Interactions between Output Growth and the Environment [1]

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ABSTRACT

Environmental pessimists contend that increases in economic output degrade the environment. This results in policy dilemmas, whereby "green" policies must be traded off against output. We question this view. Even if increased output directly causes environmental degradation, environmental services can enhance output growth. This gives rise to models which may reverse the pessimistic outcome. For instance a "green" technology designed to enhance the environment, but ostensibly harming output growth, can raise output levels. Or a "dirty" technology, designed to increase output, can reduce the equilibrium levels of both output and the environment. These results invite a reassessment of the standard policy trade off between economic growth and the environment.

1. INTRODUCTION

Environmental pessimists contend that increases in economic output degrade the environment. This results in policy dilemmas, whereby "green" policies must be traded off against output. We question this view. Even if increased output directly causes environmental degradation, environmental services can enhance output growth. This gives rise to models which may reverse the pessimistic outcome.

For example, a "green" technology designed to enhance the environment, but ostensibly harming output growth rates, can *raise* output levels. On the other hand, a "dirty" technology designed to increase output growth rates can reduce the equilibrium levels of *both* output and environmental services.

We also present the conditions under which total environmental degradation might occur. These conditions help to identify environmentally "at risk" countries or scenarios and suggest remedial policy actions. We show that standard productivity-enhancing policies, which take no account of their environmental impacts, might be inappropriate for such economies. Throughout the paper the models are used to suggest a broad framework for policy.

2. THE BASIC MODEL

Let Y represent the level of output, net of investment in environmental services, and E the level of environmental services. Output growth refers to increases in physical output (such as that of a single good or an aggregate like national income). Environmental services relate to the benefits provided by the natural environment, which we define broadly to include both stock and flow effects. For example, either the depletion of natural resources or the emission of pollutants by production may depreciate the services provided by the natural environment.

The growth of Y and E are modelled by the differential system:

$$\frac{dY}{dt} = F(Y, E, \underline{\tau})Y$$
$$\frac{dE}{dt} = G(Y, E, \underline{\tau})E, \qquad (1)$$

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where $\underline{\tau} = (\tau_1, \tau_2, \ldots, \tau_n) \in \Re^n$ is a vector of parameters representing the state of technology existing in the economy. The growth rates F and G are C^1 functions of the non-negative variables E and Y.

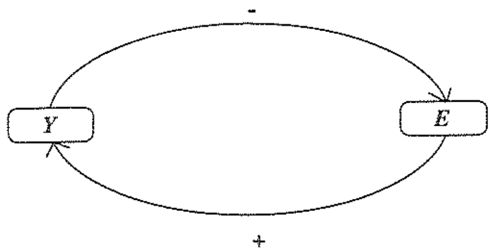
Given the level of technology, $\underline{\tau}$, a long run equilibrium or steady state of the system may only exist where $\frac{dY}{dt} = \frac{dE}{dt} = 0$. Points (E^*, Y^*), with $F(Y^*, E^*, \underline{\tau}) = 0$ are points satisfying output equilibrium, since here output has no tendency to change. Similarly, if $G(Y^*, E^*, \underline{\tau}) = 0$, then (E^*, Y^*) is an environmental equilibrium.

By allowing the growth rate of each variable to be affected by the presence of the other, the system (1) can demonstrate a pessimistic or optimistic view on the growth-environment debate, depending on the relationship assumed between the variables.

3. THE PESSIMISTIC VIEW: OUTPUT GROWTH DEGRADING THE ENVIRONMENT

The purported negative link between growth and environmental degradation is of primary concern to some environmentalists and even economists. This concern is heightened in the case of developing countries, since some of the most populous nations are growing at, or are poised to grow at, very high rates by historical standards. Much of the concern with the environmental consequences of output growth is motivated by a belief that high output growth rates place heavy demands on the stock and assimilative capacity of natural resources. The negative relationship is summarised by the top arrow in Figure 1. The implication of this pessimistic view is that long run environmental sustainability requires curtailing output growth. We modify this approach by introducing positive feedback links, as indicated by the bottom arrow in Figure 1.

Figure 1 *Interactions between output and environmental services*



To model the pessimistic view and feedback links, we make the following set of assumptions:

(i) $F_Y < 0, F_E > 0, G_Y < 0, G_E < 0$. That is, Y inhibits its own growth and also that of the environment. E inhibits its own growth but spurs the growth of output (ie, all else being equal, countries or production systems with a higher natural resource base and lower pollution levels have faster output growth).

We assume initially that $F_{\tau_i} \geq 0 \forall i$. This implies that technological change maintains or increases the ability of output to grow, for example through more efficient use of resources. For now we make no assumptions about the impact of technological change on the growth of the environment: G_{τ_i} can be greater than, less than or equal to zero.

