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Abstract:
The environmental impacts on an economy is studied over time using endogenous growth theory. Externalities from the environment on production are central in the analysis, and we examine whether an optimal path realizes more rapid economic growth. The paper is mainly focusing on developing countries, where production is largely influenced by the environmental quality. The result of the analysis indicates that the economic growth rate does not depend on the internalization of the environmental externality, but rather on the internalization of the human capital externality. The level of economic activity does, however, generally depend on the internalization of both externalities.

Keywords: Developing countries, endogenous growth, environmental externalities.

JEL classification: O13, O40, Q20

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1. Introduction

The environment influences economic activity in different ways, both indirectly through restrictions, abatements etc., and directly through its impact on production. In this paper we want to study the interactions between economic activity and the environment in the long run. By constructing an endogenous growth model with *environmental externalities*, it is analysed how these aspects affect the equilibrium growth rates. We also examine whether unregulated development not only results in an ineffective static allocation, but causes a lower than optimal growth rate, too. In particular, we want to study whether an improved environmental policy may enhance economic growth.

There are large differences across sectors and countries regarding the immediate dependence on the environment. While production in developed countries has become more and more independent, developing countries still have a large share of their production in sectors where the environment is a crucial factor. The focus of this paper will mainly be on the latter countries, but the analysis can be applied to industrialized contries as well. Ultimately, most production depends on the environment; if not directly, then indirectly through infrastructure and supply of inputs.

Many developing countries struggle with poverty and environmental degradation. There often seems to be a conflict between fighting these conditions. To take care of the environment requires resources that otherwise could be used on food production, education etc. On the other hand, one of the gists of the World Commission on Environment and Development's (WCED) 1987 report is that in order to decrease poverty, one has to stop environmental degradation. The reason is, as mentioned above, that the environment is crucial for much of the production in developing countries. Thus, it seems that the conflict mainly occurs in the short run, so that it corresponds to a traditional consumption-investment problem.

We want to analyse this problem more closely in our model. What kind of development will be realized on an optimal path, and what happens when the development is unregulated? Before proceeding, we want to emphasize three main reasons which explain why an unregulated economy may be on a suboptimal path, and we describe what effects they may have on the environment in particular. First, the environment is characterized by extensive external effects. Local environments are very dependent on neighbouring environments, and ecological relations are so complex that it is often impossible to calculate the full consequences of an individual's actions. The result is that when the single farmer invests in his land, he frequently has to pay the costs himself, while the benefits are shared with others. Second, there exist external effects of human capital, which implies that too little resources are used in education. This can lead to lower economic growth, and give less opportunities to invest in the environment in the future. Finally, time preference is probably high in many developing countries, i.e., the present is valued much more than the future. For example, the struggle to survive in the present is more important than next year's crop yield. Since many deteriorating actions on the environment create benefits today and costs in the future, the environment is often tormented.

In the next section a brief overview of the endogenous growth theory literature used in this analysis is provided. Section 3 develops the model of environment and growth, and section 4 contains the analysis and the results.

2. Endogenous growth theory[1]

This paper mainly follows Lucas (1988). In his paper, human capital is defined as human knowledge and skills accumulated by individuals (or groups of individuals). Increased human capital makes a person a more effective worker. An individual can continuously choose between an allocation of time devoted to production and to human capital accumulation. Human capital is accumulated with constant relative returns. In addition to the effective work force and physical capital, there is a positive external effect in the production. This is the average level of human capital. In the model, the endogenous economic growth rates vary between the unregulated and the optimal case. Thus, according to Lucas' model, a society can enhance economic growth by using more resources in human capital accumulation.

Both Lucas (1988) and Romer (1986) conclude that population growth contributes to growth in consumption per capita because of increasing returns. Their analyses do not, however, include environmental aspects.

A central question in this paper is how the environment influences economic growth. In Musu and Lines (1993) and Michel and Rotillon (1993), endogenous growth is combined with negative externalities (i.e. pollution) from economic activity on the environment, and this affects the utility of the individuals. These effects naturally limit the optimal economic growth rate. Gradus and Smulders (1993) extend the Lucas (1988) model by incorporating negative effects of pollution from economic activity on the marginal returns to education. Thus, long term production level is lowered. Van den Bergh (1993) has written an article about the interactions between economic growth, the environment and development. A good environment can, for instance, have positive influences on the economy, while economic activity can have negative effects on the environment.

[1] For a thorough survey of endogenous growth theory, see King (1992) and Hammond and Rodríguez-Clare (1993).

This paper takes an approach quite similar to Van den Bergh (1993), and incorporates the interactions between the environment and economic activity into an endogenous growth model similar to Lucas (1988). Then we try to analyse whether the environment has the same characteristic as human capital has in Lucas (1988), i.e. whether environmental policy has significance for economic growth.

3. The model of environment and growth

In this section the economic and environmental conditions of a region in a developing country are described, and this is used to construct the model. The principal focus is on an agricultural community, but the model can also be used for other societies which have other sorts of environmental characteristics. A community based on small, privately-owned farms is modelled. The individuals and the size and the quality of their land, are all assumed to be identical.

As mentioned before, the model is an extension of the Lucas (1988) model. The state of the economy is characterized by the two state variables; human capital and environmental quality. The individuals in the region maximize the utility of their consumption stream. At each point of time they allocate their working time between production and human capital accumulation, and they choose how much to produce of consumption goods. Production has deteriorating effects on the environment. Even though the future is uncertain, the model is deterministic.

