reduction and $\Phi(z)$ represents the production of pollution, given the output and technology. A naturally polluting economy has a high Φ for a given z. Abatement expenditures can be made explicit: $A = (1 - z)Y$ and the index of technology $z = 1 - A/Y$.

The social planner maximizes utility subject to the constraint $Y = C + A$. Substituting the constraint, the problem becomes:

$$\underset{C}{\text{maximize}}\ U(C, P(C, Y - C)).$$

[6] In this model, pollution comes from consumption rather than production. It would involve a minor change to specify pollution as a function of Y. Let $\text{PO}(Y, A)$ be pollution as a function of output and abatement. Then we can substitute the income equals output equation $Y = C + A$ so that $\text{PO}(Y, A) = \text{PO}(C + A, A)$. Now abatement has two effects: it causes an increase in pollution because it is part of output and, when used as abatement, it reduces pollution. The pollution generating function in the text is just net pollution: $P(C, A) \equiv \text{PO}(C + A, A)$.

[7] An equivalent formulation would posit utility as a function of environmental quality and quality as equal to a constant less pollution. The book-keeping is easier with pollution in the model, rather than environmental quality. The sole difference is the sign of the slope of the indifference curve, but not the degree of curvature. See also footnote 8.

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When $A > 0$, maximizing requires

$$U_C(C) + U_P(P)P_C = U_P(P)P_A.$$

Abatement will be zero as long as $U_C(Y) > -U_P(\mathrm{P(Y,O)})(P_C(Y) - P_A(0))$. Now suppose that Y increases. The first-order conditions can be differentiated and solved for dP (results are available in a separate appendix, available from the author):[8]

$$dP = [P_C(-U_P P_{AA}) + P_A(-U_{CC} - U_P P_{CC})]\frac{dY}{-\Delta}. \tag{2}$$

(Δ is the negative determinant of the comparative statics matrix.) In a simple static model of EKC, where pollution reduces household utility, this is the coefficient of dY. Pollution increases with income if the positive first term (product of P_C) outweighs the negative second term.

With additive preferences, the inverted U shape cannot be induced by changes in the sign of the income elasticity of demand for environmental quality—the income elasticity is always positive.

To illuminate the role of the income elasticity of demand for environmental quality, it is possible to construct this elasticity from components of the utility function. Suppose a household purchases consumption goods c at a price of one and environmental quality q at a constant price of π_q. This is a counterfactual model because in practice environmental quality cannot be purchased. The household's utility is $u(c, p)$, where lower case letters denote this counterfactual model, in which the household can reduce pollution by purchasing environmental quality. Then the income elasticity of demand for environmental quality for a household is given by:[9]

[8] This model has only one person and it may appear to obscure the role of the elasticity of demand when there are many people. When there are N persons in the economy the change in pollution is

$$dP = [P_C(-N^2 U_P P_{AA}) + P_A(-U_{CC} - N^2 U_P P_{CC})]\frac{dY}{-\Delta.}$$

Increases in the number of people (N) attenuate the influence of the income elasticity on the growth in pollution. The qualitative nature of the discussion in the text does not depend on having only one person.

[9] Purchasing environmental quality can be considered as purchasing reductions in pollution. The marginal utility of increases in q is the marginal utility of reductions in pollution, and the change in marginal utility is the same for both. Let $q = q_{\max} - p$ (or $p = q_{\max} - q$) where $q_{\max}$ is the best environmental quality available, p is pollution, and q is actual environmental quality. Lower-case letters here distinguish between this model of individual preferences and the social planner's model of optimal pollution. The lower-case models show only preferences and will permit the direct construction of the income elasticity of demand in terms of the utility function. The household divides income between expenditures on c, purchased at a price of unity and expenditures on q, $q\pi_q$, where π_q is the price of q, in order to maximize the utility $u(c, p)$, which is increasing in c, decreasing in p and concave in both arguments. This problem is counterfactual because households cannot purchase environmental quality directly. When the household maximizes $u(c, q_{\max} - q)$ subject to $y = c + q\pi_q$, the income elasticity of demand for q is given by:

$$(y/q)\partial q/\partial y = (y/q)\frac{(\pi_q u_{cc} + u_{pc})}{(\pi_q{}^2 u_{cc} + 2\pi_q u_{pc} + u_{pp})}.$$

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$$(y/q)\partial q/\partial y = (y/q)\frac{(\pi_q u_{cc} + u_{pc})}{(\pi_q{}^2 u_{cc} + 2\pi_q u_{pc} + u_{pp})}. \quad (3)$$

This is the 'traditional' elasticity that would apply to a consumer in a standard model with a linear budget constraint. The denominator and u_{cc} are negative, so a sufficient condition for the income elasticity of demand for q to be positive for u_{pc} to be non-positive. The income elasticity of demand will only be negative when u_{pc} is sufficiently positive.

