

ECONOMIC GROWTH AND ENVIRONMENTAL RESOURCE ALLOCATION

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Abstract

This paper examines the relationship between economic growth and environmental quality in a theoretical framework. We find that a U-shaped pattern for environmental quality, a so-called environmental Kuznets curve, can occur either with increasing income per capita or with rising population for wide ranges of parameter values, and that this result holds for standard symmetrical models involving homothetic, constant-returns to scale functions, such as simple CES models. These findings arise in part because environmental resources are “endowments” which tend to be relatively abundant initially, but become relatively scarce as growth proceeds. Similar results are shown to arise in decentralized economies under either homogeneous or heterogeneous income levels.

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I. Introduction

The relationship between economic growth, natural resources, and environmental quality has been the subject of debate for centuries. The contemporary view that, if the economy is growing then so must be environmental degradation, was advanced by Boulding (1966) and formalized in the materials-balance model of Ayres and Kneese (1969). More recently the “neo-Malthusian” view has emphasized the fragility of the environment and the impact of economic and population growth on the natural capital stock. Beginning in the early 1990s, however, empirical evidence began to emerge suggesting a U-shaped relationship between environmental quality and per capita income. This so-called “environmental Kuznets curve” suggested that environmental quality might first decline, and then improve, with rising per capita income (Grossman and Krueger 1993; World Bank 1992),¹ and evidence of a U-shaped pattern for growth in population was observed by Patel, Pinckney and Jaeger (1995).

The idea of an environmental Kuznets curve has elicited conflicting reactions. The strength of the empirical evidence has been disputed by some (see, for example, Harbaugh, Levinson and Wilson 2002), and the generality of the pattern across different types of pollutants has been questioned by others (Bradford, Schlieckert and Shore 2000). See Stern, Common and Barbier (1996) for a survey.

Evidence of these U-shape patterns spawned considerable speculation as to its underlying causes, including the suggestion that it is an artifact of structural changes in an economy as it passes through “stages of development” from agrarian to industrial where there is often a reliance on heavy, highly-polluting industries, and subsequently to high-income service and information economies which are inherently less polluting (e.g., Panayotou (1993)). A second explanation suggests that environmental quality is a “luxury good” emphasizing the role of a

high income elasticity of demand for environmental amenities to lead countries to allow increased pollution as an acceptable side effect of economic growth (e.g., Arrow et al. (1995)). The implication of this second argument cautions against the interpretation that economic growth may be good for the environment, since the empirical evidence may simply reflect an international redistribution of pollution and polluting industries between relatively richer and relatively poorer nations, consistent with the so called 'pollution havens' hypothesis.

Beginning in the mid-1990s a number of explicit theoretical models have illustrated several possible underlying mechanisms that can give rise to a U-shaped pattern for rising per capita income. Each of these models involves some restriction on either preferences or technology in order to generate the desired shape of the income-pollution path (Copeland and Taylor, forthcoming). The mechanisms by which these U-shape paths emerge are classified by Copeland and Taylor as involving either income effects, threshold effects or increasing returns to abatement.²

In the case of income effects, Lopez (1994) has demonstrated that when preferences are non-homothetic, a U-shaped pattern can emerge with rising per capita income provided that the income elasticity of the environmental good is sufficiently large. This provides formal treatment of the idea that when the environment is a luxury good, demand will rise at high income levels. Lopez also demonstrates, however, that when preferences and production are homothetic that monotonically rising pollution can be expected.

The threshold effects class of models involves an initial range of income levels over which no abatement takes place. After some threshold has been breached, abatement begins to be implemented and pollution declines with rising income provided appropriate assumptions about

technology and tastes. The models of John and Mecchino (1994), Seldon and Song (1995), Stokey (1998), and Pfaff Chaudhuri and Nye (forthcoming) fit into this class.

The third class involves increasing returns to abatement. Andreoni and Levinson (2000) develop a simple model in which the abatement technology exhibits increasing returns to scale so that as income rises and the scale of the economy grows, the relative cost of abatement declines relative to the cost of goods production. This attribute of technology produces a reversal from rising pollution toward declining pollution.

For all three classes of models, then, there is a “built-in” asymmetry or curvature in preferences or production which shifts outcomes away from pollution inputs or goods and toward non-polluting inputs or goods as growth proceeds, and this leads to the possibility of a U-shaped trajectory. Generalizations do not come easily, however, from these disparate examples; and they offer little reason to expect generalized U-shaped patterns to emerge, in part due to the lack of a priori justification for the restrictions imposed. In addition, none of these models include rising population as a component of economic growth, so that they offer a limiting characterization of observable contemporary growing economies which tend to exhibit both rising income per capita and rising population. And although several of these papers include explicitly dynamic models where income growth is endogenous, none has incorporated population growth whether deterministic or endogenous.³

The current analysis complements and extends these recent contributions by appealing to a framework in which both preferences and production technologies of arbitrary generality may be considered when examining the effects of economic growth on environmental quality. This approach enables us to establish more general conditions under which economic growth – attributable to changes in any economic parameters including population or per capita income –

may lead to the improvement of environmental quality or, alternatively, its decline. We go on to consider decentralized economies and income inequality. Indeed, this approach can encompass changes in any of the parameters defining the underlying economic system – including the social parameters and institutional mechanisms by which individual agent’s choices may or may not be coordinated.

In contrast to the literature cited above, the analysis presented below finds that a U-shaped pattern is possible for a wide range of parameter values in conventional models, including standard symmetrical models involving homothetic, constant-returns to scale functions, such as simple CES models. These results arise in part because environmental resources are characterized as “endowments” which tend to be relatively abundant initially, but become relatively scarce as growth proceeds, a shift which creates the possibility of a U-shaped path. Moreover, these results indicate not only plausible U-shaped trajectories for rising income when holding population constant, but also for rising population when holding income per capita constant, and for decentralized economies under either homogeneous or heterogeneous income levels.

