Political Economy and the Decomposition of Environmental Income Effects

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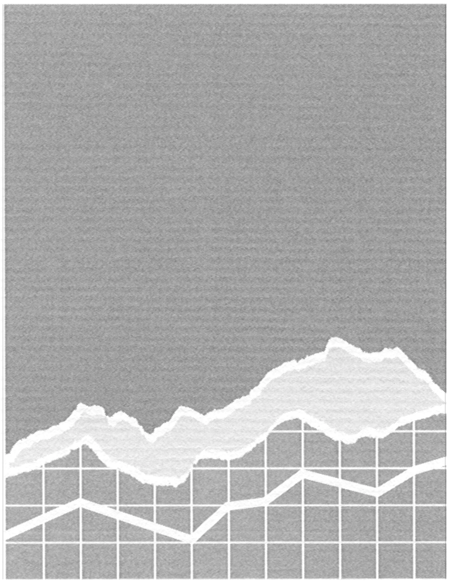

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Introduction

In their widely-read paper on economic growth and the environment, Grossman and Krueger (1995) wrote "a limitation of the reduced-from approach...is that it is unclear why the estimated relationship between pollution and income exists." They referred to their work as "an important first step," effectively putting forward a challenge to develop microeconomic foundations for "environmental Kuznets' curves" and launching a large literature. While much of this literature further explores the reduced-form relationship between per capita income and different dimensions of environmental quality, several authors have focused on tracing the ultimate theoretical sources of observed income paths [see for example Lopez and Mitra (2000), Andreoni and Levison (2001)], and on "factoring" environmental income effects into meaningful components [see Hilton and Levinson (1998)]. In the current vernacular, the "scale effect" on environment results from an economy's increased capacity to generate pollution as it grows, but a "technique effect" mitigates this as higher incomes result in greater demand for environmental quality [see Antweiler, et al (2001)]. The early literature was motivated by concern over the likely environmental impacts of a NAFTA still under negotiation [Grossman and Krueger (1995), Shafik and Bandyopadyay (1992), World Bank (1992)], and substantial theoretical insight (including the above terminology) has come from work on trade and environment.

The importing of dirty goods, and the effects of trade liberalization on the environment in general, have understandably received a great deal of attention. However, some of the most pressing environmental problems have notably little to do with international trade. The primary sources of air pollution, particulate matter and sulfur dioxide for example, are electic power generation and automobile exhaust. By focusing on non-traded sources of pollution, this paper provides a complement to the trade and literature in the effort to develop microeconomic foundations for environment – development relationships in two ways. First, a demand-side model traces the environmental impacts of changes in the income distribution to the household level. This aggregation exercise highlights the obvious fact that pollution is not *really* a function of per capita income, but of demand for both private and public goods by millions of households whose incomes are characterized by a whole distribution. The relationship of income inequality as well as mean income to pollution levels is explored formally and estimated empirically for several air pollution measures.

Second, a simple model of the political-economy process by which the public good of environmental protection is provided by government in response to demand for abatement generates a valuable insight: "abatement" (technique) effects are fundamentally interacted with government in a way that "gross emissions" (or scale) effects are not, leading to a econometric specification capable of identifying them separately. The structural specification is to my knowledge new to the literature, as are the resulting estimates of income elasticities of demand for pollution abatement. These estimated elasticities are found to be large, lending support to the notion that environmental quality is a luxury good. Estimated "scale" elasticities are smaller, giving rise to the likelihood that an inverted-U relationship exists for some pollutants. The now-traditional calculation of a "turning point" level of per capita income is provided for each pollutant under different conditions. The results suggest a central role for government responsiveness in the income paths of environmental variables: *unmet* demand for public goods yields no technique effect, so weaker government pushes the turning point outward at least, and increases the likelihood that one doesn't exist.

A model of demand for pollution and abatement

There are two key income effects at the household level with respect to the environment. The first is increasing demand for (normal) goods, some of which generate pollution at the stage of production (eg. electric power) or consumption (e.g. gasoline). As consumption of these "dirty goods" expands, the economy-wide capacity to generate pollution increases. The second effect derives from the fact that the environment itself is a normal good, so higher income leads also to increasing demand for pollution control. The net result of these two effects on the environment is not immediately clear, but the notion that the first dominates at lower levels of income and the second at higher levels is a modern folk theorem for inverted-U shaped environment – development relationships. This explanation is incomplete

Utility maximizing households demand a vector of goods, $\mathbf{x}$, potentially representing both private goods consumption and household production activities. The vector of (uncompensated) demands by household i is written as a deterministic function of income, y_i, and a vector of prices, $\mathbf{h}$, plus a zero mean, idiosyncratic component, $\boldsymbol{\varepsilon}_i$:

$$(1) \qquad \mathbf{x}_i = \mathbf{x}(y_i, \mathbf{h}) + \boldsymbol{\varepsilon}_i.$$

In this framework $\mathbf{h}$ summarizes all supply side effects, the discussion of which is largely suppressed here.The function $\mathbf{x}(\cdot)$ captures any systematic relationship between demand and income, leaving the idiosyncratic component ε uncorrelated with y. If utility depends separably on a set of public goods and bads, $\mathbf{P}$, indirect utility for a household can be written:

$$(2) \qquad V(y, \mathbf{h}; \mathbf{P}).$$

GDP is distributed such that incomes of N individuals are drawn from a p.d.f. $f(y; \mu, \sigma) \in (0, \infty)$ with parameters μ and σ, representing the mean and dispersion of household income in the population.[1] Aggregate emissions are then decomposed as follows: x_j is an element of $\mathbf{x}$ for which production or consumption is associated with a pollution externality. Uncontrolled or *gross* emissions associated with x_j, E_j^0, are proportional to total consumption if the emissions intensity of x_j, ϕ_j, is a constant.

$$(3) \qquad E_j^0(\phi_j^0 N, \mu, \sigma, \mathbf{h}^0) = \phi_j^0 N \cdot \overline{x}(\mu, \sigma, \mathbf{h}^0) = \phi_j^0 N \int_0^\infty x_j(y, \mathbf{h}^0) \cdot f(y; \mu, \sigma)\, dy$$

