Environmental policy in dynamic models with pollution by consumers: The greening and blackening of preferences

Barthel, Jens

Humboldt-Universität zu Berlin, Wirtschaftswissenschaftliche Fakultät

23 October 2007

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Jens Barthel
Humboldt-Universität zu Berlin
School of Business and Economics
Discussion Paper - Economics Series
201

October 23, 2007

Abstract

The paper discusses questions resulting from a study of the interaction of a change of preferences and environmental policy. In a model with pollution as a side effect of consumption environmental policy is introduced in the form of a consumption tax with or without a subsidy on eco-friendly investments. In simulations we observe the dynamic behavior of models before and after sudden changes of exogenous variables. These shocks are jumps in the preference structure of individuals towards more environmental-friendly or consumption-friendly attitudes. Additionally we examine the effect of a lagged reaction of the policy agents.

1 Introduction

It's no secret that considerations about the protection of the environment have not only to take the welfare of individuals living today but also of yet unborn generations into account. This turns out to be very complicated. In addition to the difficulties resulting from uncertainty about the welfare of different individuals living today the changes of variables that are more or less constant in the short run must be considered. Future tastes, technological developments and even available resources are only a few examples. Nevertheless, in economics environmental policy is usually evaluated in static models and consequently these variables are modelled as exogenously given. Some exceptions can be found in literature on the interaction of environmental policy and economic growth. Bovenberg and de Mooij (1997), Bovenberg and Smulders (1995, 1996), Forster (1973), Gradus and Smulders (1993), Huang and Cai (1994), Lighthart and van der Ploeg (1994) and Smulders and Gradus (1996) published fundamental studies. Conrad (1999) summarizes the literature on computable general equilibrium models.

Bohm and Russell (1985) discuss among other criteria flexibility and dynamic incentives of policy instruments. Flexibility is the facility to adjust the chosen environmental policy instrument to changes of exogenous variables if a certain environmental target level should be reached. Dynamic incentives of policy instruments are effects on the development of new technologies, on the impact on relative factor prices and its consequences on locational decisions. In this paper we tie up to the aspect of flexibility.

Using the model developed in Barthel (2005, 2007b) we explore the effects of shocks on the economy. In steady state equilibrium models, variables remain constant or change with a (common) constant rate over time (Chiang (1984), p. 499). Here we investigate the consequences of a jump in the weight of environmental quality in the utility.[1] The apparent idea is of course the "greening" of preferences. At least two reasons could be offered to support this idea. At first one could argue that new scientific knowledge leads to a more careful attitude with regard to environmental problems. The second explanation is the so-called environmental Kuznets curve. It is widely assumed - and it exists empirical evidence - that after reaching a certain level of economic welfare indiduals focus their demand increasingly on environmental quality and goods produced with environmental-friendly technologies.

A development in the opposite direction, the blackening of preferences, is probably not that evident. But there are several examples. Obviously with the beginning of the industrialization process environmental concerns disappear in favor of high growth rates of the economy. In some countries, the discovery of new production and consumption possibilities is the reason for this trend, whereas "keeping-up-with-the-Joneses" in other countries leads to a change of preferences with respect to the environment.

[1] A similar idea was used by Hettich (2000). In a discrete formulation of the Uzawa-Lucas growth model he discusses the impact of a shock towards greener preferences in a planned economy.

Besides a genuine change of preferences of the entire population the aggregated preferences can also be altered by a shift of the income distribution. If we assume different attitudes toward environmental quality depending on income a growing average income may result in rising demand for environmental quality whereas an impoverishment of large fractions of the population may lead to a disregard for environmental requirements. But since we do not explicitely deal with distributional aspects of the problem and the aggregated effect of a change of the income distribution may be captured in concepts such as the Environmental Kuznets Curve we abstain from a further discussion of the problem.

In the following we will deal with several solutions of the models. The examination of the unregulated or market economy implies a decentralized optimization of the households and represents the resulting aggregated solution. The optimal solution or the case of the planned economy assumes a mechanism, e.g. a benevolent planner or dictator that ensures the internalization of all external effects in the process of optimization. The optimal environmental policy is a combination of instruments resulting in a solution equivalent to the optimal solution reached by a planner *in* the equilibrium but not necessarily on the track *to* the equilibrium. Naturally, none of these solutions reflects any real economy. Probably in all real economies the government tries to internalize at least some of the external effects but surely not all. Therefore, images of real world economies could be found presumably between the extreme solutions we find in our models. It is especially necessary to keep in mind that a planned economy as defined here has nothing in common with planning known from the so-called socialist countries. The aim of planning in these countries was rarely the internalization of external effects. On the contrary, planning was a tool to reach a certain exogenously determined goal. Coincidentally, this could be an optimal solution according to our understanding; in general it would be something completely different.

Usually it takes time before individuals' preferences are perceived and before they make history. Therefore, we will analyze the consequences of a lag in the adjustment of environmental policy instruments to the new conditions.

The paper is organized as follows: In the next section we introduce the basic model. Section (3) discusses the impact of changes towards a greener preference structure in models with or without environmental policy. Section (4) addresses the effect of blackening preferences. Section (5) investigates the consequences of a delayed adjustment of environmental policy after a shock whereas Section (6) deals with errors in the adjustment process. Section (7) summarizes the results and gives a brief outlook on possible extensions and variations of the model.[2]

[2] If the headlines sound familiar to you: "Save the Whales!", from Country Joe McDonald: "Into the Fray", 1982; "Paint It Black", from The Rolling Stones: "Aftermath", 1966; "Big Sleep", from Simple Minds: "New Gold Dream (81-82-83-84)", 1982; "On the Edge" from Klaus Schulze: "History", 1988.

2 The Basic Model

2.1 Environment

The environmental quality $N(t)$ depends only on the flow of pollution. There is no accumulation of pollutants. It is assumed that all pollutants that are not eliminated due to environmental protection vanish in the next moment. This is equal to a situation with infinite but somewhat lagged self-regenerating capacity of the environment. Examples of pollutants of this type are noise, light or malodor. The burden on the environment depends on the share of income devoted to cleaning the environment or preventing pollution $E(S)$. Pollution is a damaging side effect of consumption $P(C)$. Without economic activity the natural quality is $\overline{N}$. It follows:

$$N = N\left(E(S), P(C), \overline{N}\right)$$

with:

$$N_E > 0 \qquad N_P < 0$$

2.2 Households and Preferences

All n households are identical, especially of equal size, and small. The representative household exhibits preferences over consumption goods and environmental amenities. The size of the population is assumed to be constant. The rate of time preference is ρ. The elasticity of substitution, σ, and the relative weight of environmental amenities in utility, $\phi > 0$, are constant. The utility function of the individual household can be written as:

$$W_i = \int_0^\infty U(c_i, N, \phi) \cdot e^{-\rho \cdot t} dt \tag{1}$$

with the household's consumption being c_i and environmental quality N. For the average consumption and investment into the regenerative capacity of the environment follows:

$$C = \sum_{i=1}^{n} c_i \qquad c = \frac{C}{n}$$

$$S_{(N)} = \sum_{i=1}^{n} s_{(N)_i} \qquad s_{(N)} = \frac{S_{(N)}}{n}$$

Households supply one unit of labor and receive a wage w. Each household holds assets a with a rate of return r. Part of the household's income can be used to improve the regenerative capacity of environment. The endogenous rate of these environmental expenditures is $s_{(N)}$. The remaining income can be used for consumption c and saving $\dot{a}$. The flow budget constraint for the household is:

$$w + r \cdot a = \dot{a} + c + s_{(N)} \tag{2}$$

The household's optimization problem is to maximize (1) subject to the budget constraint (2). As derived in Appendix 8.1 the control variables change according to:

$$g_{(c)} \equiv \frac{\dot{c}}{c} = \frac{\xi_4 - \xi_2}{\xi_1 \cdot \xi_4 - \xi_3 \cdot \xi_2} \cdot \frac{(\rho - r)}{c} \quad (3)$$

$$g_{(s)} \equiv \frac{\dot{s}}{s} = \frac{\xi_1 - \xi_3}{\xi_1 \cdot \xi_4 - \xi_2 \cdot \xi_3} \cdot \frac{(\rho - r)}{s} \quad (4)$$

with

$$\xi_1 \equiv \frac{\begin{array}{c} U_{cc} + U_N \cdot n \cdot \left(N_P \cdot P_{CC} + P_C^2 \cdot N_{PP}\right) \\ + U_{cN} \cdot P_C \cdot N_P \cdot (n+1) + U_{NN} \cdot P_C^2 \cdot N_P^2 \cdot n \end{array}}{U_N \cdot N_E \cdot E_S}$$

$$\xi_2 \equiv \frac{\left(\left(U_{NN} \cdot N_E \cdot N_P + U_N \cdot N_{EP}\right) \cdot P_C + U_{cN} \cdot N_E\right) \cdot n}{U_N \cdot N_E}$$

$$\xi_3 \equiv \frac{\left(U_{NN} \cdot N_E \cdot N_P + U_N \cdot N_{EP}\right) \cdot P_C \cdot n + U_{cN} \cdot N_E}{U_N \cdot N_E}$$

$$\xi_4 \equiv \frac{\left(U_N \cdot E_{SS} \cdot N_E + U_{NN} \cdot E_S^2 \cdot N_E^2 + U_N \cdot E_S^2 \cdot N_{EE}\right) \cdot n}{U_N \cdot N_E \cdot E_S}$$