In the next section we develop our general model and results for growth, addressing increasing income per capita separately from rising population. In section III we consider decentralized economies (that is, ones where government controls, coordination or collective action are assumed to be impossible or prohibitive in cost), as well as for equal and unequal per capita income levels. In the last section the interpretations and implications of our results are discussed.

II. General Methods and Results

We begin by introducing a general framework for analyzing the tradeoffs made between environmental quality and consumption in contexts of evolving social parameters such as per capita income, population levels, and resource endowments. A simple static framework is employed to explore these relationships where environmental damage is assumed to be short-lived and stock effects can be ignored. This simplifying assumption will be a reasonable one for many kinds of air and water pollution which dissipate relatively quickly, but will be less satisfactory for biological resources which regenerate slowly, or for long-lived stock pollutants as in the case of climate change. These results will also be relevant to situations in which government decision makers themselves only have short run objectives. In that case, the behavior of a myopic social planner with regard to long-lived stock pollutants would be similar to that of a farsighted planner with short lived pollutants, assuming the single period structure is indistinguishable.

The absence of environmental stock effects eliminates the need for a social planner to be forward-looking in terms of the environment. And we can abstract from the determinants of economic growth itself by assuming that there is an exogenous path of changes in “basic economic parameters” which in turn have a strictly monotonic impact on income and/or population. We further assume that agents have identical preferences and, as a starting point, equal incomes. With these assumptions, a representative household approach implies that we can ignore intergenerational conflicts as well.

Consider a population of identical consumers whose preferences over environmental quality e and private consumption c may be characterized by a strictly concave utility function;

where e and c are assumed to be univariate for expository clarity. Letting σ represent the profile of social parameters relevant to production possibilities, we define $P(\sigma)$ to be the set of all (e, c) profiles that can feasibly be induced by some public policy, collective action, or other coordinating mechanism.⁴ Note that that a central government is *not* assumed to be an all-powerful social planner. Indeed, the construction of $P(\sigma)$ simply incorporates whatever influence a government or other coordinating institution may be able to exert. The framework can represent a range of situations from coordination within a household to international treaties. As such, $P(\sigma)$ can be thought of as a per capita “production possibilities” set. $P(\sigma)$ is assumed to be convex and exhibit free disposal, the latter implying that if $(c, e) \in P(\sigma)$ and $(c', e') \leq (c, e)$ then $(c', e') \in P(\sigma)$.

It is useful to introduce the concepts of production and consumption elasticities. We define *production elasticity* at any point (c, e) on the production possibilities frontier as the frontier’s slope (in absolute value) divided by the ratio c/e , i.e., the percentage change in c divided by the percentage change in e . Similarly, define we define *consumption elasticity* as the corresponding indifference curve’s slope (in absolute value) divided by c/e . The introduction of these elasticity concepts allows us to articulate an insightful and succinct characterization of the impact arbitrary parametric changes have on environmental quality.

THEOREM 1: A parametric change will increase optimal environmental quality if and only if the change increases production elasticity relative to consumption elasticity at the initially optimal environmental quality level.

Proof: Consider a shift from an initial profile of social parameters σ^0 to a new profile σ^1 . Let (c^0, e^0) denote the optimal outcome in $P(\sigma^0)$, i.e., that which maximizes consumer utility, and let (c^1, e^0) be the point on the frontier of $P(\sigma^1)$ corresponding to the original level of environmental quality e^0 . Convexity of $P(\sigma^1)$ implies that if its frontier is steeper than the consumer's indifference curve at (c^1, e^0) , then the optimal environmental quality given σ^1 must exceed that given σ^0 , as demonstrated in Figure 1. The reverse must be true if the frontier is less steep. Applying the definitions of production and consumption elasticity, it immediately follows that the change from σ^0 to σ^1 will increase optimal environmental quality if and only if it leads to production elasticity that exceeds consumption elasticity at the point (c^1, e^0) . QED

Cobb-Douglas preferences provide a particularly transparent framework for examining “trajectories” of environmental quality as the corresponding consumption elasticities are everywhere constant. A direct implication of Theorem 1 is that parametric changes in such settings induce increased environmental quality if and only if production elasticity is increased, a result we summarize in the corollary below.

COROLLARY 1: If preferences are Cobb-Douglas, then a parametric change will increase optimal environmental quality if and only if production elasticity increases at the initially optimal environmental quality level.

We now turn to a series of general expository examples demonstrating the application of these results. It is interesting to note that in each of these model types, growth in either income per capita or in population, can eventually lead to improved environmental quality.

III. Expository Analysis

III A. Growth in income per capita

In this section we treat per capita income as a parameter of the economic environment. This treatment is equivalent to considering an exogenously given path of changes to “more basic” economic parameters which have a strictly monotonic impact on income. Expository examples follow.