A social planner is assumed to maximize the discounted utility of the consumption stream, c(t), summed over all individuals in the region, N(t):[2]

$$(1) \qquad maks\int_0^\infty \frac{N(t)}{1-\sigma}(c(t)^{1-\sigma}-1)e^{-\rho t}dt$$

The discount rate $\rho>0$ is equal to the time preference of the consumers. This parameter is treated as a constant, and plays a crucial role in our analysis. Initially, we assume that the private discount rate is equal to the social discount rate. However, in the end of section 4 we study the consequences of a difference between the private and the social discount rate. Utility depends continuously on the intertemporal elasticity of substitution $\sigma^{-1}>0$, which is also treated as a constant in our analysis. The choice of welfare function implies that in a

[2] In the beginning of section 4 we return to the question of how the socially optimal and the unregulated cases are treated.

growing population the utility of a representative individual in a future generation will be assigned a higher weight than a representative individual in the present generation (adjusted by the discounting factor).[3] The choice can be justified because a transfer of (discounted) utility from an individual at one point of time to an individual at another point of time leaves welfare unchanged. Finally, the population growth rate π is assumed to be exogenously given.

Production of consumption goods, Y(t), is expressed by the following function:

$$(2) \qquad Y(t) = f(h(t), s(t), u(t), i(t))$$

where h(t) and s(t) are the state of human capital or knowledge, and environmental quality respectively. The environment is frequently taken into analyses with a negative point of view (environmental problems, pollution etc.). However, Myers (1989) claims that the environment should be regarded as an overarching sector that addresses the dynamic interactions among other sectors. Thus, the environmental quality, such as soil fertility, water quality etc., is regarded as an important production factor in our analysis. Further, equation (2) states that production is also a function of two other variables. These are related to the *changes* in the state variables. u(t) is the share of working time devoted to production; the remaining time being used to accumulate human capital. i(t) is an indirect variable, and denotes the economic activity's impact on the environment, where positive impacts are defined to give positive values to i(t). For instance, environmental quality can be improved by tree planting, which increases soil fertility in later periods. This will naturally decrease production of consumption goods in the present, and hence production is decreasing in i(t). On the other hand, the farmers can squeeze the environment, e.g. their land, in order to produce more food or other consumption goods. If we for instance consider s(t) as water quality, and let -i(t) denote emission of pollution into the water, then the change in water quality is a decreasing function of -i(t), i.e. an increasing function of i(t). A restriction on the admissible emission, -i(t)≤k, could reduce production. The tighter the restriction is, the lower is production. Hence, if the restriction is binding, production would be increasing in actual emission, -i(t), and hence decreasing in i(t). It follows from the definitions and assumptions that the partial derivatives of f() with respect to h(t), s(t) and u(t) are positive, and the partial derivative with respect to i(t) is negative. From the definitions of u(t) and i(t), and the sign of the partial derivatives, we see that production is indirectly a decreasing function of both changes in the state variables.

We now assume that the change in environmental quality, denoted $\dot{s}(t)$, can be expressed in the following way:

[3] The criterion function is a Benthamite welfare function, and is the same function used in Lucas (1988).

$$(3) \qquad \dot{s}(t) = i(t) + \eta s(t)^{\theta_1} s_a(t)^{\theta - \theta_1}$$

where $s_a(t)$ denotes the average environmental quality in the region, η and θ are assumed to be positive constants, and θ_1 a constant between 0 and θ.[4] As mentioned above, the change in environmental quality is a function of economic activity, and from the definition of i(t) above, $\dot{s}(t)$ is an increasing function of i(t). Since the unit of measurement of neither s(t) nor i(t) is yet specified, we choose a linear relationship. Furthermore, it seems that nature, if released from damaging encroachment, has a remarkable ability to clean itself, and raise its own quality. However, in many cases, nature has a somewhat sliding critical load, such that its ability to clean diminishes when the environment deteriorates. This means that as the environmental quality worsens, less is required to deteriorate the environment further, all else being equal. Thus, if the farmers squeeze their land, fertility will decline slower if the quality initially is good than if it is bad. The result is that the cumulative effect of individual activities is often larger than the sum of the individual activities (Dixon *et al.* 1986). We therefore assume that the change in environmental quality is an increasing function of the *level* of environmental quality.

Musu and Lines (1993) use a similar model of nature's ability to clean itself. They assume that this ability is a decreasing function of accumulated pollution, which is equivalent to our specification. On the other hand, Michel and Rotillon (1993) assume that nature's ability to clean is proportional to accumulated pollution.

The assumption that nature's ability to improve itself increases when its quality improves, becomes difficult to accept as the quality approaches the quality of untouched nature. However, there is at least one reason for retaining this assumption. Since the environment is very deteriorated in most developing countries, a significant amount of time is needed for the environment to reach a virginal level. This means that the process towards this point of time is worth studying.

Finally, it is also natural to think that the environmental quality in the neighbouring areas is important for the evolution of the quality in a specific area. Desertification is an illustrative example. Tree planting prevents the wind from spreading sand, both in the area where the trees are planted, and in the surrounding areas. The chosen functional form $\eta s^{\theta_1} s_a^{\theta - \theta_1}$ assumes in addition that nature's ability to clean itself in a specific area does not function particularly well when the neighbouring environment is deteriorated, even if the quality of that particular area is good.

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[4] We discuss further restriction on θ in section 4.

For simplicity we now assume that the production function f() can be additively separated in the following way:

$$(4) \qquad f(h(t),s(t),u(t),i(t)) = g(h(t),s(t),u(t)) - i(t)$$

That is, a certain increase in tree planting in order to protect the environment, decreases production of consumption goods with a certain amount, irrespective of the level of the state variables and the variable u(t) (as long as they don't change). This is similar to the relationship between consumption and investment goods in an ordinary economic model. If we consider -i(t) as emission of pollution, then a decrease in emission caused by stronger restrictions would again decrease production with a certain amount, irrespective of the other variables. This is a natural assumption when we assume that *unrestricted emission* is a linear function of production, because then a certain emission reduction would require the same production reduction for different states of the economy, not considering abatement possibilities. Assuming that abatement possibilities are a constant share of emissions, then the separability assumption could still be maintained.