Comparing the 'traditional' elasticity in equation (3) with the coefficient of dP in the EKC in equation (2), we can summarize the connection between the elasticity of demand for environmental quality and the EKC. The higher the income elasticity of demand for environmental quality, the slower the growth in pollution when positive or the faster the decline in pollution when negative. Pollution can decline even if the elasticity of demand for environmental quality is zero ($U_{CC} = 0$). Finally, there is no particular role attached to an income elasticity equal to one.

In the empirical literature, turning points are calculated for various prominent pollutants where $dP = 0$. Preferences can influence the sign of dP only through U_{CC}, which is related to the income elasticity of demand for the environment. More inelastic schedules of the marginal utility of consumption increase the income elasticity of demand for the environment and reduce the growth in pollution. Completely inelastic marginal utility schedules fix consumption at a level, and allow additional income to be used to abate pollution.

Non-additive preferences

The assumption of additivity restricts income elasticities to be positive. When utility functions are not additive, the customary assumption is that increases in pollution decrease the marginal utility of consumption ($U_{PC} < 0$). ($U_{CP} < 0$ is associated with a positive income elasticity of demand for environmental quality—see equation (3)). However, this may not always be the case. For example, increased air pollution may increase the marginal utility of air conditioning. When preferences are not additive, the change in pollution is given by:

$$dP = \{-P_C U_P P_{AA} + P_A(-U_{CC} - U_P P_{CC} + U_{CP}(P_A - P_C))\}\frac{dY}{\Delta^*} \quad (4)$$

where Δ^* is a negative determinant. U_{CP} may be positive or negative—large enough values will change the sign of dP. If U_{CP} is positive and big enough, there will be a negative income elasticity for environmental quality. A high and positive U_{CP} encourages pollution to grow because its factor $P_A(P_A - P_C)$ is positive. The coefficient U_{CP} is a measure of the ability of pollution to injure as consumption increases. A positive U_{CP} occurs in the air conditioner–air pollution case or when the purchase of bottled water for reasons of taste reduces exposure to water pollution. U_{CP} will be negative if the consumption of recreation increases the exposure to water pollution. But, in concept, positive U_{CP} can be large enough to give a negative income elasticity of demand for environmental quality and yet pollution will still decline if the marginal damage of pollution is high enough.

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When pollution reduces output.

A case can be made that pollution reduces output. Freeman (1993, Chapter 9) surveys empirical research on the impact of pollution on income. The quality of the environment is an input to the production process for many goods. For example, acid rain deposition has been shown to reduce forestry yields in the eastern part of the United States.[10] Low-level ozone has a demonstrated negative impact on experimental crop yields and there is further evidence that it reduces harvests.[11] Improvements in the water quality of bays and estuaries increase commercial fish output. Sulphur dioxide causes material damage. Perhaps the largest impact of pollution on production is caused by health effects from air and water pollution, which impair a country's labour force, hence reducing output. Air-borne lead has been shown to influence mental abilities. Alberini *et al.* (1996) measured households' willingness to pay to avoid particular illnesses that might be induced by water or air pollution. This damage can be measured through households' collective willingness to pay to abate the health effect or through the forgone production (although the latter would underestimate the full social damage because it omits the direct cost and disutility of illnesses).

The effects of the environment on output are likely to be greater for poorer countries. When a higher portion of output comes from production with natural resources, the elasticity of substitution between the quality of the environment and purchased inputs is likely to be lower.

Suppose that income can be impaired when pollution is not abated: $Y = Y(P, G)$ where G is an index of inputs and pollution has a negative impact on income ($Y_P \leq 0$, $Y_{PP} < 0$).[12] The social planner has the problem:

$$\underset{A,C}{\text{maximize}}\ U(C, P(C, A)) + \lambda(Y(P(C, A), G) - A - C).$$

At positive abatement this requires:

$$U_C(C) + U_P(P)P_C + \lambda(Y_P P_C - 1) = 0$$

$$U_P(P)P_A + \lambda(Y_P P_A - 1) = 0$$

$$Y(P(C, A)) - C - A = 0.$$

The implied path of pollution when G increases exogenously is given by:[13]

$$dP = \{P_C(Y_P P_C U_P P_{AA} + Y_P{}^2 P_C P_{AA}\lambda - U_P P_{AA} - \lambda Y_P P_{AA}) + P_A(U_{CC} Y_P P_A - U_{CC} + U_P P_{CC} Y_P P_A - U_P P_{CC} + \lambda Y_P{}^2 P_{CC} P_A - \lambda Y_P P_{CC})\}\frac{dY}{-\Delta}.$$

[10] Some of the evidence on the impact of pollution on forests in the USA and Europe is summarized in MacKenzie and El-Ashry (1989).

