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Household Production and Environmental Kuznets Curves

Examining the desirability and feasibility of substitution

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Abstract. This paper provides a theoretical explanation for the widely debated empirical finding of "Environmental Kuznets Curves", i.e., U-shaped relationships between per-capita income and indicators of environmental quality. We present a household-production model in which the degradation of environmental quality is a by-product of household activities. Households can not directly purchase environmental quality, but can reduce degradation by substituting more expensive cleaner inputs to production for less costly dirty inputs. If environmental quality is a normal good, one expects substitution towards the less polluting inputs, so that increases in income will increase the quality of the environment. It is shown that this only holds for middle income households. Poorer households spend all income on dirty inputs. When they buy more, as income rises, the pollution also rises. they do not want to substitute, as this would reduce consumption of non-environmental services for environmental amenities that are already abundant. Thus, as income rises from low to middle levels, a U shape can result. Yet an N shape might eventually result, as richer households spend all income on clean inputs. Further substitution possibilities are exhausted. Thus as income rises again pollution rises and environmental quality falls.

Key words: development, environment, growth, substitution

JEL classification: D11, D13, O12, Q25, Q42

1. Introduction

A number of empirical papers have suggested the existence of U-shaped relationships between per-capita income and various indicators of environmental quality (e.g., air or water quality) at the aggregate level.[1] Such "Environmental Kuznets Curves" suggest that while economic growth may initially be associated with degradation of the environment, continued growth may reverse initial adverse effects. Theoretically, an existing literature makes use of a representative agent framework to explore optimal intertemporal tradeoffs between current consumption, investment in capital, and pollution control.[2] Gruver (1976), for example, extends the standard neoclassical growth model by incorporating the portfolio choice between investments in productive capital and pollution-control capital. Under certain parameter configurations, in the initial stages of growth the accumulation of productive capital increases output and pollution but, once a target stock of productive capital is reached, savings are shifted towards pollution-control capital, leading to reductions in pollution.

The representative agent framework used for such analysis, however, lacks a political economic or other explicit mechanism through which the initial environmental effects of economic growth might in reality be reversed. Further, *aggregate* non-monotonic relationships may be relatively complex. They could also result from differential growth rates among economic sectors during development, or from trade. As a country grows richer, it might cease to produce goods featuring "dirty" production processes, and instead simply import the finished goods.[3]

We step back from these aggregate complications to explicitly consider the way that households respond to income when they have a high degree of control over environmental quality, assuming only that environment is a normally valued good.[4] Results for households will be intrinsic to any economy, and once we have better understood the household we can explicitly add complications such as voting.

Our household production model emphasizes two features.[5] First, degradation of the environmental endowment is a by-product of household activities. Household production uses marketed inputs to generate a "good", desired non-environmental services, and a "bad", degradation of the environment. Second, while households can not directly purchase environmental quality, they can reduce degradation by substituting more expensive cleaner inputs to production for less costly dirty inputs.

However, if environmental quality is a normal good, the Engel curves for environment ought to be positively sloped at all incomes. That is, one expects household substitution towards more expensive but less environmentally degrading marketed commodities, so that rising income increases environmental quality monotonically.[6] We show that the possibility of a non-monotonic relationship between household income and environmental quality can still arise quite naturally.[7]

Specifically, such substitution occurs for middle incomes only, while natural constraints on its desirability and feasibility generate ranges of income in which substitution does not occur. Poorer households spend all income on dirty inputs. As income rises and they spend more, pollution rises and environmental quality falls. They do not want to substitute. This would reduce consumption of non-environmental services for environmental amentities that are already abundant. Thus, as income rises from low to middle levels, a U shape for environmental quality can result. Yet an N shape might eventually result, as richer households spend all income on clean inputs. Substitution possibilities towards cleaner inputs are exhausted. Thus, as income rises further, again pollution rises and environmental quality falls.

Below, Section 2 outlines our household-production framework and illustrates how demands for non-environmental services and substitution that increases environmental quality can yield a non-monotonic environmental Engel curve. Section 3 provides analytical results. In a two-good case, the choice of "how much" versus "how clean" illustrates the reasons given above for why substitution does not occur. Then a three-good case illustrates a third reason for an absence of substitution. Section 4 concludes with a brief discussion and implications for further research.

