

## **Draft**

### **Environment, Poverty and Development**

Paper presented at the Griffin Festschrift, Amherst, April 2004

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#### **Abstract**

The Brundtland Report suggested that there are close causal links between environmental change and poverty. However, the empirical evidence of the effects of poverty on the use made of environmental assets or natural capital is ambiguous. This paper focuses on the relation between poverty and the relative importance of natural and produced capital. Poverty affects stocks of natural and produced capital through its effect on savings. In this respect the paper seeks to explain two things. One is the link between poverty and 'genuine' savings and investment. The other is the link between genuine savings and environmental assets in common property. It is shown that if society derives utility both from the consumption of marketed goods and the state of the environment, and if poverty is defined in terms of the level of consumption, it will lead to a reduction in natural relative to produced capital.

#### **1. The problem**

The Brundtland Report supported the notion that there are close causal links between environmental change and poverty, both within and between generations. This reflected existing evidence of a correlation between poverty and accelerating environmental degradation in many countries, especially in Sub-Saharan Africa. Since that time, considerable effort has been committed to uncovering the microeconomic connections between poverty, resource degradation and population growth. In two seminal studies, Dasgupta (1993, 2001) has explored the connection between poverty, fertility decisions and environmental change. Others have focused on the connection between poverty and discount rates (Perrings, 1989; Holden, Shiferaw and Wik, 1998), poverty and savings/investment rates (Bartolini and Bonatti, 2002), or poverty and institutional conditions (Lopez, 1992; Heath and Binswanger, 1996). The empirical evidence is, however, ambiguous (Ekborn and Bojo, 1999; Duraiappah, 1996; Markandya, 2000, 2002).

This paper reconsiders the relation between poverty and assets, noting that the stock of assets includes not only produced capital, but also natural or environmental capital. Most existing measures of capital neglect the latter. The most inclusive of all SNA measures,

Net National Product (NNP), still excludes depreciation of both human and natural capital along with transboundary environmental flows. One attempt to capture at least the first of these is the genuine savings index (GSI) due to Hamilton and Clemens (1999) and Hamilton (2000). Dasgupta (2001) has developed the same idea, calling it genuine investment. It is a measure of the change in a country's wealth. If wealth at a moment in time,  $t$ , is defined as  $V_t$ , a sufficient condition for wealth to be non-declining at that moment is that  $dV_t/dt \geq \sum_i p_{it} dK_{it}/dt \geq 0$ ,  $K_{it}$  being the  $i$ th type of capital (produced, human or natural) at time  $t$ , and  $p_{it}$  being the social opportunity cost of that type of capital.

In principle, NNP is simply the sum of consumption and genuine investment. That is  $NNP_t = C_t + dV_t/dt$ , where  $C_t$  is consumption at time  $t$ . It follows immediately that a test of the sustainability of consumption is whether it is less than or equal to NNP. Dasgupta (2001) showed that countries that recorded strongly positive average annual percentage rates of change in per capita GNP during the last three or four decades, showed strongly negative rates of change in per capita wealth over the same period. Consistent with this, Hamilton (2000) found that the majority of countries with less than the median world income have been declining in terms of per capita wealth.

In fact the poor fit between measures of performance based on income (GNP per capita) and wealth (genuine investment) causes concern not just because it masks the sustainability of economic development, but also because it misleads us as to the depth, the incidence and the causes of poverty. The genuine investment data show that many of people in Africa and South Asia are dissaving to maintain consumption. Few are drawing down savings accounts or converting financial assets to do so. Most are dissaving by converting real assets, usually environmental assets held in common rather than private property. While this comes at the cost of lower productive potential in the future, it is largely ignored by institutions concerned with both poverty and development. Indeed, it is regarded as an environmental problem of little or no relevance to the development process. In reality, by changing the portfolio of assets available to the poor, it has important implications for their development prospects.

## **2 Environmental assets in the decision process.**

Wealth - the value of the assets over which people have rights or entitlements - comprises both marketed private assets whose prices will reflect the discounted stream of incomes they yield, and non-marketed public assets to which people have rights of access though not ownership. The private value of these assets reflects the discounted stream of private benefits they yield. Their social value includes the impact on private benefit streams of the interactions between users of those assets.