[11] Westerbarger and Frisvold (1995) report an empirical study of corn and soybeans in the eastern United States, estimating the mean elasticities with respect to ozone exposure of −0.19 for corn and −0.54 for soybeans (p. 163).

[12] In a sense, allowing an exogenous growth factor G makes the model quite similar to the Lopez model. One may think of G as aggregated and exogenously growing factors. However, this model makes no pretence of being dynamic, while the Lopez model allows output to grow from technical change and factor growth.

[13] This result is established in a separate appendix, available from the author.

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The role of individual preferences is much attenuated. When health damages are counted as losses in production rather than losses in household valuation, the production effects could be quite large. Then, even when household preferences are operative, the EKC may bend without too much influence from such preferences.

More extreme results come from assuming that utility is not influenced by pollution, so that U_P and U_{PP} equal zero. One could think of a combination of a relatively poor economy and a pollutant, such as agricultural externalities, which would influence the aggregate agricultural output, but for which the household demand for environmental quality is always zero. Then changes in pollution follow changes in income according to:

$$dP = \{P_C(Y_P^2 P_C P_{AA}\lambda - \lambda Y_P P_{AA}) + P_A(U_{CC} Y_P P_A - U_{CC} + \lambda Y_P^2 P_{CC} P_A - \lambda Y_P P_{CC})\}\frac{dY}{-\Delta^+}.$$

where Δ^+ is the negative determinant. The curvature of tastes (U_{CC}) and technology (P_{CC} and P_{AA}) jointly determine whether pollution is increasing or decreasing. No tradeoff between consumption and the environment influences the growth in pollution. No household demand for environmental quality is necessary for an environmental Kuznets curve when pollution has a negative impact on production.

Given that the efficiency conditions for positive abatement hold, abatement can be zero because of the political difficulties in aggregating benefits and controlling the emissions of individual pollutants. The political process can fail to aggregate the marginal damage of pollution correctly for a variety of reasons. Only some preferences are counted. Decisions may be made non-democratically or inefficiently. Aggregation may be difficult if the marginal values of pollution reduction are small and widely dispersed, while the costs are high for a small number of agents. Inefficient decisions may result when households take defensive action to avert damage that might have been averted more cheaply through public actions. For some cities with water connections, households take a variety of defensive actions, such as buying bottled water and using electronic filter systems. For those households with electronic filter systems, the marginal value of public water treatment would be low. When the capital stock of habits for averting the effects of contaminated drinking water is developed, then marginal benefit–cost analysis for public actions may be low.

The propensity to take averting actions in response to air and water pollution (bottled water, air conditions, residential choice) with increases in income may make the collective demand for environmental improvements less responsive to income. Suppose that at the inception of pollution, before households have responded, higher-income households are willing to pay more for pollution. Then as pollution grows, higher-income households take a variety of averting actions. Following these averting actions, a cross-section study of households might show that higher-income households are not more willing to pay for pollution abatement.

The costs of abatement are frequently as difficult to measure as the benefits of abatement. But abatement has the additional problem of control. Non-point-source pollution has provided opportunities for evasion of

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restrictions and enforcement difficulties, resulting in little abatement. Good case studies of non-point-source difficulties can be found in attempts to control groundwater pollution though controls on farms (especially in developed countries) and in efforts to control certain kinds of automobile emissions. Low levels of abatement can be a result of poor political organization and low marginal product of abatement, as well as high marginal cost of abatement.

The simple models of this section illustrate the role of household valuation in the EKC. However, this role is different from the common notion that the EKC is created in part by a high income elasticity of demand for environmental quality. Preferences that are equivalent to high income elasticities of demand for environmental quality can be attenuated by additional factors, such as low marginal effectiveness of abatement, the effect of pollution on output or, in a more practical world, the simple failure to make social choices based on benefits and costs.