2. Household Production Model

We begin with the observation that many environmental services cannot be directly purchased. Rather, households start with endowments of environmental amenities, which are degraded through the consumption of marketed commodities. For instance, in many poor, developing economies, the consumption of marketed fuels such as firewood or kerosene results in the joint production of services that households value (e.g., heat) and reductions in existing indoor air quality. We formalize this observation within a household-production/characteristics framework. We use the simplest possible model to demonstrate that non-monotonic environmental Engel curves, such as household-level environmental Kuznets curves, may arise.

Let s denote a household's consumption of a generic non-environmental service, and let a denote the level of the environmental amenity enjoyed by the household. Neither s nor a can be directly purchased. Instead, they are jointly produced (in the case of a, degraded from the endowed level) through the consumption of marketed commodities. Consider a situation in which households have a choice between two marketed goods, a "dirty" (more environmentally destructive) good d and a "clean" good c. Assuming that s is generated linearly from the use of these goods, we can, without further loss of generality, redefine the units in which the two goods are measured so that the total volume of valued services s is given by:

$$s(\vec{q}) = q_d + q_c \tag{2.1}$$

where $\vec{q} = (q_d, q_c)$ are quantities of the dirty and clean goods respectively. Without losing any of the basic intuitions, we can also assume that the degradation of the environmental amenity a is fully linear in the marketed commodities. We assume both that the total emissions level e is linear in the purchased goods:

$$e(\vec{q}) = \alpha q_d + \beta q_c \tag{2.2}$$

where $\alpha > \beta > 0$, and that the environmental amenity is linear in total emissions, where A is the initial environmental endowment and $A > 0$:

$$a(e) = A - e \tag{2.3}$$

The household chooses the marketed $\vec{q}$ to maximize (2.4) subject to (2.5):

$$U(s, a) \tag{2.4}$$

$$p_d q_d + p_c q_c = y \tag{2.5}$$

where y is household income and p_d and p_c are, respectively, the per-unit (of services) prices of the dirty and clean goods. We also assume that $p_d < p_c$.

In this two-good case, it is instructive to recast the problem as a household choice of: (i) the level of services s; and (ii) how those services are produced. Let:

$$\pi \equiv \frac{q_c}{q_d + q_c} \tag{2.6}$$

be the share of the clean good in the overall service consumption of the household. The $s(\vec{q})$, $a(\vec{q})$ technologies then imply a function $a(s, \pi)$ such that:

$$a_s \equiv \frac{\partial a}{\partial s} < 0 \quad \text{and} \quad a_\pi \equiv \frac{\partial a}{\partial \pi} > 0 \tag{2.7}$$

In other words, holding constant the share of clean goods, increased service consumption leads to a deterioration in environmental quality (this is often called the "scale effect"), and holding constant overall services, substitution to the clean good improves environmental quality (this is often called the "technique effect"[8]).

Households then choose s and π to maximize (2.8) subject to (2.9):

$$U(s, a(s, \pi)) \tag{2.8}$$

$$\begin{aligned} p_d(1-\pi)s + p_c \pi s &= y \\ 0 \leq \pi &\leq 1 \end{aligned} \tag{2.9}$$

We assume that $U(.)$ is increasing and concave in both arguments, and that preferences are such that the demands for s and a would be normal were households able to directly purchase them. With these assumptions, it is straightforward to show that the household's optimal choices of both s and π will be weakly increasing in y, household income. That immediately raises the possibility that the relationship between household income and environmental quality may be non-monotonic, since:

$$\frac{da(s(y), \pi(y))}{dy} = \frac{\partial a}{\partial s}(.)\frac{ds}{dy}(y) + \frac{\partial a}{\partial \pi}(.)\frac{d\pi}{dy}(y) \tag{2.10}$$

For example, it could be that the demand for services s would rise rapidly from lower to middle incomes and then flatten, while that for "being cleaner", i.e., for π, would rise only at higher levels of household income. This could produce a U-shaped Engel curve.[9] The intuition here is that the ability to substitute between marketed goods allows a separation of two decisions: how much service to consume, and how to produce that service. The fact that these two decisions may move independently with respect to income allows for their combined effect to be non-monotonic.