For the change of the quality of nature we can write:

$$\begin{aligned} \dot{N} &= N_E \cdot E_S \cdot \dot{S} + N_P \cdot P_C \cdot \dot{C} \\ &= n \cdot \left(N_E \cdot E_S \cdot \dot{s} + N_P \cdot P_C \cdot \dot{c}\right) \end{aligned} \quad (5)$$

2.3 Production

The technology to produce goods in this economy can be described by a linear-homogenous production function with labor L and capital K in efficiency units.

$$Y = F(K, L) \quad (6)$$

Since each of n households supplies one unit of labor and owns the same share of total capital K it follows:

$$\begin{aligned} Y &= F(K, n) = n \cdot F\left(\frac{K}{n}, 1\right) \\ k &\equiv \frac{K}{L} \\ f(k) &\equiv F(k, 1) \end{aligned}$$

Output per capita can be expressed by:

$$y \equiv \frac{Y}{n} = f(k)$$

The marginal productivities are then given by:

$$\begin{aligned}
\frac{\partial Y}{\partial K} &= n \cdot \frac{\partial f(k)}{\partial k} \cdot \frac{1}{n} \\
&= \frac{\partial f(k)}{\partial k} \\
\frac{\partial Y}{\partial L} &= f(k) + n \cdot \frac{\partial f(k)}{\partial k} \cdot \frac{\partial k}{\partial n} \\
&= f(k) - \frac{K}{n} \cdot \frac{\partial f(k)}{\partial k}
\end{aligned}$$

Output is equal to the sum of the marginal productivities of the factors multiplied by the quantities:

$$\begin{aligned}
Y &= \frac{\partial Y}{\partial K} \cdot K + \frac{\partial Y}{\partial L} \cdot L \\
&= \frac{\partial f(k)}{\partial \frac{K}{n}} \cdot K + \left[f(k) - \frac{K}{n} \cdot \frac{\partial f(k)}{\partial k} \right] \cdot n \\
&= f(k) \cdot n
\end{aligned}$$

In equilibrium, supply and demand on capital and labor markets should be equal. This results in factor payments equal to marginal productivities:

$$\begin{aligned}
r &= \frac{\partial Y}{\partial K} = \frac{\partial f(k)}{\partial k} \\
w &= \frac{\partial Y}{\partial L} = f(k) - k \cdot \frac{\partial f(k)}{\partial k}
\end{aligned}$$

Equilibrium on the capital market ensures that savings are equal to investments. The total amount of capital equals the total amount of assets:

$$a \cdot n = K$$

The interest rate, therefore, is equal to the marginal return to investment; the wage rate is equal to the output per capita reduced by capital costs:

$$\begin{aligned}
r &= \frac{\partial f(a)}{\partial a} \\
w &= f(a) - a \cdot \frac{\partial f(a)}{\partial a}
\end{aligned}$$

In equilibrium, wage and interest rate depend consequently only on the size of the capital stock. The household's budget constraint can be written as:

$$\dot{a} + c + s_{(N)} = f(a)$$

2.4 Steady State

In this model - with no other engine of growth than capital accumulation - a steady state is characterized by constant variables. It follows:

$$
\begin{aligned}
\frac{\dot{\theta}_{(a)}}{\theta_{(a)}} &= \rho - r = 0 \\
\rho &= r && (7) \\
U_c + U_N \cdot N_P \cdot P_C &= U_N \cdot N_E \cdot E_S = \theta_{(a)} \\
\frac{U_c}{U_N} &= N_E \cdot E_S - N_P \cdot P_C && (8) \\
\dot{a} &= 0 \\
c + s_{(N)} &= w + r \cdot a = f(a) && (9)
\end{aligned}
$$

For given parameter values, these equations allow to compute solutions for the steady state values c^*, s^* and a^*.

2.5 The Optimal Solution and a First-Best Policy

As a benchmark we derive the optimal solution of the model.[3] The benevolent dictator considers the trade-offs between higher consumption and consequential increased pollution and between expenditures for environmental quality and lower consumption but higher environmental quality. The behavior of the system can be described by:

$$
\begin{aligned}
g_{(a)} &\equiv \frac{\dot{a}}{a} = \frac{f(a) - c - s_{(N)}}{a} && (10) \\
g_{(c)} &\equiv \frac{\dot{c}}{c} = \frac{\xi_2 - \xi_3}{\xi_2^2 - \xi_1 \cdot \xi_3} \cdot \frac{\rho - f_a}{c} && (11) \\
g_{(s)} &\equiv \frac{\dot{s}}{s} = \frac{\xi_2 - \xi_1}{\xi_2^2 - \xi_1 \cdot \xi_3} \cdot \frac{\rho - f_a}{s} && (12)
\end{aligned}
$$

with:

$$
\begin{aligned}
\xi_1 &\equiv \frac{U_{cc} + \left[\begin{array}{c} U_N \cdot \left(N_P \cdot P_{CC} + P_C^2 \cdot N_{PP} \right) \\ + U_{NN} \cdot N_P^2 \cdot P_C^2 \end{array} \right] \cdot n^2 + 2 \cdot U_{cN} \cdot P_C \cdot N_P \cdot n}{U_N \cdot N_E \cdot E_S \cdot n} \\
\xi_2 &\equiv \frac{U_{cN} + U_{NN} \cdot N_P \cdot P_C \cdot n}{U_N} + \frac{N_{EP} \cdot P_C \cdot n}{N_E} \\
\xi_3 &\equiv \frac{U_{NN} \cdot N_E \cdot E_S \cdot n}{U_N} + \frac{N_{EE} \cdot E_S \cdot n}{N_E} + \frac{E_{SS} \cdot n}{E_S}
\end{aligned}
$$

[3] See Appendix 8.2.

The steady state of the optimal solution is characterized by:

$$
\begin{aligned}
\frac{\dot{\theta}_{(a)}}{\theta_{(a)}} &= \rho - f_a = 0 \\
\rho &= f_a && (13) \\
U_c + U_N \cdot N_P \cdot P_C \cdot n &= U_N \cdot N_E \cdot E_S \cdot n = \theta_{(a)} \\
\frac{U_c}{U_N} &= (N_E \cdot E_S - N_P \cdot P_C) \cdot n && (14) \\
\dot{a} &= 0 \\
c + s_{(N)} &= w + r \cdot a = f(a) && (15)
\end{aligned}
$$

As a first-best policy we introduce a combination of taxes on consumption and subsidies on environmental expenditures that ensure the optimal level of consumption and environmental expenditures in the steady state.[4] As a consequence, the optimal quality of nature and the maximal utility level will be reached. The budget constraint of household i is now given by:

$$w_i + r \cdot a_i = (1+d) \cdot c_i + (1-p) \cdot s_{(N)i}$$

The control variables change according to:

$$
\begin{aligned}
g_{(c)} &\equiv \frac{\dot{c}}{c} = \frac{(\xi_5 - \xi_2) \cdot (\rho - r) - \xi_3 \cdot \xi_5 \cdot \dot{d} + \xi_2 \cdot \xi_6 \cdot \dot{p}}{\xi_1 \cdot \xi_5 - \xi_4 \cdot \xi_2} \cdot \frac{1}{c} \\
g_{(s)} &\equiv \frac{\dot{s}}{s} = \frac{(\xi_1 - \xi_4) \cdot (\rho - r) + \xi_3 \cdot \xi_4 \cdot \dot{d} - \xi_1 \cdot \xi_6 \cdot \dot{p}}{\xi_1 \cdot \xi_5 - \xi_4 \cdot \xi_2} \cdot \frac{1}{s}
\end{aligned}
$$

with:

$$
\begin{aligned}
\xi_1 &\equiv \frac{\begin{array}{c} U_{cc} + U_N \cdot \left(N_P \cdot P_{CC} + N_{PP} \cdot P_C^2\right) \cdot n \\ + U_{NN} \cdot P_C^2 \cdot N_P^2 \cdot n + U_{cN} \cdot N_P \cdot P_C \cdot (n+1) \end{array}}{\frac{1+d}{1-p} \cdot U_N \cdot N_E \cdot E_S} \\
\xi_2 &\equiv \frac{((U_N \cdot N_{EP} + U_{NN} \cdot N_E \cdot N_P) \cdot P_C + U_{cN} \cdot N_E) \cdot n}{\frac{1+d}{1-p} \cdot U_N \cdot N_E} \\
\xi_3 &\equiv -\frac{1}{1+d} \\
\xi_4 &\equiv \frac{(U_N \cdot N_{EP} + U_{NN} \cdot N_E \cdot N_P) \cdot P_C \cdot n + U_{cN} \cdot N_E}{U_N \cdot N_E} \\
\xi_5 &\equiv \frac{\left(U_N \cdot N_E \cdot E_{SS} + U_{NN} \cdot N_E^2 \cdot E_S^2 + U_N \cdot N_{EE} \cdot E_S^2\right) \cdot n}{U_N \cdot N_E \cdot E_S} \\
\xi_6 &\equiv \frac{1}{1-p}
\end{aligned}
$$

To run numerical simulations, we have to specify the general equations used so far.

[4] See Appendix 8.3.