The findings of this section pertain to the relationship between the theoretical EKC and the income elasticity of demand for environmental quality (or the income elasticity of demand for avoiding pollution). Concerning a social planner's optimal path:

- Higher income elasticities result in slower increases or faster declines in pollutants.
- The income elasticity need not be positive for pollution to decline.
- There is no special significance of an income elasticity equal to one.
- When pollution causes reduction in output, not only the income elasticity but the household's marginal value for reductions in pollution may be zero for a decreasing relationship between pollution and income for the conceptual EKC.

Microeconomic evidence on the value of environmental quality. Conceptual models show that the influence of preferences in general and the income elasticity in particular maybe weakened by production and abatement relations. However, if income elasticities are positive enough, preferences can help reduce pollution. Since the income coefficient which is estimated in the empirical EKC is an amalgam of various forces, we have to look elsewhere for more specific information on income and preferences for environmental quality. The most fruitful source of evidence on preferences for the environment comes from non-market valuation. There are hundreds of such studies.[14] To exploit these studies, it is necessary to understand what kinds of environmental services have been valued and how the values have been measured.

The link between ambient pollutants and household valuation is complicated by the fact that households typically value services that are somehow affected by pollutants, but not directly the pollutants. For example, households value days free of minor respiratory ailments, not

[14] Kristrom and Riera (1996) have carried out an aggregate analysis of European studies, showing that mean willingness to pay for environmental quality is a declining function of the income of the country.

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reductions in ozone or they value potable water without intestinal distress, but not reductions in faecal coliform. Studies of household behaviour and valuation focus on the services in the households' preference functions. In practice, this is almost never the pollutant. The quality of the service is a function of the pollutant, which is publicly determined. However, private actions, such as averting behaviour, consumption choices, residential location and labour–leisure tradeoffs, influence these services, which are also determined by ambient pollution. Consequently most evidence from non-market valuation deals with pollution only indirectly. Hence, there is no 'demand for environmental quality', even though there is a value from improving the environment.

Non-market valuation deals with the valuation of environmental quality in two distinct ways, depending on whether contingent valuation or behavioural methods are used. The essence of behavioural methods is to estimate the degree to which exogenously given pollutants change behaviour toward a good or service that is complementary to the pollutant (see for example, Bockstael and McConnell, 1993). Consequently, the value of environmental quality must be inferred from changes in behaviour, making it quite difficult to estimate the impact of income on the value of such amenities. For behavioural models, the interaction between the pollutant and environmental quality determines the income effect for such models. Not surprisingly very few models are specified to estimate such an effect.

In contrast, contingent valuation models are specified from a valuation function such as an indirect utility function, and yield estimates of willingness to pay that are direct functions of income. For most settings, except with quasi-linear utility functions, willingness to pay is a function of income. Most of the good evidence cited below comes from contingent valuation.

Because the literature is so voluminous, I summarize only a few areas in terms of the effects of income: risk reductions, sanitation, recreation and some amenities. These provide indirect evidence on the demand for reductions in pollution.

Reductions in risk

There is good theoretical reason and some empirical evidence that households with higher incomes will pay more for reductions in risk. The theoretical evidence stems from the fact that a household's willingness to pay to reduce risk of mortality is partly dependent on the present discounted utility of future consumption, which will be higher when income is higher. Willingness to pay to reduce risk of morbidity should increase with wage rates, which will also increase with income. Evidence from various CV studies (e.g., Alberini *et al*., 1996, for Taiwan) supports the idea that willingness to pay to reduce risk increases with income.

Exposure to risk

The conceptual and empirical evidence on the influence of income on exposure to risk is mixed. To the extent that any *a priori* statements are possible, it would appear that exposure to risk declines with income. Households purchase goods, such as air conditioners and residential

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location, that have the partial effect of reducing risk. This *a priori* result is corroborated empirically in Ostro (1983) and Portney and Mullahey (1990), which show that days of illness is reduced by increases in income. This may stem from higher opportunity costs of lost work that come from higher wages or from more averting actions.

The demand for recreation

Water pollutants influence the utility derived from water-based recreation. In the theory of the demand for environmental quality, when this quality is weakly complementary to an activity such as recreation, the marginal value of the environmental quality can be inferred from changes in the demand for a recreation site. There are two kinds of evidence: behavioural and contingent valuation.