In (3) ϕ_j^0 is emissions intensity and $\mathbf{h}^0$ is the price vector in the absence of regulation. The superscripts on ϕ and $\mathbf{h}$ are necessary because government regulation aimed at emissions abatement is likely to operate through these parameters, a subject taken up shortly. Crucially, (3) holds only when X_j (quantity demanded) equals domestic production, or for "consumption externalities" where the environmental impact is at the point of consumption regardless of where the good was produced. This framework is therefore explicitly not about trade. As we will see,

E_j^0 is not the observed emissions level however if effective abatement policy is implemented by government. Let A_j represent abatement of j emissions, and $a_j = \frac{A_j}{E_j^0}$ represent the fraction of gross emissions abated. Net emissions and the concentration of pollutant j, respectively, can then be written:

$$(4a) \qquad E_j = E_j^0 - A_j = E_j^0(1 - a_j)$$

$$(4b) \qquad P_{js} = \Psi(E_j^0 - A_j) = \Psi\left(E_j^0(1 - a_j)\right),$$

where Ψ is a transfer function relating j emissions to concentrations at site s. This transfer function is assumed to be linear.[2]

Optimal and actual abatement

How much abatement is undertaken depends on abatement costs, willingness-to-pay for abatement, and the efficiency of public good provision by government. For the remainder of this section, the j

subscripts will be suppressed, though the focus remains on an individual pollutant. Assume abatement costs are a general function of abatement and gross emissions:

$$(5) \qquad C(A, E^0)$$

In (5) costs are increasing in abatement, but decreasing in gross emissions (holding abatement constant). Efficient pollution control policy equates the marginal cost of abatement to the aggregate marginal willingness-to-pay for abatement. Marginal willingness-to-pay for an individual is derived from the indirect utility function in (2), using (4*b*):

$$(6) \qquad \frac{dy}{dA} = \frac{V_P}{V_y}\Psi \equiv w(y,P)\Psi$$

Imposing constant marginal damages for simplicity, willingness-to-pay for abatement at the aggregate level is:

$$(7) \qquad W = \Psi N \int_0^\infty w(y) f(y;\mu,\sigma)\, dy$$

Using equations (5) and (7), the operative Samuelson condition is:

$$(8) \qquad C_A(A^*, E^0) = W.$$

Inverting (8) yields optimal abatement as a function of both gross emissions and marginal willingness-to-pay, and ultimately their component elements:

$$(9) \qquad A^*(W, E^0) = A^*(\Psi, \phi_j^0 N, \mu, \sigma, \mathbf{h}^0)$$

Finally, for a host of reasons government do not have the capacity or inclination to implement optimal regulation. This interaction with political economy affects abatement, but not gross emissions. We model this interaction using a policy efficiency parameter, γ, as follows:

$$(10a) \qquad E = E^0(1-a) = E^0(1-a^*)^\gamma,$$

where $a^* \equiv \frac{A^*}{E^0}$. In this specification $\gamma = 1$ implies efficient regulation, where the full amount of optimal abatement is undertaken; $\gamma = 0$ implies no regulation, where net emissions are equal to gross emissions. For values of γ in an intermediate range, net emissions are between optimal and gross emissions. (The possibility that $\gamma > 1$, reflecting over-zealous regulation, is not ruled out). More on the nature of γ follows in a discussion of its measurement in the empirical section. From (4*b*), the observed concentration of the pollutant at site *s* is:

$$(10b) \qquad P_s = \Psi[E^0(1-a^*)^\gamma \ .$$

Income effects on net emissions

From the above we can decompose pollution changes resulting from a change in the income distribution into elasticities of demand for both private (x) and public (a) goods. Furthermore, this macro-level decomposition derives from individual-level demands, and income effects on demand at that level provide predictions about the corresponding aggregate elasticities. These predictions are summarized in Table 1, with formal proofs provided in the Appendix. The decomposition yields:

(11a) $\varepsilon_{P\mu} = \varepsilon_{E^0\mu} - \gamma \frac{a^*}{1-a^*} \varepsilon_{a^*\mu}$

(11b) $\varepsilon_{P\sigma} = \varepsilon_{E^0\sigma} - \gamma \frac{a^*}{1-a^*} \varepsilon_{a^*\sigma}.$

Equation (11a) captures the change in pollution along the typical environmental Kuznets curve: pollution concentration can rise or fall with a change in per capita income, the outcome determined by the relative magnitude of relevant elasticities. From (3), $\varepsilon_{E^0\mu} = \varepsilon_{\overline{x}y}$: the elasticity of emissions with respect to mean income is simply the elasticity of mean consumption of x_j with respect to household income (proof in Appendix). This increase in mean income holding the dispersion of income constant amounts to a rightward shift in the income p.d.f.: a marginal increase in income “across the board”, which corresponds to increases in consumption if x_j is a normal good. The elasticity of a^* with respect to mean income has two components: $\varepsilon_{a^*\mu} = \varepsilon_{a^*W} \bullet \varepsilon_{W\mu} + \varepsilon_{a^*E^0} \bullet \varepsilon_{E^0\mu}$. The first term derives from demand for pollution control, and is positive as long as this too is a normal good (by similar reasoning to that for x, see Appendix). Under a rather strong restriction on the abatement cost function, $C(\bullet)$, $\varepsilon_{a^*E^0} = 0$ and $\varepsilon_{a^*\mu}$ reduces to $\varepsilon_{a^*W} \bullet \varepsilon_{W\mu}$.[3] In such a case this elasticity can be interpreted as a pure abatement demand effect; otherwise it is combined with a gross emissions interaction effect. As with total demand for x, the response of total willingness-to-pay for abatement to an income shift can be reduced to an average household-level response: $\varepsilon_{W\mu} = \varepsilon_{\overline{w}y}$ (see Appendix).Crucially, the effects of $\varepsilon_{a^*\mu}$ is interacted in (11a) with the political parameter, γ. It is insufficient that abatement simply be optimal; in order for this effect to be observed it must be “provided” by a political process in a way that the gross emissions effect does not. At the same time, political efficiency and capacity are surely correlated with per capita income, highlighting the need to carefully control for political “regimes” in empirical work if one is to identify the first two effects.