Model 1. We first consider a model in which there are two inputs, the first being more productive but also more harmful to the environment than the second input. Letting x_1 and x_2 represent employment levels of inputs 1 and 2, production technology is characterized by the production function $c=c(x_1,x_2)$ while environmental quality is characterized by $e=E-\delta(nx_1)$, where E represents the initial endowment of environmental quality, n is the population size, and δ represents a differentiable environmental degradation function. As we do throughout this paper, we measure inputs on a scale for which each unit has a price of 1 so that each agent’s budget constraint can be concisely represented by $x_1+x_2=y$; where y is per capita income. Given per capita income y and a point (c,e) on the production possibilities frontier corresponding to positive levels of x_1 and x_2 , and letting c_i represents the partial derivative of c with respect to x_i , production elasticity can be expressed by:

$$\varepsilon = -(de/dc)/(e/c) = [n\delta' / (c_1 - c_2)] / (e/c)$$

For instance, suppose that c is a concave function taking the form $c(x_1, x_2) = c(x_1 + \beta x_2)$ for some $\beta < 1$. It follows $c/(c_1 - c_2) = c/(1 - \beta)c'$. For each given level of e , ε is thus implicitly an increasing function of y whenever the production function c is concave. If one further assumes that preferences are Cobb-Douglas, application of Corollary 1 implies that the income trajectory of environmental quality is increasing in income for all income levels beyond which positive levels of input 2 are utilized.

Model 2. Let us now suppose that output is an increasing function of input 1, i.e., the production function is of the form $c = c(x_1)$. Assume that input 2 is used solely to abate environmental degradation caused by the production process. Once again, inputs will be measured on a scale such that $x_1 + x_2 = y$. Suppose that environmental quality is endowed at an initial level E and degrades increasingly with respect to aggregate consumption, but decreasingly so with respect to the aggregate abatement. To be precise, $e = E - \delta(nc, nx_2)$, where n denotes population size and δ represents a differentiable degradation function as described. Given per capita income y , a point (c, e) on the production possibilities frontier corresponding to positive abatement efforts, and letting δ_1 and δ_2 denote partial derivatives of δ with respect to aggregate consumption and abatement, production elasticity can be expressed by:

$$\varepsilon = -(de/dc)/(e/c) = -[-(n\delta_1 c' - n\delta_2)/c']/(e/c) = n\delta_1 c/e - n\delta_2 c'/e$$

For instance, suppose that $c(x_1) = kx_1^b$ for constants $k, b > 0$. Further assume that whenever aggregate abatement expenditure is at least “one dollar” ($nx_2 \geq 1$) then $\delta(nc, nx_2) = h(nc)^\alpha / (nx_2)^a$ for constants $h, a, \alpha > 0$. For $nx_2 < 1$ let $\delta(nc, nx_2) = h(nc)^\alpha$. The reader may note that

the structural form $\delta(nc, nx_2) = h(nc)^\alpha / (nx_2)^a$ emerges from a Cobb-Douglas “technology” for environmental degradation.⁵ Assuming $nx_2 > 1$, ε reduces to $\varepsilon = (\delta/e)(\alpha + ar/b)$, where $r = \lambda/(1-\lambda)$ and $\lambda = x_1/y$. It follows that ε is increasing in y if and only if λ is increasing in y . Implicit differentiation of this relationship yields $d\lambda/dy = (a-b\alpha)\lambda(1-\lambda)/[b\alpha y(1-\lambda) + a\lambda y]$, thus $d\lambda/dy > 0$ if and only if $a > b\alpha$. If one further assumes that preferences are Cobb-Douglas, application of Corollary 1 implies that if $a/\alpha > b$, the income trajectory of environmental quality will be increasing in income for all income levels beyond which $nx_2 > 1$. In other words, unless abatement is ineffective relative to returns to scale in production of c , the income trajectory of environmental quality must be eventually increasing.

Model 3. In this model we assume that both the production and utility functions are of the constant elasticity of substitution (CES) form. Let $c(x_1, x_2) = (a_1x_1^\alpha + a_2x_2^\alpha)^{1/\alpha}$ and $u(c, e) = (b_1c^\beta + b_2e^\beta)^{1/\beta}$ denote production and utility functions, where $\alpha, \beta \leq 1$, $\alpha, \beta \neq 0$, and $a_1, a_2, b_1, b_2 > 0$. Assume environmental quality is of the form $e = E - \delta(nx_1)$ for some increasing function δ with bounded derivative. Production and consumption elasticities can be written as $\varepsilon = -(de/dc)/(e/c) = [a_1x_1^\alpha + a_2x_2^\alpha]n\delta' / [a_1x_1^{\alpha-1} - a_2x_2^{\alpha-1}]e$ and $\eta = -(de/dc)/(e/c) = (b_1/b_2)(c/e)^\beta$, respectively. Letting $r = x_2/x_1$, the inequality $\varepsilon \geq \eta$ is equivalent to:

$$(b_2/b_1)n\delta'x_1^{1-\beta}e^{\beta-1} \geq (a_1 + a_2r^\alpha)^{(\beta-\alpha)/\alpha}(a_1 - a_2r^{\alpha-1}). \quad (1)$$

Let $e(y)$ denote the income trajectory of environmental quality and let $e^* = \lim_{y \rightarrow \infty} e(y) \geq 0$. Consider any value e' which is on the income trajectory and “close” to e^* . Fix environmental quality at e' , thus fixing the left hand side of inequality (1), and consider increasing y beyond the

point at which $e(y)=e'$. Observe that as y diverges to infinity, so does r . For large r , the right hand side is on the order of $(a_1+a_2r^\alpha)^{(\beta-\alpha)/\alpha}$ which is decreasing in r if $\beta<\alpha$, implying production elasticity is increasing relative to consumption elasticity. By Theorem 1 we may thus conclude the income trajectory of e must be eventually increasing whenever $\beta<\alpha$, or equivalently, whenever the elasticity of substitution in the production function ($=1/1-\alpha$) exceeds the corresponding elasticity of substitution in the utility function ($=1/1-\beta$). To the extent that our “essential,” or most important environmental goods (e.g., breathable air) are characterized by preferences with low elasticities of substitution, then they may also be the most likely to exhibit a U-shaped path. Inessential environmental goods (relatively high β), by contrast, may be less likely to exhibit a U-shaped path.