2.6 Specific Functions for Numerical Simulations

2.6.1 Utility Function

The focus of the following analyses will be on models with a Cobb-Douglas utility function that is characterized by an elasticity of substitution equal to one ($\sigma = 1$):[5]

$$U = c^{\alpha} \cdot (\phi \cdot N)^{1-\alpha} \tag{16}$$

2.6.2 Environmental Quality

For simplicity, the following function is chosen for the environmental quality:

$$N = \overline{N} + E(S) - P(C) \tag{17}$$

The relevant derivatives are now:

$$\begin{aligned} N_E &= 1 \\ N_P &= -1 \\ N_{EE} &= N_{PP} = N_{EP} = 0 \end{aligned}$$

We assume the followin impact of economic activities on natural quality:

$$E(S) = \tau_{(S)} \cdot S^{\gamma} \tag{18}$$

$$P(C) = \tau_{(C)} \cdot C^{\beta} \tag{19}$$

$$0 < \gamma < 1 < \beta$$

$$0 \leq \tau_{(S)}, \tau_{(C)}$$

The relevant derivatives are:

$$E_S = \tau_{(S)} \cdot \gamma \cdot S^{\gamma-1} > 0 \tag{20}$$

$$E_{SS} = \tau_{(S)} \cdot \gamma \cdot (\gamma - 1) \cdot S^{\gamma-2} < 0 \tag{21}$$

$$P_C = \tau_{(C)} \cdot \beta \cdot C^{\beta-1} > 0 \tag{22}$$

$$P_{CC} = \tau_{(C)} \cdot \beta \cdot (\beta - 1) \cdot C^{\beta-2} > 0 \tag{23}$$

This implies decreasing marginal effects of investments into environmental quality and increasing marginal damages due to consumption.

2.6.3 Production Function

We use a Cobb-Douglas production function:

$$Y = F(K, L) = A \cdot K^{\delta} \cdot L^{1-\delta} \tag{24}$$

[5] The impact of the elasticity of substitution is discussed in Barthel (2005, 2007b).

In the Cobb-Douglas case, output per head and interest rate are then given by:

$$\begin{aligned} y &= A \cdot k^{\delta} \\ r &= \delta \cdot A \cdot k^{\delta-1} \end{aligned}$$

It follows that the single equilibrium is determined by the parameters. The equilibrium capital stock is given by:

$$k^{*} = \left(\frac{\delta \cdot A}{\rho}\right)^{\frac{1}{1-\delta}}$$

The labor supply is one unit per head. In the economy there are n households. This results in:

$$k = a$$

3 Save the Whales! The Impact of Greening Preferences

With the specified functions we can rewrite condition (8) in the following way:

$$U_c = U_N \cdot (E_S + P_C)$$

It follows:

$$\begin{aligned} \xi_1 &\equiv \frac{U_{cc} - U_N \cdot P_{CC} \cdot n - U_{cN} \cdot P_C \cdot (n+1) + U_{NN} \cdot P_C^2 \cdot n}{U_N \cdot E_S} \\ \xi_2 &\equiv \frac{(U_{cN} - U_{NN} \cdot P_C) \cdot n}{U_N} \\ \xi_3 &\equiv \frac{U_{cN} - U_{NN} \cdot P_C \cdot n}{U_N} \\ \xi_4 &\equiv \frac{\left(U_N \cdot E_{SS} + U_{NN} \cdot E_S^2\right) \cdot n}{U_N \cdot E_S} \end{aligned}$$

The path of the system is now determined by the equations:

$$g_{(c)} \equiv \frac{\dot{c}}{c} = \frac{\xi_4 - \xi_2}{\xi_1 \cdot \xi_4 - \xi_3 \cdot \xi_2} \cdot \frac{\rho - r}{c} \tag{25}$$

$$g_{(s)} \equiv \frac{\dot{s}}{s} = \frac{\xi_1 - \xi_3}{\xi_1 \cdot \xi_4 - \xi_2 \cdot \xi_3} \cdot \frac{\rho - r}{s} \tag{26}$$

$$g_{(a)} \equiv \frac{\dot{a}}{a} = \frac{f(a) - c - s_{(N)}}{a} \tag{27}$$

Initially, the following parameter values are used: $A = 5$, $n = 1000$, $\alpha = 0.75$, $\beta = 1.1$, $\gamma = 0.9$, $\delta = 0.5$, $\rho = 0.05$, $\phi = 0.5$, $\overline{N} = 1000$, $\tau_{(S)} = 5$ and

$\tau_{(C)} = 0.05$.[6] Various methods can be used to find the correct initial value of the control variables.[7] However, we use the method of backward integration as described by Brunner and Strulik (2002). The trajectories correspond to a time path that approaches 99.5% of the equilibrium capital stock in $t = 0$.

3.1 Numerical Results for an Unregulated Market Economy

In this section we analyze the impact of a sudden change in preferences towards increased environmental care. In $t = 0$, the parameter of the utility function α jumps from 0.75 to 0.74, 0.70, 0.6 or 0.5. Thus, the range of the changes goes from very small to remarkably large. The shocks are unanticipated - even for consumers. But once the new parameter value is reached the change and all of its consequences are common knowledge. There is no stochastic element in the model. Consequently, sensible formation of expectations before $t = 0$ is impossible.

Note that the dashed trajectories correspond to a reference scenario without shocks.

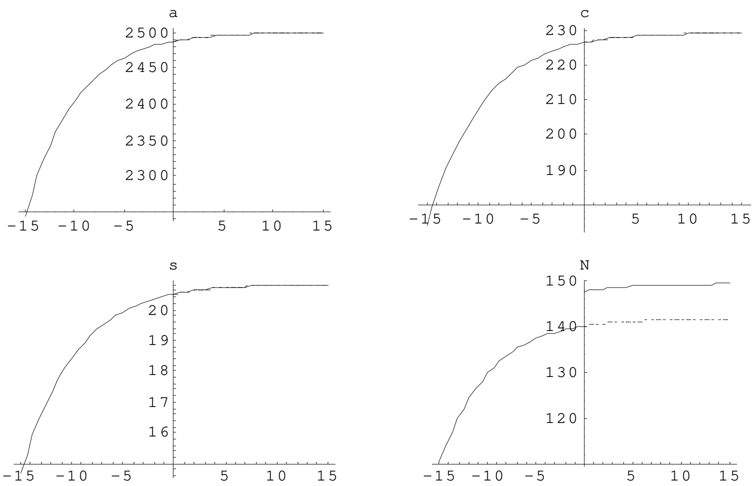

Figure 3.1: Change of α from 0.75 to 0.74: assets, consumption, environmental expenditures and environmental quality

[6] In equilibrium, a rate of time preference of $\rho = 0.05$ results in an interest rate of $r = 0.05$. This indicates a one-year period. The other parameter values are more or less arbitrarily chosen provided that they fulfill the conditions mentioned above and result in a model that can be solved numerically in reasonable time.

[7] For an overview see Barro and Sala-i-Martin (1995), pp. 471-491.

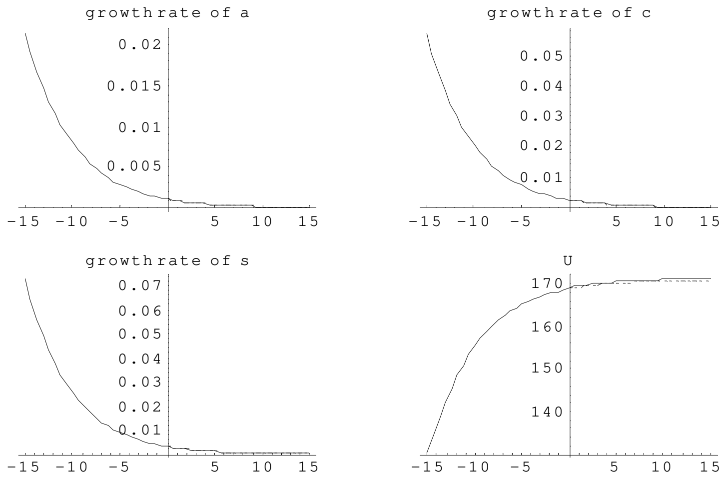

Figure 3.2: Change of α from 0.75 to 0.74: growth rate of assets, consumption and environmental expenditures, and utility level

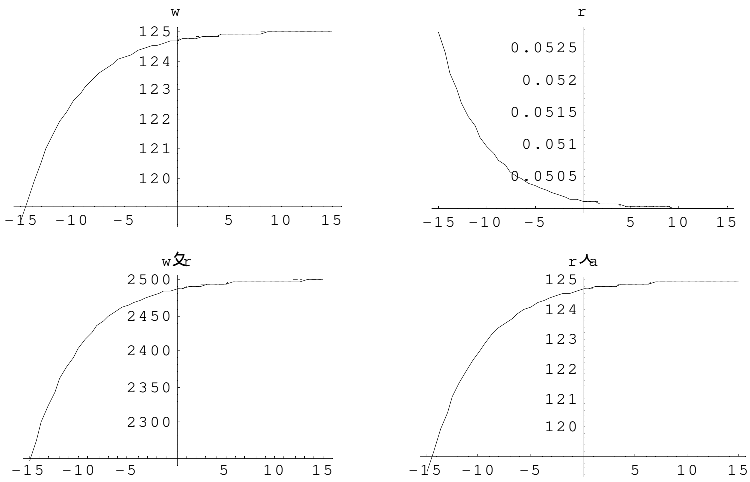

Figure 3.3: Change of α from 0.75 to 0.74: wage rate, interest rate, relation between wage and interest rate, and capital income

The changes of variable values in the presented example are small except for the jump in the quality of nature. With a more intense change of preferences, the direction of the variable changes become more apparent.

Table 3.1: Percentage change of variables in $t = 0$ following a change of preferences

$\Delta\alpha$	Δc	Δs	ΔN	ΔU
$0.75 \rightarrow 0.74$	0.010	0.034	5.412	0.205
$0.75 \rightarrow 0.70$	0.046	0.174	28.611	1.729
$0.75 \rightarrow 0.60$	0.111	0.548	100.125	10.758
$0.75 \rightarrow 0.50$	0.147	1.004	200.176	29.307

As an illustration we show in the next figures the behavior of the system after an enormous change of the preference parameter from 0.75 to 0.50. That implies a jump of the value of environmental quality in $t = 0$ to about 300%.