The function g() is assumed to be given by the Cobb-Douglas function:

$$(5) \qquad g(h(t),s(t),u(t)) = A(u(t)h(t)N(t))^{\alpha}s(t)^{\beta}h_a(t)^{\gamma}s_a(t)^{\omega}$$

The effective workforce and the effective environmental resource (i.e. land, forest etc.) are *internal inputs*. In endogenous growth theory, the *effective workforce* (or a similar variable) is central. Following Lucas' (1988) notation: The product u(t)h(t) measures an individual's effective workforce in production at each point of time. $u(t) \in [0,1]$ denotes the fraction of the working time devoted to production, and h(t) indicates effectivity per working time. h(t) can take on values ranging from 0 to ∞. However, we assume h(0)>0. For example, a person with a human capital factor of 2h(t) is the productive equivalent of two persons, who each have a factor of h(t). Since all individuals are assumed to be identical, the total effective workforce in production becomes u(t)h(t)N(t).

The variable s(t) represents an extension of endogenous growth theory by implementing the *environmental effectiveness* as an input variable. The size of the environmental resources is assumed to be constant over time, and thus s(t) measures environmental quality. The variable can take on values from 0 to ∞, and we assume s(0)>0. There are many examples showing that environmental quality has a large influence on production. The World Bank (1990) refers to a pilot project in China where several programs were initiated to reverse environmental degradation. These programs resulted in reduced erosion, and increased grain production per capita by more than 30 percent. De Franco *et al.* (1993) have analysed the macroeconomic effects of soil erosion in Nicaragua, and they found that after a period of 10 years, gross domestic product and private consumption were reduced by 14 and 13 percent respectively compared to a scenario without agricultural productivity loss induced by erosion.

The elasticities of the function g() for the effective work force and the environmental quality, are respectively α and β. The former is assumed to be between 0 and 1, but it is difficult to ascertain the value of β, especially because the unit of measurement of s(t) is unclear. In equations (3) and (4) we have chosen a specific functional form for the relationship between the change in s(t) and the production function, and this restricts the choice of unit of measurement. An alternative specification could have been to adjust the unit of measurement such that an area with environmental quality equal to $\hat{s}(t)$ produced as much as an area with doubled size and quality equal to $\frac{1}{2}\hat{s}(t)$, all else being equal. This would have been parallel to the specification of h(t). In this case, one could have argued that $\beta=1-\alpha$, because the production function is then linear in the internal inputs. However, then we would have been forced to choose a more general functional form in equation (3) or (4). We will return to the size of β in the analysis.

Physical capital is not included in the production function because this would have complicated the model without changing the qualitative results.[5] For example, one can think that physical capital is built into h(t)N(t), such that this denotes an aggregate of the work force and capital. In this case it must be assumed that the capital stock grows with the population growth rate, π.

In addition to the internal inputs, some *external inputs* also exist. Following Lucas (1988), we define the average human capital in the region, $h_a(t)$. The factor $h_a(t)^\gamma$ in the production function implies that production on each farm increases with the aggregate knowledge in the region, not only with the knowledge of the workers on a particular farm. The explanation for this is that farms have contact with each other, and share techniques and ideas. At the macro level, innovations that are made in one place can generate innovations in other places. Since we have assumed identical individuals, $h_a(t)=h(t)$. However, the notation $h_a(t)$ is still used when it is appropriate to distinguish between these variables. There is no need to impose any upward restriction on γ in the analysis, so we only assume $\gamma\geq 0$.[6]

The average environmental quality in the region, $s_a(t)$, can be defined in the same manner as $h_a(t)$. The factor $s_a(t)^\omega$, where $\omega\geq 0$, denotes an environmental externality. This means that one farm's fertile soil or abundance of trees make production on the surrounding farms larger.

[5] In many agricultural regions in developing countries the supply of physical capital is scarce. Furthermore, there are financial and other institutional conditions that make it difficult for rural people to purchase the scarce capital.

[6] In Lucas (1988), the following estimates based on U.S. data are obtained: $\alpha=0.75$ and $\gamma=0.417$. (Thus, $\alpha+\gamma>1$.)

According to Pearce and Markandya (1989) externalities often extend over wide geographic areas, and negative externalities may well be pervasive because of extensive eco-system linkages. The environment almost turns out to be a public good, especially in regions where the property rights are at best unclear. Thus, this factor is an important part of the production function. For instance, in several developing countries deforestation occurs both to provide fuel and to introduce livestock. However, when trees disappear, soil in the surrounding areas may erode, because of both downwind and downstream effects. Then the soil becomes less fertile, and agricultural productivity declines (Anderson 1987). Since s(t) has the same value for all environmental resources, $s_a(t)=s(t)$. Again, $s_a(t)$ will be used when it is approriate to distinguish between these variables. Until further, we will not impose any restriction on ω, but we return to this in the analysis.

We assume that produced consumption goods are consumed immediately. Thus, by substituting Y(t) with N(t)c(t), we obtain from equations (2)-(5):

$$(6) \qquad \dot{s}(t) = A(u(t)h(t)N(t))^{\alpha} s(t)^{\beta} h_a(t)^{\gamma} s_a(t)^{\omega} - N(t)c(t) + \eta s(t)^{\theta_1} s_a(t)^{\theta-\theta_1}$$

In the explanation of equation (5) we wrote that s(0)>0, and that s(t) can take on values from 0 to ∞. The latter specification does not automatically follow from the former, so the terminal condition $\lim_{t\to\infty} s(t)\geq 0$ must prevail. In the solution, this boundary is not binding.

