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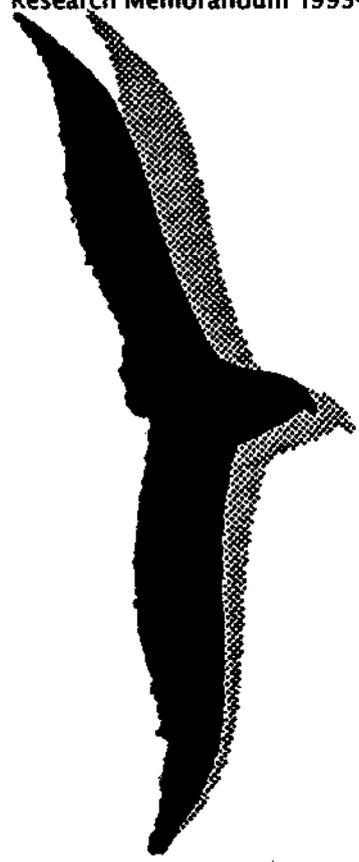
# Serie research memoranda

## SUSTAINABLE DEVELOPMENT WITH EXTRACTIVE AND NON-EXTRACTIVE USE OF THE ENVIRONMENT IN PRODUCTION

F.A.G. den Butter  
M.W. Hofkes

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# SUSTAINABLE DEVELOPMENT WITH EXTRACTIVE AND NON-EXTRACTIVE USE OF THE ENVIRONMENT IN PRODUCTION

by

F.A.G. Den Butter

and

M.W. Hofkes <sup>\*)</sup>

## **Abstract**

This paper considers an economy in which the environment plays a role both in welfare and production. An endogenous growth model, which allows for abatement activities, is formulated in order to study the impact of pollution on welfare and long-term growth. Conditions for optimal and balanced economic growth are discussed and a numerical example is given to provide some insight in the mechanisms at work in the model.

<sup>\*)</sup> Vrije Universiteit, Department of Economics, Applied Labour Economics Research Team / Tinbergen Institute Amsterdam-Rotterdam. Correspondence to: Vrije Universiteit, Department of Economics, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands.



# 1. Introduction

The growing concern for the environment in the last decades has placed the trade-off between economic growth and environmental quality, both at the global and at the national level, in the centre of the economic policy debate. It has made a full integration of the environment into economic welfare theory very urgent. This integration is tried along two lines. Firstly the Weitzman (1976) and Hartwick (1990) approach (see also Mäler (1991)) which, in the context of national accounting, aims at including the value of (changes of) environmental wealth in national income as a measure of welfare. The second, much related, approach is to analyze the trade-off using macroeconomic models and more specifically using models of economic growth.

This paper follows the second approach and investigates various aspects of the environment in a simple Ramsey type model of endogenous economic growth. The integration of the environment into models of this type is hampered by the fact that the environment has so many dimensions, both in space and in time, and that the environment can only be build into the growth model in a highly aggregated and abstract manner so that the model does not become too complicated. This need for aggregation poses problems of interpretation when we are to translate real world environmental phenomena into these models. In this respect the present paper focuses on the following economic aspects of the environment:

1. Environmental quality as a production factor; i.e. the non-extractive use of the environment in production;
2. Environmental services as a production factor; i.e. the extractive use of the environment in production;
3. Environmental quality as an (additional) indicator of economic welfare, which implies inclusion of environmental quality as an argument in the welfare function;
4. The influence of abatement activities on environmental quality;
5. The regenerative capacities of the environment.

The aim of the paper is to integrate these aspects of the environment into a model of endogenous economic growth and to clarify the mechanisms at work which are relevant for an empirical analysis of the trade-off between economic growth and environmental quality. This analysis is instrumental to the integration of the environment in empirical macroeconomic policy models, as it may indicate which mechanisms are relevant to be modelled, and which empirical knowledge is needed for the design of such models.

In economic policy analysis models of economic growth are used to calculate the conditions for balanced (or 'steady state') economic growth. If a social welfare function has been specified the 'optimal' balanced growth path can be calculated, i.e., the balanced growth path which

yields the largest amount of welfare discounted over an infinite horizon. Balanced (and optimal) economic growth is often associated with sustainable development. Section 2 surveys this relationship between the concept of sustainable development and models of economic growth. Section 3 specifies the model of this paper and discusses the conditions for balanced and optimal economic growth. Since the analytical solution of the model is too complicated to provide enough insight for practical policy analysis, section 4 gives an interpretation of the mechanisms at work in the model using a numerical example. Section 5 concludes.