Equation (11b) similarly details how a change in the distribution of income, holding mean income constant, affects pollution levels. First, since $\varepsilon_{E^0\sigma} = \varepsilon_{X^0\sigma}$, gross emissions change as marginal income is redistributed among individuals. The fraction of a marginal dollar spent on “dirty goods” will not in general be equal for individuals in different parts of the income distribution, leading to a net change in X. Specifically, if demand for x is concave in income, greater inequality will *reduce* X^0 (and therefore E^0), as income is redistributed toward individuals who will spend a smaller fraction of a marginal dollar on the good. By symmetry, where demand is convex in income (greater proportions of marginal income are spent on the good as income rises) greater inequality will increase X^0.[4] (See Appendix for proof). The elasticity of a^* with respect to mean income (11b) also has two components: $\varepsilon_{a^*\sigma} = \varepsilon_{a^*W} \bullet \varepsilon_{W\sigma} + \varepsilon_{a^*E^0} \bullet \varepsilon_{E^0\sigma}$. Aggregate marginal willingness-to-pay for pollution control is also affected by an income redistribution as long as demand for this good is non-linear in income at the household level (see Appendix). It is an empirical question whether individuals are willing to pay greater proportions of marginal income for pollution control, but there is certainly common belief that the environment is a luxury good. If so, greater inequality would actually *increase W* all else constant, a somewhat counterintuitive result. Finally, (11b) suggests a third source of an empirical relationship between income inequality and the environment. It is extremely likely that inequality, measured by σ, is (negatively) correlated with γ, measuring political responsiveness, capacity, and representation. It is this last subject on which Torras and Boyce [14] focused. They point out that income inequality and political power are closely related, and that therefore demand for abatement among the poor is ignored in many societies.

Empirical specification and identification

Specify the following functional forms for E^0 and a^*:

$$E^0 = e^{\beta_0}\mu^{\beta_1}\sigma^{\beta_2} \qquad\qquad a^* = \frac{e^{\beta_3}\mu^{\beta_4}\sigma^{\beta_5}}{1 + e^{\beta_3}\mu^{\beta_4}\sigma^{\beta_5}}.$$

Gross emissions are here a log-linear function of the parameters, implying that $\varepsilon_{E^0\mu} = \beta_1,$ and $\varepsilon_{E^0\sigma} = \beta_2.$ The logistic functional form for a^* is chosen to constrain predicted values of a^* to the unit interval. This function implies $\varepsilon_{a^*\mu} = \beta_4(1 - a^*)$ and $\varepsilon_{a^*\sigma} = \beta_5(1 - a^*).$ Substituting the above functions into (10) yields the structural environmental Kuznets equation

$$(12) \qquad \ln P_{jst} = \beta_0 + \beta_1 \ln\mu_{st} + \beta_2 \ln\sigma_{st} - \gamma_{st}\ln[1 + \exp(\beta_3 + \beta_4\ln\mu + \beta_5\ln\sigma \ + \boldsymbol{\beta}_6(N \bullet \Psi) + (v_s + u_{st})$$

where v_s is the time-invariant fixed effect at the observational level of the dependent variable (either city or country), and $N \bullet \Psi$ will be proxied for with population density (see data section below). Other unobserved geographic or economic factors, including $\mathbf{h}^0,$ are assumed to be time-invariant and therefore absorbed by v_s. Remaining unobserved factors are represented in u_{st}, where

$$E(u_{it})^2 = \sigma_u^2 \qquad E(u_{it}u_{js}) = 0 \ \forall i \neq j, t \neq s.$$

The parameters in (12) can be estimated using non-linear least squares, with the v_s estimated by fixed effects dummy variables.[5] A log-linear form for a^* yields a version of (12) that could be estimated with standard panel data methods, but such a function would not constrain the implied value of a^* to be positive. Results from a log-linear specification of a^* indicate this is a substantial misspecification. Equation (12) is employed in the next section essentially unchanged for CO_2, which is measured in tons of emissions rather than as a pollution concentration. The site-specific effects on pollution concentrations include "assimilative capacity" and other geographic characteristics, but for CO_2 emissions they should be regarded as controlling only for economic characteristics.

From (12), the elasticity of net pollution is $\varepsilon_{p\mu} = \beta_1 - \gamma\beta_4 a^*.$ The non-linearity introduced by the logistic form of a^* makes this elasticity a decreasing function of μ when $\beta_4 > 0$. The "turning point", or maximum pollution income level, that has received so much attention in this literature is possible but not imposed by this specification. A turning point, $\overline{\mu},$ occurs where the elasticity above is zero, i.e. where $a^* = \frac{\beta_1}{\gamma\beta_4}$.[6] This condition reveals several key features about the parameters in the model and their relationship to the "Kuznets curve". Theory predicts only that β_1 and β_4 are positive. Their relative magnitudes along with the variables σ and γ determine the shape of the per capita income – environment relationship. As a^* can only asymptotically approach 1 as μ increases, if $\frac{\beta_1}{\gamma\beta_4} > 1$ there is no turning point. This has two clear implications, both of which are highly intuitive: (1) if $\beta_1 > \beta_4$ there is no turning point; and (2) a decrease in γ increases $\overline{\mu}$, and ultimately leads to no turning point. The first says that if demand for polluting goods grows faster than demand for abatement, pollution will not improve even if the provision of the public provision of pollution control is efficient $(\gamma = 1).$ The second is more central to the current analysis. The *expression* of demand for abatement is reduced when γ decreases, so pollution increases at all levels of income and the likelihood that no turning point exists increases. Estimated $\overline{\mu}$ are reported in the results section for $\gamma = 1,$ $\gamma = .75,$ $\gamma = .5,$ and $\gamma = .25.$ (Notice that where $\gamma = 0$ and $\beta_1 > 0$ there is no turning point). The centrality of public goods provision to the "inverted-U" Kuznets curve shape in this model is opposite the mechanism presented by Andreoni and Levinson (2001), who argue that the shape may arise from factors independent of political economy.

The fact that E^0 and a^* are functions of the same variables raises an identification question. This is the econometric manefestation of the central issue: how to separate the gross emissions (scale) and abatement (technique) effects of income on pollution. Identification is provided by the fact that demand for abatement is fundamentally interacted with political effectiveness.[7] The expression of a gross emissions effect from higher incomes does not rely on political provision, but the expression of an abatement effect does. Pollution observed in countries with effective political institutions is therefore net of abatement, while income effects on pollution in countries without effective institutions are purely from gross emissions. Therefore with a measure of political effectiveness these two effects can be separated.