Finally, it is assumed that human capital grows exponentially, and that the growth rate is $\varepsilon(1-u)\geq 0$, where ε is a constant:

$$(7) \qquad \dot{h}(t) = \varepsilon(1-u(t))h(t)$$

This process is assumed to take place internally, inside a group of people (e.g. a family).[7] Since h(0)>0 and $\dot{h}(t)\geq 0$, the terminal condition for h(t) is not binding.

4. Analysis of the model of environment and growth

Before we begin our analysis, it is important to emphasize the differences between the optimal and the unregulated cases. In the optimal case, the welfare function in (1) is maximized given the equations (6) and (7) and the conditions $h_a(t)=h(t)$ and $s_a(t)=s(t)$. The unregulated case is somewhat more complicated to describe. (1) is again maximized given the equations (6) and (7). The maximization builds on the idea of eternal individuals or dynasties, as formulated by Barro (1974). The idea is that individuals who live today, care

[7] This is completely analogous with Lucas (1988).

about their descendants as much as they care about themselves, adjusted by the time preference. Each individual's descendants, or dynasty, are assumed to grow at the same rate as the population growth. Thus, each person wants to maximize a constant share of the expression in (1). Furthermore, it is also assumed that the individuals take the exogenous paths of $h_a(t)$ and $s_a(t)$ for granted. Equilibrium is attained when these paths coincide with the paths for h(t) and s(t), respectively.[8]

The current value Hamiltonian, H^c, will have the following form in both cases:[9]

$$H^c = \frac{N}{1-\sigma}(c^{1-\sigma}-1) + \mu_1[A(uhN)^\alpha s^\beta h^\gamma s^\omega - Nc + \eta s^{\theta_1} s^{\theta-\theta_1}] + \mu_2[\varepsilon(1-u)h] \tag{8}$$

It follows from the assumptions that h_a=h and s_a=s. However, we still allow for the possibilitiy to distinguish between external and internal effects. $\mu_1(t)$ and $\mu_2(t)$ are the Pontryagin multipliers, and they can be intepreted as the shadow prices of the state variables s(t) and h(t), respectively. This implies that μ_1 and μ_2 must always be positive, since an increase in s or h will always increase the criterion function.

In both instances, the solution maximizes H^c with respect to c and u. Since H^c is concave in c and u, an interior solution is equivalent with the fulfilment of the first-order conditions. The restriction on c is that the consumption is positive, such that all permitted values of c are interior points. Thus, a maximum is obtained where the first-order condition is fulfilled:

$$\frac{\delta H^c}{\delta c} = Nc^{-\sigma} - \mu_1 N = 0 \quad \Leftrightarrow \quad c^{-\sigma} = \mu_1 \tag{9}$$

Equation (9) expresses that the marginal utility of increased consumption shall be equal to the alternative cost, given by the shadow price of the environment. The price of consumption goods is equal to this shadow price because a negative change in environmental quality is used indirectly as an input in the production function in a one-to-one manner (see equations (3) and (4)), and production is equal to consumption in the model.

The variable u lies in the interval [0,1], so we cannot rule out the possibility that the maximum is a corner solution. However, if we have an interior solution, we obtain:

[8] For a more detailed description, see Lucas (1988).

[9] From now on we omit the parameter t in the functions, except when it is necessary for clarification. We also ignore the possibility that μ_0=0.

(10) $$\frac{\delta H^c}{\delta u} = \mu_1 \alpha A u^{\alpha-1} N^{\alpha} h^{\alpha+\gamma} s^{\beta+\omega} - \mu_2 \varepsilon h = 0 \Leftrightarrow \mu_1 \alpha A u^{\alpha-1} N^{\alpha} h^{\alpha+\gamma} s^{\beta+\omega} = \mu_2 \varepsilon h$$

This relation expresses that the marginal value of working time should be equal in production and human capital accumulation. Here, too, the shadow price of the environment is used as a price of production.

At a maximum, changes in the shadow prices should be of the following form, where the subscript u denotes the unregulated case and o the optimal one:[10]

(11_u) $$\dot{\mu}_1 = \rho\mu_1 - \mu_1 \beta A (uN)^{\alpha} h^{\alpha+\gamma} s^{\beta+\omega-1} - \mu_1 \theta_1 \eta s^{\theta-1}$$

(11_o) $$\dot{\mu}_1 = \rho\mu_1 - \mu_1 (\beta+\omega) A (uN)^{\alpha} h^{\alpha+\gamma} s^{\beta+\omega-1} - \mu_1 \theta \eta s^{\theta-1}$$

(12_u) $$\dot{\mu}_2 = \rho\mu_2 - \mu_1 \alpha A (uN)^{\alpha} h^{\alpha+\gamma-1} s^{\beta+\omega} - \mu_2 \varepsilon (1-u)$$

(12_o) $$\dot{\mu}_2 = \rho\mu_2 - \mu_1 (\alpha+\gamma) A (uN)^{\alpha} h^{\alpha+\gamma-1} s^{\beta+\omega} - \mu_2 \varepsilon (1-u)$$

Here, maximizing with respect to s and h is different in the two cases. In the unregulated case, individuals regard the external factors as exogenously given, while in the optimal one, the external variables are internal for the system as a whole. The outcome is that for given values on the variables, the second and the third part of (11_u) have lower absolute values than the corresponding parts of (11_o), since $\beta \leq \beta+\omega$ and $\theta_1 \leq \theta$. Similarly, the second part of (12_u) has a lower absolute value than the corresponding part of (12_o), since $\alpha \leq \alpha+\gamma$.