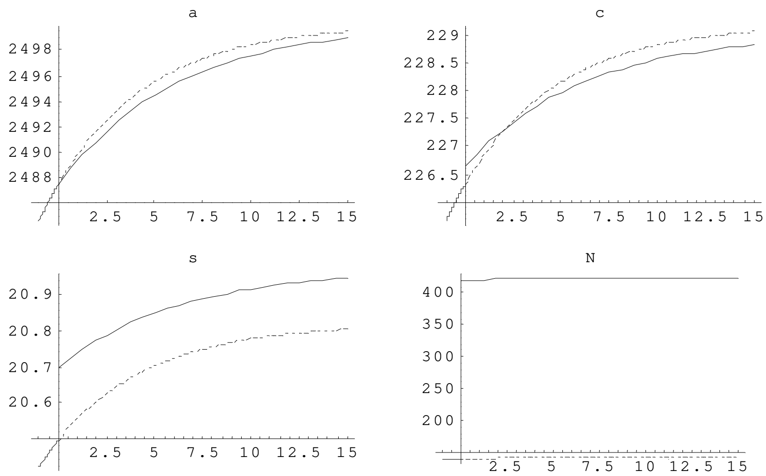

Figure 3.4: Change of α from 0.75 to 0.50: assets, consumption, environmental expenditures and environmental quality

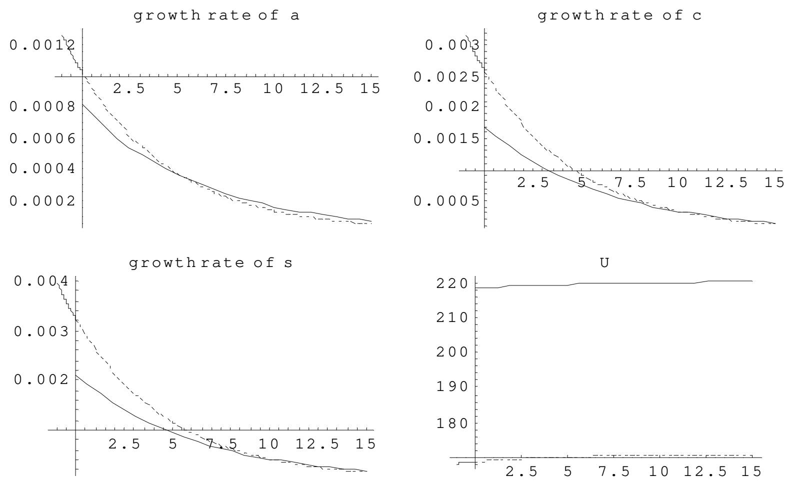

Figure 3.5: Change of α from 0.75 to 0.50: growth rate of assets, consumption and environmental expenditures, and utility level

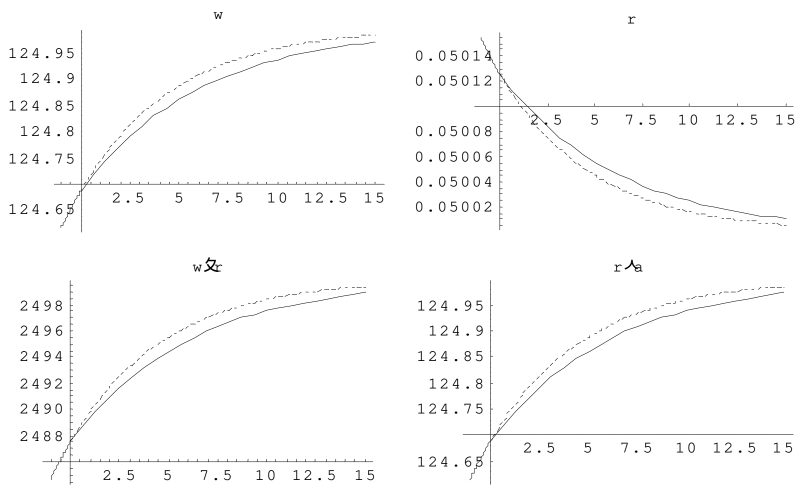

Figure 3.6: Change of α from 0.75 to 0.50: wage rate, interest rate, relation between wage and interest rate, and capital income

The increase in environmental quality is accompanied by increasing consumption and increasing expenditures for environmental quality. This is possible since the change in the preference parameter makes it optimal to slow down the economy. The increase of expenditures for environmental quality is relatively higher; hence the rise of pollution can be compensated. The simultaneous increase of environmental quality and consumption causes a jump of the utility level. The growth rates of capital, consumption and environmental-friendly expenditures fall initially. However, the equilibrium value of the capital stock is only determined by exogenous variables. Therefore, in later periods the growth rates are higher than on the reference path with unchanged preferences. Since the capital endowment is lower the wage rates are lower than on the reference path with unchanged preferences. The decline of the interest rate to its equilibrium value is slower. Nevertheless, capital income is lower, mirroring the lower wage rate.[8]

The equilibrium value of the capital stock remains unchanged. But the structure of expenditures changes slightly, resulting in higher environmental quality and a higher utility level. The apparent discrepancy between small changes in the private expenditure structure and comparatively high utility gains due to a formidable increase in the quality of nature is caused by the external effects that each household creates by its change of behavior. The following table illustrates the changes of equilibrium variable values in dependence on the change of preferences.

Table 3.2: Percentage change of equilibrium values of variables following a change of preferences

$\Delta\alpha$	Δc	Δs	ΔN	ΔU
$0.75 \rightarrow 0.74$	-0.002	0.020	5.402	0.192
$0.75 \rightarrow 0.70$	-0.010	0.105	28.547	1.668
$0.75 \rightarrow 0.60$	-0.033	0.367	99.867	10.585
$0.75 \rightarrow 0.50$	-0.067	0.733	199.602	29.004

3.2 Numerical Results in a Planned Economy

In the following we look at the effects of the same type of shock in a planned economy. The benevolent dictator is not able to anticipate the preference shock, but his immediate reaction ensures that the economy will be on the long-run optimal path at once. Again we will illustrate the behavior of the system for a small change of the preference variable from 0.75 to 0.74.

[8] Note that in the case of a Cobb-Douglas production function the ratio of wage and capital income is determined by the distribution parameter in the production function. Here, the parameter value of $\delta = 0.5$ ensures equal shares of the production factors.

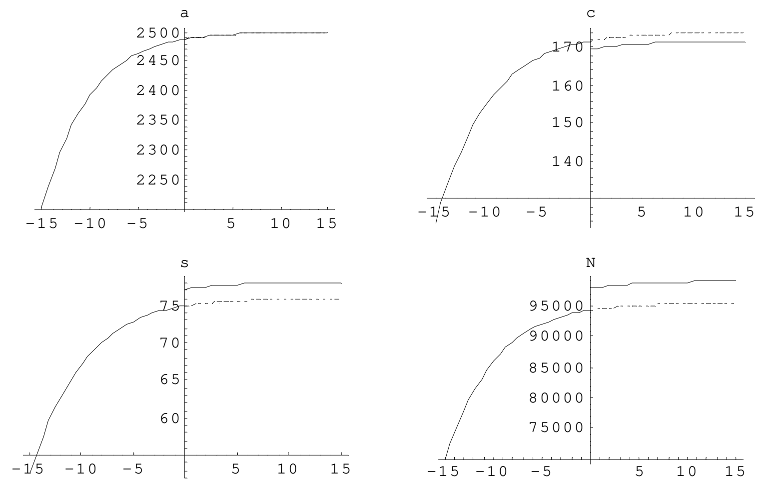

Figure 3.7: Change of α from 0.75 to 0.74 in a planned economy: assets, consumption, environmental expenditures and environmental quality

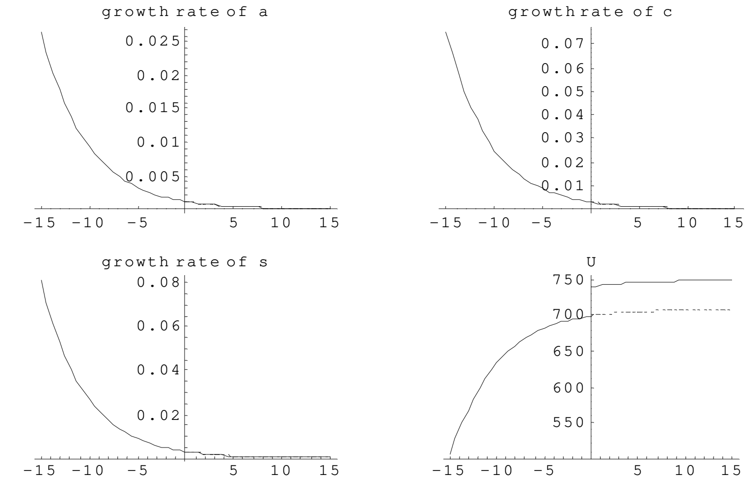

Figure 3.8: Change of α from 0.75 to 0.74 in a planned economy: growth rate of assets, consumption and environmental expenditures, and utility level

