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Sustainability in One and Two Sector Endogenous Growth Models: A Note

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SUSTAINABILITY IN ONE AND TWO SECTOR ENDOGENOUS GROWTH MODELS: A Note

by

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Abstract
In this paper one and two sector growth models which take account of environmental deterioration and abatement are analyzed. A growth model is formulated in which environmental resources are used in production. As a consequence of the use of environmental resources the quality of the natural environment deteriorates which has in turn a negative effect on production and welfare. On the other hand the natural environment has self-regenerating capacities. Furthermore, pollution can be diminished by devoting some part of the output from the production process to abatement activities. It appears that in a one sector model, in a situation of balanced growth, production, consumption, investment in physical capital, abatement and the use of environmental resources have equal (positive) growth rates, while the quality of the natural environment remains constant. If we add to the model a sector which produces knowledge about the efficient use of environmental resources, we find that in a situation of balanced growth all growth rates must be equal to zero. So, we find the counterintuitive result that adding the possibility of the production of knowledge of an efficient use of environmental resources breaks the balanced growth rate of the economy down to zero. The only way out is to relax the definition of balanced growth, in order to be able to study sustainable development in growth models in a meaningful way.

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1. Introduction

In recent years, economists have been showing a growing interest in environmental issues. Especially the link between environmental policies and economic growth has the attention of both economists and politicians. The concept of sustainable development plays a central role in the discussion. With sustainable development one refers to ecologically sustainable development, which means maintaining the natural (i.e. ecological) basis of economic development. In order to be able to analyse the conditions under which sustainable development is possible, the interactions between the environment and the economy have to be modelled. On the one hand the environment influences production possibilities and welfare, while on the other hand production diminishes the quality and quantity of environmental resources, by the use of resources and through pollution. A continuously decreasing quality and quantity of natural resources cannot support growing or even constant levels of physical economic output in the distant future.

In the seventies and eighties the impact of pollution, which arises as an inevitable side-product of economic activity, was studied in the context of Ramsey type growth models (see e.g. Forster (1973), Gruver (1976) and Van der Ploeg and Withagen (1991)). In the past few years, in the slipstream of the new endogenous growth theory, the interest in growth models which incorporate the environment is renewed. Gradus and Smulders (1993) analyse two endogenous growth models in which pollution arises as an inevitable by-product from the use of capital in production and enters the social welfare function as a disutility. Although in such models the conventional balanced growth paths can be derived, nothing can be said about the ecological sustainability of the economy in the long run. In order to be able to analyse the ecological sustainability, the absorption and regenerative capacities of the natural environment have to be modelled. Bovenberg and Smulders (1993) develop a growth model in which the natural environment on the one hand deteriorates as a consequence of a polluting production process, but on the other hand has certain self-regenerating capacities. The regeneration function they use is based on Tahvonen and Kuuluvainen (1991). This regeneration function is such that the higher the level of pollution the lower the self-regenerative capacities of the natural environment.

In this paper one and two sector growth models are developed, in which the environment plays a role both in production and welfare. On the one hand the environment deteriorates due to production and on the other hand it has certain self-regenerative capacities. Moreover, the models allow for abatement activities. It appears that in a one sector model, in a situation of balanced growth, production, consumption, investment in physical capital, abatement and the use of environmental resources have equal (positive) growth rates, while the quality of the natural environment remains constant. If we add to the model a sector which produces knowledge about the efficient use of environmental resources, we find that in a situation of balanced growth all growth rates must be equal to zero. So, we find the counterintuitive result that adding the possibility of the production of knowledge of an efficient use of environmental resources breaks the balanced growth rate of the economy down to zero. In sections 2 and 3 conditions for optimal and balanced growth in one respectively two sector models are analysed. Section 4 gives some suggestions to relax the definition of balanced growth in order to make the models less restrictive. Finally, section 5 concludes.

2. Abatement in a one sector model

Consider an economy with only one production-sector producing a final good, Y, using physical capital, K, and environmental resources, Q, as inputs. Q can be thought of as the use of natural resources like energy, or other kinds of polluting use of environmental resources. Without loss of generality we assume that Y has constant returns with respect to K and Q. Furthermore, the natural environment, i.e., the aggregate stock of natural capital, E, serves as an input in the production process. A better state of the natural environment involves for example healthier workers with higher marginal productivity. So, we assume that there is both extractive use (Q) and non-extractive use (E) of the natural environment.

The use of environmental resources in the production of Y reduces the quality of the natural environment. On the other hand the quality of the environment can be improved by abatement activities (A). These abatement activities go at the expense of consumption and investment in physical capital, as final goods can either be consumed, or invested in order to accumulate physical capital, or used for abatement activities. We distinguish between gross and net pollution. Net pollution P is a function of the amount of environmental resources Q used in production (gross pollution) and the amount of abatement activities A.