III B. Growth in population

The relationship between population, environmental resources, and economic growth is arguably the earliest question to be carefully studied in economics, including the dire predictions of Thomas Malthus. Contemporary theoretical and empirical literatures on this topic have sometimes been categorized into pessimists such as the neo-Malthusians, optimists such as Julian Simon (1981), and revisionists who contend that the effect of population on growth and resource use varies with time, place, and circumstance (see Birdsall (1988)). Theoretical models have found that higher population growth will lead to lower environmental quality, including models in which the natural resource has amenity value as well as productive value (see Robinson and Srinivasan 1997). Empirical studies in this area have generally asked whether there is evidence that population growth exacerbates environmental degradation in ways that are separate from the role of per capita income growth, implying that the sign of the effect is expected to be

independent of income. In general, this literature has led to the suggestion that slowing population growth may be a way to halt the rate of environmental degradation (see, for example, Jha et al. 1993). In part due to the emphasis on growth in income per capita in the empirical literature on the environmental Kuznets curve, none of the corresponding theoretical literature has included rising population despite it being a ubiquitous component of contemporary economic growth.

With the present framework, we can readily determine the effects population growth may have on environmental quality; one need only compare the relative impacts on production and consumption elasticity. If production elasticity increases (decreases) relative to consumption elasticity then environmental quality must increase (decrease). Let us again turn to our expository models to provide a specific context for this analysis.

Model 1 (continued). We now consider production elasticity as a function of n rather than y . (For notational convenience we treat n as a continuous variable throughout this analysis.) As demonstrated earlier, $\varepsilon = -(de/dc)/(e/c) = [n\delta'/(c_1-c_2)]/(e/c)$. It follows that ε is increasing in n , holding e fixed, if and only if $nc/(c_1-c_2)$ is increasing in n . For instance, suppose $c = (x_1+\beta x_2)^a$ for some $\beta < 1$ and $a > 0$. It follows that $nc/(c_1-c_2) = n(x_1+\beta x_2)/(1-\beta)a = [(1-\beta)nx_1+n\beta y]/(1-\beta)a$, which is increasing in n (recall nx_1 is fixed when e is fixed). We conclude that if preferences are Cobb-Douglas, population increases will lower the income trajectory of environmental quality at sufficiently low levels of income (where all income is devoted to the most productive input) and increase environmental quality for higher levels of income. The trajectory will bottom out at lower income levels and will rise above the initial trajectory somewhere before the initial trough. The population trajectory of environmental quality (holding per capita income fixed) will itself

be U-shaped as environmental quality will again decrease at low population levels where “environment” is relatively abundant, and then increase once the environmentally friendly input begins to be used.

Model 2 (continued). Recall that production elasticity in this model is increasing in λ , and let us continue the assumption of Cobb-Douglas preferences. Implicitly differentiating the identity $\delta(nc, n(1-\lambda)y) = \text{constant}$ (which must hold if environmental quality is unchanging) yields $d\lambda/dn = (a-\alpha)\lambda/n(b\alpha(1-\lambda)+a\lambda)$, implying λ is eventually increasing in n only if $a > \alpha$. We conclude that when $a < \alpha$, population increases will decrease λ and thus lower the income trajectory at all income levels. If $a > \alpha$ then population increases will lower the income trajectory initially (for those low levels of income at which no abatement investments are made), but, like the previous model, the trajectory will bottom out at lower income levels and will rise above the initial trajectory somewhere before the initial trough. Here again the population trajectory of e with rising population will be U-shaped for constant per capita income levels.

Model 3 (continued). Note that $(b_2/b_1)n^{1-\beta}\delta'x_1^{1-\beta}e^{\beta-1} \geq (a_1+a_2r^\alpha)^{(\beta-\alpha)/\alpha}(a_1-a_2r^{\alpha-1})n^{-\beta}$ follows from reorganizing inequality (1). Holding environmental quality fixed, this implies that aggregate pollution $P=nx_1$ is fixed and the left hand side of this inequality must also be fixed. Given $P=nx_1$ and y fixed, the right hand side of the reorganized inequality can be written entirely as a function of n . Indeed, $r = x_2/x_1 = (y-x_1)/x_1$ and $x_1 = P/n$, implying $r = ny/P - 1$. The precise relationship between population size and optimal environmental quality depends on the parameters a_1, a_2, α, β , as well as per capita income. Even so, the signs α and β can be used to determine the direction of environmental quality for large n . In particular, in every case except

for α and β both being negative, the right hand side of the reorganized inequality necessarily converges to zero, implying that environmental quality must eventually be increasing.

If, on the other hand both functions reflect CES substitution possibilities that are inelastic, (i.e., $\alpha, \beta < 0$), then $(a_1 + a_2 r^\alpha)^{(\beta - \alpha)/\alpha} (a_1 - a_2 r^{\alpha - 1})$ converges to $a_1^{\beta/\alpha}$ and $n^{-\beta}$ diverges to infinity as n increases without bound. As this implies consumption elasticity exceeds production elasticity in the limit, it follows environmental quality must be eventually decreasing.

These results are consistent with some evidence in the empirical literature. For example, Patel, Pinckney and Jaeger (1995) find a U-shaped relationship between forest cover and population density (holding income constant) for rural Kenya. In their study area, rural populations had long ago reduced tree cover densities relative to the initial endowment by clearing land and collecting fuel wood, and recent increases in population density have forced reductions in average farm size. However, these recent changes have been accompanied by increased tree plantings at the farm level, which in turn have resulted in higher numbers of trees per acre, or a U-shaped pattern between environmental quality (tree density) and population. Also, Cropper and Griffiths (1994) find evidence of an environmental Kuznets curve (inverted-U for rising income) for deforestation among non-OECD countries—although most of their observations fall to the left of the peak. Their analysis shows that an increase in rural population density shifts this curve up (greater deforestation) in the case of Africa, and they also find that the turning point occurs at a lower per capita income in Africa than in Latin America. Both of these results are consistent with our expository analysis.