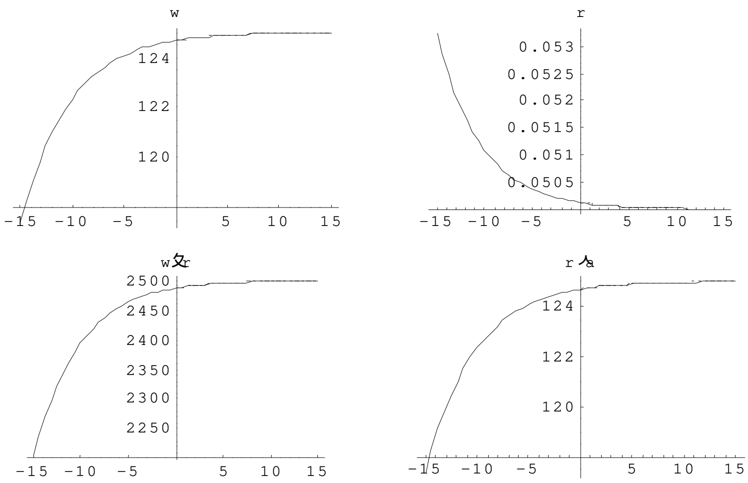

Figure 3.9: Change of α from 0.75 to 0.74 in a planned economy: wage rate, interest rate, relation between wage and interest rate, and capital income

Since the equilibrium capital stock depends only on exogenous parameters, its time path differs not much from the path in the market solution. The major difference is in the speed of convergence.[9] The planned economy converges faster than the market economy. The changes of consumption and environmental expenditures in $t = 0$ are now clearly visible. Needless to say, the reason for the bigger dimension of these changes is the consideration of the positive external effects that are associated directly with environmental expenditures and indirectly with less pollution since consumption is reduced. Consequently, the environmental quality is much higher. Note that there is no increase of consumption in $t = 0$; even in the case of a small change of preferences consumption falls.[10] The percentage changes of variables in $t = 0$ are given in Table 3.3.

Table 3.3: Percentage change of variables in $\mathbf{t = 0}$ following a change of preferences in a planned economy

$\Delta\alpha$	Δc	Δs	ΔN	ΔU
$0.75 \rightarrow 0.74$	-1.255	2.911	3.802	5.814
$0.75 \rightarrow 0.70$	-6.292	14.580	18.947	33.288
$0.75 \rightarrow 0.60$	-19.000	43.961	56.473	144.736
$0.75 \rightarrow 0.50$	-31.890	73.708	93.717	367.630

[9]Here speed of convergence means the possibility to close a gap between an initial value and a target level of a certain variable, i.e. in our case capital stock. The easiest way to evaluate the speed of convergence is a comparison of growth rates: relatively high growth rates at the beginning and low growth rates at the end of the considered period indicate a high speed of convergence, provided that the variable converges at all.

[10]For a comparison with the case of an unregulated economy see Table 3.1.

The planner takes the external effects into account, hence the attained utility level is higher than in the market solution. The time paths of the growth rates as well as of wage and interest rate and capital income reflect the faster convergence of the planned economy. Compared with the market solution, in a planned economy the changes of the equilibrium values of variables are bigger.

Table 3.4: Percentage change of equilibrium values of variables following a change of preferences

$\Delta\alpha$	Δc	Δs	ΔN	ΔU
$0.75 \to 0.74$	-1.266	2.897	3.793	5.802
$0.75 \to 0.70$	-6.339	14.506	18.894	33.216
$0.75 \to 0.60$	-19.107	43.722	56.288	144.385
$0.75 \to 0.50$	-32.025	73.283	93.372	366.624

Again, three figures illustrate the behavior of the system after the preference change for the case of the most severe shock. The main differences of the market solution are (1) the degree of change of the expenditure structure, (2) the degree of change of natural quality and subsequently utility, and (3) the attained level of natural quality and utility. Table 3.5 compares the equilibrium values of the market and the planned economy. The behavior of the system over time does not change qualitatively, hence all arguments given in the previous section apply accordingly.[11]

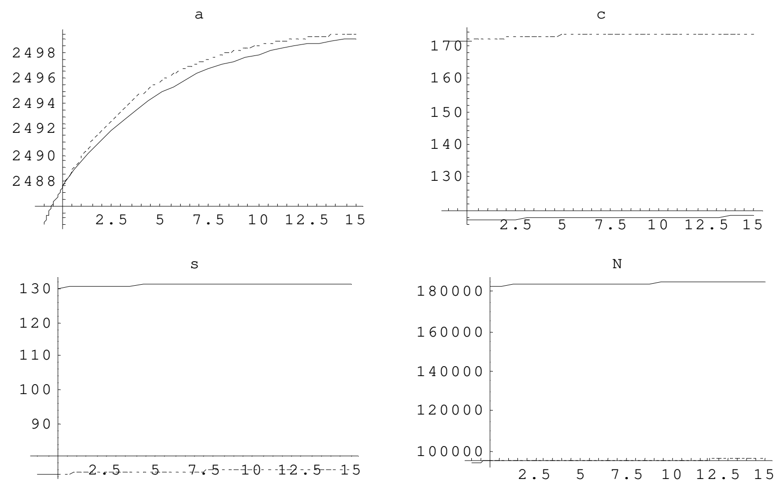

Figure 3.10: Change of α from 0.75 to 0.50 in a planned economy: assets, consumption, environmental expenditures and environmental quality

[11] Note that the "flat" curves of consumption and environmental expenditures have the same shape as the equivalent curves in Figure 3.4. The different scale makes them look flat.

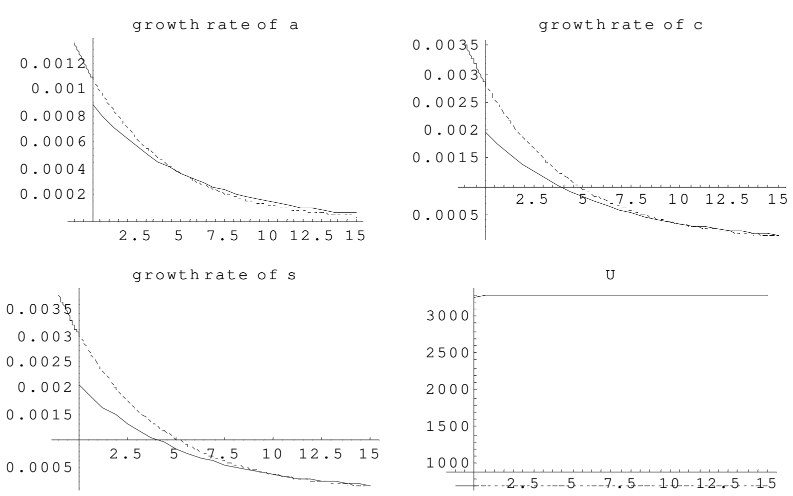

Figure 3.11: Change of α from 0.75 to 0.50 in a planned economy: growth rate of assets, consumption and environmental expenditures, and utility level

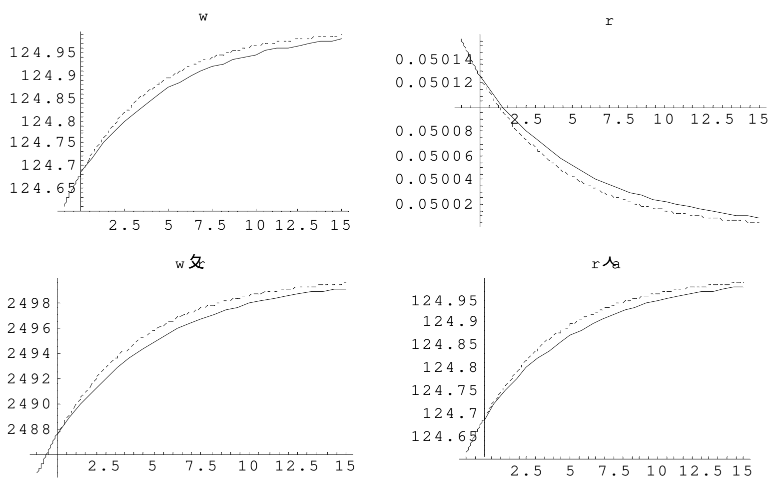

Figure 3.12: Change of α from 0.75 to 0.50 in a planned economy: wage rate, interest rate, relation between wage and interest rate, and capital income

Table 3.5: Equilibrium values of variables for the unregulated and the planned economy

	α	c	s	N	U
	0.75	229.181	20.819	141.617	170.866
unregulated	0.74	229.176	20.824	149.266	171.194
economy	0.70	229.159	20.841	182.044	173.716
	0.60	229.104	20.896	283.045	188.951
	0.50	229.028	20.972	424.286	220.424
	0.75	173.973	76.027	95476	708.072
optimal	0.74	171.771	78.229	99097	749.152
solution	0.70	162.945	87.056	113515	943.268
	0.60	140.732	109.268	149218	1730.42
	0.50	118.258	131.742	184624	3304.03

3.3 Numerical Results with an Optimal Environmental Policy

The decentralized economy attains the optimal equilibrium if two external effects are internalized. First we have to correct the negative external effect of pollution by taxing consumption, second we have to internalize the positive external effect of environmental expenditures by a subsidy. Moreover, a combination of both instruments can be adjusted in a way that a balanced budget of the government is reached in the long-run equilibrium. For simplicity we assume constant tax and subsidy rates.[12] Consequently, in the short run a budget surplus or deficit is possible.