Assumptions (ii) - (v) are made for each level of technology $\underline{\tau}$:

(ii) $F(0,0,\underline{\tau}) > 0$ and $G(0,0,\underline{\tau}) > 0$. That is, each variable will increase if both are small.

(iii) There exists $Y_\tau > 0$ such that $G(Y_\tau, 0, \underline{\tau}) = 0$. That is, an equilibrium level of production exists that will exhaust the environmental resources in an environmental equilibrium. Even if small, environmental services cannot grow in the presence of too large a level of output, since output is a competing variable.

(iv) There exists $y_\tau > 0, E_\tau > 0$ such that $F(y_\tau, 0, \underline{\tau}) = G(0, E_\tau, \underline{\tau}) = 0$. For example, $F(y_\tau, 0, \underline{\tau}) = 0$ means that in the absence of a change in the level of environmental services or technology, the economy cannot grow beyond size y_τ. This could be the result of factors such as resource constraints or the size of domestic and international markets.

(v) For each E there exists $\overline{Y}$ such that $F(\overline{Y}, E, \underline{\tau}) < 0$. This assumption effectively ensures the existence of a bound to output in output equilibrium.

Lemma 1 With assumptions (i)-(v), the equations $F(Y, E, \underline{\tau}) = 0$ and $G(Y, E, \underline{\tau}) = 0$ implicitly define continuous functions $Y = f(E, \underline{\tau})$ and $Y = g(E, \underline{\tau})$, respectively. These are both defined on the interval $[0, E_\tau]$ for each τ and satisfy:

(a) $f_E > 0$, $g_E < 0$

(b) $g(E_\tau, \underline{\tau}) = 0$

(c) $f(0, \underline{\tau}) = y_\tau$, $g(0, \underline{\tau}) = Y_\tau$

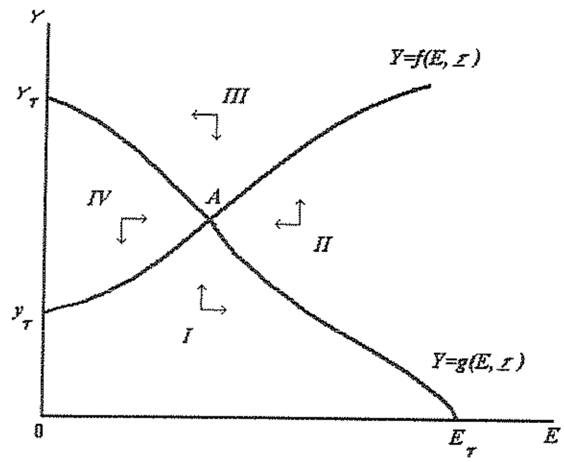
(d) f and g are one-to-one.

Proof Let τ be a technology and suppose that $E \in [0, E_\tau]$. As $F(0,0,\underline{\tau}) > 0$ and $F_E > 0$, then $F(0, E, \underline{\tau}) > 0$. By assumption (v), there exists $\overline{Y}$ with $F(\overline{Y}, E, \underline{\tau}) < 0$ and by the intermediate value theorem there is a value Y_1 such that $F(Y_1, E, \underline{\tau}) = 0$. As $F_Y < 0$ for all Y this is unique, and thus $f(E, \underline{\tau}) = Y_1$ defines our function f. Similarly, we may define g. Both f and g are differentiable with respect to E on their domains as $f_E = {-F_E}/{F_Y}$ and $g_E = {-G_E}/{G_Y}$. Properties (a), (b), (c) and (d) follow from our assumptions. •

Assume (i)-(v) hold and let $\underline{\tau}$ be a technology satisfying $Y_\tau > y_\tau$. Strutt, Lim and Harland [1997] show that a stable long run solution Y^*, E^* to the system (1) exists, with $Y^* > 0$, $E^* > 0$.

Figure 2 shows the phase diagram for this scenario. The curves $Y = f(E, \underline{\tau})$ and $Y = g(E, \underline{\tau})$ represent isoclines, since along these curves F=0 (output equilibrium) and G=0 (environmental equilibrium), respectively.

Figure 2 ***Phase diagram***



The axes, f and g generate four open sets, where $\dot{Y} \neq 0$ and $\dot{E} \neq 0$. These are:

$$I: \left\{(E,Y): \dot{Y} > 0, \dot{E} > 0\right\},$$

$$II: \left\{(E,Y): \dot{Y} > 0, \dot{E} < 0\right\},$$

$$III: \left\{(E,Y): \dot{Y} < 0, \dot{E} < 0\right\},$$

$$IV: \left\{(E,Y): \dot{Y} < 0, \dot{E} > 0\right\}.$$

Point $A = (E_\tau^*, Y_\tau^*)$ is the stable equilibrium point.