III.C. Discussion

For all three model types exhibiting a U-shaped trajectory for rising income, we also find ranges of parameter values for which rising population will produce a U-shaped pattern. Since contemporary economic growth tends to involve increases in both population and income per capita, these results suggest the possibility of U-shaped trajectories in economies that are compatible with the functions and parameters indicated above. In the case of model 1, all trajectories will show an eventual increase in environmental quality for rising income per capita and population where preferences are Cobb-Douglas. In the case of model 2 and Cobb-Douglas preferences, increasing returns to scale in an absolute sense, and relative to production of c , will eventually result in increasing environmental quality for generalized growth involving rising income per capita and/or population. (Of course, the assumption of Cobb-Douglas preferences simply makes for convenient expository examples and it is not a necessary condition for such results.) And in the case of model 3, environmental quality must eventually increase with rising population and income per capita if substitutions between inputs in the CES production function are elastic (i.e., $(1/1-\alpha) > 1$) in an absolute sense, and also relative to the (CES) substitution elasticity in the utility function (i.e., $(1/1-\alpha) > (1/1-\beta)$) (where here we are referring to the CES definition of elasticity).

The intuition for these results may be seen with reference to figure 2 where production and consumption possibilities for the two goods, c and e , are represented, but where the expansion of production possibilities is anchored to the upper left corner rather than the origin due to the initial endowment of E . Rather than expecting a rise in income or population to produce an expansion path emanating from the origin, in this case the path emanates from the upper left, and we can see the distinct possibility of a decline, followed by a rise, in environmental quality with the expansion of production possibilities. As an economy moves

from a situation where environmental quality is relatively abundant to situations where it becomes relatively scarce, choices are also likely to shift from ones that are relatively “environment-using” to ones that are relatively “environment-conserving.”

These results and intuition differ from the recent literature which suggests that some kind of asymmetry in preferences or technology is necessary to generate a U-shaped path. A key source of these contrasting findings stems from the way in which the environment is modeled in the utility function. In the current analysis, utility is assumed to be increasing in environmental quality; whereas in the recent literature utility has typically been modeled as decreasing in pollution. Assumptions such as homotheticity in the first model carry with them different implications than their symmetric counterpart in the second model.

Figure 3 conveys how, in contrast to figure 2, an expansion of production and utility outcomes for a world where preferences and technology are defined to be homothetic and constant returns-to-scale in terms of goods and “bads” (pollution), the income trajectory can be expected to generate a monotonic path extending out from the origin – with increasing pollution as income rises. Since, from this perspective, growth amounts to an outward expansion from the origin, there is no reason to expect a non-monotonic path.⁶

However, when preferences are defined to be homothetic and constant returns-to-scale in terms of goods and environmental quality (E), and a starting point that is not at the origin but where e is initially abundant relative to c , the intuition for curvature in the environmental path becomes apparent as in figure 2. Thus, a priori restrictions imposing asymmetries in preferences or production are not necessary to produce a U-shaped path. Rather an inherent asymmetry in the initial relative abundance of e versus c , when combined with standard, neutral assumptions about preferences, can generate a U-shaped path with rising income per capita or population.

IV. Decentralized Economies

We now consider the implications of a completely decentralized regime in which consumers need not be homogeneous. To establish a baseline, we consider as our point of departure, decentralization with income distributed uniformly.

IV A. Uniform Income Distribution

In this framework, the production possibilities of a given agent i depend not only on individual income, but also the production decisions of other agents. Letting the profile $\lambda_{-i} = (\lambda_j)_{j \neq i}$ characterize the production strategies employed by each agent $j \neq i$, $P(\lambda_{-i}, \sigma)$ will represent the production possibilities set for a given agent i under decentralization. We shall assume that for each parameter profile σ , there exists a unique symmetric equilibrium for the resulting non-cooperative game in which agent i is free to unilaterally choose its own production strategy λ_i .

Note that the production possibility sets in the centralized and decentralized settings are closely related. Each point (c, e) on the frontier of $P(\sigma)$ corresponds to some “production technology” λ which, if employed by all agents, results in an output of c units and an environmental quality level of e . Thus if λ_{-i} consists of a profile in which $\lambda_j = \lambda$ for each $j \neq i$, then the frontiers of $P(\lambda_{-i}, \sigma)$ and $P(\sigma)$ will intersect at the point (c, e) ; where agent i is also choosing λ . Let us now further assume that for a given per capita income level, environmental degradation can be written as a function of $\sum_j \lambda_j$ and production by agent j is a function of λ_j . (This was the case for each of our previous models as the ‘technology’ choice λ can be represented by $\lambda = x_1/y$.)

It follows that the production elasticity of $P(\lambda_i, y)$ at the frontier point (c, e) is $1/n$ times the production elasticity of $P(y)$ at the same point. A direct implication of this proportionality is that for each of our specific classes of models 1, 2, and 3, the income trajectory of environmental quality shares the same qualitative shape in both centralized and decentralized regimes.