Data

Dependent variables and demand-side sources

A. SO_2, CO_2, and suspended particulates: heavy and "smoke"

Burning fossil fuels to generate electricity is a primary source of several pollutants, among them CO_2, SO_2, and suspended particulates. Since electric power is rarely traded across countries, it is accurate to describe the quantity of electricity generated with equation (3). Suppose $x_{A_1}(y)$ is electricity demand for a household with income y. Electricity consumption is a normal good, but is the income elasticity greater or less than (or equal to) 1? The empirical literature shows short-run elasticities are positive and *generally* less than one [see Branch (1993), Dahl (1992)]. This matches intuition: households spend more on electricity as they become wealthier, but the marginal contribution of additional income to electricity demand declines.

Automobile exhaust is in many cities the primary source of urban air pollution. Urban ozone, particulates, and lead are among the pollutants associated with driving that cause concern for the respiratory health of urban dwellers and urban aesthetics. Automobile emissions are a consumption externality, meaning even though the ultimate source of pollution–fossil fuels–may be imported, the environmental impact can be broken down by consumer demand for vehicle miles. Let $x_{A_2}(y)$ be gross demand for driving miles. Estimated income elasticities also indicate that driving miles increase with income, but at a decreasing rate [see Yu (1990)]. Define the function $e(x_{A_2})$ as emissions of CO_2, SO_2, and particulates generated from the activity of driving. Linearity assumes driving 10 miles generates twice the pollution of 5 miles. This may not be the case if engines burn cleaner when they are warm, etc. If anything, $e(\cdot)$ is a concave function also, which only reinforces the concavity of $x_{A_2}(\cdot)$. The combination of this reasoning and the results outlined in Table 1 suggests that, if electricity and automobile pollution together are primary sources of air pollution emissions, $\varepsilon_{E_A^0\mu} > 0$ and $\varepsilon_{E_A^0\sigma} < 0$.

While the sources of CO_2 emissions are largely the same as the above pollutants, and the gross emissions effects are likely to be the same, this represents a different kind of environmental problem. CO_2 has no direct negative health or aesthetic impacts, and has until very recently never been treated as a pollutant. The result is that there has been no basis–again, until recently–for willingness-to-pay to reduce emissions. In the current context, one the expects emissions elasticity of income from historical data will be a pure gross emissions effect. Indeed this is what cross-national studies of CO_2 emissions have shown.CO_2 emissions data are taken from the World Development Indicators, the other pollution concentration data are from the Global Environmental Monitoring System (GEMS).Table 2 summarizes the environmental indicators used in this study and the predicted effects of μ and σ on gross emissions and abatement.

Independent variables

The above environmental indicators form the dependent variables in empirical applications of (17). The two parameters of the income distribution μ and σ, and the political indicator γ are the independent variables of focus, but several control variables are clearly necessary as well. Per capita income data are virtually all from the Penn World Tables Mark IV. In a small number of cases, measured per capita GDP (PPP) are available from the World Development Indicators, and unavailable in the PWT. The resulting per capita income variable consists of 96% PWT data. A brief description of the sources, measurement, and implementation of the other independent variables follows.

Inequality: Gini coefficients

Income inequality (within countries) must be measured with microeconomic data. Measuring inequality has a long history in the development literature [see Deaton (1997)], and there is no way to capture inequality in a manner that is both simple and entirely satisfactory. The most common summary measure of inequality is the Gini coefficient (or ratio). While computational shortcuts exist [Cowell (1995), Deaton (1997)], the gini coefficient is intuitively derived from the Lorenz curve, where it is interpretable as 2 times the area between the 45^0 line and the cumulative income share distribution. Deineger and Squire (1996) have collected gini coefficients from an exhaustive review of household surveys from 135 countries. These collected gini coefficients make up the variable $\ln\sigma$ in the data used here. (As this measure is already a ratio, In some cases, there are competing Gini coefficient estimates for the same country in the same year. I selected among these based on Deineger and Squires reported 'quality' of each study. These are based on coverage of the sample, income vs. expenditure, etc. In only 6 cases were there competing estimates of the same quality. In a reassuring sign, the estimates in these cases are similar, and I used a simple average of the competing estimates. What remains is a sample of gini coefficients for 1,170 country-years, 1,153 post-1950. This last group composes the universe of possible observations in the analysis that follows.

Measuring γ: Political systems

The political data employed are from Polity 98 (Gurr and Jaggers) data measuring democracy. The logic here is that γ depends most critically on representation. That is, a more representative government is more likely to fully consider willingness-to-pay to improve environmental conditions among its citizens in designing policy. It is supposed here that democracies are more representative and therefore policy in democracies is more likely to reflect citizens' preferences [see Deacon (1999)]. γ is constructed from the two summary variables provided in Polity 98 for nearly 6,500 country-years after 1950. The authors have scored regimes on a number of objective criteria, including the competitiveness of the nominating process, institutional structures for political expression, and the extent to which non-elites are able to access these structures. The judgements are summarized with a 'democracy' score and an 'autocracy' score. Each variable takes values between zero and ten. Following a convention suggested by the authors, γ is constructed as the difference between the democracy and autocracy scores, scaled to the unit interval. A γ value of 1 suggests a complete democracy, where the government in that country in that year satisfied all of the conditions for a democracy and none for an autocracy. A value of 0 indicates the opposite: a complete dictatorship. For some country-years, the authors offer no judgement, stating rather that government was in transition, a colonial construct, or no effective authority existed. (Examples: Spain 1975, Iran 1979, South Africa, 1993). For these cases γ was set equal to zero and a dummy variable for *TRANSITION* was generated ($= 1$ if country in transition).

Government or regime type is correlated with income inequality, so that not properly controlling for the presence of γ will also bias estimates of the effect of inequality on pollution levels.[8] For instance, communist regimes have low income inequality and are likely to have poor environmental protection. In such a case we would not want a low level of abatement to be attributed to the low inequality if it is in fact due to a regime unresponsive to demand for public consumption goods like environmental quality.It is common in this literature to further control for effects specific to communist regimes, both out of concern for the quality of the data in general and because pollution appears to indeed have been worse than income and other controls would predict. This additional control is not undertaken here. The structural model presented emphasizes the role of the income distribution and government's willingness to provide public goods. The unique features in this area of communist countries in these dimensions are viewed as a valuable test of the basic propositions.