The transversality conditions, illustrated in (13), will automatically be fulfilled:[11]

(13) $$\lim_{t\to\infty} e^{-\rho t}\mu_1(t) = 0$$
$$\lim_{t\to\infty} e^{-\rho t}\mu_2(t) = 0$$

To solve the problems of the two cases completely, we assume that the conditions for balanced growth are fulfilled. This means that consumption, environmental quality and human capital each grow at constant rates, the two shadow prices decline at constant rates,

[10] When we later remove the subscripts and refer to, for instance, equation (12), we are referring to both (12_u) and (12_o).

[11] We consider that the boundary on s is not binding in the solution. The fulfilment of (13) is seen directly from (11) and (12).

and the time allocation variable u(t) is constant. We don't study what happens outside the equilibrium path, i.e. how the state variables eventually converge towards this path.

In appendix A we solve this problem, assuming $\theta=1$. We then obtain the following equations:

$$(14) \qquad \frac{\dot{h}}{h} = \frac{1}{\alpha+\gamma}\left((1-\beta-\omega)\frac{\dot{s}}{s}-\alpha\pi\right)$$

For given population growth, there must be a fixed proportion between the growth rate of human capital and the growth rate of environmental quality. We notice that $\beta+\omega=1$ is inconsistent with interior solution, because positive population growth then requires that human capital h(t) decreases, which is impossible in the model. We also notice that if $\beta+\omega>1$, positive population growth requires that environmental quality s(t) decreases, assuming an interior solution, and from (15) below that consumption per capita c(t) also decreases, independent of the value of ρ. This may seem to be in accordance with empirical observations; several developing countries experience negative growth in consumption per capita (World Bank 1990), and Schramm and Warford (1989) write that environmental destruction is becoming norm rather than exception in most of the developing world. However, as proven in appendix B, this solution can not be optimal for sufficiently low values of ρ. Thus, if $\beta+\omega>1$, an interior solution may not be feasible. Since we are concentrating on possible interior solutions, from now we assume in the calculations that $\beta+\omega<1$, which means that the marginal productivity of s(t) and $s_a(t)$ together is decreasing when the other variables are constant. In this case we see from (14) that the environmental quality will grow so long as the population grows. This may not seem to be consistent with the empiri, as mentioned above, but it may indicate the direction of an optimal path.

As proven in appendix A, we also have:

$$(15) \qquad \frac{\dot{s}}{s} = \pi + \frac{\dot{c}}{c}$$

This relation states that both increased population growth and increased growth in consumption per capita go hand in hand with improved environmental quality. Thus, there is no antagonism between economic growth and environmental conservation in the model. This is in accordance with what Schramm and Warford (1989) write, i.e. that findings show, more often than not, that economic development and environmental protection go hand in hand. This positive interaction applies especially to developing countries, that make use of their natural resources more directly in production and consumption than industrial countries do.

Finally, the growth rates in consumption per capita become:

$$(16_u) \qquad \left(\frac{\dot{c}}{c}\right)_u = \frac{\varepsilon(\alpha+\gamma) - (\alpha+\gamma)\rho - (1-2\alpha-\beta-\omega-\gamma)\pi}{(\alpha+\gamma)\sigma + 1 - \alpha - \beta - \omega - \gamma}$$

$$(16_o) \qquad \left(\frac{\dot{c}}{c}\right)_o = \frac{\varepsilon(\alpha+\gamma) - \alpha\rho - (1-2\alpha-\beta-\omega)\pi}{\alpha\sigma + 1 - \alpha - \beta - \omega}$$

and the growth rates in environmental quality and human capital can then be calculated by using equations (14) and (15).

At first glance it is difficult to see which rate of consumption growth is the highest. However, if we assume that the intertemporal elasticity of substitution is less than or equal to 1 (i.e. $\sigma \geq 1$), it can be shown that u>0 implies that the optimal growth rate is highest. If σ is too small, the model does not make sense.[12]

The condition for growth in consumption per capita can now be found from equations (14)-(16). From (14) and (15) we find that if

$$(17) \qquad \alpha > 1 - \beta - \omega > 0$$

then per capita consumption grows, even if the resulting value of u is approximately equal to 1, and human capital almost constant. This condition applies to both cases. On the other hand, if (17) is not fulfilled, we find from equation (16) the following conditions for growth in c(t):

$$(18_u) \qquad \rho < \varepsilon + \pi - \frac{(1-\alpha-\beta-\omega)\pi}{\alpha+\gamma}$$

$$(18_o) \qquad \rho < \varepsilon\left(1 + \frac{\gamma}{\alpha}\right) + \pi - \frac{(1-\alpha-\beta-\omega)\pi}{\alpha}$$

Here, too, it is difficult to immediately establish whether condition (18_u) is stronger than (18_o). However, if we still assume that $\sigma \geq 1$, it can be shown that an interior solution implies that condition (18_u) is stronger. This means that consumption growth in the unregulated case implies consumption growth in the optimal case; but not vice versa.

[12] A detailed study by Hall (1988) showed that the intertemporal elasticity of substitution is small ($\sigma^{-1}<1$), if positive at all. Ragnar Frisch (1962) referred in a lecture three different calculations which all gave the result $\sigma=2$. These findings are all from developed countries, but there are no reasons to believe that σ should be any smaller in developing countries.