Again we assume that the preference change is unanticipated. But after the preferences are changed, the tax and subsidy rates are adjusted immediately.[13] A change of the preference parameter to 0.74, 0.7, 0.6 and 0.5 requires an increase in the tax rate of about 4.214%, 22.245%, 77.615% and 154.770%, respectively. The simultaneous change of the subsidy rate is rather small; it is equal to -0.0016%, -0.0085%, -0.0298% and -0.0597%, respectively. But since the subsidy rate is nearly equal to 1, the effect of the decrease of the subsidy rate is overcompensated by the decrease of consumption due to the

[12] The ideal first-best policy in this dynamic model is simply unrealistic. It would imply a permanent adjustment of tax and subsidy rates if the economy is out of the steady state equilibrium. In this case the time path of variables would be equivalent to the path derived in the model of the planned economy. However, prohibitively high transaction costs should prevent the implementation of this policy. An alternative policy to the combination of instruments used here is a constant tax rate with subsidies depending on the momentary tax revenue. Theoretically, the budget of the government would be balanced in the long and in the short run. But given that policy there exists a set of initial points without trajectories converging to the equilibrium that are consistent with the first order conditions. As a consequence, corner solutions of the optimization problem have to be considered. For the sake of simplicity we abandon a deeper discussion of this problem.

[13] The consequences of delays in the adjustment process are discussed in section 5.

higher tax rate; the overall effect is a shift of expenditures from consumption to environmental expenditures.

The overall picture is very much alike the one we have drawn for the planned economy. Naturally, the equilibrium values are equal to the values given in Table 3.5. The major difference to the models introduced previously appears to be the considerable increase in the speed of convergence. This is caused by the assumption of constant tax and subsidy rates. In the early periods the rates are simply too high. A comparison of Figure 3.13 and Figure 3.8 illustrates this fact using the trajectories of the growth rates and of utility.

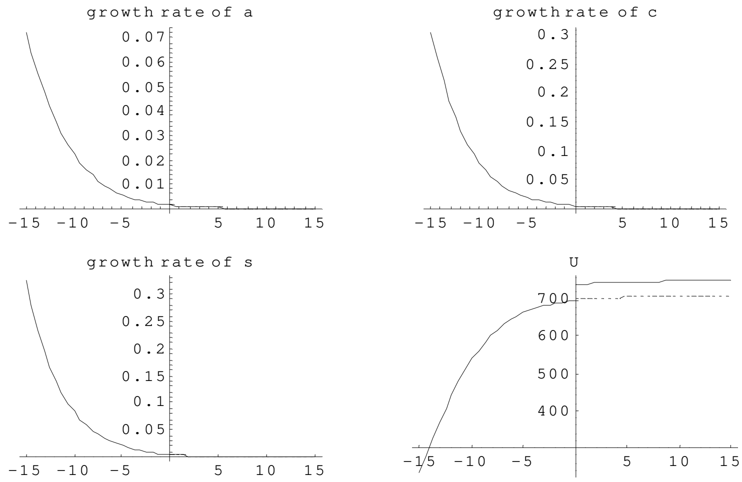

Figure 3.13: Change of α from 0.75 to 0.74 with optimal policy: growth rate of assets, consumption and environmental expenditures, and utility level

The magnitude of the jumps in the variable values in $t = 0$ is comparable to the changes in the planned economy. Again, the remaining differences to the model of the planned economy can be explained with the too high tax and subsidy rates in $t = 0$.

Table 3.6: Percentage change of variables in $\mathbf{t = 0}$ following a change of preferences with an optimal policy

$\Delta\alpha$	Δc	Δs	ΔN	ΔU
$0.75 \to 0.74$	-1.238	2.931	3.819	5.833
$0.75 \to 0.70$	-6.219	14.678	19.028	33.393
$0.75 \to 0.60$	-18.856	44.238	56.716	145.172
$0.75 \to 0.50$	-31.729	74.149	94.117	368.744

The budget cash flow is very small and remains well below 0.5% of the tax revenue or subsidy payments in all examined cases (see Table 3.7). In $t = 0$, tax revenue and subsidy payments increase. Nevertheless, the budget cash flow decreases slightly due to the change in the expenditure structure. Figure 3.14 illustrates the change of the budget cash flow over time for a shift of the preference parameter from 0.75 to 0.74.

Table 3.7: Tax revenues, subsidies and budget cash flow over time and change after shock in absolute values

$\Delta\alpha$	$\int_{-15}^{15} T$	$\int_{-15}^{15} S$	$\int_{-15}^{15} B$	$\Delta T\|_{t=0}$	$\Delta S\|_{t=0}$	$\Delta B\|_{t=0}$
$0.75 \to 0.74$	2071.18	2060.98	10.202	2.184	2.186	−0.0018
$0.75 \to 0.70$	2202.76	2192.57	10.194	10.933	10.942	−0.0085
$0.75 \to 0.60$	2533.77	2523.60	10.170	32.946	32.968	−0.0216
$0.75 \to 0.50$	2868.39	2858.25	10.144	55.205	55.236	−0.0318

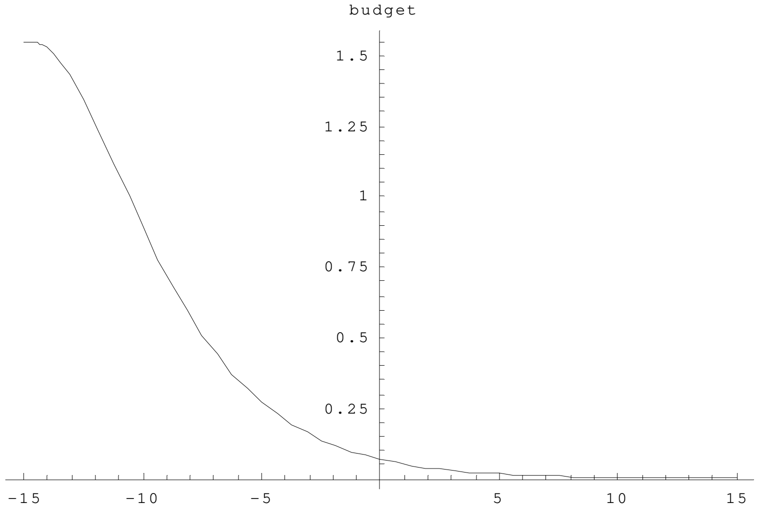

Figure 3.14: Change of α from 0.75 to 0.74 with optimal policy: budget cash flow

4 Paint It Black: Increasing Preferences for Consumption

In this section we want to analyze a change of preferences towards consumption. Although the "greening" of preferences dominates without doubt the discussion, a change of preferences that leads to more consumption and less environmental protection is at least in some countries a realistic description of the state of affairs. Especially the adoption of technologies that make more consumption possible but escalate the pressure on environmental capacities are prominent examples.[14]

[14] China can be taken as an example: Over the last 15 years the average growth rate has been 10.1% per year. Despite efforts by the government to cope with the environmental

There is an obvious choice for the starting points and the intensity of preference changes: To make comparisons possible we will analyze changes of the preference parameter from 0.50, 0.60, 0.70, and 0.74 to 0.75. That mirrors the parameter changes in the previous section.

4.1 Numerical Results for an Unregulated Economy

As expected, in the case of a change of the preference parameter from 0.74 to 0.75 the changes of variables in $t = 0$ are small. The exception is - as in the model with greening preferences - the jump of the natural quality. A comparison of Tables 3.1 and 4.1 reveals the same dimension of the changes of variables - naturally with inverted algebraic signs.

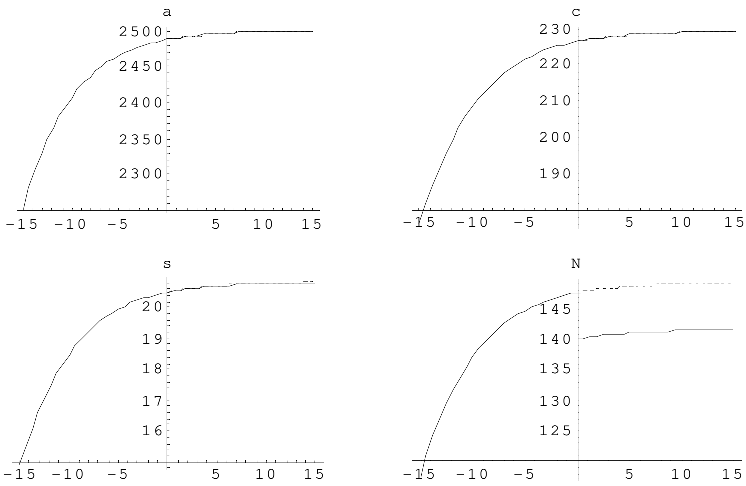

Figure 4.1: Change of α from 0.74 to 0.75: assets, consumption, environmental expenditures and environmental quality

deterioration Chinese cities reach levels of air pollution that are among the worst in the world, energy intensity is 20% higher than the OECD average and about a third of the water resources are severly polluted (OECD, 2006). See also Liu and Diamond (2005) and World Bank (2007).

