Household Production, the Bundling of Services and Degradation, and Non-monotonic Environmental Engel Curves

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Abstract

In this paper, we step back from the literature on "environmental Kuznets curves" (inverted-U relationships at the aggregate level between various indicators of environmental degradation and per-capita income) to consider one possible component of such relationships, i.e. the link between household income and household choices that impact upon the environment. Our approach is distinguished by explicit modeling of a household-level mechanism linking income to changes in environmental quality. Two facts are emphasized: (1) a household can not directly purchase environmental quality; and (2) a household starts with a positive endowment of environmental quality, which is degraded through consumption. We propose a household production model, in which households purchase marketed commodities that bundle a "good", non-environmental services, with a "bad", environmental degradation. We show that even if the environment is a normal good, household substitution towards less environmentally degrading marketed commodities, combined with natural constraints on the household's shifts between marketed commodities, could produce a non-monotonic relationship between household income and environmental quality, i.e. a non-monotonic environmental Engel curve.

Keywords: environment, household production, Engel curve, bundling

1. Introduction

A number of recent papers using aggregate cross-country data have suggested the existence of an inverted-U relationship, at the aggregate level, between various indicators of environmental degradation (e.g., air or water pollution) and per-capita income.[1] This finding—termed the environmental Kuznets curve—suggests that while economic growth may initially be associated with degradation of the environment, continued growth may reverse any initial adverse effects.

An existing literature in the neoclassical growth tradition provides one way of thinking about pollution and growth; it makes use of a representative agent framework to explore optimal intertemporal tradeoffs between current consumption, investment in capital, and pollution control.[2] A good example is Gruver (1976), which extends the standard neoclassical growth model by incorporating the portfolio choice between investments in productive capital and pollution-control capital. A key result is that under certain parameter configurations it is possible for the optimal growth path to be unbalanced. The emphasis in the initial stages of growth is on the accumulation of productive capital, which implies increasing levels of 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. Such analysis is certainly suggestive. However, the use of the representative agent framework provides neither political economic nor other mechanisms through which the environmental effects of economic growth might in fact be reversed.

The mechanisms underlying the aggregate relationship between growth and the environment, though, can be relatively complex. For instance, even if all households value the environment, given externalities it is not clear how such preferences would be aggregated to produce pollution control policies that diminish environmental impacts. Also, the mechanisms explaining aggregate relationships may involve economy-wide shifts in consumption, such as differential growth rates among economic sectors during development. Finally, these mechanisms might also involve trade. For instance, as a country grows richer it might cease to produce goods featuring "dirty" production processes, and simply import the finished goods.[3]

We step back from these complications to consider one building block of such aggregate relationships, i.e. the way that households will change their environmental quality, in response to changes in household income, when they have a high degree of control over that quality. Once we have better understood the household dynamic, we can add complications. Regarding the household problem, the role of preferences (be those of the social planner or of the household) is suggested by previous work.[4] In this paper, given a standard utility function, we emphasize a particular household mechanism that allows for the possibility of non-monotonic environmental Engel curves. We emphasize two facts: (1) a household can not directly purchase environmental quality; and (2) a household starts with a positive endowment of environmental quality, which is degraded through consumption. In light of these facts,

[1] E.g., Grossman & Krueger (1995), Selden & Song (1994), Shafik (1994), World Bank (1992).

[2] See, for instance, Plourde (1972), Keeler et al. (1972), D'Arge and Kogiku (1973), Forster (1973), Gruver (1976), Stevens (1976), Asako (1980), Becker (1982), Tahvonen and Kuuluvainen (1993), Selden & Song (1995) and Stokey (1998).

[3] Effects of trade have been discussed by, among others, Saint-Paul (1995) and Jaeger (1998).

[4] For example, Lopez (1994) and Selden and Song (1995).

we propose a household production model, in which households purchase marketed commodities that bundle, i.e., jointly produce, a "good", non-environmental services valued by households, with a "bad", environmental degradation.[5]

We expect environmental services to be valued, and to be normal or perhaps even luxury goods. But that implies that the Engel curves for environmental services ought to be positively sloped at all incomes. The basic contribution of this paper is to show that even when households value environmental services, the *possibility* of a non-monotonic relationship between household income and environmental quality arises quite naturally given the two facts just emphasized.[6] In addition to the environment being degraded from a positive endowment, the crucial issue is a household's ability to "purchase" environment by substituting among a range of marketed commodities that represent different bundles of non-environmental services valued by the household and degradation of the environment.