Before proceeding, it is worth noting that the difference between the unregulated and the optimal growth arises from the external effect of *human capital*, whereas the external effect of environmental quality does not create different growth rates in consumption. This is shown in appendix A. Why is there asymmetry between the two state variables? In the Cobb-Douglas function g() they are of the same form, so the difference is in how the development of human capital and environmental quality is specified. The distinction could arise from the fact that in the expression of the production function, the development of environmental quality $\dot{s}(t)$ is *additively-related* to the other variables (through the "impact variable" i(t)), while the development of human capital $\dot{h}(t)$ is related to the production function through the working time variable u(t), which is *multiplicatively-related* to the other variables. Thus, in the long run the effects of improving the environmental quality will be relatively smaller compared to human capital investments. Furthermore, it is also possible that the asymmetry is caused by the completely different ways in which the state variables change. The human capital is accumulated by relinquishing working time, while the environmental quality arises by renouncing production of consumption goods, which is also a part of the objective function (since Y=Nc), in favor of environmental improvements.

It is important to emphazise that the *level* of consumption can depend on whether the environmental externality is internalized. However, it is difficult to establish whether consumption is larger, or just the same, in the optimal case. Still, if it is assumed that human capital and its shadow price are not changed by internalizing the environmental externality, it can nevertheless be shown that both environmental quality and consumption per capita will increase.

We can see from equation (16) that consumption per capita grows more rapidly as ρ and σ become smaller, and ε becomes larger. A larger time preference ρ makes consumption today even more valuable compared to future consumption, such that less resources are left for investments. It is important to emphasize the time aspect in this analysis, because there often is a considerable lag between the time an investment to increase human capital or environmental quality is undertaken, and the time the benefits have effect. Similarly, if the environment is polluted, the farmer doesn't have to face the costs before after some time. Related to this, Pearce and Markandya (1989) claim that the theory of externalities needs to be broadened, because "the externalities have a temporal aspect in that resource degradation now precludes the benefits of future resource use." Anderson (1987) presents possible explanations why deforestation, which is a large problem in many developing countries, occurs, and one of them is a high time preference in combination with a lag between the time of felling trees and the time soil loses its fertility.

Lower elasticity of substitution, i.e. higher σ, brings about a higher valuation of uniform consumption compared to consumption growth with a lower start level. Increased effectiveness in human capital accumulation, represented by ε, makes larger economic growth attainable with unchanged relative resource use.

Increased population growth reinforces the growth in consumption per capita when the parameters in the production function satisfy the condition $(1-2\alpha-\beta-\omega)<0$.[13] Moreover, assuming a balanced growth solution, the growth of environmental quality will be larger when population growth increases, independent of the values of the parameters. These results follow because a larger population makes a particular production level attainable with less pollution of the environment or, equivalently, makes a larger production level possible without increasing the pollution of the environment. Moreover, the growth in production possibilities becomes larger as the parameters in the production function (especially α) become larger. In addition, individuals are assumed to put larger weight to future generations when the population growth increases (i.e., because of the dynasty behavior previously described). However, whether these effects are large enough to increase the growth in consumption per capita, depends as mentioned above on the condition $(1-2\alpha-\beta-\omega)<0$, which presumably is fulfilled. This result does not seem to agree with some of the usual predictions that have been made (e.g. WCED 1987). However, our result is in accordance with other articles mentioned in section 2 on endogenous growth.

Both the internal and the external effects of the environmental quality, expressed by β and ω respectively, have positive influences on the consumption growth rate. This applies to the unregulated, as well as the optimal case. The reason is obviously that improving the environment leaves greater proceeds, as the values of these parameters become larger. The external effect of human capital, expressed by γ, has positive influence on the consumption growth rate in the optimal case, while the influence is unclear in the unregulated case. This is because a higher γ increases the incentives for investments in human capital for a social planner, but not for a single individual. The internal effect of effective work force, expressed by α, has unclear final effects on the growth rates. This can be due to the fact that individuals wish to consume some of the increased production today, which means that the consumption *growth* will not necessarily be higher as α becomes larger.

[13] In the unregulated case, the condition $(1-2\alpha-\beta-\omega-\gamma)<0$ is sufficient.

Setting σ equal to 1, we are able to calculate the difference between optimal and unregulated growth:

$$(19) \qquad \left(\frac{\dot{c}}{c}\right)_o - \left(\frac{\dot{c}}{c}\right)_u = (\rho - \pi)\frac{\gamma}{1 - \beta - \omega}$$

Equation (19) is analogous with the corresponding equation in Lucas (1988). The result shows that the ineffectiveness of the unregulated case is small if the external effect of human capital is small ($\gamma \approx 0$), or if the time preference rate is approximately equal to the population growth rate ($\rho - \pi \approx 0$).[14] We see that the external effect of environmental quality does not have the same importance, although ω, too, affects the difference. As mentioned above, this occurs because the environmental externality does not give rise to different growth rates.

In the analysis we have assumed that ρ has the same value in the two cases. However, there are good reasons to expect that the time preference that is applied in the unregulated case, is larger than the social discount rate. In many respects, this is a normative question which economists do not have exclusive rights to answer. On the other hand, it is helpful to clarify this question.

First, is it *right* for a government to be paternalistic towards their inhabitants, i.e. interfere not only with market failure, but with "utility failure", too? Eventually, this is in conflict with traditional economic thinking. Second, do consumers *wish* that a government should be paternalistic in this way towards themselves? It has been shown that individual time preference is not necessarily consistent with individual lifetime welfare maximization (Pearce *et al.* 1990). Finally, should the government take into consideration other people than those who live and have influence today, especially future generations? The latter question is probably the most frequently addressed in this debate, and the one in which most people affirmatively agree upon. Sen (1982) refers to the argument that members of the present generation may be more concerned about the welfare of future generations in their public or political roles than in their day-to-day market activities (i.e. the dual-role argument). This implies that the social discount rate is lower than the market rate. In the model we have analysed, individuals think of their descendants as of themselves, so we have covered this consideration. However, it may be unrealistic to assume that this is fulfilled in the unregulated case.