Other controls

In the theory population N and the "transfer function" Ψ enter the emissions equation multiplicatively. This interaction of population and geographic features of the landscape is parsimoniously captured by population density (population per km^2). The coefficient on this variable represents the combined effect of these variables through gross pollution and demand for abatement. The convention in this literature is to assume that effects common to observational units that do not vary over time are random variables [Grossman and Krueger (1995), Shafik (1998)]. This specification perhaps deserves more scrutiny that it has received, as the random effects estimator is inconsistent when these effects are correlated with other omitted variables [Hsiao (1990)]. The attraction of the random effects estimator is clear: the approach controls for effects common to observational units over time (geographic and other physical measures, for instance). But unlike the fixed effects estimator, random effects uses some of the between- (across-) group variation in the sample.

The fixed effects dummy variables approach employed here is consistent under more general conditions, but will not make use of potentially model-identifying variation in income and pollution levels across countries. The role of the fixed effects in this approach is as control for all other ommitted variables, including $\mathbf{h}^0$– which reflects supply side endowments in the economy, openness to trade, and other fundamental factors. The fixed effects will control for these factors to the extent that they do not vary over time within the sample. In the sense that economies can only slowly change their resource or capital intensiveness, this is reasonable if not strictly correct.

Results

Table 3 presents the results for eight non-linear least squares regressions with fixed city- or country-level effects.[9] Estimated standard errors in parentheses. Coverage of the inequality data constrain the observations available for estimation of (12) for all four environmental measures. Separate regressions are therefore estimated with and without the restriction $\beta_2 = \beta_4 = 0$. The coefficient β_1 in each regression represents the elasticity of gross emissions with respect to average income, which the theory suggested reduces to an average income elasticity for "dirty goods" at the household level. These are all estimated to be positive, though the large standard errors (a product partially of fixed effects estimation) make them statistically insignificant in 4 of the models estimated. These measured "gross emissions" effects are somewhat sensitive to the inclusion of the Gini ratios further characterizing the income distribution, though this likely reflects in part the non-random reduction in the sample: Gini coefficients are more widely available for developed economies. The volatility of the measured gross emissions effect for small particulates in Table 3 provides little information about its magnitude.

The measured impacts of inequality on gross emissions measured by β_2 appear significant, but the direction of impact appears to depend on the pollutant. The negative elasticity measured for CO_2 is consistent with the motivation that the underlying dirty goods are relatively income-inelastic (also supported by the estimated β_1), but for SO_2 and small particulates inequality appears to increase gross emissions. This suggests that characteristics of the income distribution other than the mean may be important omitted variables in the standard analysis, but the direction of the bias is uncertain.

The income elasticity of demand for abatement is measured by the estimates of β_4.[10] The positive and significant estimates in Table 3 strongly suggest that the specification in (12) is capable of identifying this effect separate from gross emissions. The zero (even negative in one equation) measured effect for CO_2 only reinforces this view since we know that this by-product, now considered the largest component of potentially damaging greenhouse gases, has until recently never been regarded as a pollutant requiring regulation. For the other pollutants, which have been addressed through pollution policy to some degree worldwide, the estimated income elasticities are all greater than one, and are extremely large for SO_2. While β_4 represents a pure willingness-to-pay effect only as a special case, these results provide substantial evidence that environmental protection is a luxury good in the technical sense. Further evidence of this is provided by the positive estimates of β_5. Recall that if willingness-to-pay for abatement increases in household income at an increasing rate ($w'' > 0$), greater inequality would actually increase aggregate willingness-to-pay (see Appendix).

Positive values for both β_1 and β_4 was the starting point for the discussion of "turning points" in the empirical specification section. The data find this with the noted exception of CO_2, for which it was not expected. The combination of these elasticities are reflected in the income elasticity of total pollution: $\varepsilon_{p\mu} = \beta_1 - \gamma\beta_4 a^*$. The estimated turning points implied by the estimated values are reported for each equation at the bottom of Table 3. Consistent with the earlier discussion, these increase as γ decreases and in some cases become infinite (no turning point). Of course no turning point is estimated for CO_2 for any γ, but the most illustrative cases are for particulates, where a turning point is estimated to exist for higher values of γ but not for lower values. The sensitivity of the estimated turning points to inclusion of Gini coefficients in the model is characteristic of this literature, but contain a valuable cautionary message. In questions of how economic growth will affect the environment, the answer may depend on the part of the income distribution in which that growth is concentrated.

The fitted values of the dependent variables are plotted for each pollutant in the Appendix. Only for SO_2 does the estimated relationship immediately appear to fit the “inverted-U” pattern. For particulates the fitted relationship is better described as strictly falling over the range of income values in the data, and for CO_2 nothing appears to correlated with emissions other than per capita GDP. An alternative illustration of these results is presented in Tables 4 and 5. Income and political data are jointly available for 105 countries in 1990. In this sample, per capita income (measured in 1985 US dollars) ranges from 399 in Chad to 18,054 in the United States. When this sample is split into “poor” and “rich” countries at the median (Algeria), the average characteristics of the two groups are those reported in Table 3. In addition to higher income, it is perhaps also no surprise that the rich group is substantially more democratic and more equitable on average. The first column in Table 4 reports the predicted levels of four environmental indicators for a hypothetical country with the all of the characteristics of the poor group. The second column reports the predicted levels for a fictional country with the all of the characteristics of the rich group, and so on. For these predicted values, the other independent variables are set to their means, including the estimated fixed effects.