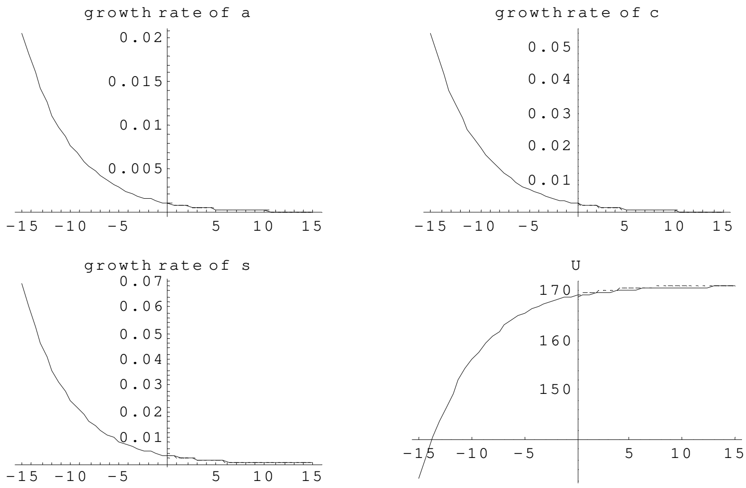

Figure 4.2: Change of α from 0.74 to 0.75: growth rate of assets, consumption and environmental expenditures, and utility level

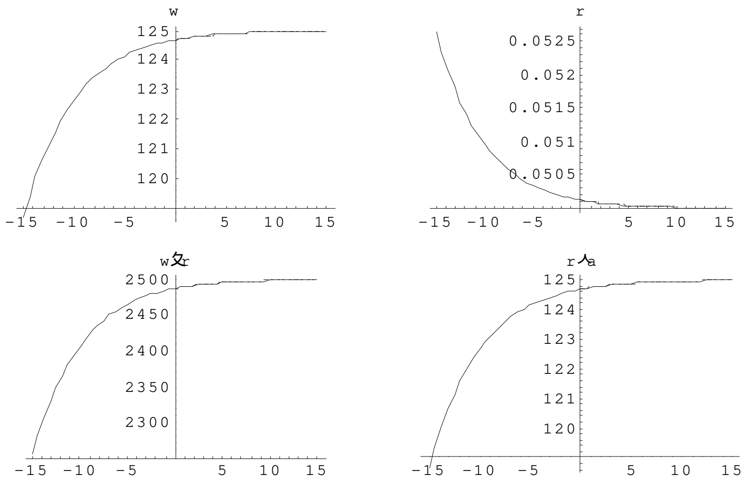

Figure 4.3: Change of α from 0.74 to 0.75: wage rate, interest rate, relation between wage and interest rate, and capital income

Table 4.1: Percentage change of variables in t = 0 following a change of preferences

$\Delta\alpha$	Δc	Δs	ΔN	ΔU
$0.74 \rightarrow 0.75$	-0.0098	-0.0345	-5.135	-0.204
$0.70 \rightarrow 0.75$	-0.0453	-0.1736	-22.246	-1.699
$0.60 \rightarrow 0.75$	-0.1104	-0.5456	-50.031	-9.714
$0.50 \rightarrow 0.75$	-0.1467	-0.9944	-66.686	-22.685

Again we want to illustrate the behavior of the system by assuming an extreme case of a change of the preference parameter from 0.50 to 0.75. At the same time we show the trajectories without most of the periods before the change happens.

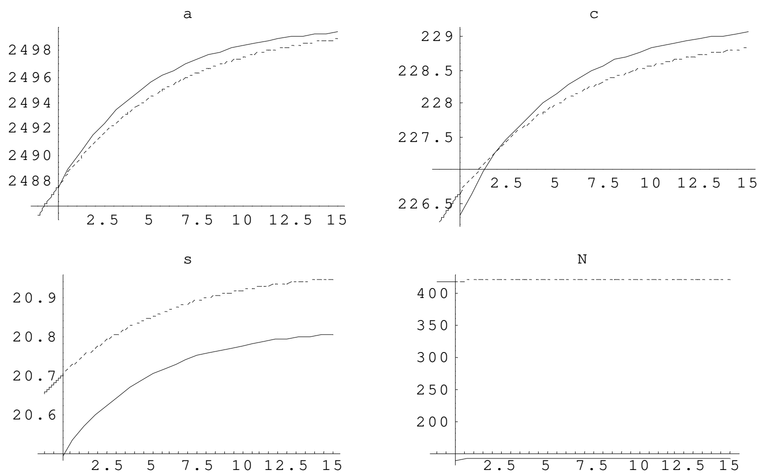

Figure 4.4: Change of α from 0.50 to 0.75: assets, consumption, environmental expenditures and environmental quality

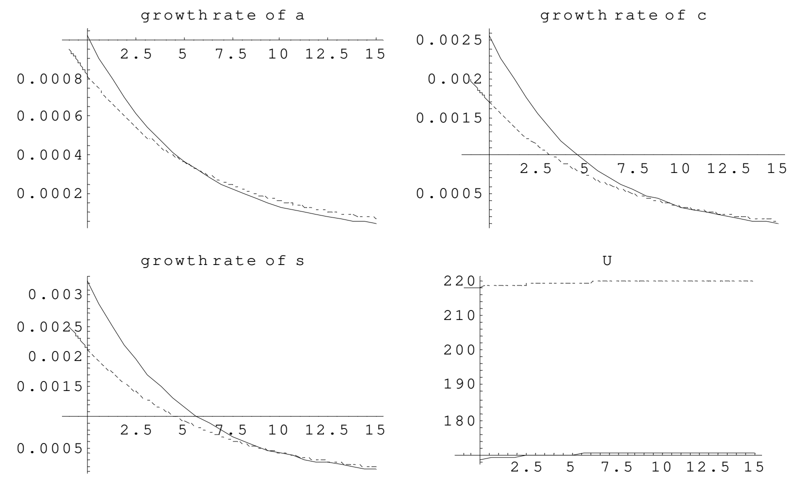

Figure 4.5: Change of α from 0.50 to 0.75: growth rate of assets, consumption and environmental expenditures, and utility level

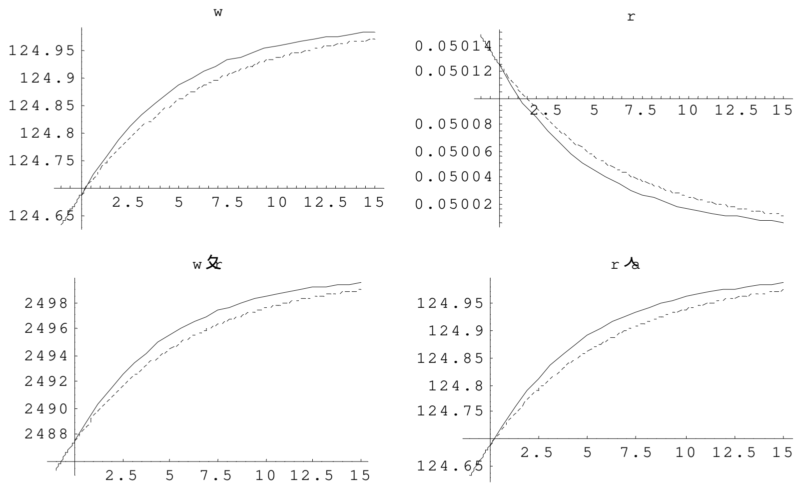

Figure 4.6: Change of α from 0.50 to 0.75: wage rate, interest rate, relation between wage and interest rate, and capital income

Despite the decrease of the environmental quality there is no increase of consumption in the first periods after $t = 0$. The explanation is analogical to the explanation given in paragraph 3.1: Here, it is optimal to increase the speed of convergence of the economy in the next periods. Therefore, the growth rate of assets suddenly increases indicating a sudden increase of the saving rates. The result is an initial decrease not only of eco-friendly expenditures but also of consumption. Since the equilibrium value of the capital is unchanged, after a while the growth rate of assets has to be lower compared to the rate in an economy without a change of preferences. The jump of the growth rate of assets is accompanied by jumps of the growth rates of consumption and environment-friendly expenditures. The households expect higher income in the future and react with an increase of total expenditures.

The increase of the amount of capital in the production results in an increase of the wage rate and of capital income. At the same time we observe a faster decrease of the interest rate since capital approaches faster its equilibrium value.

Table 4.2 illustrates the change of the equilibrium values of variables. The small gains from an increase of consumption is overcompensated by the losses due to the external effects of the reduced environment-friendly expenditures resulting in an remarkable decrease of the attainable utility level. The absolute values of the changes of equilibrium values are comparable to the changes in the case of greening preferences (see Table 3.2).

Table 4.2: Percentage change of equilibrium values of variables following a change of preferences

$\Delta\alpha$	Δc	Δs	ΔN	ΔU
$0.74 \rightarrow 0.75$	0.002	−0.019	−5.125	−0.191
$0.70 \rightarrow 0.75$	0.010	−0.105	−22.207	−0.641
$0.60 \rightarrow 0.75$	0.033	−0.365	−49.967	−9.572
$0.50 \rightarrow 0.75$	0.067	−0.727	−66.622	−22.483

4.2 Numerical Results in a Planned Economy

In this model, the benevolent planner does not act paternalistically, i.e. he changes his policy after a change of the preference parameter even if this results in a decrease of the utility level. The following figures illustrate the case of a small change of the preference parameter from 0.74 to 0.75.