If both such non-environmental services and the environment are normal goods, increases in income will produce two changes with opposing effects on the environment: first, an increased demand for non-environmental services, and thus an increased use of environmentally-degrading marketed commodities to produce services; and second, a shift towards more environmentally-friendly (but more expensive) commodities. The interaction of these two effects creates the *possibility* of a U-shaped, or more generally a non-monotonic relationship between household income and the level of environmental quality that the household enjoys. For instance, we show that natural constraints on the household's choices of marketed commodities generate two regimes (or ranges of incomes) in which the second effect is non-existent. When these are preceded or followed by ranges of incomes in which the second effect exists and dominates, a non-monotonic relationship will result.

Such consideration of the household-level, pollution-income relationship has value for positive work on the aggregate relationship, in that it suggests hypotheses from whose testing we can learn about underlying mechanisms. For instance, following this theoretical analysis, we might empirically examine how households in fact change environmental quality as income rises (when they can affect that quality), in order to learn something of relevance to how more complex choices of national pollution policies change as GNP rises. Also, our discussion of substitution suggests the testable prediction that after most consumption is being derived from the cleanest marketed commodities, further increases in income must lower environmental quality unless further substitution is made possible through innovation.

The remainder of the paper is as follows. Section 2 outlines a simple household-production framework, and then describes in some detail how a non-monotonic Engel curve for environmental quality might arise within this framework, even when environmental quality would be a normal good if it could be directly purchased. Section 3 concludes with a brief discussion and implications for further research.

[5]Classic early references in the household production literature include Gorman (1980), Becker (1965), Lancaster (1966a, 1966b).

[6]There is, though, no reason why such the household-level relationship between income and environmental quality has to resemble an inverted-U. It might take on any number of shapes, including a monotic rise in quality. This indeterminacy turns out to be an attractive positive property. Despite the attention given to evidence of an inverted-U relationship, a more robust finding is that the relationship is potentially non-monotonic, and in some situations there does not appear to be any significant relationship at all.

2. Household production & non-monotonic environmental Engel curves

2.1. 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 use of marketed fuels such as firewood or kerosene results in the joint production of services that households value (e.g., heat) and reductions in indoor air quality. We formalize this observation within a household production/characteristics framework. We then show that even when households value environmental amenities—and the demand for the amenities would be normal if they could be directly purchased—a U-shaped relationship between household income and the environment can arise precisely because the environmental amenity cannot be directly purchased and is degraded. We use the simplest possible model to demonstrate this and to develop the basic intuitions.

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. The critical assumption we make is that s and a cannot be directly purchased and are, instead, jointly produced (in the case of a, degraded) through the use of the marketed inputs. Consider a situation where households have a choice between two marketed inputs, a "dirty" (more environmentally destructive) input d and a "clean" input c. Assuming that s is generated linearly from the use of these inputs, we can, without further loss of generality, redefine the units in which the two inputs are measured so that the total volume of valued services s is given by:

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

where q_d and q_c are the quantities used of the dirty and clean inputs 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 inputs. For instance, we will assume both that the total emissions level e is linear in the inputs:

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

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

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

The household's problem is to choose marketed inputs q to maximize:

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

subject to:

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

where y is household income and p_d and p_c are, respectively, the per-unit (of services) prices of the dirty and clean inputs (we also assume that $p_d < p_c$).[7]

[7] Certainly this could be more general, with J different marketed goods available to the house-

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

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

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

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

In other words, holding constant the share of clean inputs, increased service consumption leads to a deterioration in environmental quality, and holding constant overall services, switching to the clean input improves environmental quality.

Households choose s and π to maximize:

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

subject to:

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

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.[8] 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,

hold, q_j signifying the consumption of marketed good j, and household production technologies:

$$\begin{aligned} s &= s(q_1, ..., q_j, ..., q_J) \text{ with } \frac{\partial s(.)}{\partial q_j} > 0 \\ a_h &= a(q_1^h, ..., q_j^h, ..., q_J^h) \text{ with } \frac{\partial a(.)}{\partial q_j^h} < 0 \end{aligned}$$

While all inputs produce services but lower environmental quality, we assume that different inputs may bundle services and reductions in environmental quality in different ways. Thus, the partial derivatives, $\frac{\partial s}{\partial q_j}$ and $\frac{\partial a}{\partial q_j}$ will, in general, differ across the inputs $j = 1, ..., J$. The household's problem is to choose $(q_1, ..., q_j, ..., q_J)$ to maximize its utility subject to a budget constraint.

[8] Specifically, we assume that:

$$\begin{aligned} U_a U_{sa} - U_s U_{aa} &> 0 \\ U_s U_{sa} - U_a U_{ss} &> 0 \end{aligned}$$

where we use the notation F_x to represent the partial derivative of a function $F(.)$ with respect to the argument x. Note also that for the particular $a(s, \pi)$ function implied here, $a_{ss} = 0$, $a_{\pi\pi} = 0$, and $a_{s\pi} > 0$, which given linear $e(q)$ makes the problem well-defined.