## 2. Sustainable development

As mentioned in the introduction the concept of sustainable development plays a central role in policy discussions on the relationship between environmental quality and economic development. With sustainable development one refers to ecologically sustainable development, which means maintaining the natural (i.e. ecological) basis of economic development. According to the Brundlandt-report (World Commission on Environment and Development (1987)), "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". 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 within the context of Ramsey type growth models (see e.g. Forster (1973), Gruver (1976) and Van der Ploeg and Withagen (1991)). The main conclusion to be drawn from these studies is that the optimal capital stock will be lower in models which allow for pollution. A major short-coming of these neo-classical growth models is, however, that economic growth is exogenously determined. Consequently, it is impossible to study the link between environmental policy and economic growth. In the past few years a new stream of literature is emerging in which long-term growth aspects of environmental economics are studied. In these models the environment arises as an argument in the welfare function and/or as an argument in the production function.

Endogenous growth can be modelled in different ways. Gradus and Smulders (1993) analyse two endogenous growth models which incorporate environmental issues. The first

model is an extension of the so-called AK-model (Rebelo (1991)), in which endogenous growth arises because the reproducible factors exhibit constant returns to scale. In the Rebelo-model growth is unintentional, but arises rather mechanically as a side product of investment. In their second model, Gradus and Smulders build on Lucas (1988). In the Lucas-model growth arises from investment in human capital. Bovenberg and Smulders (1993) take a further step by developing a growth model with endogenous pollution-saving technology which takes the form of knowledge of an efficient use of renewable resources. In this paper a growth model is formulated with only one sector of production with physical capital, environmental resources and environmental quality as inputs. Endogenous growth arises from constant returns to scale with respect to the first two (reproducible) factors of production.

The impact of the environment on welfare and production can take the form both of a stock and of a flow. Reduction of the stock of the natural environment, for example by the usage of non-renewable resources or air and ground pollution which have a lasting impact on the state of the environment, can exert a negative influence on marginal welfare. But also a flow of pollution, think for example of noise, can decrease marginal utility. In Keeler, Spence and Zeckhauser (1971) a stock of pollution with negative marginal social utility is introduced. In Forster (1973) and Gruver (1976) the flow of pollution exerts a negative influence on welfare. Van der Ploeg and Withagen (1991) analyse a model which allows for both stocks and flows of pollution. In all these models the conclusion can be drawn that too much physical capital is accumulated when the negative impact of pollution on social welfare is not taken into account. Also in the production function both flows and stocks can be modeled. In Gradus and Smulders (1993) pollution is modeled as a flow which arises from the use of capital in production. Furthermore, Gradus and Smulders allow for abatement activities, which are activities that aim at cleaning up (part of the flow of) pollution. In Bovenberg and Smulders (1993) the state (i.e. stock) of the environment influences marginal productivity. The environment on the one hand deteriorates as a consequence of the use of environmental resources in production, but on the other hand the environment has certain self-regenerative capacities.

In our model the environment is included both in the welfare function and in the production function. In the welfare function only the stock of the environment plays a role, while in the production function a distinction is made between flows and stocks in the specification of the environment as a factor of production. Welfare derived from environmental services is not explicitly considered, because this aspect is implicitly modelled in the production process in case it relates to extractive use (e.g. water consumption or recreational services which lead to a degradation of the environment); the case of non-extractive use (recreational services which do not lead to a degradation of the environment) is implicit in the environmental quality indicator in the welfare function. Note that extractive use of the environment in production which has negative effects on welfare, think for example of smoke or noise, enters the welfare function through the environmental quality indicator

(which falls as a consequence of the extractive use in production). Furthermore, the model allows for investment in environmental capital which takes the form of abatement by improving the state of the environment. Finally, like Bovenberg and Smulders (1993) we formulate a regeneration function which reflects the deterioration of the environment due to the use of environmental resources on the one hand and its self-regenerative capacities on the other hand.

In growth models the concept of sustainable development is related to balanced (or steady-state) growth. An economy is said to be on a balanced growth path if all variables grow at a constant (possibly zero) rate. Now, under certain assumptions with respect to the production and welfare function and the regenerative capacities of the environment, it can be shown that there exists a balanced growth path of the economy on which the quality of the environment is constant. Both in Bovenberg and Smulders and in Gradus and Smulders it appears that when the state of the environment is not an argument in the production function then in case of a shift towards greener preferences long-term steady-state growth falls (or can at most be maintained). However, when the state of the environment does play a productive role itself, long-term steady-state growth can be higher under greener preferences. The intuition behind this result is that the positive impact of environmental quality on production can dominate the adverse effect of reduced pollution on productivity.