Furthermore, the natural environment has some self-regenerative capacities which depend upon the quality of the natural environment itself and upon the level of net pollution. Like Bovenberg and Smulders we follow Tahvonen and Kuuluvainen (1991) for the specification of the regeneration function of the natural environment. The regenerative capacity of the natural environment decreases with an increasing level of net pollution, while the level of net pollution decreases with an increasing level of abatement. Furthermore, it is assumed that the higher the quality of the natural environment the larger the (negative) influence of pollution on the regenerative capacity. So, when the quality of the natural environment improves it becomes increasingly difficult to reach further improvements of the same (relative) size. Finally, the higher the level of (gross) pollution, the larger the effect of an extra unit of abatement. This means that reducing pollution gets increasingly difficult. As we will see in the sequel, these assumptions will restrict the set of feasible balanced growth paths seriously. It must, however, be noted that the assumptions made presuppose that the quality of the natural environment is such that it is not the case that some point of no return is passed, beyond which irreversible damage has occurred. Beyond such a point of no return, it could be the case that the (negative) influence of pollution on the regenerative capacities of the natural environment increases as the environment deteriorates.

The final good can either be consumed (C), used for abatement (A) or invested ($\dot{K}$) in order to accumulate physical capital, which serves future consumption and abatement. Social welfare, W, is assumed to be dependent upon the utility of a representative consumer, who is supposed to be infinitely lived. Instantaneous individual utility depends upon individual consumption c (c=C/L, where C is aggregate consumption and L is population which is assumed to be constant over time[1]) and upon the quality of the natural environment: u(c,E). The rate of time preference is given by θ.

Mathematically the model looks as follows:

$$W = \int_0^\infty e^{-\theta t} u(c,E) \, dt$$

$$\dot{K} = Y(K,Q,E) - C - A$$

$$\dot{E} = N(E,P(Q,A))$$

with $N_P<0$, $N_{PP}<0$, $N_{EP}<0$, $P_Q>0$, $P_A<0$, $P_{QA}<0$ and $P_{AA}>0$. A dot represents a time derivative, subscripts attached to a function symbol denote partial derivatives.

We will now consider under which conditions balanced growth is feasible. Balanced growth is defined as a situation in which all variables grow at a constant (possibly zero) rate and in which the allocative variables, i.e., C/Y and A/Y, are constant. It is easy to see that in a situation of balanced growth A, C, Y and $\dot{K}$ grow at the same rate and consequently also K grows at this common rate. Let us denote this common growth rate by g and the growth rates of Y, C, K, A, Q and E respectively by g_Y, g_C, g_K, g_A, g_Q and g_E. So, in balanced growth we have:

$$g = g_Y = g_C = g_A = g_K \tag{2.1}$$

From the production function we have:

$$g_Y = \alpha g_K + (1-\alpha) g_Q + \mu_E \, g_E \tag{2.2}$$

where α is the production-elasticity of K, (1-α) is the production-elasticity of Q and μ_E is the

[1]Although labour is not modelled explicitly in the production function, it can be assumed that the production function is dependent upon the size of the working force.

production-elasticity of E. Furthermore, from the regeneration function we have :

$$g_{\dot{E}} = \lambda_E \, g_E + \lambda_P \, (\lambda_Q \, g_Q + \lambda_A \, g_A) \tag{2.3}$$

where λ_E is the regeneration-elasticity of E, λ_P is the regeneration-elasticity of P, λ_Q is the pollution-elasticity of Q and λ_A is the pollution-elasticity of A. In a situation of balanced growth we have that:

$$\dot{g}_E = g_{\dot{E}} - g_E = 0 \tag{2.4}$$

Now we can derive from (2.1), (2.2), (2.3) and (2.4) that, in a situation of balanced growth, we have the following relations between the growth rate of the quality of the natural environment and the growth rate of abatement and between the growth rate of the use of environmental resources and the growth rate of abatement:

$$\left(1 - \lambda_E + \lambda_P \, \lambda_Q \, \frac{\mu_E}{(1-\alpha)}\right) g_E = \lambda_P \, (\lambda_Q + \lambda_A) \, g_A \tag{2.5}$$

and

$$\begin{aligned} g_Q &= g_A - \frac{\mu_E}{(1-\alpha)} \, g_E \\ &= \left[1 - \frac{\mu_E}{(1-\alpha)} \cdot \frac{\lambda_P \, (\lambda_Q + \lambda_A)}{\left(1 - \lambda_E + \lambda_P \, \lambda_Q \, \mu_E / (1-\alpha)\right)}\right] g_A \end{aligned} \tag{2.6}$$