3. Analysis

3.1. TWO GOODS – "HOW MUCH" VERSUS "HOW CLEAN"

To derive analytical results, we now specify (2.4) further, in order to use the example of homothetic, Cobb-Douglas preferences for non-environmental services and environmental quality (the latter is simply normally valued, not a luxury good)

$$U(s, a) = s^m a^n, m + n = 1 \tag{3.1}$$

and maximize (3.1) subject to (2.9) through the choice of s and π. This gives rise to a non-linear programming problem, the first-order Kuhn-Tucker conditions of which lead one to consider the following three cases: $\pi^* = 0$; $0 < \pi^* < 1$; and $\pi^* = 1$. These correspond to using only the dirty good, using a mix of marketed goods, and using only the clean good. As developed further below, it is clear that when the first or third cases are optimal, rising income will cause environmental quality to fall. This is because the share of the clean good is fixed (at zero or one), i.e., no substitution is occurring as income rises, such that the last term in (2.10) is zero. In the second case, substitution occurs and environmental quality rises with income.

3.1.1. *Not Clean & Environment Degraded*

In this model, $\pi^* = 0$ ("not clean") is optimal for poorer households, i.e.:

$$y \leq \frac{Amp_d(p_c - p_d)}{p_d(1 - m)(\alpha - \beta) + \alpha(p_c - p_d)} \tag{3.2}$$

For these households, service demanded (or "how much") will rise with income, while environmental quality must fall, as seen in the following:

$$s^* = \frac{y}{p_d};\ a^* = A - \frac{\alpha y}{p_d};\ \frac{da^*}{dy} = -\frac{\alpha}{p_d} \tag{3.3}$$

Recall, at zero income the household receives zero services but a positive endowment of environmental quality. This asymmetry makes it likely that the marginal utility of services is higher than that of environment. A poor household could use the cleaner good, but desires not to, preferring to obtain services as rapidly as possible. For larger m and A, even higher income households use only

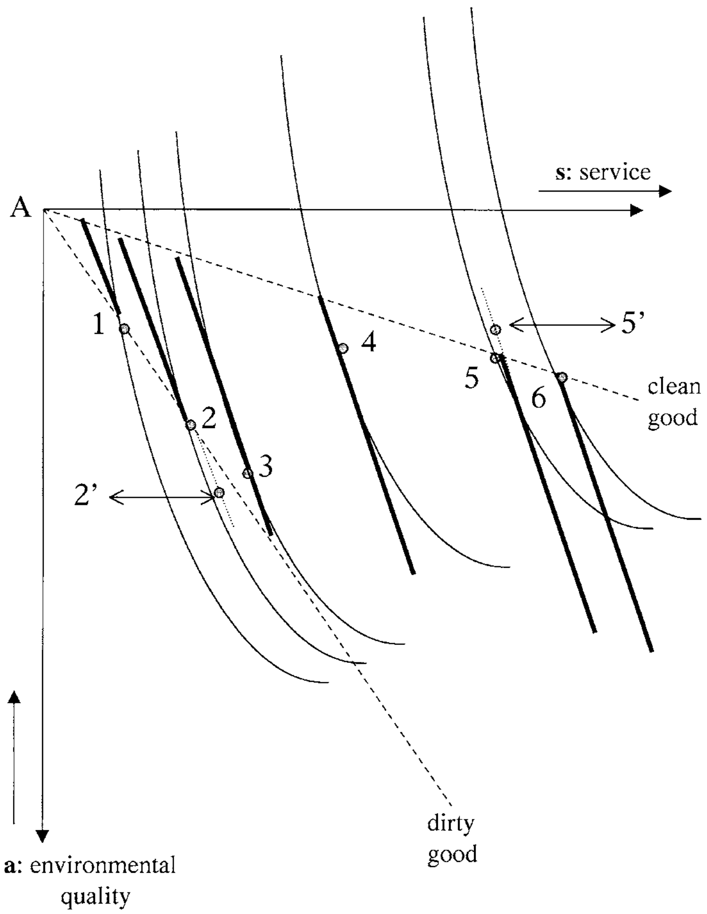

Figure 1. Two goods.

the dirty good. The greater the weight on services and the greater the endowment, the more the household will consume the dirty good for services while degrading the endowment before substituting to more expensive but less degrading goods.

Figure 1 helps to develop this intuition. The endowment A is at the upper left ($s = 0$, $a > 0$). The dashed rays are the combinations of a and s attainable through exclusive use of one good. The solid lines connecting the rays are budget constraints for different levels of income; larger budgets are further from the endowment. The budget slopes indicate the relative shadow price of environment and services – i.e., the rate at which households can trade off environment and services given the underlying technologies and the prices of the marketed goods being consumed. The negative slope reflects our assumption that dirtier goods are cheaper than cleaner goods per unit of service produced. The shape of the indifference curves comes from the concavity of the utility function, into which both a and s enter positively.