For behavioural models, the marginal willingness to pay can be written as the change in consumer surplus from access to a recreation site induced by the change in water quality. Inferring the effect of income is quite similar to the exposure to risk case. The effect of income on the demand for recreation is mixed for two reasons. First, many models are estimated from the discrete choice among sites and typically do not include income. Second, recreational demand models are site specific and frequently show negative income elasticities as higher income implies higher opportunity cost of time and, further, site switching as households with higher incomes often take much longer trips, out of the locale where the site is studied. Given the mixed effect of income on the demand for recreation, there is little that can be said about the empirical evidence on the effect of income on the marginal value of environment quality.

Hedonic models

Many air pollutants have appeared as characteristics in hedonic models. (See Smith and Huang, 1993, for a summary of these models.) These models show the marginal value of attributes and they provide cogent evidence that people value reductions in air quality. By themselves however, hedonic models cannot give direct evidence on the income effect on willingness to pay because a properly specified hedonic model does not include household traits. However, there is clear indirect evidence of the effect of income on the willingness to pay to avoid air pollutants and other health risks. Casual observation shows that wealthier households live in locations which have better air quality and other measures of environmental quality. This, however, is a long way from evidence on the income elasticity of demand for reductions in air pollutants or other pollutants experienced.

Miscellaneous amenities

The contingent valuation method gives convincing results on the effect of income on the demand for various amenities, including non-use values. For example, in two major natural resource damage studies, research found that income was a significant and increasing determinant of willingness to pay to avoid some loss of ecosystem function (Carson *et al.*, 1994, 1996).

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Visibility

One of the major non-health effects of air pollution from power plants and auto emissions is impairment of visibility. Smith and Osborne (1996) review the various studies of visibility that have been done in the USA. The visibility evidence comes from two kinds of studies: hedonic models and contingent valuation studies. For reasons discussed, the hedonic models do not reveal any information about the impact of income on the willingness to pay for attributes. However, the CV studies tend to show that the willingness increases slowly with income. For example, a national parks study showed the income elasticities for willingness to pay for visibility to be between 0.5 and 2.4.[15]

Urban sanitation

Various international agencies support the construction of water supply and waste treatment facilities. Benefit estimation has become routine in planning for these facilities. As a consequence, there is quite a large set of contingent valuation studies on households' willingness to pay for sanitation services. These services are partly private services and partly environmental. The CV studies are typically conducted as referendum questions about the willingness to pay for improved sanitation. The evidence is fairly systematic that households with higher income are willing to pay more for sanitation services. For example, all eight unpublished studies reviewed for willingness to pay for sanitation services in Latin America showed that willingness to pay was an increasing function of household income.

The evidence from non-market valuation does not provide unambiguous support for the idea that preferences for environmental quality are consistent with high income elasticities of demand. There are two reasons for this—one pertaining to the nature of the research and the other to behaviour and preferences. Behavioural evidence from non-market research relies on the empirical relationship between changes in environmental quality and changes in the demand for market commodities and services—water quality on recreation, air quality on housing prices, etc. To measure income effects requires a second-order effect, that is, how this impact of environmental quality changes with income. This effect is difficult to estimate with the kinds of cross-section data typically available. Hence the nature of this research makes the influence of income difficult to detect, even when it is there. Further, there is some evidence of zero or negative effects for local environmental goods, such as water quality. There is also evidence that higher income households do more averting of pollution, making them less willing to pay for public intervention.

Conclusion

Empirical research has established that several common pollutants increase at low levels of per capita income and decline at high levels. This aggregate empirical evidence has spawned a suite of aggregate growth models that explain the empirics. Initial explanations of this phenomenon

[15] Personal communication, Bob Rowe.

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cited the income elasticity of demand for environmental quality as an important force. This paper assess the role of preferences and, in particular, the income elasticity of demand for environmental quality on the pollution–income path. By decomposing the reduced-form effect of autonomous income changes on pollution, one can gain some understanding of the role of preferences. Preferences that are consistent with a high income elasticity of demand for environmental quality are neither necessary nor sufficient for pollution to grow with income. Simple models show that preferences that are consistent with a high income elasticity of demand for environmental quality are attenuated by high and rising abatement costs or a high impact of pollution on production. Hence, it would be feasible for pollution to decline with a zero income elasticity of demand for environmental quality, or to increase with a high income elasticity of demand for environmental quality.

The microeconomic evidence on the influence of income on the demand for environmental quality is not sufficiently strong to support a major role for the income responsiveness of preferences in the EKC. The behavioural evidence is inconclusive for several reasons. First, out of necessity, such evidence is based second order effects—the difference in how behaviour changes with environmental quality, depending on income. Further, behavioural evidence is suppressed when higher-income households protect themselves from environmental injury with defensive expenditures.

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