Note that the specification of the regeneration function implies certain restrictions with respect to the growth rate of the quality of the natural environment on a balanced growth path. The quality of the natural environment can only increase at a constant rate if net pollution decreases at an increasing rate, which would require either abatement to grow at an increasing rate or the use of natural resources to decrease at an increasing rate. Hence on a balanced growth path the quality of the environment and the level of net pollution have to be constant ($g_E = g_P = 0$). But then we derive from (2.5) and (2.6) that the growth rates of abatement and the use of environmental resources are equal to each other ($g_A = g_Q$). Furthermore, in order to keep the growth rate of net pollution equal to zero, it is necessary that the pollution-elasticity of abatement is equal to minus the pollution-elasticity of the use of environmental resources ($\lambda_A = -\lambda_Q$). The latter equality is rather restricting, since it implies that, given the assumptions with respect to the regeneration function, only for a very special relationship between on the one hand net pollution and on the other hand the use of environmental resources and abatement there is a feasible balanced growth path.

Finally, we will analyse the conditions under which balanced growth is also optimal. Society's optimisation problem is given by:

$$\max \int_0^{\infty} e^{-\theta t}\, U(c(t),E(t))\, dt$$

$$s.t.\ \dot{K} = Y(K,Q,E) - C - A$$

$$\dot{E} = N(E,P(Q,A)) \tag{2.7}$$

The social optimal plan implies the following conditions:

$$\frac{\dot{c}}{c} = \frac{1}{\rho}\left[\frac{\partial Y}{\partial K} + \frac{U_{cE}\,\dot{E}}{U_c} - \theta\right] \tag{2.8}$$

where $\rho = -c.U_{cc}/U_c$, and

$$\frac{\partial Y}{\partial K} = \frac{\partial N}{\partial P}\frac{\partial P}{\partial A}\left[L\,\frac{U_E}{U_c} + \frac{\partial Y}{\partial E}\right] + \frac{\partial N}{\partial E} + \frac{\dot{\mu}}{\mu} - \frac{\dot{\lambda}}{\lambda} \tag{2.9}$$

where λ and μ denote respectively the shadow price of physical capital and of natural resources.

Equation (2.8) gives the optimal allocation between current and future consumption. Consumption is postponed if the marginal contribution to future utility of consumption foregone exceeds the rate of time preference. The marginal contribution to future utility of consumption foregone, which can be called the social interest rate, is represented by the first two terms in long brackets in equation (2.8). Savings add to the physical capital stock and increase future output of the final good. Furthermore, future consumption is higher valued if the environment improves. So, a necessary condition for positive per capita growth is that the social interest rate exceeds the rate of time preference.

Equation (2.9) states that the natural environment should yield the same return as physical capital. Returns on the natural environment (right hand side of equation (2.9)) consist of increased marginal utility, increased marginal productivity, and increased regenerative capacity of the natural environment and furthermore it consists of changes in relative prices (capital gains).

On a balanced growth path (2.8) and (2.9) can be written as

$$g = \frac{1}{\rho}\,(r-\theta) \tag{2.10}$$

respectively

$$r = \frac{\partial N}{\partial P}\frac{\partial P}{\partial A}\left[L\frac{U_E}{U_c} + \frac{\partial Y}{\partial E}\right] + \frac{\partial N}{\partial E} + g \qquad (2.11)$$

where

$$r = \frac{\partial Y}{\partial K}$$

The optimal balanced growth rate is now given by the intersection of the two lines represented by (2.10) and (2.11). (2.10) gives the growth rate associated to any rate of return (r) that is preferred given intertemporal preferences, while (2.11) gives the growth rate that is sustainable for any r in the long run and that is consistent with optimal allocation.

3. Abatement in a two sector model

Let us consider an economy consisting of two sectors. Following Bovenberg and Smulders (1993) we add a knowledge or learning sector, producing knowledge, h, about an efficient or pollution-saving use of environmental resources. Like the final good sector, also the knowledge sector exhibits constant returns to scale with respect to its two inputs physical capital and effective use of environmental resources. The effective input of environmental resources is given by h.Q. Now the total stock of physical capital and the total effective use of environmental resources is allocated between the final good sector and the knowledge sector. Let u respectively v be the share of physical capital and the share of effective environmental resources used in the final goods sector, and let (1-u) respectively (1-v) be the share of physical capital and the share of effective environmental resources used in the knowledge sector: K_Y = u.K, h.Q_Y = v.h.Q, K_H = (1-u).K and h.Q_H = (1-v).h.Q. Let the growth of knowledge be given by:

$$\dot{h} = H(K_H, h.Q_H)$$

Analogously to the one-sector model, we have in a situation of balanced growth:

$$g_Y = g_C = g_K = g_A \qquad (3.1)$$

From the production function of the final good we have:

$$g_Y = \alpha g_K + (1-\alpha)(g_Q+g_h) + \mu_E\, g_E \tag{3.2}$$

while from the production function of knowledge we have:

$$g_H = \epsilon g_K + (1-\epsilon)(g_Q+g_h) \tag{3.3}$$

where ϵ is the knowledge-elasticity of physical capital and $(1-\epsilon)$ is the knowledge-elasticity of the use of environmental resources.

In a situation of balanced growth $g_H=g_h$ and $g_{\dot{K}}=g_K$. Using (3.1), (3.2) and (3.3) we can derive that:

$$g_Q = -\epsilon \frac{\mu_E}{(1-\alpha)}\, g_E \tag{3.4}$$

Furthermore, using (2.3) we have that:

$$\left(1 - \lambda_E + \epsilon\, \lambda_P\, \lambda_Q \frac{\mu_E}{(1-\alpha)}\right) g_E = \lambda_P\, \lambda_A\, g_A \tag{3.5}$$

Like in the one sector model the specification of the regeneration function implies that in a situation of balanced growth the quality of the environment will be constant, i.e., $g_E=0$. But then, using (3.4), also the growth rate of the use of environmental resources has to be zero. Consequently, also the growth rate of abatement has to be zero in order to keep net pollution constant (see also (3.5)). But then, using (3.1), also the growth rates of Y, C and K have to be equal to zero. In other words the only feasible balanced growth path of the two sector economy with abatement is one where all the growth rates are equal to zero. So, we find the counterintuitive result that adding the possibility of the production of knowledge of an efficient use of environmental resources breaks the balanced growth rate of the economy down to zero. The intuition behind this result is that the production of knowledge suffices to attain constant growth rates of Y, C and A, keeping Q constant. However, the regeneration function requires that net pollution remains constant in a situation of balanced growth. Constant net pollution, given constant use of environmental resources requires a constant level of abatement, which in turn requires the level of Y to be constant to maintain a constant allocation.

The above result breaks down to a result comparable to the result in the one sector model, if the knowledge sector would exhibit decreasing returns to scale with respect to its inputs. In the case of decreasing returns to scale knowledge production alone would not suffice to keep the production of the final good growing at a constant rate without increasing the use of environmental resources. Analogously to the one sector case, in a situation of balanced growth the use of environmental resources will also be growing at a constant rate. Furthermore, in order to maintain a constant allocation abatement will have to grow at the same rate as production, consumption and investment. But then again, given the growth rates of abatement and the use of environmental resources, the quality of the environment will only be constant if the pollution elasticities of Q and A are such that the growth rates of Q and A exactly outweigh each other given these pollution elasticities, such that net pollution remains constant. It can be derived that, in order to guarantee the feasibility of balanced growth, the following relation should hold with respect to the pollution elasticities of abatement and of the use of environmental resources: $\lambda_A / \lambda_Q = \delta + \epsilon - 1$, where δ is the knowledge-elasticity of physical capital and ϵ is the knowledge-elasticity of the use of environmental resources.

4. Relaxing Balanced Growth

In the previous sections we have seen that the introduction of a regeneration function in the context of balanced growth implies some serious restrictions with respect to the pollution function. The introduction of a regeneration function and its restrictive implications is closely related to the concept of sustainable development. Introducing sustainable development in the context of balanced growth models implies that not only all traditional economic variables should grow at a constant rate, but also that the quality of the natural environment should grow at a constant (possibly zero) rate, which is a strong condition to impose. It seems natural to drop the balanced growth restriction with respect to the quality of the environment and replace this requirement with the restriction that the growth rate of the quality of the natural environment should be greater than or equal to zero at all times. This in turn requires the growth rate of net pollution to be smaller than or equal to zero. Note, however, that the growth rate of the quality of the natural environment influences the growth rate of output, since the quality of the natural environment is also a factor of production. Consequently, when we drop the assumption of a constant growth rate of the quality of the natural environment, we will also have to drop the assumption of a constant growth rate with respect to one or more other (economic) variables. In the following we will discuss some suggestions to relax the definition of balanced growth in the different models.