This figure shows the optimal consumption points of the household at six different levels of income. The two income transitions from point 1 to point 3 involve degradation of environmental quality. Juxtaposing the indifference curves with the budget sets shows that in the lowest income transition, from 1 to 2, while the household could substitute it does not. Because of the endowment, moving as rapidly as possible to greater balance of s and a is preferable. This dictates using only the dirty good and thus no substitution to less degrading commodities occurs.

In the transition from 2 to 3, i.e., as the household starts to substitute (when tangency starts to occur within the feasible cone, e.g., at 3), rising income can lower environmental quality since over much of this income range no substitution is preferred. Figure 1 highlights that the household would at first (when tangency to the budget occurs outside the cone, e.g., at 2') like to substitute the other way, to a cheaper and dirtier good.[10] In sum, at low incomes the asymmetric endowment discourages substitution to cleaner goods, and rising income degrades the environment.

3.1.2. *Partially Clean & Environment Improved*

The $0 < \pi^* < 1$ ("partially clean") case is optimal for middle incomes:

$$\frac{Amp_d(p_c - p_d)}{p_d(1-m)(\alpha-\beta) + \alpha(p_c - p_d)} < y < \frac{Amp_c(p_c - p_d)}{p_c(1-m)(\alpha-\beta) + \beta(p_c - p_d)} \tag{3.4}$$

For these households, as suggested above, since environmental quality is a normally valued good π^* (or "how clean") will rise enough with income to offset the fact that "how much" service is demanded (or s^*) will also rise with income. The end result is that environmental quality increases with income:

$$s^* = \frac{m[A(p_c - p_d) + y(\alpha - \beta)]}{(\alpha p_c - \beta p_d)} \tag{3.5}$$

$$\frac{da^*}{dy} = \frac{(\alpha-\beta)^2 p_d(1-m) + (\alpha-\beta)\alpha(pc - pd)(1-m)}{(\alpha p_c - \beta p_d)(p_c - p_d)} > 0 \tag{3.6}$$

In Figure 1, in the transition from 3 to 4 environmental quality improves. Substitution is both desirable and feasible, so household choice can raise both s and a. Thus, the transitions from 1 to 4 trace out a U-shaped relationship between y and a, i.e., a household-level environmental Kuznets curve over this range of incomes.

3.1.3. *Completely Clean & Environment Degraded*

The $\pi^* = 1$ ("completely clean") corner solution is optimal for richer households:

$$y \geq \frac{Amp_c(p_c - p_d)}{p_c(1-m)(\alpha-\beta) + \beta(p_c - p_d)} \tag{3.7}$$

For these households, "how much" service is demanded still rises with income, and again environmental quality must fall, as seen in the following:

$$s^* = \frac{y}{p_c};\ a^* = A - \frac{\beta y}{p_c};\ \frac{da^*}{dy} = -\frac{\beta}{p_c} \tag{3.8}$$

The intuition here is that the household can no longer substitute. While substitution remains desirable, it is no longer feasible since the household is using only the cleanest good.[11] Again, the values of m and A affect the income range.[12] Figure 1 shows that environmental improvement is infeasible once the household is at point 5, using only the clean good. Thus, the full set of transitions traces out an "inverted N" relationship of air quality to income, as in the top half of Figure 3.[13]

3.2. THREE GOODS – QUANTITY CHOICE

We introduce a third marketed commodity, a "transitional" good (denoted q_t) cleaner than the dirty good but dirtier than the clean good. Now the household's problem is to choose $\vec{q}$ to maximize (3.1) subject to non-negativity constraints on $\vec{q}$ and to (3.9) and (3.10) below (in which $\alpha > \gamma > \beta > 0$ and $p_d < p_t < p_c$):

$$s(\vec{q}) = q_d + q_t + q_c;\ a(\vec{q}) = A - (\alpha q_d + \gamma q_t + \beta q_c) \tag{3.9}$$

$$p_d q_d + p_t q_t + p_c q_c = y \tag{3.10}$$

We must consider five cases: (1) $q_d > 0, q_t = 0, q_c = 0$; (2) $q_d > 0, q_t > 0, q_c = 0$; (3) $q_d = 0, q_t > 0, q_c = 0$; (4) $q_d = 0, q_t > 0, q_c > 0$; and (5) $q_d = 0, q_t = 0, q_c > 0$. The first and fifth cases are analogous to the low and high income cases for π above, in which environmental quality must fall with income. The second and fourth are analogous to the middle income case for π, where substitution is desirable and feasible.