### 3. Specification of the Model

Our model is a theoretical elaboration of the archetype model of Den Butter and Verbruggen (1993). This theoretical model is specified as follows. The production side of the economy produces a final good ( $Y$ ), using physical capital ( $K$ ) and environmental resources ( $Q$ ) as inputs. We assume that the production of the final good  $Y$  exhibits constant returns with respect to physical capital and environmental resources. Furthermore, the natural environment ( $E$ ) is an input in the production of final goods. 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-regenera-

tive 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, which is given by:

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

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. Furthermore, it is assumed that the pollution elasticities of  $Q$  and  $A$  are constant over time and that the absolute value of the pollution elasticity of  $Q$  is equal to the absolute value of the pollution elasticity of  $A$ . So,  $|P_Q \cdot (Q/P)| = |P_A \cdot (A/P)|$ . 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, the higher the quality of the natural environment the larger the (negative) influence of pollution on the regenerative capacity. Finally, the higher the level of (gross) pollution, the larger the effect of an extra unit of abatement. It must be noted that these assumptions with respect to the marginal regenerative capacities of the environment and the marginal effects of abatement 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 the signs of  $N_{EP}$  and  $P_{QA}$  are likely to change.

Social welfare is assumed to depend upon the utility of a representative consumer over an infinite time horizon. Individual utility depends upon individual consumption  $c$  ( $= C/L$ , where  $C$  is aggregate consumption and  $L$  is population which is assumed to be constant over time<sup>1</sup>) and upon the quality of the natural environment.

Society's optimisation problem is given by:

$$\begin{aligned} \max \int_0^{\infty} e^{-\theta t} U(c(t), E(t)) dt \\ \text{s.t. } \dot{K} = Y(K, Q, E) - C - A \\ \dot{E} = N(E, P(Q, A)) \end{aligned} \tag{3.1}$$

where  $\theta$  represents the rate of time preference.

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<sup>1</sup>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.

Command optimum

The social optimal plan implies the following conditions:

$$\frac{\dot{c}}{c} = \frac{1}{\rho} \left[ \frac{\partial Y}{\partial K} + \frac{U_{cE} \dot{E}}{U_c} - \theta \right] \quad (3.2)$$

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

$$\frac{\partial Y}{\partial K} = \frac{\partial N}{\partial P} \frac{\partial P}{\partial A} \left[ L \frac{U_E}{U_c} + \frac{\partial Y}{\partial E} \right] + \frac{\partial N}{\partial E} + \frac{\dot{\mu}}{\mu} - \frac{\dot{\lambda}}{\lambda} \quad (3.3)$$

where  $\lambda$  and  $\mu$  denote respectively the shadow price of physical capital and of natural resources.

Equation (3.2) 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 (3.2). 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 (3.2) is a variant of the well-known Ramsey rule, which can also be written as follows:

$$\frac{\partial Y}{\partial K} = \theta - \frac{\dot{U}_c}{U_c} \quad (3.4)$$

representing the trade-off between investment and consumption: postponement of consumption by investment in capital should yield a rate of return which compensates for the rate of time preference and the change over time in the marginal value of consumption. Equation (3.3) states that the natural environment should yield the same return as physical capital. Returns on the natural environment (right hand side of equation (3.3)) 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).

Furthermore, the optimal choice of Q and A requires:

$$\frac{\partial Y}{\partial Q} = - \frac{\frac{\partial N}{\partial P} \frac{\partial P}{\partial Q}}{\frac{\partial N}{\partial P} \frac{\partial P}{\partial A}} \quad (3.5)$$

which says that the marginal productivity of the use of environmental resources should equal its marginal costs, where the marginal costs are given by the marginal damage that the use of environmental resources causes on the environment measured in terms of the marginal benefits of abatement.

#### Balanced growth

On a balanced growth path it is required that all variables grow at a constant (possibly zero) rate. 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. This imposes some restrictions on the specifications of the ecological relations. 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. Since we assumed that the absolute value of the pollution elasticity of Q equals that of A, a constant level of net pollution requires Q and A to grow at equal rates.

It must be noted that the specification of the regeneration function restricts the set of feasible balanced growth paths, i.e. paths on which all variables grow at a constant rate, seriously. As a matter of fact, it can be shown (see Hofkes (1993)) that the assumption with respect to the pollution elasticities of A and Q is not an arbitrary one but a necessary one. The introduction of a regeneration function and its restrictive implications is closely related to the concept of sustainable development. Sustainable development in the context of balanced growth models requires strong conditions with respect to the regeneration function. In Hofkes (1993) it is therefore argued that the concept of balanced growth should be relaxed in growth models which encompass the environment.