The fundamental question motivating this literature is what a “poor” country should expect in terms of environmental impact as it looks forward to a level of wealth comparable to the “rich” country. Table 5 demonstrates that the answer will in general depend on whether income inequality and political system evolve to reflect the characteristics of the rich country as well. As we have seen, little in the historical data suggest anything other than income is correlated with CO_2 emissions. However, for the other three pollutants the results illustrate the importance of the political responsiveness. Compare the middle column (“rich” income and inequality characteristics, but “poor” government effectiveness) to the last column (where the political effectiveness of “rich” countries is imposed as well). Predicted SO_2 concentrations fall by 54%, “smoke” by 34%, and heavy particulates by 25%. Similar reductions are associated with political development when the Gini ratio is held constant at .41 (column 2 vs. column 4 in Table 5). The effects of reduced inequality are less obvious. Comparing columns 2 and 3, or columns 4 and 5, isolates the effect of reduced inequality when the other characteristics are held constant. Lower inequality is associated with lower concentrations of SO_2 and smoke, but higher concentrations of heavy particulates. Regardless, these results strongly indicate that increases in per capita income alone without development in these other variables leads to a different path of environmental indicators than political and economic development together.

Conclusion

The environmental Kuznets’ curve literature has been plagued by two closely related problems. First, the complexity of the relationship between income and environmental quality means that no *simple* microeconomic foundations are entirely satisfying. This has lead the vast majority of researchers to approach empirical studies through a reduced form, which leads to the second problem: the estimated income effects are a really a combination of effects (e.g. scale and technique) that cannot easily be separated. This paper has addressed the “microfoundations” problem by abstracting away from international trade, an assumption roughly consistent with the evidence for several prominent air pollutants, thereby allowing pollution to be traced to the ultimate source of household decisions. The political economy component of the resulting semi-structural model then allowed for the decomposition of income effects into parts associated with gross emissions and demand for abatement. The empirical results are consistent with the theory that demand for both “dirty goods” and abatement increase with income but demand for the second, a public good, is reflected to a greater extent in more democratic political systems. As a consequence, economic growth alone (without political development) will not result in improved air quality at higher levels of average income, and weaker political institutions always delay or eliminate the arrival of such improvements.

End notes:

1. That is, GDP $\equiv N\int_0^{\infty} y \cdot f(y;\mu,\sigma)dy$

2. It should include baseline, non-anthropogenic concentration of the pollutant as an intercept, but in the absence of good data this will be dropped in the empirical work in favor of site-level random effects. The true relationship between emissions and concentrations is enormously complex, but linear "transfer coefficients" are believed to be a reasonable physical specification.

3. The restriction is that $\frac{\partial C}{\partial A}$ be homogeneous of degree zero in A and E^0. That is, that increases of gross emissions and abatement of equal proportions don't change *marginal* abatement costs.

4. For normal goods, if $x(0) = 0$ and the income elasticity is a constant, "concave" and "convex" demands are equivalent to income elasticities greater than and less than 1, respectively. By this logic it is demand for luxury goods that are convex in income, though not by the specific definition of "luxury" in consumer theory.

5. See Greene (1999) for the consistency of fixed effects in non-linear models.

6. Algebraically, $\overline{\mu} = \left(\frac{\beta_1}{\gamma\beta_4-\beta_1}\right)^{\frac{1}{\beta_4}} e^{-\frac{\beta_3}{\beta_4}} \sigma^{-\frac{\beta_5}{\beta_4}}$.

7. Technically, identification is feasible in the current specification from the form of a^*.

8. Causation here is an entirely different question: does dramatic inequality provide fertile ground for dicators, or do non-democratic governments tend to serve elites interests at the expense of the poor? Either cause, or others, would lead to omitted variable bias.

9. Reported adjusted $R^2 = 1 - \frac{u'u}{P'P}$, not the within- and between-group R^2 frequently reported for panel data models. The dummy variables implementation of fixed effects for this non-linear model lead to the very high proportion of variation explained by all models. As a reference, the estimation of (12) without fixed effects still results in high R^2s: CO_2: .79, SO_2: .16, small particulates: .47, and large particulates: .68.

10. From (12), β_3 should be regarded as a kind of intercept term in the relationship between optimal abatement and the income distribution. Its interpretation is not central here.

Aggreg.	**Micro.**
$\text{sign}(\varepsilon_{X\mu}) =$	$\text{sign}(\frac{\partial x}{\partial y})$
$\text{sign}(\varepsilon_{X\sigma}) =$	$\text{sign}(\frac{\partial^2 x}{\partial y^2})$
$\text{sign}(\varepsilon_{W\mu}) =$	$\text{sign}(\frac{\partial w}{\partial y})$
$\text{sign}(\varepsilon_{W\sigma}) =$	$\text{sign}(\frac{\partial^2 w}{\partial y^2})$

Table 1

Pollutant	*predicted* $\varepsilon_{E^0,\mu}$	*predicted* $\varepsilon_{E^0,\sigma}$	*predicted* $\varepsilon_{a^*,\mu}$	*predicted* $\varepsilon_{a^*,\sigma}$
SO_2	+	−	+	?
CO_2	+	−	0	0
heavy particulates	+	−	+	?
Smoke	+	−	+	?

Table 2

	SO_2		CO_2		Large particulates		Small particulates	
level:	city		country		city		city	
β_1	.486 (.441)	.601 (.597)	.774 (.011)	.791 (.030)	.462 (.140)	.239 (.246)	.207 (.337)	1.54 (.595)
β_2	———	.057 (.015)	———	–.016 (.002)	———	–.006 (.007)	———	.027 (.014)
β_3	–59.2 (7.29)	–38.5 (7.23)	.574 (1.24)	–1.86 (2.58)	–8.11 (2.76)	–14.6 (7.63)	–17.1 (8.98)	–26.6 (7.36)
β_4	6.68 (.798)	4.24 (.864)	–.317 (.162)	–.370 (.300)	1.04 (.323)	1.51 (.693)	1.88 (1.01)	2.83 (.877)
β_5	———	.052 (.026)	———	–.017 (.026)	———	.023 (.021)	———	.045 (.027)
Population density	–1.79 (1.58)	.–1.63 (1.49)	.000 (.000)	.003 (.001)	2.63 (3.59)	10.0 (7.99)	–3.79 (5.82)	–6.97 (5.36)
Political transition	.064 (.352)	———	–.141 (.035)	–.271 (.064)	–.205 (.091)	–5.61 (4.37)	–.285 (.181)	–1.89 (3.45)
β_0	–.170 (3.07)	–2.01 (4.91)	–4.92 (.083)	–4.24 (.262)	1.66 (.909)	3.02 (1.45)	2.76 (2.97)	–11.9 (4.98)
Adj. R^2	.542	.550	.791	.818	.857	.844	.709	.681
Sample	1472	955	3601	899	1090	719	601	339
Estimated “turning points” ($1985) $\gamma = 1$	4821	5482	∞	∞	2026	4795	2940	12206
$\gamma = .75$	5054	5945	∞	∞	3616	6051	3504	16157
$\gamma = .5$	5414	6734	∞	∞	19199	8692	4563	∞
$\gamma = .25$	6176	8923	∞	∞	∞	20650	7881	∞