The case that introduces a new feature is the third one, in which only the transitional good is consumed and thus environmental quality must fall as s^* rises. This case is optimal for the following income range:

$$\frac{Amp_t(p_t - p_d)}{(1-m)(\alpha p_t - \gamma p_d) + m\gamma(p_t - p_d)} \leq y \leq \frac{Amp_t(p_c - p_t)}{(1-m)(\gamma p_c - \beta p_t) + m\gamma(p_c - p_t)} \tag{3.11}$$

$$a^* = A - \frac{\gamma y}{p_t};\ \frac{da^*}{dy} = -\frac{\gamma}{p_t} \tag{3.12}$$

As in the first case, substitution is feasible but not desirable, but the reasoning has changed. Substitution is not desirable because the household faces a discrete shift in the price for further substitution when it would involve replacing the dirty

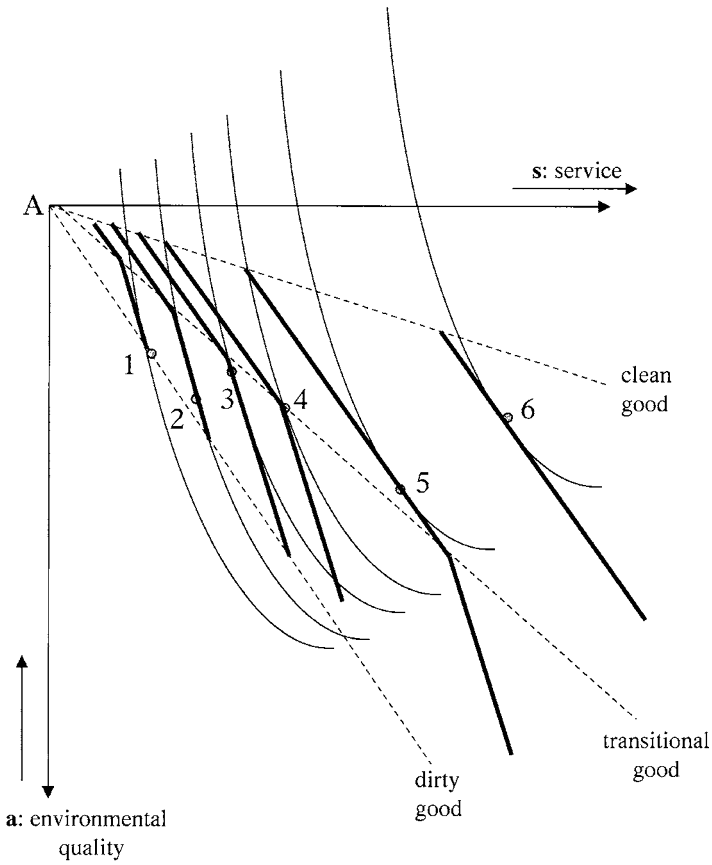

Figure 2. Three goods.

good with the clean good in the mix with the transitional good. For a range of incomes, this jump in the "cost of clean" discourages further substitution. Thus, only the transitional fuel is used, and environmental quality must fall with income.

Figure 2 helps to develop this intuition. Lower income transitions (1 to 3) trace out a U-shaped income-environment relationship. Lower and middle incomes (1 to 4 or 5) trace out a inverted–N-shaped relationship even before the clean good is used. When an increase in income leads to a shift in the goods mix, as in the shift from 3 to 5, the relative price of environmental quality clearly rises. This results in a fall in environmental quality as income rises past the transition point.[14]

Finally, rising income given this new mix of goods again permits substitution and increasing environmental quality (from 5 to 6), as in this linear characteristics case the relative price of s and a is constant while the household consumes the same mix of goods. Then as in Figure 1, environmental quality will of course fall when only the clean good is used. Thus, the existence of the transitional good permits multiple income ranges in which environmental quality decreases, increases, and