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.

2.2. Graphical analysis

Additional intuition is most easily developed diagrammatically. Consider Figure 1. The household's initial endowment point is at the upper left corner, where the household enjoys a base level of the environmental amenity but no services. Again, this asymmetric starting point is crucial; it implies that at low levels of income, the marginal utility of additional services is likely to be relatively high compared to that of additional units of the environmental amenity.[10] The dashed rays originating from this point depict $a(s,0)$ and $a(s,1)$, i.e., the combinations of a and s attainable through *exclusive* use of one or the other of the inputs. The solid lines connecting $a(s,0)$ and $a(s,1)$ represent the household's budget constraints at different levels of income. Increasing income is reflected in budget constraints further from the endowment point. The slopes of the budget constraints indicate the relative shadow prices of the non-marketed goods, environmental quality and services—i.e., the slopes indicate the rate at which, given the underlying technologies and the prices of the marketed inputs, households are able to trade off between environmental quality and other valued services. The negative slope of the budget constraints reflects our assumption that dirtier inputs are cheaper than cleaner inputs (per unit of service produced). The shape of the indifference curves comes from the concavity of $U(.)$ and the fact that both a and s enter positively into the household's utility. Indifference curves further up and to the right reflect higher levels of utility.

2.2.1. Limits on substitution

Figure 1 shows the optimal consumption points of the household at six different levels of income. The increases in income that lead to the shifts from point A to point C, as well as those which cause the shifts from point D to point F, are accompanied by a deterioration in environmental quality. The subset of transitions from point A to point D, however, together trace out a U-shaped relationship between y and a. This is because in the transition from point C to point D, the increase in income brings with it an improvement in environmental quality. The intuition behind the

[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:

$$\frac{da(q(y))}{dy} = \sum_j \left(\frac{\partial a(q)}{\partial q_j}\right)\frac{\partial q_j}{\partial y}(y) \tag{2.11}$$

The key point to note here is that the demand for the marketed inputs is *derived* from the household's preferences for s and a. Thus, there can be no presumption that the demand for a marketed good will be normal. In fact, within a characteristics/household production framework, inferior marketed goods can be quite common (Deaton and Muellbauer (1980), Lipsey and Rosenbluth (1971)). If, therefore, dirty inputs are inferior (after a certain income) while clean inputs are normal, it is quite possible that the Engel curve for the environmental amenity will be U-shaped.

[10] Stokey (1998) also notes within a static model the importance of such marginal utility ratios.

latter transition is relatively straightforward. Households value both a and s. The possibility of input substitution, by providing households with the added degree of flexibility to choose both s—i.e., "how much of the service to consume"—as well as π—i.e., "how to produce that level of service"—allows them to increase both s and a by switching to increased use of the clean input.

The other four transitions, in which a rise in income is accompanied by a decline in environmental quality, demonstrate the importance of natural constraints on the household's choice of marketed inputs. These result from what we call a lack of substitution possibilities, or binding non-negativity constraints on input use, given the existence of both a "dirtiest" input and a "cleanest" (but still environmentally degrading) input. At a relatively low income level, such as at the lowest budget constraint shown in the figure, the utility-maximizing point A involves use of only dirty inputs. That is not surprising given that the household begins with a positive endowment of the environmental amenity but no services. Increases in income shift out the budget constraint, but initially lead the household to only move along the dirty inputs locus to a point such as B. Thus, increasing incomes from a relatively low base leads to more services but lower environmental quality.

Perhaps slightly more surprising is that even when the household is willing to pay for some environmental quality, i.e. starts to use the clean input, increased income might again lead to more services but lower environmental quality. This is shown in the shift from B to C. What this transition highlights is the fact that at B, the household is, in a sense, constrained by the lack of a cheaper, dirtier input - at the same income, had a cheaper, dirtier input been available, the household could have chosen a point such as B'. Note also that the household's preferences are such that, had the household not been constrained by the lack of substitution possibilities at B, demand for environmental quality would have increased with income in the shift to C. The transition from D to E is analogous to that from B to C, although in this case the household is constrained by the lack of a more expensive, cleaner input - at the same income, had such an input been available, the household could have chosen a point such as E'. Finally, after the household has fully substituted to the clean input, further increases in income will inevitably lead to reductions in the environmental amenity level, as in the transition from E to F.