## 4. Example

In this section we analyse the influence of changing parameter values on the long-term steady state growth rates for specified production, consumption and regeneration functions. We assume that the production of the final good  $Y$  is given by a Cobb Douglas function, i.e.,  $Y = \Lambda \cdot K^\alpha Q^{1-\alpha} E^\beta$ , where  $\Lambda$  is a technology parameter. Furthermore, the utility function is characterized by a constant intertemporal elasticity of substitution, where we choose the substitution elasticity to be equal to 1:  $u(c, E) = \ln(c \cdot E^\delta)$  ( $\ln$  denotes the natural logarithm). Finally, the regeneration function of the natural environment is given by:

$$N(E, P(Q, A)) = -\gamma EP^2 - (E - \bar{E})^2 + \Gamma,$$

with  $P = Q/A$  and where  $\bar{E}$  and  $\Gamma$  are constants. For each level of net pollution there is a stable level of the quality of the natural environment, i.e. a level such that  $N=0$  and the quality of the natural environment remains the same over time.

Under these specifications (3.5) reads:  $(1-\alpha)Y = A$ . So the growth rate of the final good is equal to the growth rate of abatement which is, on a balanced growth path, equal to the growth rate of the use of environmental resources (see section 3). From the production function, we have that, on a balanced growth path, the growth rate of the physical capital stock is equal to the growth rate of the final good. Finally, using the capital accumulation equation it can be inferred that the growth rates of per capita consumption and physical capital are equal. We will denote this common growth rate by  $g$ . So  $g$  denotes the (common) balanced growth rate of abatement, use of environmental resources, physical capital, output and per capita consumption, while the quality of the natural environment and the level of net pollution remain constant on a balanced growth path.

Solving the first order conditions of the optimization problem it can be shown that the balanced growth rate,  $g$ , is given by:

$$g = \frac{\alpha}{(1-\alpha)} \frac{A}{K} - \left[ \frac{Q}{A} \right]^2 \left[ 2\delta\gamma\theta \frac{K}{A} + \frac{2\beta\gamma}{(1-\alpha)} - \gamma \right] + 2(E - \bar{E})$$

where

$$\frac{A}{K} = \left[ \Lambda(1-\alpha) \left[ \frac{Q}{A} \right]^{1-\alpha} E^\beta \right]^{\frac{1}{\alpha}}$$

and

$$\left(\frac{Q}{A}\right)^2 = \frac{\Gamma - (E - \bar{E})^2}{\gamma E}$$

and where E solves

$$\theta = \frac{\Gamma - (E - \bar{E})^2}{\gamma E} \left[ 2\delta\gamma\theta \left[ \Lambda(1-\alpha) \left( \frac{\Gamma - (E - \bar{E})^2}{\gamma E} \right)^{\frac{1-\alpha}{2}} E^\beta \right]^{-\frac{1}{\alpha}} + \frac{2\beta\gamma}{1-\alpha} - \gamma \right] - 2(E - \bar{E})$$

In order to give an economic interpretation of the mechanisms at work in this long-run solution we need a numerical example. In the model 5 parameters and 3 initial conditions characterise the relationship between economic activity and the environment. These are:

- $\alpha$ : the weight of capital in the production function; hence  $(1-\alpha)$  is the weight of environmental resources;
- $\beta$ : the weight of environmental quality in the production function;
- $\gamma$ : the impact of pollution on the regenerative capacity of the natural environment;
- $\delta$ : the weight of environmental quality in the social welfare function;
- $\theta$ : the discount rate as indicator of time preference;
- $\bar{E}, \Gamma$ : the constants of the regeneration function.
- $\Lambda$ : the efficiency constant of the production function representing the state of technology.

By way of sensitivity analysis Table 1 gives the long-run solutions for some specific parameter values. In the benchmark the parameter values are given by:  $\alpha=0.75$ ,  $\beta=0.001$ ,  $\gamma=0.3$ ,  $\delta=1$ ,  $\theta=0.05$ ,  $\bar{E}=\Gamma=100$  and  $\Lambda=0.3$ . In the first row of table 1 the long run solution of the model in the benchmark is given. In each other row of Table 1 the long run solution of the model is given if the value of one of the parameters is changed with respect to the benchmark. So,  $\delta=3$  means that only the value of  $\delta$  is changed with respect to the benchmark, while the values of the other parameters are the same as in the benchmark.