Environmental assets comprise the resources of the biosphere that support the provision of environmental goods and services. Environmental goods and services are typically necessary both for life support and for the production of marketed goods and services, but are not themselves marketed. Environmental services include the regulation of atmospheric chemical composition; the regulation of global temperature, precipitation,

and other biologically mediated climatic processes; the regulation of hydrological flows; the storage and retention of water; soil retention and soil formation; the cycling, processing, and acquisition of nutrients; the movement of floral gametes; the trophic-dynamic regulation of populations and the provision of habitat (Daily, 1997).

To model the use of environmental assets, I assume that society has two sorts of capital available. Produced capital comprises durable manufactured assets. Natural capital comprises non-marketed environmental assets. These are usually subject to common property. The social decision problem is assumed to take the following form:

$$\text{Max}_{c_t, z_t} \int_0^{\infty} e^{-\rho t} u(c_t, f(k_t, r_t)) dt \quad (1)$$

subject to:

$$\dot{k}_t = z_t - \delta k_t \quad (2)$$

$$\dot{r}_t = f_r(k_t, r_t) - c_t - \delta r_t \quad (3)$$

$$f(k_t, r_t) - c_t - z_t = w \quad (4)$$

$$f(k_t, r_t) \geq \bar{c} \quad (5)$$

where:

$u(c_t, f(k_t, r_t))$  is a measure of social well-being

$k_t$  is the stock of produced capital

$r_t$  is the stock of environmental assets

$f(k_t)$  is output of private goods

$z_t$  is investment in produced capital

$w_t$  is 'investment' in natural capital

$\delta(k_t)$  is the depreciation rate of produced capital

$\delta(r_t)$  is the density net natural growth rate of environmental or natural capital.

$c_t$  is the consumption rate

$\rho$  is the discount rate.

(5) is a minimum consumption constraint and does not have a role to play immediately.  $u(\cdot)$ , social well-being, is a function of consumption and the state of the environment. It is assumed to be continuous, twice differentiable and to satisfy  $u_c > 0$  and  $u_{cc} < 0$  for. It depends both on consumption of marketed goods and the state of the environment.  $f(k_t)$  is net national product. It is also concave, continuous and twice differentiable:  $f_k > 0, f_{kk} < 0$ .

Initially, it is assumed that there are two choice or control variables available to the social decision-maker:  $c_t$ , the consumption rate, and  $z_t$ , investment in produced capital. Net 'investment' in natural capital is therefore determined residually. It captures the net

effect of activities that depreciate or degrade the environment, and activities that conserve or protect it. The stylised fact captured by this assumption is that the level of environmental pressure and the resources available to protect the environment tend to be inversely related to the rate of return on produced capital. That is, they tend to be procyclical.

The equation of motion for  $k_t$  describes the net growth of the produced capital stock in terms of investment,  $z_t$ , and a rate of depreciation that depends on the state of the environment,  $\delta(r_t)$ . The equation of motion for  $r_t$  describes the net growth of environmental assets in terms of a density-dependent growth or regeneration function,  $\gamma(r_t)$ , and the residual net investment in environmental protection,  $w_t$ .

The marginal efficiency of investment in each capital stock depends on the marginal impact on NNP of an increase in the capital stock due to investment, and the marginal impact of current investment on future capital growth.

To see how the interdependence between capital stocks is reflected in the dynamics of the system, we first take the case where  $c_t < 1$  for all  $t$ . From the current value Hamiltonian:

$$\tilde{H} = u(c_t, k_t, r_t) + \lambda_t [f(k_t) - \delta(r_t)k_t - c_t] + \mu_t [\gamma(r_t) - z_t - \eta(r_t)k_t] \quad (6)$$

the first order conditions for the maximisation of social utility include:

$$\tilde{H}_c = u_c - \lambda_t = 0 \quad (7)$$

$$\tilde{H}_z = \mu_t = 0 \quad (8)$$

$$-\tilde{H}_r = \lambda_t \delta'(r_t)k_t + \mu_t [\gamma'(r_t) - \eta(r_t)k_t] = 0 \quad (9)$$

$$-\tilde{H}_k = \lambda_t [f'(k_t) - \delta(r_t)] - \mu_t \eta(r_t)k_t = 0 \quad (10)$$

$$\tilde{H}_\lambda = f(k_t) - \delta(r_t)k_t - c_t - z_t = 0 \quad (11)$$

$$\tilde{H}_\mu = \gamma(r_t) - z_t - \eta(r_t)k_t = 0 \quad (12)$$

and the appropriate transversality conditions. Taking the time derivatives of (7) and (8), and substituting into (10), the condition on the evolution of the shadow (imputed) price of natural capital yields the following condition on the rate of change in the consumption rate:

$$\dot{\lambda}_t = \frac{u_c}{u_{cc}} \lambda_t - f'(k_t) - \delta'(r_t)k_t + \frac{u_f}{u_{cc}} f_k c_t \quad (13)$$