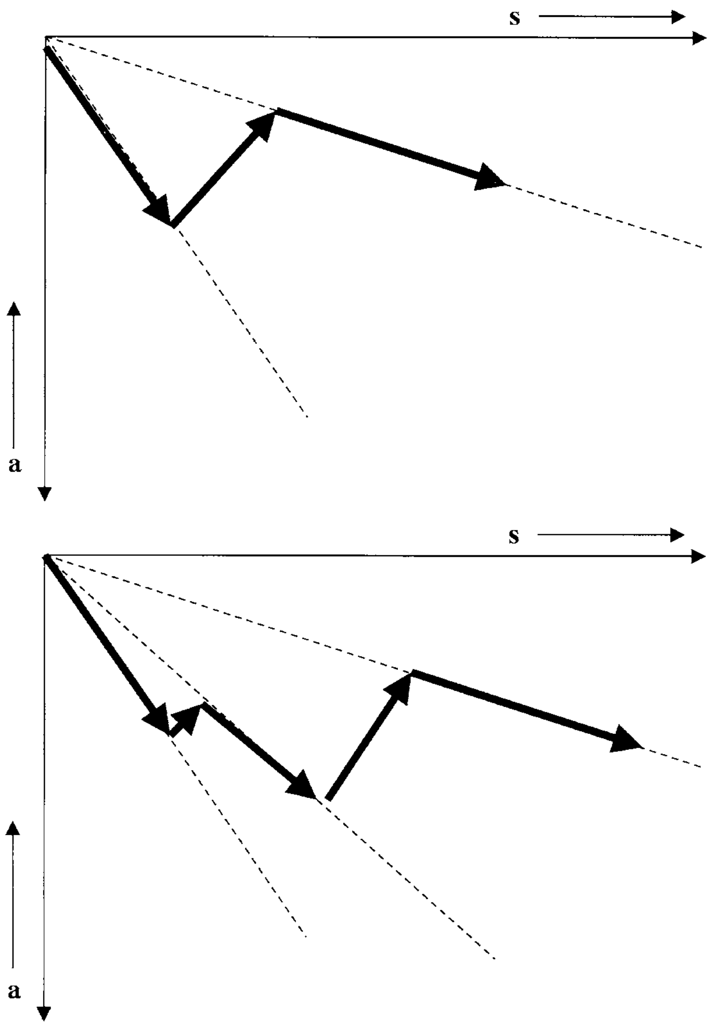

Figure 3. Paths as income rises.

then decreases again as income rises (see the bottom half of Figure 3). This would continue if additional transitional goods existed, or if cleaner ones were invented.

4. Conclusion

This paper has provided one clear perspective on whether "Environmental Kuznets Curves" should be expected based on households' choices. Our household-production model emphasized that: (1) degradation of the environmental endowment is a by-product of household activities; and (2) a household can shift to cleaner inputs to production to lessen degradation. If environmental quality is a normal good, then household substitution towards less polluting inputs should occur, such that rising household income would always result in an increase in environmental quality.

However, we show that this result holds only for middle income households. Poorer households spend all income on dirty inputs. As income rises and they spend more, pollution rises and environmental quality falls. Poorer households do not want to substitute, i.e., reduce consumption of non-environmental services for environmental amentities that are already abundant. Thus, as income rises from low to middle levels, a U shape for environmental quality can result. Yet an N shape might eventually result, as richer households spend all income on clean inputs. Substitution towards cleaner inputs is desirable but the possibilities are exhausted. Thus as income rises further, again pollution rises and environmental quality falls.

This kind of modeling has value for positive work on the aggregate relationship. It suggests hypotheses whose testing may illuminate underlying mechanisms. For instance, Chaudhuri and Pfaff (2002) pursue its implications by examining Pakistani households' shifts between fuels as household income rises. Also, once the household problem and its implications are better understood, we can add the complications that arise when many agents interact to produce the environmental outcome.

For instance, our household production framework suggests the possibility of endogenously increasing (environmental) product variety and quality during the process of income growth. With incomes rising, as more households are willing to substitute towards cleaner and potentially more expensive inputs, firms will have more incentive to provide newer, cleaner inputs. To our knowledge, this has not been explored, and we plan to pursue this in future research.

In addition, while we have neither emphasized the common property characteristics of many environmental amenities nor performed the explicit aggregation that would provide a direct link between our household-level analysis and aggregate phenomena, our framework provides the building blocks for a more explicit treatment of aggregation and free-rider issues. Within politico-economic models that emphasize a regulatory channel through which an environmental Kuznets curve might arise, application of our framework should permit a more detailed characterization of why and how environmental voting behavior might change with income.