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[14] When $\sigma=1$, interior solution is only feasible when $\rho>\pi$. Otherwise, u=0, and the individuals will keep postponing consumption forever.

If we now assume that ρ_o is less than ρ_u, we get the following difference between the growth rates (for $\sigma = 1$)

$$\left(\frac{\dot{c}}{c}\right)_o - \left(\frac{\dot{c}}{c}\right)_u = (\rho_u - \pi)\frac{\gamma}{1-\beta-\omega} + (\rho_u - \rho_o)\frac{\alpha}{1-\beta-\omega} \tag{20}$$

(20) is similar to (19), except for an additional term. This term is proportionate to the difference between the two time preference rates.

6. Conclusion

A comparison between unregulated and optimal development has indicated that *increased economic growth*, including growth in environmental quality, may be possible, if an optimal path is chosen. However, the results also state that it is the external effect of human capital that originates too little growth in an unregulated case. The environmental externality only originates different *levels* of consumption and environmental quality. Finally, it was also shown that a higher time preference rate may result in lower growth, and in the worst case, determine that the growth in consumption per capita is negative instead of positive. It is important to note, however, that these conclusions build on some controversial assumptions, and we have also restricted our analysis to possible interior solutions.

The environment is deteriorating to a large extent in many places, especially in developing countries. This is not captured in the interior solutions we have studied in this analysis, even in the unregulated case. However, we observed that with particular values on some parameters, the results could be quite different, with corner solutions rather than interior solutions. Thus, in any case there is a need for a closer examination to understand which mechanisms operate. For instance, it could be interesting to incorporate uncertainty and informational aspects.

Finally, it is worth noting that the results state that growth in consumption goes hand in hand with an improved environment. This confirms that it is important to take nature into consideration when making economic decisions.

Appendix A

Differentiating (9) gives:

$$(A1) \qquad -\sigma\frac{\dot{c}}{c} = \frac{\dot{\mu}_1}{\mu_1}$$

(11) can be written:

$$(A2_u) \qquad \frac{\dot{\mu}_1}{\mu_1} = \rho - \beta A(uN)^{\alpha} h^{\alpha+\gamma} s^{\beta+\omega-1} - \theta_1 \eta s^{\theta-1}$$

$$(A2_o) \qquad \frac{\dot{\mu}_1}{\mu_1} = \rho - (\beta+\omega) A(uN)^{\alpha} h^{\alpha+\gamma} s^{\beta+\omega-1} - \theta \eta s^{\theta-1}$$

Substituting (A1) into (A2), we obtain:

$$(A3_u) \qquad \rho + \sigma\frac{\dot{c}}{c} - \theta_1 \eta s^{\theta-1} = \beta A(uN)^{\alpha} h^{\alpha+\gamma} s^{\beta+\omega-1}$$

$$(A3_o) \qquad \rho + \sigma\frac{\dot{c}}{c} - \theta \eta s^{\theta-1} = (\beta+\omega) A(uN)^{\alpha} h^{\alpha+\gamma} s^{\beta+\omega-1}$$

Because of analytical reasons it is convinient to look at the specific case $\theta=1$. From the assumptions on balanced growth, the left hand side of (A3) is then constant over time. Thus, differentiating the right-hand side gives for both cases (when $\dot{N}/N^2$ is replaced by π):

$$(A4) \qquad \alpha\pi + (\alpha+\gamma)\frac{\dot{h}}{h} + (\beta+\omega-1)\frac{\dot{s}}{s} = 0 \quad \Leftrightarrow \quad \frac{\dot{h}}{h} = \frac{1}{\alpha+\gamma}\left((1-\beta-\omega)\frac{\dot{s}}{s} - \alpha\pi\right)$$

Equation (6) can be written like this (for $\theta=1$):

$$(A5) \qquad \frac{\dot{s}}{s} = A(uN)^{\alpha} h^{\alpha+\gamma} s^{\beta+\omega-1} - \frac{Nc}{s} + \eta$$

We observed that the right-hand side of (A3) must be constant. Thus, the first part of the right-hand side of (A5) must also be constant, and the growth rate of s and the parameter η are constant as well. This implies that Nc/s must be constant over time, too, such that:

$$(A6) \qquad \frac{\dot{s}}{s} = \pi + \frac{\dot{c}}{c}$$

Replacing (10) into (12) gives further:

$$(A7_u) \qquad \frac{\dot{\mu}_2}{\mu_2} = \rho - \frac{\mu_1}{\mu_2}\alpha A(uN)^{\alpha}h^{\alpha+\gamma-1}s^{\beta+\omega} - \varepsilon(1-u) = \rho - \varepsilon$$

$$(A7_o) \qquad \frac{\dot{\mu}_2}{\mu_2} = \rho - \frac{\mu_1}{\mu_2}(\alpha+\gamma)A(uN)^{\alpha}h^{\alpha+\gamma-1}s^{\beta+\omega} - \varepsilon(1-u) = \rho - \varepsilon - \frac{\gamma}{\alpha}(\varepsilon - \frac{\dot{h}}{h})$$

We differentiate (10) and obtain the following equation:

$$(A8) \qquad \frac{\dot{\mu}_1}{\mu_1} + \alpha\frac{\dot{N}}{N} + (\alpha+\gamma)\frac{\dot{h}}{h} + (\beta+\omega)\frac{\dot{s}}{s} = \frac{\dot{\mu}_2}{\mu_2} + \frac{\dot{h}}{h}$$