We are interested in the effect of small changes in technology on the long run solutions. That is, if the parameter τ_i changes, how are Y and E affected?

Consider the system (1) with assumptions (i)-(v) and let $Y = f(E, \underline{\tau})$, $Y = g(E, \underline{\tau})$ be solutions to $F = 0$ and $G = 0$, respectively. Strutt, Lim and Harland [1997]show that for a technology parameter τ_i:

$$\frac{\partial E}{\partial \tau_i} > 0 \Leftrightarrow \frac{\partial g}{\partial \tau_i} > \frac{\partial f}{\partial \tau_i}$$

$$\frac{\partial Y}{\partial \tau_i} > 0 \Leftrightarrow \frac{\partial g^{-1}}{\partial \tau_i} > \frac{\partial f^{-1}}{\partial \tau_i} \qquad (2)$$

where f^{-1}, g^{-1} are defined such that $f(f^{-1}(Y,\underline{\tau}),\underline{\tau}) = Y$, $g(g^{-1}(Y,\underline{\tau}),\underline{\tau}) = Y$.

3.1 Comparative Dynamics

The equations in (2) have several important implications, depending on the shifts and relative magnitudes of $\partial f/\partial\tau_i$ and $\partial g/\partial\tau_i$. We examine the implications of two possible cases separately:

Case 1: *"Dirty" technology*

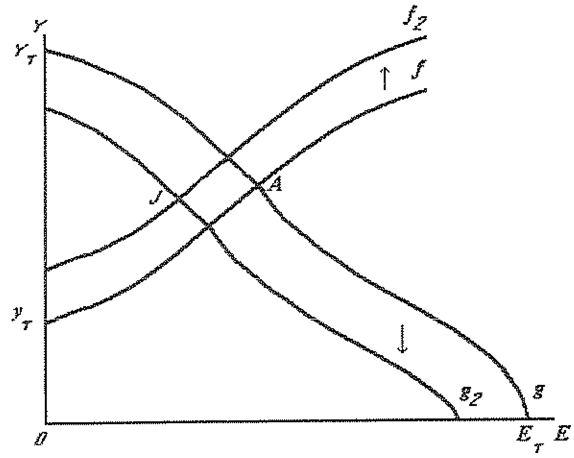
Let $\partial g/\partial\tau_i < 0, \partial f/\partial\tau_i > 0$. Here technology reduces the growth rate of E and increases that of Y (ie, a "dirty" technology). From (2), small increases in this technology will hurt the environment. The effect on output is indeterminate, and may be negative even though this technology was intended to help output growth.

An illustration of a "dirty" technology is given in Figure 3. The economic system is initially at point A. The technology shifts the initial f isocline upwards to f_2, and g downwards to g_2. The movement from A to J illustrates the unambiguous negative impact of technology on the environment and a negative effect on income. (*A priori* the impact on income is clearly ambiguous.)

As the economy moves between the equilibria, the application of dirty technology causes Y to rise and then fall, possibly to a lower level than it started at. The initial rise in income with the use of dirty technology is therefore no guarantee of a rise in long run output.

An example of policy-driven "dirty" technology was the large subsidization of pesticides in Indonesia. The aim of this policy was to increase productivity and shift f upward. One of the unintended impacts of the increased pesticide usage was to harm the natural environment by wiping out natural predators of the brown planthopper. The brown planthopper outbreak caused the loss of 50-60,000 hectares of irrigated rice in 1986-87 [Barbier 1989: 889]. This effectively caused g to shift down.

Figure 3 *The application of "dirty" technology*

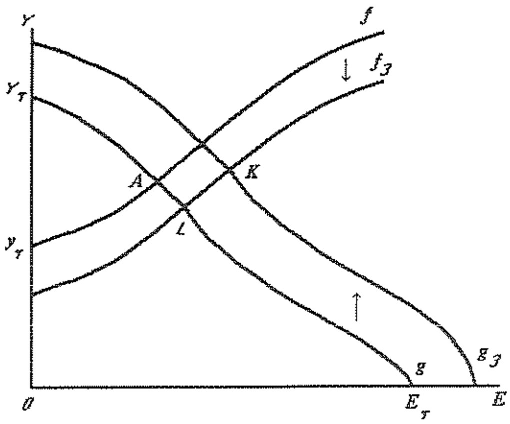


Case 2: *"Green" technology*

Now we relax the assumption that $F_{\tau_i} \geq 0 \forall i$. Let $\partial f/\partial\tau_i < 0, \partial g/\partial\tau_i > 0$. Such a technology ostensibly hurts the output growth rate, while enhancing that of environmental services (let's call this a "green" policy). Surprisingly, such a policy can actually *increase* output as well as improve the level of environmental services. Figure 4 illustrates the point, as the economy moves from A to K.