Notes

1. World Bank (1992), Selden and Song (1994), Shafik (1994), Holtz-Eakin and Selden (1995), Grossman and Krueger (1995), and special issues of Environment and Development Economics (November 1997) and Ecological Economics (May 1998).
2. See, for instance, Keeler et al. (1972), Plourde (1972), D'Arge and Kogiku (1973), Forster (1973), Gruver (1976), Stevens (1976), Asako (1980), Becker (1982), Gradus and Smulders (1993), Tahvonen and Kuuluvainen (1993), Bovenberg and Smulders (1995), Michel and Rotillon (1995), Selden and Song (1995), Withagen (1995), Beltratti (1996), Elbasha and Roe (1996) and Stokey (1998).

3. Effects of trade in the context of income growth have been discussed by, among others, Saint-Paul (1995) and Jaeger (1998). Copeland and Taylor (1995) include the effect of trade on national incomes in considering the effects of trade on the environment within a general equilibrium setting.
4. Lopez (1994) and Selden and Song (1995) describe roles for preferences, while Andreoni and Levinson (2001) posit a particular mechanism involving increasing returns to abatement to explain the environmental Kuznets curve.
5. Classic early references in the household production literature include Gorman (1980), Becker (1965), Lancaster (1966a, b).
6. We mention below the example of households switching fuels in a development context (e.g., substitution from dung and wood to kerosene and then to liquid propane and natural gas). Other examples include: paying more for wind-powered electricity generation, or for more fuel efficient air conditioners; purchasing more expensive but biodegradable garbage bags; and buying a costlier but higher mileage automobile. These examples raise the issue of household voting and regulation, since they may not feature the same degree of internalization as fuels and indoor air quality. However, some people do these things of their own accord.
7. The household-level relationship between income and environmental quality might in fact take on any number of shapes, including a monotic rise in quality. Despite the attention to U-shaped relationships, a more robust empirical finding is that the relationship is potentially non-monotonic, and some investigations find no significant empirical relationship at all.
8. The technique effect and composition effect both involve substitution, the latter between goods and the former between ways of making a given good. Whether a given change (such as a change in π above) is a case of one effect or the other depends how one delineates goods, but here "technique" seems most appropriate.
9. For a more general but perhaps less illustrative intuition, ignore for the moment the fact that the input demand functions may not be differentiable at all incomes because of binding non-negativity constraints on input use, and represent the slope of the Engel curve linking a to y as:

$$\frac{da(\vec{q}(y))}{dy} = \sum_j \left(\frac{\partial a(\vec{q})}{\partial q_j}\right) \frac{\partial q_j}{\partial y}(y) \tag{4.1}$$

The key point is that the demand for the marketed inputs is *derived* from household preferences for s and a, and should not be presumed to be normal. In a characteristics or household-production framework, inferior marketed goods can be quite common (Deaton and Muellbauer 1980; Lipsey and Rosenbluth 1971). If dirty inputs are inferior (after a certain income) while clean inputs are normal, it is possible the Engel curve for the environmental amenity will be U-shaped.
10. In the analytical results, this is suggested by the optimal π^* in this income range being negative in the absence of non-negativity constraints on π.
11. In Figure 1, that substitution remains desirable is conveyed by point 5' being preferred to point 5 (analogous to the low-income case of 2' preferred to 2).
12. A fixed cost for the clean fuel leaves these intuitions intact, although not surprisingly its magnitude affects these income ranges.
13. Here it should be noted that Stokey (1998) also finds corner solutions as part of an environmental Kuznets curve, although only for poorer households.
14. Shifting relative shadow prices of non-marketed goods characterizes such models of household production. However, only when marketed goods bundle a "good" with a "bad" could the relative price shift accompanying an increase in income outweigh the direct effect of income. In the classic model in which marketed foods provide a set of non-marketed nutrients, an increase in income will not decrease the consumption of any nutrient (unless it is a Giffen good, which is rare – a statement not to be confused with our earlier assertion that in a household-production

framework inferior or Giffen *marketed* commodities can be common). Consider the case of homothetic preferences. In the nutrients case, the mix of marketed foods and relative shadow price of nutrients faced never change as income rises. Figure 2 indicates, though, that when marketed commodities bundle a good with a bad, even with homothetic preferences a household must eventually change its mix of goods, and the relative shadow price of the environmental amenity must eventually rise.

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