IV B. Income Inequality

We now consider how income inequality may affect these results. The relationship between income inequality and the provision of a public good has been considered in other contexts. Olson (1965) and others have shown that inequality can play a positive role whereby the greater the share of collective benefits for collective action for a single member, the greater the propensity of this ‘large’ member to bear the costs involved. However, when inequality is large, ‘small’ users may be encouraged to free ride on the contribution of the ‘large’ contributor in such a way as to produce an offsetting effect. More generally, in situations where the set of contributors to the public good may change, income inequality has an ambiguous effect on the provision of a public good (Baland and Platteau 1997).

In the context of the current model, the results above can be readily applied to income inequality and its implications for environmental stewardship. Consider an example of *Model 1* for which $c=(x_1+\beta x_2)^a$ and $\delta(nx_1)=bnx_1$ for some $a, b > 0$ and where all agents share identical Cobb-Douglas preferences. Let y continue to denote average per capita income, but now some agents will receive less and some more than this average. Formally, the total population N (size n) is partitioned into the set of poor agents, N_p (size n_p), and the set of rich agents, N_r (size n_r). Incomes of poor and rich are respectively represented by $y(1-\theta_p)$ and $y(1+\theta_r)$, where $\theta_r, \theta_p \in (0, 1)$ and $n_p\theta_p = n_r\theta_r$, thus average income equals y as claimed.

The equilibrium income trajectory for decentralized choice in this setting is calculated in much the same way as previous models. When incomes are low, all agents exhaust all of their income on the most productive and most polluting input. As average income rises, the rich are first to reach a threshold at which they begin using the less productive but less polluting input. In this setting, income inequality will thus initially have a positive effect on environmental quality. Suppose that for a given average income and income differential parameters θ_r and θ_p , the rich are just barely willing to begin investing in the less polluting input. Then an increase in the income differential, but keeping average income unchanged (increase in θ_r and corresponding decrease in θ_p) will make the rich inclined to allocate more income in the less polluting input so that environmental quality must increase.

As average income increases, the rich continue to shift resources toward the environmentally benign input while the poor continue to exclusively utilize the most productive input until they reach a threshold where they too wish to begin directing resources elsewhere. Eventually an income level is reached where the rich will devote all of their income solely to the ‘clean’ input, and where this would also be the case if they were at the average income level. At this point the poor devote relatively more of their income to the polluting input compared to what would be the case at the average income level. Consequently, there necessarily comes a point where the income trajectory for equal incomes and that for unequal incomes will cross, after which the unequal income trajectory drops below that of equal income.

As an overall summary of this model, income inequality is initially beneficial to environmental quality, but at ‘high’ average income levels it eventually becomes detrimental. This result is germane to discussions of social policy. For example, the suggestion has sometimes been made that environmental and equity goals may reinforce one another. Our findings suggest

that this may only be true at high income levels, in which case economic growth may represent a means to strengthening the desirable complementarity between these two social goals.

V. Concluding comments

Economic growth that is characterized by increases in population and/or income per capita has a strong possibility of producing a U-shaped pattern for environmental quality. This result is due in part to the fact that an initial endowment of environmental resources will tend to be abundant relative to consumer goods during an early stage of growth, but becoming scarce relative to consumer goods as growth proceeds. Thus, our analysis finds that for broad classes of theoretical models, and in Pareto efficient as well as unregulated economies, environmental quality will follow a U-shaped trajectory. The likelihood of a U-shaped pattern with growth does not require any particular predisposing assumption such as increasing returns, non-homothetic preferences, or income elastic consumption.

To the extent that environmental doomsayers have based their pessimistic forecasts on a linear extrapolation of past trends, the analyses here offer a more hopeful rendering. In a fashion similar to life-cycle working hours where rising labor supply during the early decades of life do not imply unending hours of labor late in life, increased environmental degradation during early- or middle-stages of growth may only represent the initial downward slope of a U-shaped trajectory, rather than a secular trend. These results do not, of course, suggest that economic growth necessarily contains any automatic, self-correcting mechanism for eliminating inefficient levels of environmental damage. Optimal environmental allocations can only be expected to

occur in the presence of effective social, economic, and political institutions which correct for property rights failures and complex coordination problems. In decentralized economies the extent of free riding may make the path's nadir socially unacceptable or even lethal.

Although our static model does not permit explicit evaluation of dynamic questions, it is straightforward to consider, at least at a general level, how the presence of long-lived stock effects or, in the extreme, irreversible environmental damages represents a situation where failure to recognize the U-shaped-ness in the trajectory (i.e., the trajectory that would be possible in the absence of stock-effects or irreversibility) would lead to sub-optimal allocations. Similar to the failure to recognize the foreseeable rise in the "relative price" of environmental quality as incomes rise, a myopic policymaker who overlooks the inherent U-shaped-ness of an environmental trajectory will unwittingly exceed the optimal level of degradation by not recognizing the future rise in the desired level of environmental quality. In the case of irreversible damage, this will constitute a permanent social loss. While there is little evidence that policies are generally made in anticipation of U-shaped trajectories or rising environmental values, counterexamples such as the early establishment of national and urban parks and wildernesses areas are often described as visionary. Such foresightedness, however, has not been part of economists' standard methodologies where current values have generally been assumed to be the best proxy for future values, and where U-shaped trajectories for rising incomes and population have not been taken into account. These concerns may be especially relevant in cases such as species extinction, ozone depletion, and climate change.

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Figure 1. Indifference curve I_2 is less steep than $P(y^1)$ at the level of environmental quality e^0 .