2.2.2. Shifts in relative shadow price

Figure 2 introduces a third marketed input, which we call a "transitional input", and depicts optimal consumption points at four levels of income. As in the shift from C to D in Figure 1, the shift from A to B here involves an increase in the environmental normal good. The two transitions from point B to point D, however, trace out a U-shaped relationship between y and a. This demonstrates the potential importance of shifts in the relative shadow prices of the goods that the household values. In this linear characteristics case, the relative shadow price of environmental quality with respect to services remains the same, at all levels of usage, as long as the household uses the same pair of inputs. Thus, an increase in income that does not result in the household changing its mix of inputs has to be associated (if the demand for a is normal) with an improvement in environmental quality, as in the shifts from A to B and C to D. However, if an additional increase in income leads the household to shift inputs, i.e. to use a different pair out of the three inputs, the relative price of s and a will change, and in particular the relative price of environmental quality will rise. As in the move from B to C, this can result in the household choosing a reduced level of environmental quality if the substitution effect from this relative price change outweighs the direct income effect.[11]

That the environment is degraded from a positive endowment matters even for this substitution effect. The possibility of relative shadow prices of non-marketed goods shifting with increases in income is a feature of all household-production models. However, only when marketed goods bundle a "good" with a "bad" could the substitution effect of the relative price shift accompanying an increase in income outweigh the direct effect of income. Consider Figure 4, where marketed inputs, such as foods, bundle only characteristics valued by the household, such as nutrients. Starting from point A, if we move to a higher budget vertically (holding nutrient 1 constant), the relative price of nutrient 1 is necessarily equal to that at A (or lower, for even larger budgets). Similarly, if we move horizontally (holding nutrient 2 constant), the relative price of nutrient 2 is necessarily lower than that at A. Therefore, as long as household preferences are such that the demand for each nutrient is normal, an increase in income cannot lead to a decrease in the consumption of any nutrient. Only in the rare case that a nutrient is a Giffen good will an increase in income be associated with a decrease in the consumption of that nutrient.[12] The difference between this standard linear characteristics case and our Figure 2 is highlighted when preferences are homothetic. In the standard case, a household with homothetic preferences will never change its mix of inputs (or the relative shadow price faced) as its income rises. In contrast, as Figure 2 indicates, when marketed commodities bundle a good with a bad, even with homothetic preferences a household that is using the "dirtiest" input must eventually change its mix of inputs, and thus the relative shadow price of the environmental amenity must eventually rise.

[11]Figure 3 suggests that even within shifts between mixes of the same two inputs, a shift in the relative shadow price can occur if $a(s,\pi)$ is non-linear (i.e., if $e(q)$, $a(e)$ or both is non-linear). In the general non-linear case, to ensure that the household's problem is well-defined, i.e. that the budget constraints are concave as depicted, we make the following assumptions about $a(s,\pi)$:

$$\begin{aligned} a_{ss} &\leq 0 \\ a_{\pi\pi} &\leq 0 \\ a_{s\pi} &\geq 0 \\ a_{s\pi} - \frac{a_{\pi}}{s} &\geq 0 \end{aligned} \tag{2.12}$$

The first three assumptions seem quite natural: the marginal damage to the environment from the use of marketed inputs remains constant or rises with the total level of use; the marginal improvement in environmental quality from switching to the cleaner input remains constant or declines as the share of the clean input rises; and the marginal improvement from switching to the cleaner input does not fall with the total level of use. The fourth assumption is less intuitive, but is satisfied in the leading case in which $e(q)$ is linear, as above, and $a(e)$ is non-linear (in which case $a_{ee} \leq 0$, analogous to $a_{ss} \leq 0$, replaces the first three conditions above).

A non-linear $a(e)$ technology implies that the relative shadow prices of s and a change along the budget constraint. In principle, it is possible, as in the shift from C to D in Figure 3, that holding constant the level of environmental quality, an increase in the level of services is only possible at a higher relative price of environmental quality. It is worth noting, however, that for many leading non-linear $a(e)$ technologies, this sort of change in relative shadow price is not in fact possible.

[12]That it is rare for a nutrient (or any *non-marketed characteristic* valued by households) to be a Giffen good should not be confused with our earlier assertion that within a household production framework, inferior or Giffen goods can be quite common among *marketed commodities*.

2.3. Conditions for non-monotonicity

As is implicit in (2.10) and (2.11), when an environmental amenity can not be directly purchased and is degraded from a positive endowment, any number of income-environment relationships can emerge. A subset of these household environmental Engel curves will be non-monotonic, and a subset of the non-monotonic curves are U-shaped. This indeterminacy is a positive feature of any building block of an aggregate income-environment relationship, as not only non-monotonic and U-shaped but also non-monotonic but non-U-shaped relationships, as well as both monotonic and insignificant relationships have been suggested within the set of aggregate empirical studies. Here we present a few basic conditions for non-monotonicity of environmental Engel curves which follow from the crucial elements of our model.