Using (4) this implies that the steady state rate of consumption and level of investment in produced capital are, respectively:

$$c^* = \frac{u_c}{u_f} \frac{f_k}{f_k} \frac{r^*}{r^*} \quad (14)$$

and

$$z^* = \frac{r^*}{r} \frac{r_t}{r_t} \frac{u_r}{u_c} \quad (15)$$

The steady state values of the two capital stocks can then be obtained directly.  $k^*$  depends on the level of investment, on the environment-dependent depreciation rate, and the regeneration rate of natural or environmental capital.

$$k^* = \frac{1}{r} \frac{r_t}{r_t} \frac{u_r}{u_c} \quad (16)$$

The steady state value of natural capital in turn depends on net 'investment' in the natural capital stock, and hence on the level of investment in produced capital and the consumption rate. That is:

$$r^* = \frac{1}{r} \frac{r_t}{r_t} \frac{u_r}{u_c} k^* \quad (17)$$

The 'golden rule' for natural capital growth is accordingly given by:

$$r^* = a_r r^* + r k^* + u_r / u_c \quad (18)$$

That is, along the optimal path the discount rate (the opportunity cost of capital) should equal the marginal rate of regeneration of natural capital less the marginal impact of natural capital on the depreciation of produced capital plus marginal rate of substitution between consumption and the state of the environment.

The trade-off between consumption and the environment accordingly has several dimensions. An increase in current consumption may be achieved by a reduction in current investment in all types of capital. However, by reducing future capital stocks, it will reduce future social utility both in terms of the capacity to produce consumer goods and through the effect on the environment. Conversely, an increase in investment will enhance future capacity to produce consumer goods, but unless consumption is reduced by the same amount, an increase in investment in produced capital will result in a reduction in natural capital. Since the rate of depreciation of the stock of produced capital

is inversely related to the state of the environment, an increase in investment in produced capital will therefore have both positive and negative effects on future capital stocks. On the one hand it will increase the rate of depreciation of produced capital through its effect on natural capital stocks. On the other, because of the density dependent nature of natural capital growth, it will increase the rate of natural regeneration.

### 3. Poverty, savings and environmental assets

With this model in mind, we can consider the impact of poverty on the environment and the development process. First we need to define poverty. The notion of poverty applied here is 'subjective poverty'. It is defined by the decision-maker's perception of the minimum acceptable level of consumption. Such perceptions vary both from agent to agent, and from society to society. They also vary over time. An income shock that drives consumption below the current minimum acceptable level will almost always induce a sharp change in savings and investment. That change may eventually be reversed, but only with a lag that depends on the speed of adjustment of consumption expectations. Since the model solves for the steady states of the system, it is the long run elasticity that matters.

There is no inequality-related measure of poverty that would be appropriate here, even though the social minimum acceptable level of consumption may well be a relative one. The important point is that the minimum acceptable level of consumption defines a subjective poverty point. Beyond that point the social decision-maker will choose to dissave. Hence the zero savings level of income for any society is regarded as the 'subjective' poverty point for that household, while any dissaving to maintain consumption may be taken to indicate that the society is in 'subjective' poverty. This term is borrowed from Drewnowski (1977), but what matters is that the behavioural response to falling incomes at some point results in dissaving. So a society will be said to be in 'subjective poverty' if the consumption rate is greater than one.

To capture the implications of this notion of poverty, suppose that the consumption rate is required to satisfy

$$c_t f'(k_t) \geq \bar{c}$$

for all  $t$ , where  $\bar{c}$  is the subjective poverty point. Implicitly this constraint has been non-binding in what has gone before. We are interested in the case where satisfaction of the constraint drives one or both of  $z_t$  and  $w_t$  below zero. That is, we are interested in the case where poverty induces dissaving in one or more types of capital as an optimal response. If either  $z_t < 0$  or  $w_t < 0$ , society is dissaving to maintain consumption. I am particularly interested in the case where  $z_t > 0$  and  $w_t < 0$ .