In the one sector model, assuming that C/Y, A/Y and the growth rates of Y, C, A and K are constant, we have, using (2.1) and (2.2), that

$$g_Q = g_K - \frac{\mu_E}{1 - \alpha} g_E \tag{4.1}$$

Now, if the growth rate of the environment is positive, the growth rate of Q will be smaller than in the balanced growth solution of section 2. However, as g_E declines (keeping g_E constant would require an increasing growth rate of A or a decreasing growth rate of Q) the growth rate of Q will have to increase in order to keep the economy growing at a constant rate. So for decreasing g_E, g_Q increases according to (4.1) and the asymptotic growth rates will be the balanced growth rates of section 2. Finally, in order to guarantee that the growth rate of net pollution, g_P, is smaller than or equal to zero (which will guarantee that g_E is larger than or equal to zero), it is necessary that the pollution-elasticity of abatement is smaller than or equal to minus the pollution-elasticity of the use of environmental resources ($\lambda_A <= -\lambda_Q$), since the asymptotic growth rate of Q is equal to the balanced growth rate of A. This latter inequality seems less restricting than the equality between λ_A and $-\lambda_Q$ required in the balanced growth solution. However, this is still rather restricting, as it requires at least the same (absolute value of the) pollution elasticity of abatement as in the balanced growth case.

In the two sector model with decreasing returns to scale in the knowledge sector we have an analogous situation. Again an increasing growth rate of Q should compensate for a declining growth rate of E, in order to keep the economy growing in the long run. Asymptotically the economy will be in the balanced growth solution of section 3. In order to guarantee that pollution will not increase eventually, it will be necessary that $\lambda_A <= -(1-\delta-\epsilon)\,\lambda_Q$. The smaller $\delta+\epsilon$ (i.e. the more 'serious' the decreasing returns), the larger the growth rate of Q should be to compensate for the decreasing returns and the more restricting the constraint with respect to λ_A.

In the two sector model with constant returns to scale in both sectors the growth rate of Q should be negative to compensate for a positive growth rate of the natural environment. From (3.2) and (3.3) we have, using $g_H = g_h$, that

$$g_Q = - \frac{\epsilon}{1-\alpha}\, \mu_E\, g_E \tag{4.2}$$

As g_E declines, g_Q will have to increase (i.e., become less negative) in order to keep the economy growing and the asymptotic growth rate of Q will be equal to zero. Now, since g_Q is non-positive, g_P is also non-positive and no restrictions on the pollution elasticities of Q and A are required.

An alternative solution to prevent the optimal growth rate from breaking down to zero as shown in section 3 under balanced growth, is to drop the restriction of a constant allocation with respect to abatement. In the two sector model with constant returns to scale in both sectors, abatement is in fact redundant, since growing knowledge suffices to keep the final good growing at a constant rate. So, it is optimal to keep A and Q constant, i.e. $g_A=g_Q=0$. However, from the capital accumulation equation we then have that physical capital, K, will grow faster than output, Y. In a growing economy, abatement, which is kept constant, will become less and less important and the growth rate of K will asymptotically be equal to that of Y (and equal to the balanced growth rate as derived in section 3). Note, that again no restrictions are required with respect to the pollution function.

5. Conclusions

In this paper we have analysed balanced growth paths which are ecological sustainable, in one and two sector growth models which incorporate environmental issues. The state of the natural environment is described using a regeneration function based on Tahvonen and Kuuluvainen (1991). It appears that using the concept of sustainable growth in combination with the specified regeneration function imposes strong conditions on the models in order to maintain feasibility of balanced growth paths. These restrictions make the models rather unrealistic. This could, however, with respect to the regeneration function, only be circumvented if we specify a regeneration function which allows the quality of the natural environment to grow at a constant (positive) rate when abatement increases at a constant rate or the use of environmental resources decreases at a constant rate. However one could argue how realistic such assumptions with respect to the regeneration function would be.

Another possibility to avoid too strong restrictions is to relax the definition of balanced growth. It seems natural to drop the requirement that the growth rate of the natural environment should be constant. For sustainable development, i.e. no deterioration of the natural environment, it is sufficient to require that the growth rate of the natural environment is larger than or equal to zero. However, since the natural environment is also a factor of production, this will have an effect on the growth rates of other (economic) variables. Consequently, in order to guarantee sustained growth, we will also have to drop the assumption of a constant growth rate for at least one other (economic) variable. Furthermore, in two of the three models considered we still have rather strong restrictions with respect to the pollution function. Only in the two sector model where both the final goods sector and the knowledge sector exhibit constant returns to scale no restrictions with respect to the pollution function are necessary: in this case growth of knowledge suffices to keep the final goods sector growing at a constant rate, keeping the use of environmental resources at a constant level. Hence in this model pollution will not increase and consequently the environment will not deteriorate.

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