The dominant condition for non-monotonicity is that a range of incomes in which the household can substitute towards less degrading inputs as income rises is preceded or followed by a range of incomes in which it can not. When substitution is possible, the ability to separate the choice of how much s to consume from that of how to produce s using different marketed goods allows the household to increase not only the normal good s but also the normal good a in response to increases in income. A lack of substitution, though, eliminates the $\frac{d\pi}{dy}$ term in (2.10), which guarantees that the environmental endowment will be further degraded by additional consumption of s in response to increases in income.

Two leading cases stand out. First, if the household uses only the dirtiest input for the lowest incomes, but then substitutes at higher incomes, its environmental Engel curve will be non-monotonic, with a U-shaped portion. Second, if the household uses only the cleanest input for the highest incomes, but for lower incomes shifts its mix of dirtier and cleaner inputs (for a given pair of inputs or shifting across pairs) such that a rises with income (monotonically or allowing for dips from changes in relative shadow prices), its environmental Engel curve will again be non-monotonic. However, in this case the amenity level would first rise and then fall with increases in income, a curvature inverse to that for the lower-income household. Putting these non-monotonic segments together over the full range of incomes, a pattern of no substitution, then substitution, and then again no substitution suggests that the environment will fall, then rise and then fall again as income rises, yielding an "inverted N"-shaped environmental Engel curve.

The other principal condition for non-monotonicity is that over some range of incomes the substitution effect of a rise in the relative shadow price of a, which acts to lower a, outweighs the direct income effect, which raises the consumption of this normal good. This effect, like a lack of substitution possibilities, reduces the $\frac{d\pi}{dy}$ term in (2.10), so that the $\frac{ds}{dy}$ term may dominate. If so, a will fall with income across this range, yielding non-monotonicity when preceding or subsequent ranges of incomes feature substitution between inputs such that a rises with income.

The leading case is that the environmental amenity a will fall with income given the rise in the relative shadow price of a that results from a shift *between* pairs of marketed inputs, while preceding and subsequent income ranges feature shifts *within* a pair of inputs. In the linear characteristics case, any such sequence (e.g., from A to D in Figure 2) must produce a non-monotonic segment of the household environmental Engel curve. Note in particular that from B to C in Figure 2, over a range of incomes the increase in the relative shadow price of a leads the household to use only the transitional input, such that $\frac{d\pi}{dy}$ equals zero.

3. Conclusion

Theoretical explanations for the "environmental Kuznets curves" suggested within a growing empirical literature have usually been framed within optimal growth models extended to incorporate abatement or investment in pollution control. By stepping back to the household level, and thus away from many complicating factors, this paper has provided a complementary perspective on aggregate pollution-income relationships. Our approach is distinguished by explicit modeling of a specific household-level mechanism in a situation in which the household can control environmental quality—i.e., input substitution within a household production framework in which marketed inputs bundle valued services with environmental degradation. We showed that the facts that the environment is degraded from an endowmnent, and that it can not be directly purchased but instead is "purchased" through household shifts to marketed goods which are less environmentally degrading, raise the possibility of a non-monotonic environmental Engel curve at the household level.

Such consideration of the household-level, pollution-income relationship has value for positive work on the aggregate relationship, in that it suggests hypotheses from whose testing we can learn about underlying mechanisms. For instance, along these lines Chaudhuri and Pfaff (1997) examine Pakistani households' shifts between fuels as household income rises, to get a sense for how households are in fact making the sorts of tradeoffs described above regarding indoor air quality. Also, our focus on substitution leads to the testable household-level prediction that after most output is produced using the cleanest techniques, further increases in income will lower environmental quality (yielding an "N-shaped" overall relationship between pollution and income if this occurence follows an inverse-U shaped segment).

Further, once the household problem and its implications are better understood, we can start to add back 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 should be more willing to provide newer, cleaner inputs. To our knowledge, this has not been explored, and we plan to pursue this in future research. In addition, with respect to pollution policies, representative agent-based optimal growth models necessarily assume away free-rider problems and other household-level externalities that may be important in practice. In contrast, while in this paper we have not 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, the framework presented here provides the building blocks for a more explicit treatment of aggregation and free-rider issues. For instance, within politico-economic models that emphasize a regulatory channel through which an environmental Kuznets curve might come about, our framework should permit a more detailed characterization of why and how voting behavior might change with income.