By use of (A1), (A4), (A6) and (A7), growth in μ_1, h, s, and μ_2 can be expressed by exogenous parameters and the growth rate of c. Moreover, the population growth is given by the rate π. Together, this gives the following expressions for the growth in consumption per capita:

$$(A9_u) \qquad \left(\frac{\dot{c}}{c}\right)_u = \frac{\varepsilon(\alpha+\gamma) - (\alpha+\gamma)\rho - (1-2\alpha-\beta-\omega-\gamma)\pi}{(\alpha+\gamma)\sigma + 1 - \alpha - \beta - \omega - \gamma}$$

$$(A9_o) \qquad \left(\frac{\dot{c}}{c}\right)_o = \frac{\varepsilon(\alpha+\gamma) - \alpha\rho - (1-2\alpha-\beta-\omega)\pi}{\alpha\sigma + 1 - \alpha - \beta - \omega}$$

From equation (A8), from which (A9) is deduced, we note that the difference between the unregulated and the optimal growth arises from the external effect of human capital, whereas the external effect of environmental quality does not create different growth rates in consumption. This follows from the fact that only the expression of the growth of μ_2 is different for the two cases in expression (A8). In (A7) we see that this difference is due to the valuation of the external effect of human capital, expressed by γ.

Appendix B

We want to prove that an interior solution path where consumption is monotonically decreasing over time, is not optimal for sufficiently low values of the time preferance ρ:

Consider a solution path where c(t) is decreasing over time. Let $t_1<t_2$, and let T_i denote the time interval $(t_i-\delta,t_i+\delta)$ for i=1,2, where $\delta<(t_2-t_1)/2$ is a fixed, marginal constant. We construct a new path where c(t) is marginally lower in the interval T_1, and we denote this by writing dc(t)<0 for $t\in T_1$. Furthermore, dc(t)>0 for $t\in T_2$, and dc(t)=0 for all other values of t. We also require that dc(t), $t\in T_2$, is determined so that the new path s(t), $t\geq t_2+\delta$, is identical to the original path. Moreover, dc(t) is constant over each time interval T_1 and T_2. Finally, u(t) and thus h(t), are not changed. It is straightforward that this new path is feasible if the original path is feasible. If we can prove that the criterion function in (1) increases on the new path compared to the original path for sufficiently low values of ρ, then we have proved that the solution path is not optimal for these values.

From (6) we find that $d\dot{s}(t) \geq$- N(t)dc(t)>0 for $t\in T_1$. Further, in the period between T_1 and T_2, since s(t) is increased, (6) states that $d\dot{s}(t) > 0$. Thus, entering time interval T_2, we must have:[15]

$$(B1) \qquad ds(t_2-\delta) > -dc(t_1)\int_{t_1-\delta}^{t_1+\delta} N(t)dt$$

Moreover, in the time interval T_2, (6) states that $d\dot{s}(t) \geq$- N(t)dc(t). Thus, in order for ds(t)=0 for $t\geq t_2+\delta$, we must have:

$$(B2) \qquad dc(t_2)\int_{t_2-\delta}^{t_2+\delta} N(t)dt \geq -\int_{t_2-\delta}^{t_2+\delta} d\dot{s}(t)dt = ds(t_2-\delta) > -dc(t_1)\int_{t_1<\delta}^{t_1+\delta} N(t)dt$$

Now, let dW denote the change in the criterion function (1). Then we obtain:

$$(B3) \qquad dW = \int_{t_1-\delta}^{t_1+\delta} N(t)dU(t)e^{-\rho t}dt + \int_{t_2-\delta}^{t_2+\delta} N(t)dU(t)e^{-\rho t}dt$$

[15] Remember that dc(t) is constant over T_1, and thus equal to $dc(t_1)$.

where dU(t)=U'(c(t))dc(t), and U'(c(t))=c(t)$^{-\sigma}$. Substituting from (B2), we have:

$$(B4)\qquad dW > dc(t_1)\left(\int_{t_1-\delta}^{t_1+\delta} N(t)c(t)^{-\sigma}e^{-\rho t}dt - \frac{\int_{t_1-\delta}^{t_1+\delta} N(t)dt}{\int_{t_2-\delta}^{t_2+\delta} N(t)dt}\int_{t_2-\delta}^{t_2+\delta} N(t)c(t)^{-\sigma}e^{-\rho t}dt\right)$$

Note that e$^{-\rho t}$ in the first integral is less than or equal to $e^{-\rho(t_1-\delta)}$, and e$^{-\rho t}$ in the second integral is larger than or equal to $e^{-\rho(t_2+\delta)}$. Moreover, since consumption is decreasing over time, c(t)$^{-\sigma}$ in the first integral is less than or equal to c(t_1+δ)$^{-\sigma}$, while c(t)$^{-\sigma}$ in the second integral is larger than or equal to c(t_2- δ)$^{-\sigma}$. Thus, (B4) gives:

$$(B5)\qquad dW > -dc(t_1)\left(-c(t_1+\delta)^{-\sigma}e^{-\rho(t_1-\delta)}\int_{t_1-\delta}^{t_1+\delta} N(t)dt + \frac{\int_{t_1-\delta}^{t_1+\delta} N(t)dt}{\int_{t_2-\delta}^{t_2+\delta} N(t)dt}c(t_2-\delta)^{-\sigma}e^{-\rho(t_2+\delta)}\int_{t_2-\delta}^{t_2+\delta} N(t)dt\right)$$

$$= -dc(t_1)e^{-\rho(t_1-\delta)}\int_{t_1-\delta}^{t_1+\delta} N(t)dt\left(e^{-\rho(t_2-t_1+2\delta)}c(t_2-\delta)^{-\sigma}-c(t_1+\delta)^{-\sigma}\right)$$

Since c(t) is decreasing over time, we can choose sufficiently low values of ρ so that the paranthesis is positive, and then dW>0. This completes the proof.

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