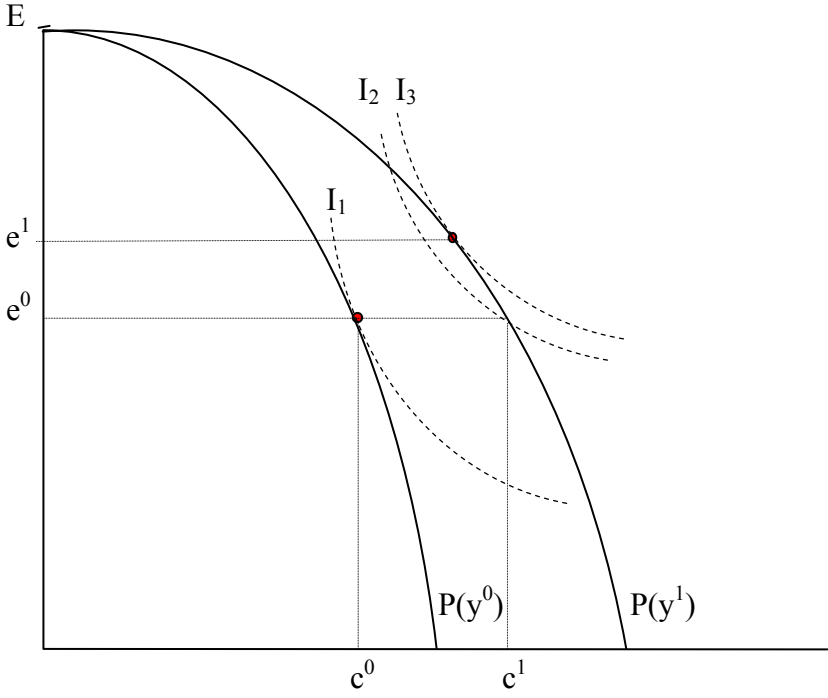


Figure 2. Efficient allocation of an environmental endowment at various income levels

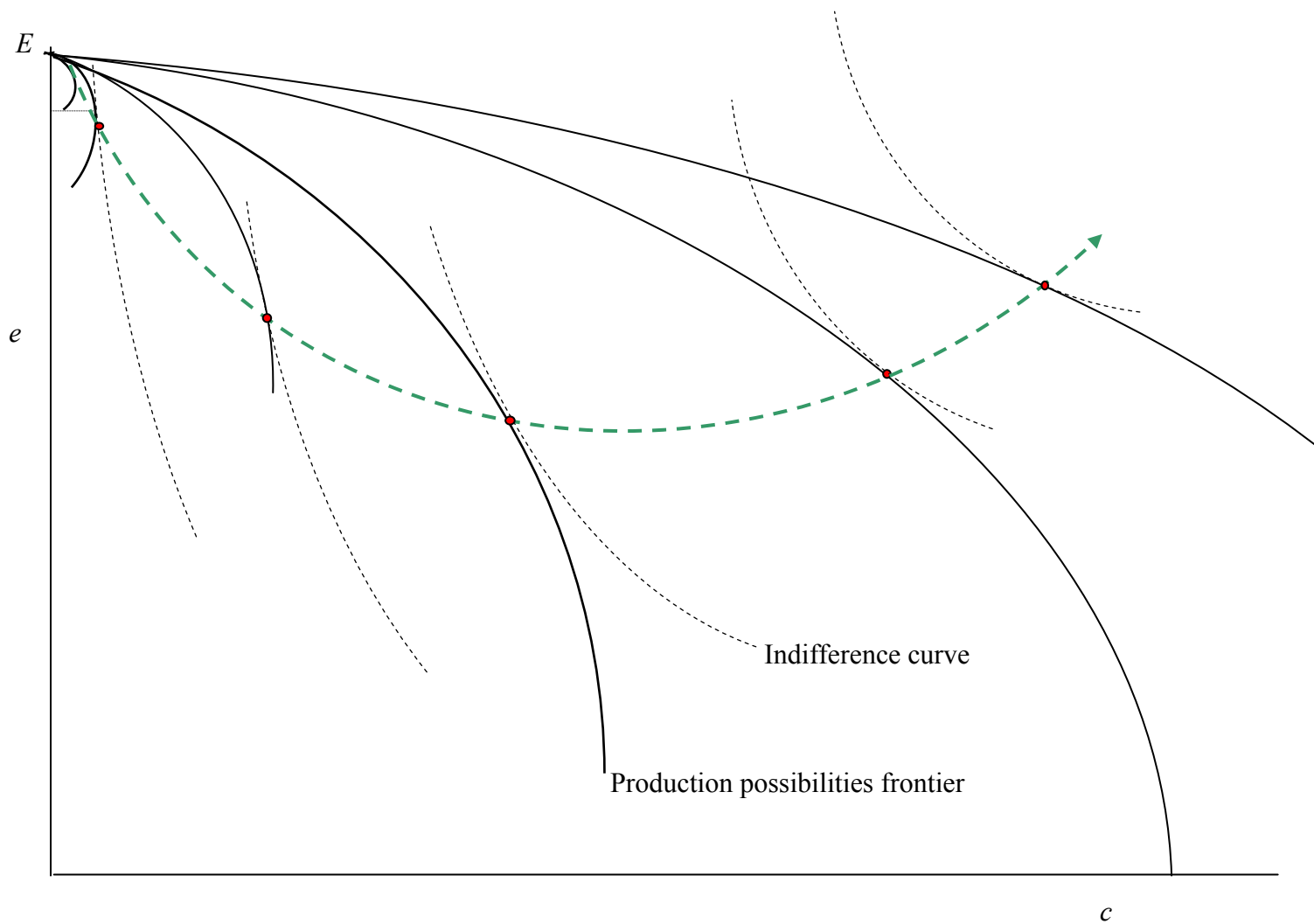
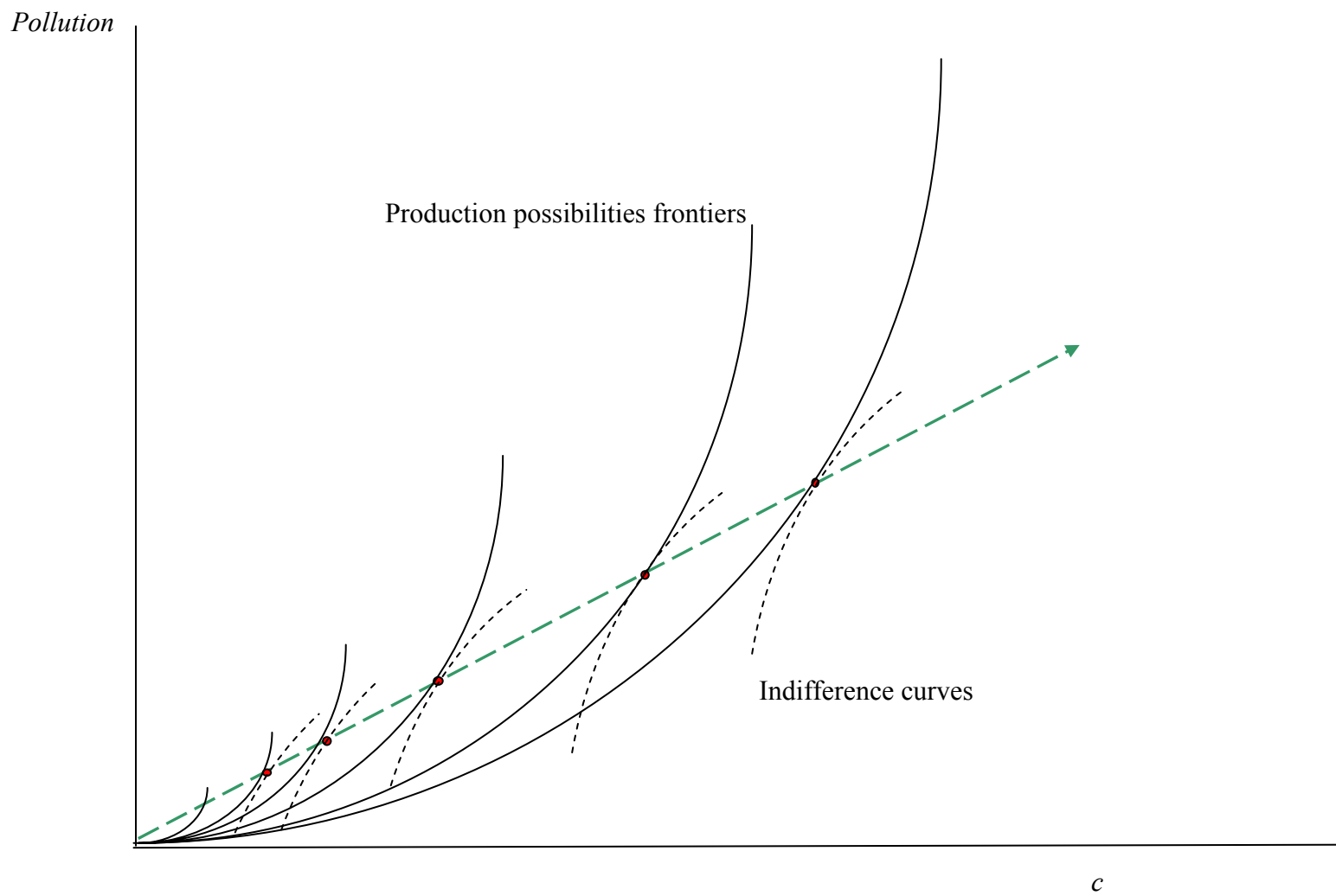