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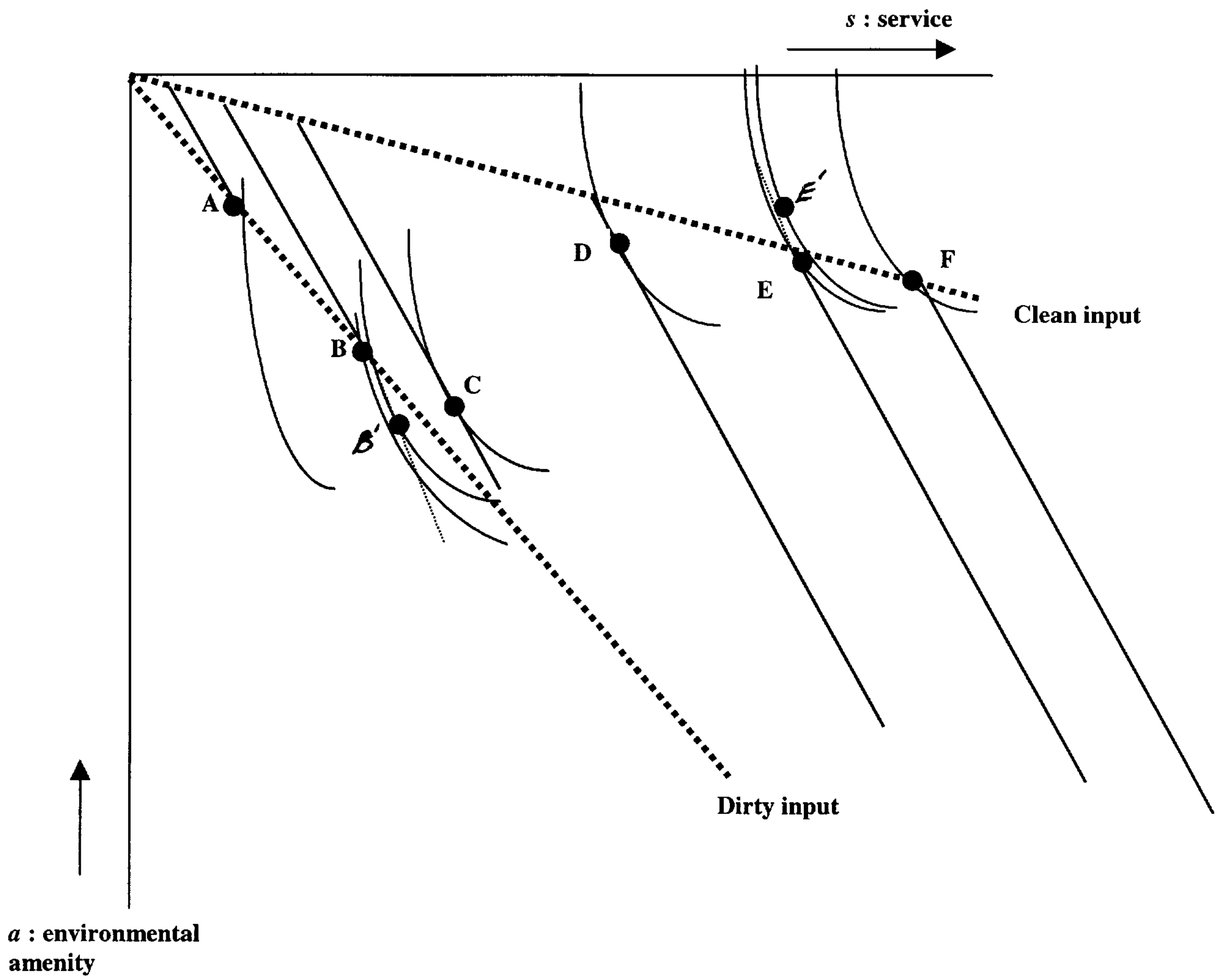
s : service
A
B
B′
C
D
E
E′
F
Clean input
Dirty input
a : environmental amenity