We see from Table 1 that increased environmental concern (increasing  $\delta$ ), lowers the long term steady state growth rate: abatement activities are increased, while the capital intensity of production increases and the environmental quality stabilizes at a higher level than in the benchmark. It is, however, theoretically possible to have increasing growth rates in this model under increasing environmental concern. When the impact of the natural environment on production is very large, this

can dominate the adverse effect of the negative impact on the absorption capacity of the environment and in this case growth rates can increase if environmental concern increases.

Table 1. Balanced growth solutions

	$g$	$Y/K$	$Q/A$	$E$	$\mu$
benchmark *	6.6%	0.16	1.8	100.8	0.39
$\alpha=0.7$	4.7%	0.14	1.8	100.7	0.42
$\beta=0.005$	6.9%	0.16	1.8	100.7	0.40
$\gamma=0.4$	6.1%	0.15	1.6	100.8	0.38
$\delta=3$	6.4%	0.15	1.7	103.0	0.43
$\theta=0.04$	7.7%	0.16	1.8	100.5	0.49

\*  $\alpha=0.75$ ,  $\beta=0.001$ ,  $\gamma=0.3$ ,  $\delta=1$ ,  $\theta=0.05$ ,  $\bar{E}=\Gamma=100$ ,  $\Lambda=0.3$

If the impact of the natural environment on production increases (increasing  $\beta$ ), growth improves while the environmental quality stabilizes at a slightly lower level than in the benchmark. The increased contribution of the natural environment to production outweighs the negative impact of the lower environmental quality due to increased growth. Furthermore, an increasing negative impact of pollution on the regenerative capacities of the natural environment (increasing  $\gamma$ ), gives an increasing intensity of abatement activities, increasing capital intensity and a lower long run growth rate. Finally, a decreased rate of time preference increases long term growth.

All in all, the sensitivity analysis illustrates that the change in the production technology has a major impact on the pace of balanced economic growth, but it does not affect environmental quality very much. The same applies for a change in regenerative capacity, given the present specification of the regeneration function. However, more knowledge is needed in particular on the proper specification and parameter values of the regeneration function. The highest level of environmental quality with balanced growth is obtained in case of green preferences. According to our numerical example economic growth is only 0.2%-points lower as compared to the benchmark growth path when the weight of environmental quality in the welfare function is triplicated. Finally we see that a lower time preference results in more economic growth, and that in this case the shadow price of natural resources is much higher than in the benchmark. On the other hand environmental quality is rather low with low time preference, which is somewhat counterintuitive.

## 5. Conclusions

This paper investigates the conditions for balanced economic growth and sustainable development in a simple model of endogenous growth, which considers both the extractive and the non-extractive use of environmental capital in production. Moreover the model allows that some of its productive capacity is allotted to abatement activities and it reckons with self-regenerative capacities of the environment. Finally, environmental quality is taken as an argument of the social welfare function.

The conditions for balanced economic growth imply that environmental quality remains constant at the optimal growth path. Hence, sustainable development can be identified with optimal balanced growth. However, the *level* of environmental quality, at which sustainable development is attained, depends upon the specification and the parameter values of the model. More specifically, it depends on the use of environmental capital and environmental services in the production process, on the regenerative capacity, on the preferences for environmental quality in the welfare function, and on the rate of time preference. Therefore, in order to identify the level of the environmental quality which corresponds to sustainable development and the optimal pace of economic growth, empirical knowledge is needed on both the technical relationships between the environment and economic activity, and on (social) preferences. We acknowledge that for an adequate empirical specification of the technical relationships, especially with respect to the self-regenerative capacity of the environment, cooperation with environmentalists is a necessity.

What can be the role of theoretical models of economic growth for the policy analysis of the trade-off between economic growth and environmental quality? The exercises of this paper show that the conditions that the model poses upon balanced growth, are very restrictive. On the other hand, although the specification of the model is kept as simple as possible, the calculation of the balanced growth path becomes rather complicated, even in a numerical example. Moreover, a balanced growth path pictures a hypothetical economic development which will never occur in practice. Therefore, for policy purposes it seems worthwhile to construct dynamic empirical models, which have the long-run properties of the endogenous growth models, but which describe how sustainable development can be reached with the actual situation as a starting point. Yet a good knowledge of the properties of the theoretical endogenous growth models is a prerequisite for building such dynamic macroeconomic model which has a fully fledged environmental sector.

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