Suppose initially that stringent environmental policies impose constraints on production, such that output falls. The fall in output reduces the pressure on the environment and E rises. This is shown in the diagram as the movement from A to L. Let the policy also help the environment directly, such that $\partial g/\partial\tau_i > 0$. Depending on the size of the shifts in the f and g isoclines, this policy could improve output and the environment. In other words, a shock which initially hurts output, countered with a policy that improves the environment, can raise the equilibrium levels of both. In general, the positive effect on the level of environmental services is clear; the effect on output is ambiguous.

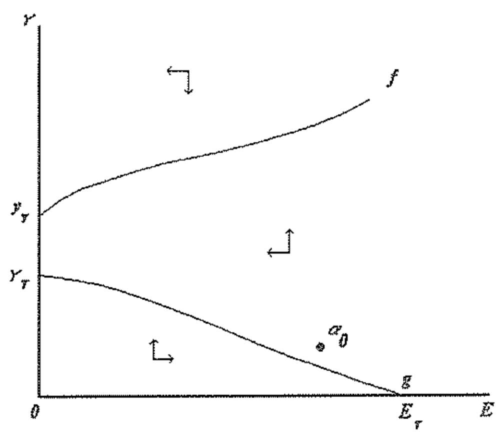
Figure 4 *Impact of a "green" policy on output*



3.2 An Extreme Case: Environmentally Fragile Systems

Now we relax the assumption that $Y_\tau > y_\tau$. Most of the assumptions in this model have been geared towards producing functions *f* and *g* that are positively or negatively sloped, defined in an appropriate interval and with an interior solution to *f*=*g*. Replacing the assumption that $Y_\tau > y_\tau$ with $y_\tau > Y_\tau$ implies corner solutions where complete degradation of the environment may occur. Figure 5 depicts this extremely pessimistic view.

Figure 5 Environmentally "at risk" system



Consider an initial point α_0, for example. Environmental services are relatively high and output is relatively low. As a country develops, economic growth raises output. If the transition to more appropriate property rights and other forms of environmental protection lags behind, the *g* isocline does not shift out, and environmental degradation results. As modelled in Figure 5, complete environmental degradation occurs if sufficient time elapses. In this case, the stable solution to (1) occurs at $(0, y_\tau)$.

The condition $y_\tau > Y_\tau$ suggests that the output associated with a zero level of environmental services (y_τ) is relatively large, and that the level of output that drives the growth rate of environmental services to zero (Y_τ) is relatively low. These two conditions conceivably hold for some large developing countries. China, for example, exhibits high output growth rates and is predicted to become the world's largest economy sometime in the next century. It is a labour surplus economy, and if it can maintain relatively high levels of output with few natural resources, then a relatively large y_τ is likely to hold. China's rising national income has had significant adverse impacts on the growth rate of its environmental services, implying that Y_τ, the level of national income at which the growth rate of environmental services falls to zero, could be relatively low.

Such countries are more "fragile" from an environmental perspective. Economic policy might concentrate on green technologies that lift Y_τ above y_τ to help the environment. Technologies that only improve the productivity of "standard" inputs, such as labour and capital, may widen the gap between Y_τ and y_τ.

4. CONCLUSIONS

The theoretical foundations for negative environmental impacts arising from economic growth have been developed in the dynamic model in this paper. We have demonstrated the potential importance of incorporating feedback effects when modelling economic growth and environmental degradation.

We showed that "green" technologies can raise output levels and "dirty" technologies can reduce both equilibrium output and environmental services. This is even under the pessimistic assumption that output growth degrades the environment.

Given the interactive model presented in this paper, we are able to derive outcomes under various assumptions to provide broad policy guidance. However, more specific policy analysis will be necessary in some cases. A fruitful area of further research might be to augment computable general equilibrium (CGE) models to take environmental consequences, including feedback mechanisms, more explicitly into account [Anderson and Strutt 1996].

5. REFERENCES

Anderson, K. and A. Strutt, On measuring the environmental effects of agricultural trade liberalization, in *Agriculture, Trade and the Environment: Discovering and Measuring the Critical Linkages*, edited by M.E. Bredahl, N. Ballenger, J.C. Dunmore and T.L. Roe, Boulder and London: Westview Press, 1996.

Barbier, E.B., Cash crops, food crops, and sustainability: The case of Indonesia, *World Development* 17(6): 879-95, 1989.

Strutt, A., S. Lim, and D. Harland, Interactions between output growth and the environment, *Discussion Paper No. 97.04*, Massey University, 1997.