FIGURE 1

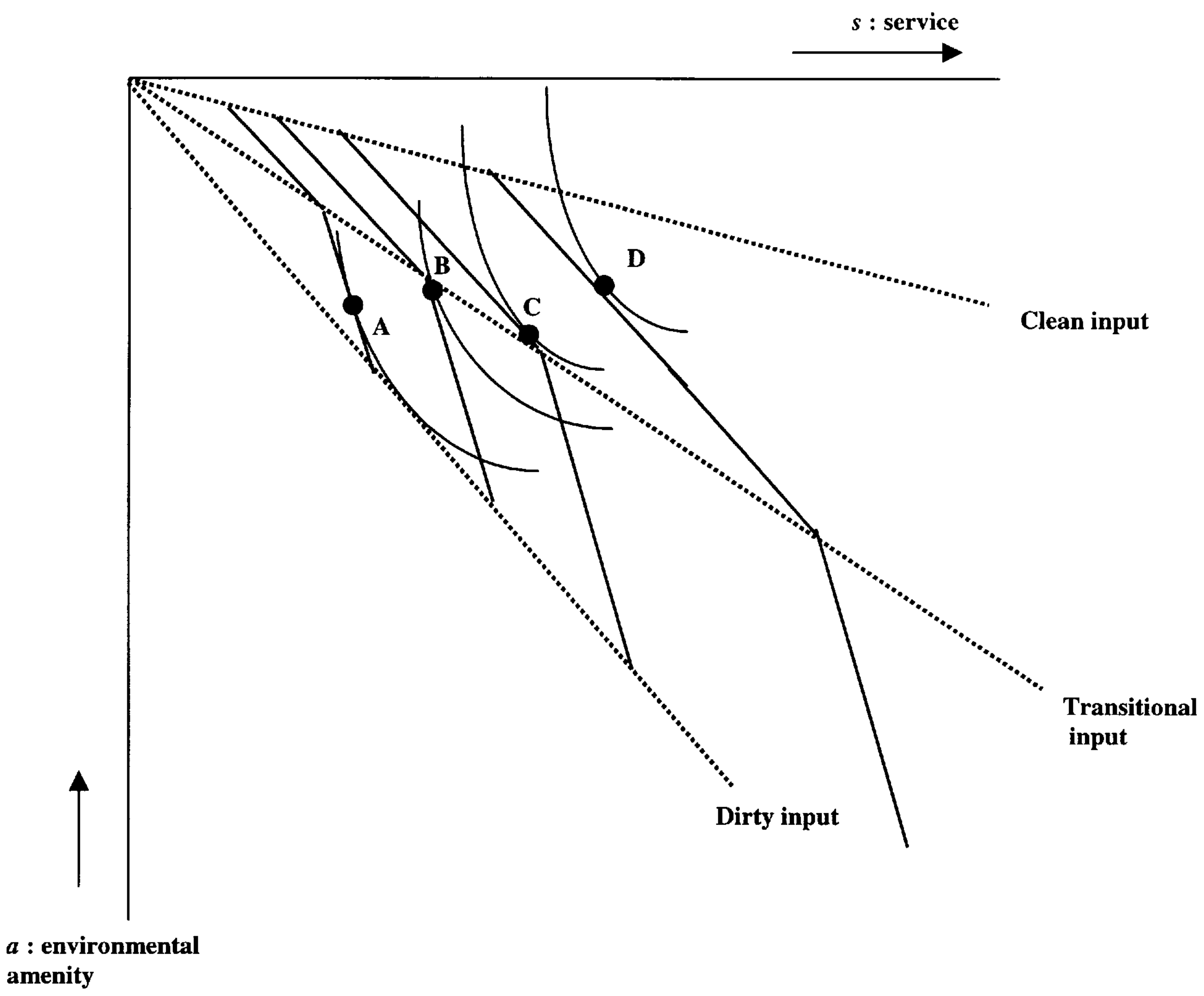
s : service
D
B
C
A
Clean input
Transitional
input
Dirty input
a : environmental
amenity