Figure 3. Efficient allocation of pollution and consumption at various income levels



¹ See also Seldon and Song 1994, Shafik 1994, Holtz-Eakin and Selden 1995, Grossman 1995, and Cropper and Griffiths 1994.

² In addition, Copeland and Taylor (forthcoming) consider a fourth “sources of growth” explanation involving a shift from polluting to non-polluting industries.

³ Moreover, identifying the impacts of poverty on population growth and the environment has been a complex and contentious task given their joint endogeneity and inconclusive empirical basis (see Robinson and Srinivasan 1997, Dasgupta 1993, and Birdsall 1988).

⁴ We assume that public policy will induce identical consumers to behave identically. Later in this paper we consider economies with nonhomogeneous consumers.

⁵ To see this, take nc to represent “potential pollution” which must be accounted for either through abatement efforts or actual pollution. The substitution possibilities between abatement and environmental waste disposal can be constructed in Cobb-Douglas form so that this relationship is expressed as $nc = h'(nx_2)^{\alpha'} \delta^{\alpha'}$ for positive constants h' , α' , and a' . Letting $a = a'/\alpha'$, $\alpha = 1/\alpha'$, and $h = (1/h')^{\alpha}$, then solving for δ yields $\delta = h(nc)^{\alpha}/(nx_2)^{\alpha}$ as claimed.

⁶ Like most prior studies, Lopez defines utility as decreasing in pollution rather than increasing in environmental quality. Assuming preferences are homothetic under this configuration, he finds that growth will necessarily lead to more pollution. However, the assumption of homotheticity in terms of pollution is implicitly contradicted by Lopez’s own claims that pollution has “maximum tolerable limits.” Indeed, no such limits can exist if doubling output and pollution will always increase welfare, as would be the case if homotheticity prevails. The present analysis avoids such inherent inconsistencies and in addition finds that a U-shaped path is quite possible in models

with homothetic preferences, but where preferences and homotheticity have been defined in terms of goods (environmental quality) rather than bads (pollution).