Table 3

	poor	*rich*
μ	1265	8562
Gini ratio	.41	.32
γ	.39	.84

Table 4

	μ_{poor} σ_{poor} γ_{poor}	μ_{rich} σ_{poor} γ_{poor}	μ_{rich} σ_{rich} γ_{poor}	μ_{rich} σ_{poor} γ_{rich}	μ_{rich} σ_{rich} γ_{rich}
SO_2	29.22	39.95	28.03	15.22	12.77
CO_2 (emissions)	1.68	8.77	8.77	8.43	8.43
Smoke	3.34	39.71	34.59	23.04	22.62
Heavy Particulates (ppm)	112.4	136.9	150.9	98.9	114.0

Table 5

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Appendix

Proposition $\varepsilon_{E^0\mu} = \varepsilon_{X^0\mu} = \varepsilon_{\overline{x}y}$

Proof From (3) :

(A1) $\overline{x} = \int_0^\infty x(y)f(y;\mu,\sigma)dy$

(A2) $\frac{\partial \overline{x}}{\partial \mu} = \int_0^\infty x(y)\frac{\partial f}{\partial \mu}(y)dy$ (A2)

Integration by parts, assigning $u = x(y)$ and $dv = \frac{\partial f}{\partial \mu}(y)dy,$ yields

(A3) $\frac{\partial \overline{x}}{\partial \mu} = \left\{\left[x(y)\frac{\partial F}{\partial \mu}(y)\right]_0^\infty - \int_0^\infty \frac{\partial F}{\partial \mu}(y)\ x'(y)\ dy\right\}.$

The income CDF $F(y;\mu,\sigma)$ has following characteristics by definition:

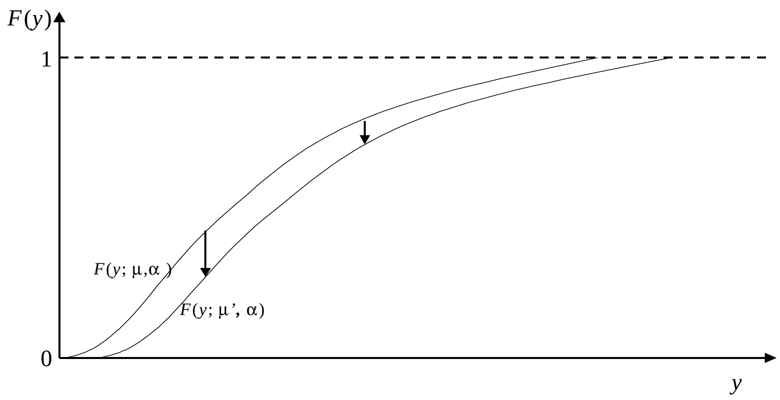
$\forall\ \mu,\sigma\ \ F(0;\mu,\sigma) = 0,\ \frac{\partial F}{\partial \mu}(0) = 0$

$\forall\ \mu,\sigma\ \ F(\infty;\mu,\sigma) = 1,\ \frac{\partial F}{\partial \mu}(\infty) = 0,$

from which it follows that

(A4) $\frac{\partial \overline{x}}{\partial \mu} = \int_0^\infty \left[-\frac{\partial F}{\partial \mu}(y)\right] x'(y)\ dy.$

Since $\frac{\partial F}{\partial \mu}(y)$ holds σ constant, this inequality-neutral income shift can be viewed as an "across the board" increase in income by the same amount, as in the figure, meaning $-\frac{\partial F}{\partial \mu}(y) = f(y) \geq 0.$ The integral then represents the mean change in demand for x in the distribution $\overline{\frac{\partial x}{\partial y}},$ and recognizing $\mu = \overline{y}$ yields $\frac{\partial \overline{x}}{\partial \mu}\frac{\mu}{\overline{x}} = \overline{\frac{\partial x}{\partial y}}\frac{\overline{y}}{\overline{x}}.$ ■



Corollary: $\varepsilon_{W\mu} = \varepsilon_{\overline{w}y}.$ (Proof: From (7), same steps as above.)

Proposition $sign\left(\frac{\partial E_j^0}{\partial\sigma}\right) = sign\left[\frac{\partial^2 x_j(y,\boldsymbol{h})}{\partial y^2}\right]$

Now differentiate $(8a)$ with respect to σ :

$$(A4) \qquad \frac{\partial E^0}{\partial\sigma} = \sigma N \int_0^\infty x(y) \frac{\partial f}{\partial\sigma}(y) dy$$

Integrate by parts to transform $(A4)$ in the same way, again using the characteristics of the CDF to eliminate the first term:

$$(A5) \qquad \frac{\partial E^0}{\partial\sigma} = -\sigma N \int_0^\infty \frac{\partial F}{\partial\sigma}(y)\ x'(y)\ dy$$

Integrate by parts once more assigning $u = x'(y)$ and $dv = \frac{\partial F}{\partial\sigma}(y)dy$.

$$du = x''(y) \qquad \text{and} \qquad v = \int_0^y \frac{\partial F}{\partial\sigma}(y)dy \equiv V(y)$$

$$(A6) \qquad \frac{\partial E^0}{\partial\sigma} = \sigma N \left\{[-V(y)x'(y)]_0^\infty + \int_0^\infty V(y)x''(y)dy\right\}$$

Refer to the figure above for the following observations about $V(y)$:

(i) $\quad V(0) = 0$

(ii) $\quad V(\infty) = 0$

(iii) $\quad V(y) \geq 0\ \forall\ y \in (0,\infty)$

(i) holds from the definition of $V(y)$: $\int_0^0(\cdot) = 0$.