FIGURE 2

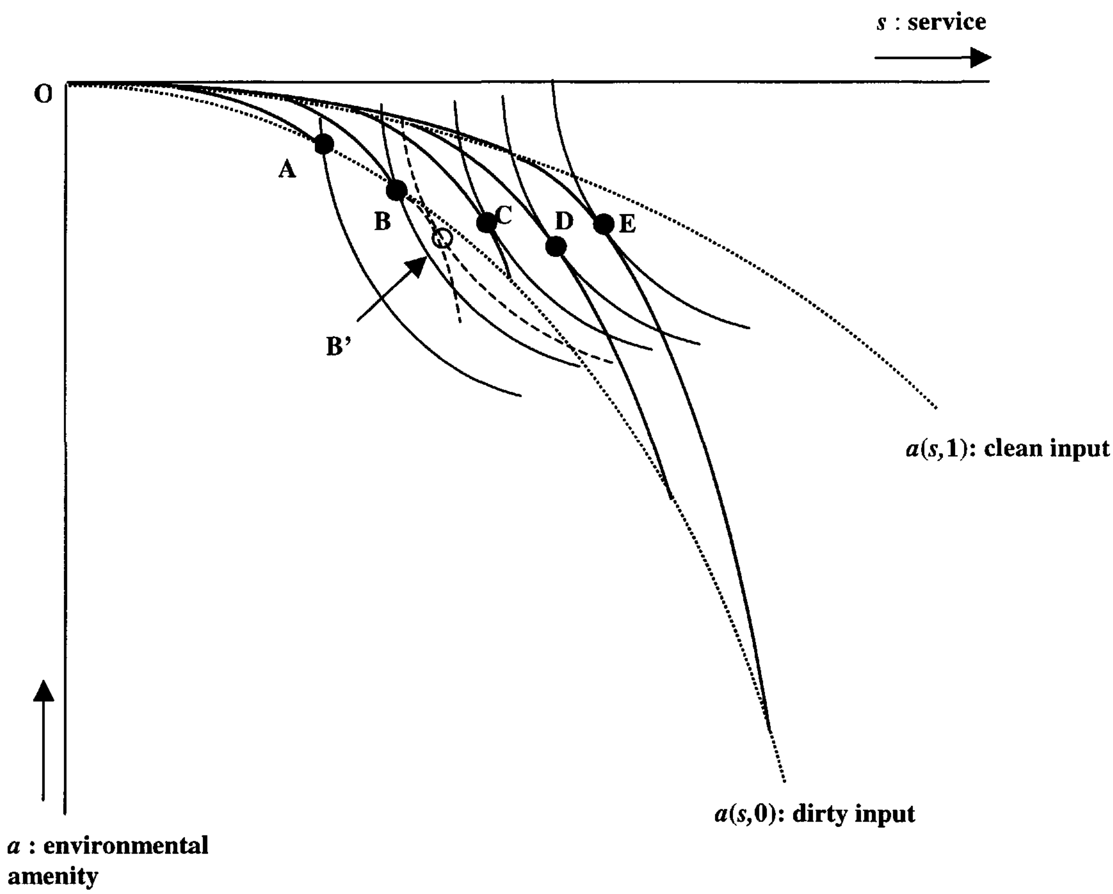
s : service
O
A
B
C
D
E
B'
a(s,1): clean input
a(s,0): dirty input
a : environmental amenity

FIGURE 3

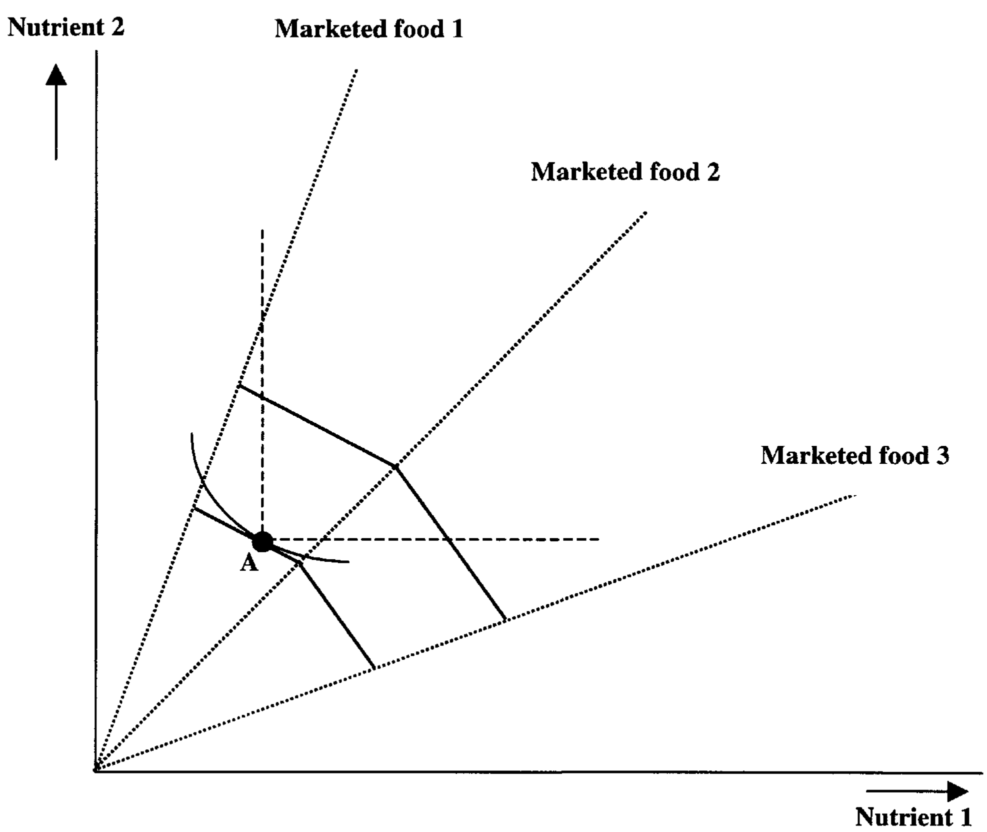
Nutrient 2
Marketed food 1
Marketed food 2
Marketed food 3
A
Nutrient 1

FIGURE 4

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