The model has the same structure as before, except that  $c_t$  is determined through choice of the investment rates,  $z_t$  and  $w_t$ , and that it is required to ensure that consumption is at least equal to  $\bar{c}$ . It now has the form:

$$\text{Max}_{w_t, z_t} \int_0^{\infty} e^{-\rho t} u(f(k_t)) z_t w_t r_t dt \quad (19)$$

subject to (2)-(5). The current value Hamiltonian and first order conditions are:

$$\tilde{H} = u(f(k_t)) z_t w_t r_t - \lambda_t (f(k_t) - c_t - r_t k_t) - \mu_t (z_t - r_t k_t) \quad (20)$$

the first order conditions for the maximisation of social utility include:

$$\tilde{H}_c = u_c f(k_t) - \lambda_t = 0 \quad (21)$$

$$\tilde{H}_z = z_t - \mu_t = 0 \quad (22)$$

$$-\dot{\lambda}_t = \lambda_t (r_t - \rho) - \mu_t r_t \quad (23)$$

$$-\dot{\mu}_t = \mu_t (\rho - r_t) - \lambda_t f_k \quad (24)$$

plus (11), (12) and the transversality conditions for the problem.

By taking time derivatives from (21) and (22), substituting in (23) and (24) and using (4) we are again able to identify the steady state values for the control variables:

$$z^* = \frac{u_f}{u_z} f_k^* \quad (25)$$

$$w^* = f_k^* \lambda^* \quad (26)$$

and hence for the capital stocks.

To see the effects of poverty on these, however, take the dynamical system that results from the optimisation of  $w_t$  and  $z_t$ .

$$\dot{k}_t = f(k_t) - c_t - r_t k_t = \frac{u_f}{u_z} f_k^* - \rho k_t \quad (27)$$

$$\dot{z}_t = f(k_t) - c_t - \rho z_t = \frac{u_f}{u_z} f_k^* - \rho z_t \quad (28)$$

and consider the properties of the system equilibria. Taking the differential of the system we have:

$$\begin{pmatrix} dk_t \\ dr_t \end{pmatrix} = \begin{pmatrix} \frac{u_f}{u_z} f_k k_t & \frac{r_t u_w}{u_z} r_t \\ f_k k_t & r_t \end{pmatrix} \begin{pmatrix} dk_t \\ dr_t \end{pmatrix} \quad (29)$$

We know that  $\frac{u_f}{u_z} f_k k_t > 0$ , and from the properties of  $r_t$  and  $u(\cdot)$  we know that  $\frac{r_t u_w}{u_z} > 0$ . The term  $r_t$  may be either positive or negative depending on the value of  $r_t$ . The two cases of interest are  $f_k k_t < 0$  and  $f_k k_t > 0$ , i.e. where there is or is not subjective poverty.

The eigenvalues of the Jacobian are the solution to  $R^2 - aR + b = 0$  where

$$a = \frac{u_f}{u_z} f_k k_t + r_t$$

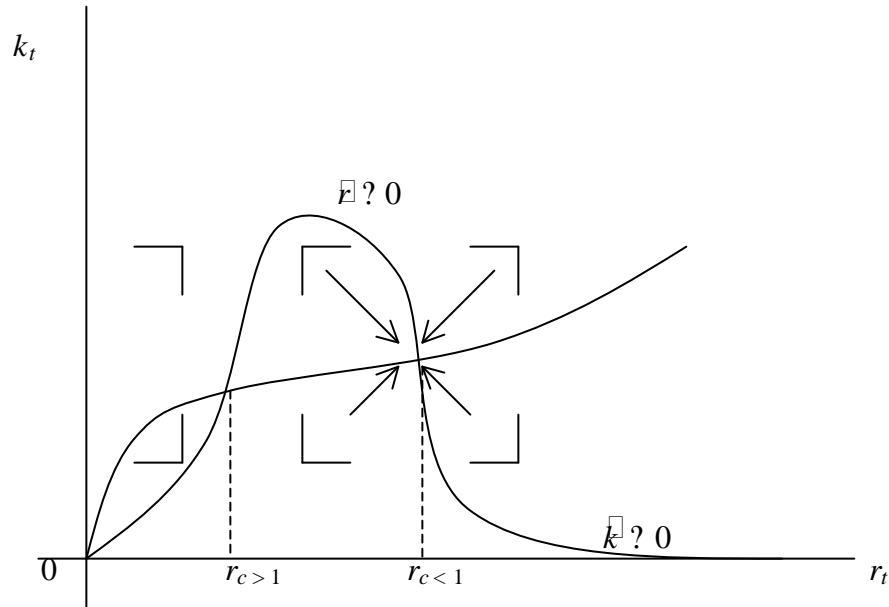
and

$$b = \frac{u_f}{u_z} f_k k_t r_t + \frac{r_t u_w}{u_z} r_t f_k k_t + c \frac{u_f}{u_z} f_k k_t$$

If  $f_k k_t > 0$  and  $w_t > 0$ , then in the steady state  $r_t < 0$ , and  $a < 0$  and  $b < 0$ , indicating that the equilibrium is a stable spiral.