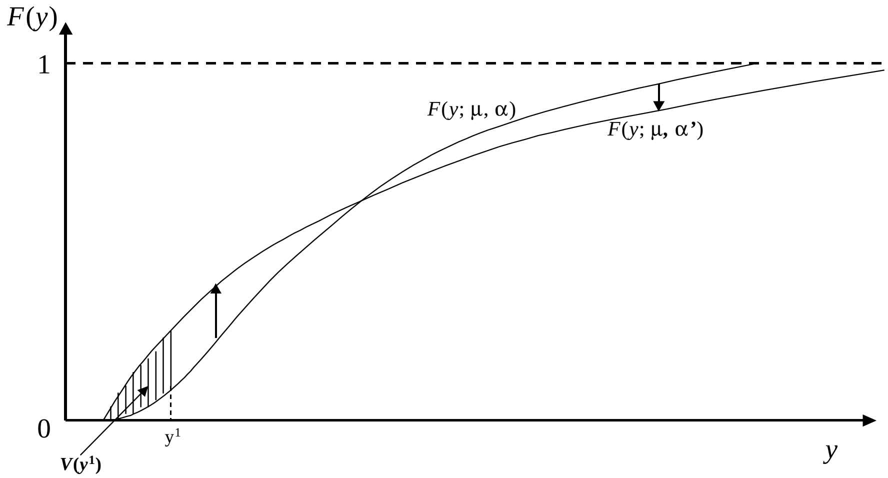
(ii) holds because the mean of the income distribution, μ, is being held constant. In Figure 3, the area above the CDF before and after the change in σ must be equal because this area is μ.

(iii) holds if the change in the income distribution is a "simple mean preserving spread" (Rothschild and Stiglitz, 1971), assuring the "old" and "new" CDFs cross only once. (This is a sufficient condition, not necessary). $V(y)$ is positive as the CDF shifts upward at first, and only returns to zero at the highest level of income in society.

Using (i) and (ii) to simplify $(A6)$ yields:

$$(A7) \qquad \frac{\partial E^0}{\partial\sigma} = \sigma N \int_0^\infty V(y)x''(y)dy$$

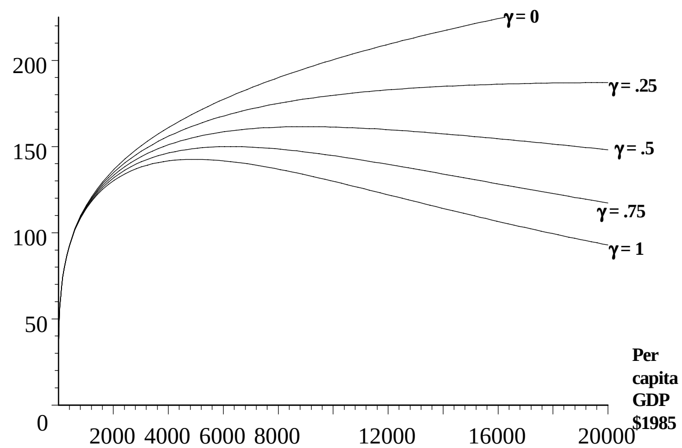
Since (iii) states that $V(y)$ is ≥ 0 over the entire integral, the expression has the same sign as $x''(y)$. ■



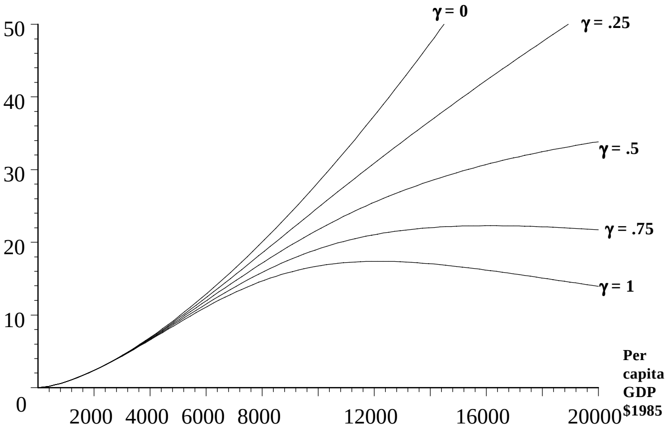
F(y)
1
0
F(y; μ, α)
F(y; μ, α')
y¹
V(y¹)
y

Estimated Income Paths

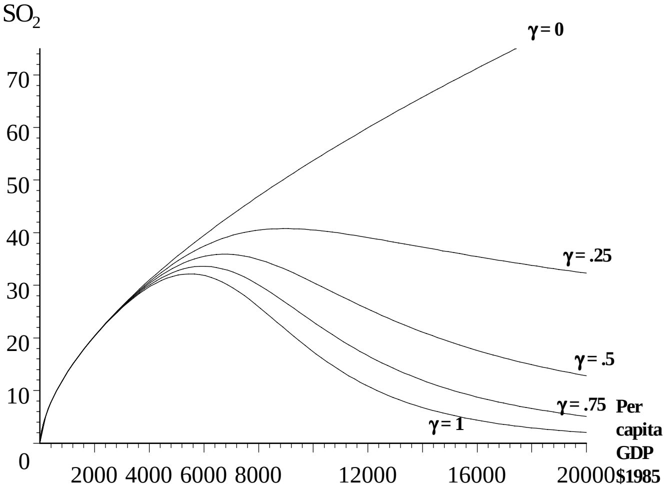
Heavy Particulates



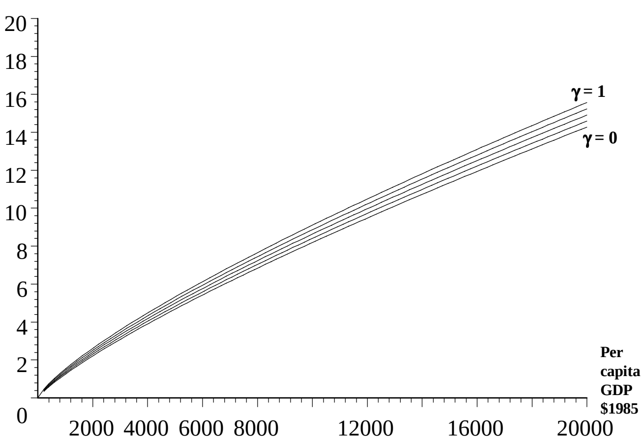
Smoke



SO_2



CO_2



Fitted Values