If  $f_k k_t < 0$  and  $w_t > 0$ , then in the steady state  $r_t > 0$ , and  $a$  may be either positive or negative and  $b > 0$ , indicating that the equilibrium is an unstable node (if  $a > 0$ ) or a saddlepoint (if  $a < 0$ ). If poverty leads to dissaving and  $a > 0$ , there exists an equilibrium at which the level of dissaving balances the rate of regeneration of natural capital, but it is unstable. Any reduction in the size of the natural capital stock below the equilibrium level will tend to result in the destruction of that stock (Figure).

**Figure 1 Poverty and unconstrained equilibria**



#### 4 Discussion

The first point to make concerns the ratio of natural to produced capital in the developing economy. The standard model of economic development assumes that the initial conversion of natural assets (through mining, land clearance etc) create the preconditions for investment in produced capital, and the Solow-Hartwick investment rule establishes the necessary conditions for this conversion to be efficient. It thus implies a monotonic decline in the ratio of natural to produced capital. This has been qualified by the literature on the Environmental Kuznets Curve, which suggests that qualitative improvements environmental assets may occur at higher levels of income. Nevertheless, the process of economic development is assumed to lead to the progressive substitution of produced for natural capital. This, together with the accumulation of produced capital, should lead to a decline in the ratio of natural to produced capital.

The ratio of natural to produced capital depends on the level of investment in each capital type, bearing in mind that investment in natural capital may take the form of conservation of the natural environment. While this reflects the relative rate of return on each capital type, it also reflects the consumption requirements of the decision-maker. We are particularly interested in the impact of consumption needs that exceed the productive potential of the economy in the case where (a) the production of consumer goods depends on the level and productivity of manufactured capital, and (b) the environment is a direct source of utility. If the consumption rate is greater than one for levels of income below the subjective poverty point, then deepening poverty will be associated with a fall in the ratio of natural to produced capital.

The degree to which poverty induces a reduction in the stock of natural capital in any given society depends on the density-dependent regenerative powers of the environment in this model. In the real world it also depends on flows of development assistance, famine relief and so on. Pressure on environmental resources is reduced by the substitution of international transfers for disinvestment in natural capital. The addition of exogenously determined international transfers to the income equation (4) would clearly reduce the environmental effect of poverty, and in a North-South model with international transfers it would be possible to endogenise these, but that is not my concern here.

Since there is a poverty-induced equilibrium level of environmental quality it implies that at some level of natural capital the regeneration rate of the environment offsets the rate at which natural capital stocks are being drawn down. This is similar to the same steady state that falls out of the literature on the optimal exploitation of renewable resources, at least in the case where  $a < 0$ . The difference is that it is driven by a consumption constraint, and the marginal rate of substitution between marketed consumption goods and non-marketed environmental assets.

The model discussed in this paper has not been estimated, but the incidence of dissaving in poor countries has become much clearer since the development of the World Bank's

genuine savings index (latterly adjusted net savings). These indices take at least some account of changes in environmental stocks. Using this data, Dasgupta (2001) considered the evidence on what he calls genuine investment in both South Asia and Sub-Saharan Africa in the last third of the 20<sup>th</sup> century. He showed average levels of dissaving in this period that varied between 0.1% in India and 3.4% in Africa. The implications of this for the future well-being of people in those regions are hard to overlook. Sub-Saharan Africa is estimated to have lost around half of its wealth in the years between 1965 and 1997, much of it in the form of environmental assets.

The insight offered by the model described here is that disinvestment in natural resources may involve not only the substitution of high yielding produced assets for low yielding natural assets, but also the drawing down of natural assets to meet the consumption needs of societies in 'subjective' poverty. In many countries this may have been mitigated by the effect of international transfers, but even where aid flows have survived the changing priorities of the North environmental assets have been progressively eroded.

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