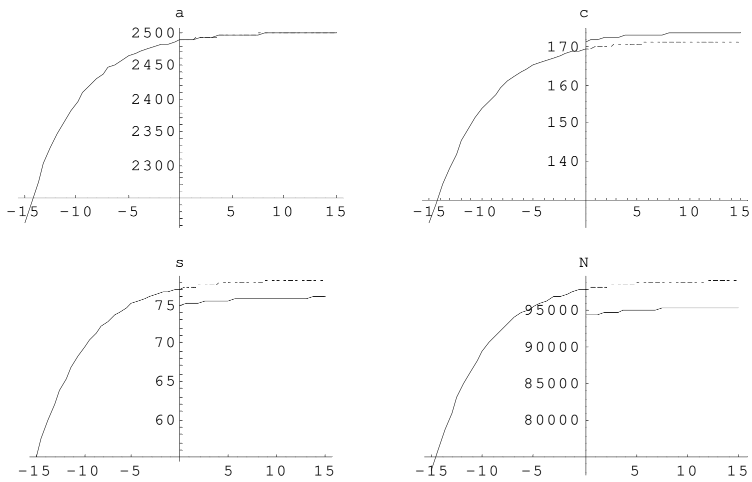

Figure 4.7: Change of α from 0.74 to 0.75 in a planned economy: assets, consumption, environmental expenditures and environmental quality

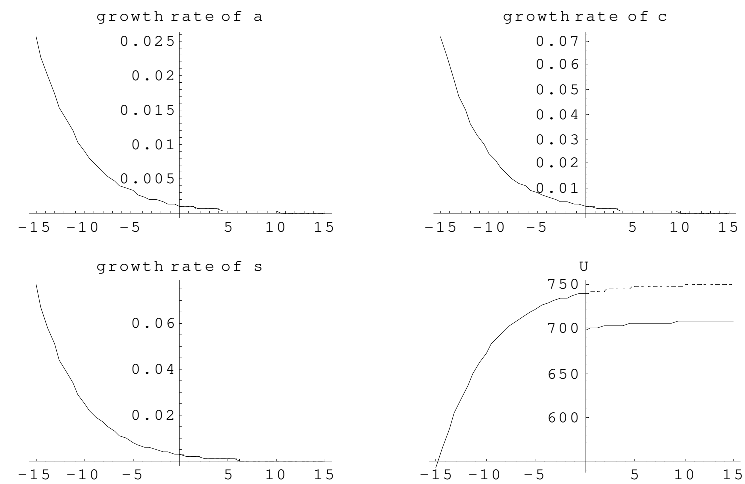

Figure 4.8: Change of α from 0.74 to 0.75 in a planned economy: growth rate of assets, consumption and environmental expenditures, and utility level

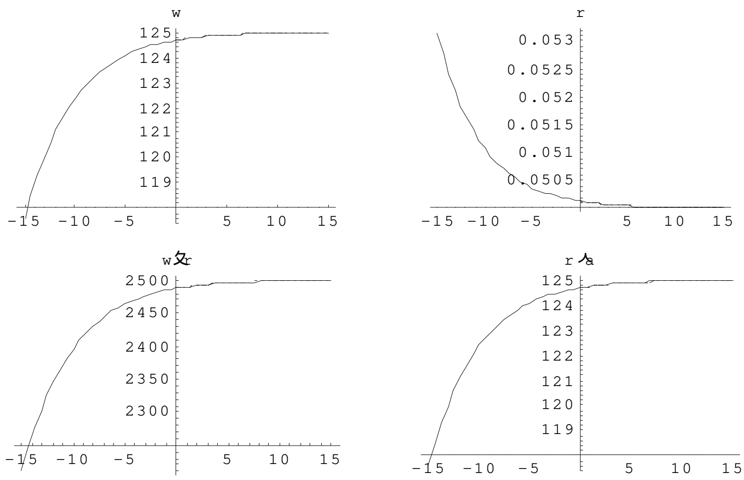

Figure 4.9: Change of α from 0.74 to 0.75 in a planned economy: wage rate, interest rate, relation between wage and interest rate, and capital income

Table 4.3: Percentage change of variables in t = 0 following a change of preferences in a planned economy

$\Delta\alpha$	Δc	Δs	ΔN	ΔU
$0.74 \rightarrow 0.75$	1.271	−2.829	−3.663	−5.494
$0.70 \rightarrow 0.75$	6.714	−12.724	−15.929	−24.974
$0.60 \rightarrow 0.75$	23.456	−30.537	−36.091	−59.140
$0.50 \rightarrow 0.75$	46.822	−42.432	−48.378	−78.616

Again we can notice that the dimension of the changes in $t = 0$ is comparable to the case of greening preferences (see Table 3.3). Unlike in the market economy the change in the expenditure structure is now visible to the naked eye. To unveil the changes in the growth rates and other variables we use again the scenario with a dramatic change of the preference parameter from 0.50 to 0.75 leaving out the periods before $t = -1$.

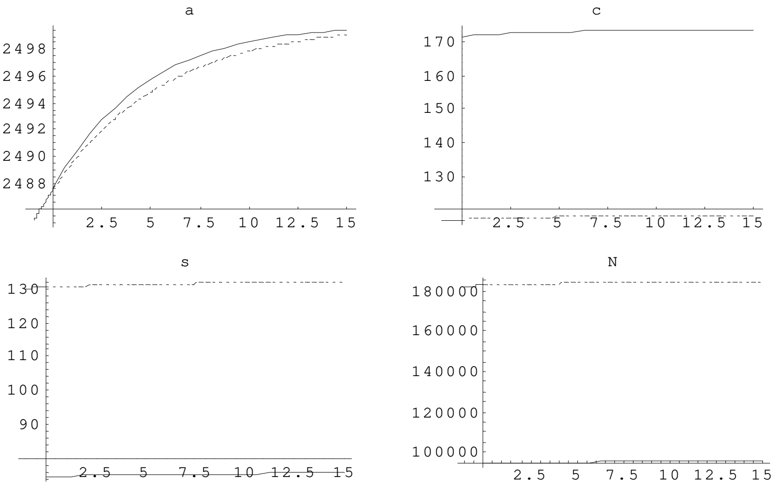

Figure 4.10: Change of α from 0.50 to 0.75 in a planned economy: assets, consumption, environmental expenditures and environmental quality

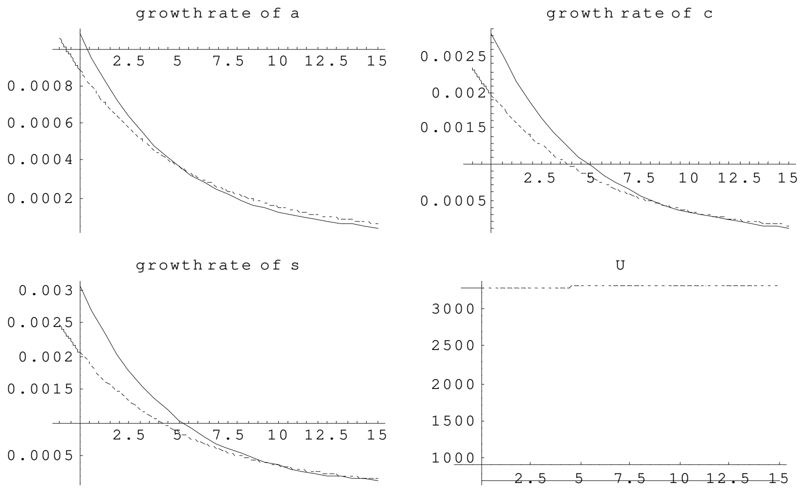

Figure 4.11: Change of α from 0.50 to 0.75 in a planned economy: growth rate of assets, consumption and environmental expenditures, and utility level

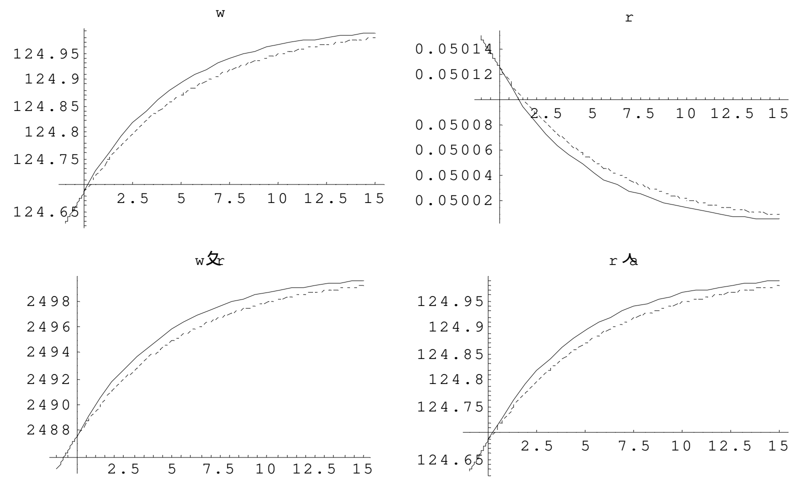

Figure 4.12: Change of α from 0.50 to 0.75 in a planned economy: wage rate, interest rate, relation between wage and interest rate, and capital income

As in the case of greening preferences the planned economy converges faster than the particular market economy. An additional similarity is the dimension of the changes of the equilibrium values - of course with changed algebraic signs. A comparison of Tables 3.4 and 4.4 illustrates this result.

Table 4.4: Percentage change of equilibrium values of variables following a change of preferences

$\Delta\alpha$	Δc	Δs	ΔN	ΔU
$0.74 \rightarrow 0.75$	1.282	-2.815	-3.654	-5.484
$0.70 \rightarrow 0.75$	6.768	-12.668	-15.892	-24.934
$0.60 \rightarrow 0.75$	23.620	-30.421	-36.016	-59.081
$0.50 \rightarrow 0.75$	47.113	-42.291	-48.286	-78.570

Note that the equilibrium values of variables for the unregulated economy and the planned economy are identical to the values given in Table 3.5.

4.3 Numerical Results with an Optimal Environmental Policy

As in the previous chapter here, too, we want to introduce an optimal tax that ensures an optimal expenditure structure and a balanced budget in equilibrium. The following figures illustrate the case of a small change of the preference parameter from 0.74 to 0.75. As in the model of the planned economy, the changes in the expenditure structure are clearly visible. The major difference is again the apparent higher speed of convergence in comparison to the planned economy as well as the market economy.[15] Table 4.5 shows that the changes of variable values in $t = 0$ are very much alike to the changes in the planned economy. Note that given the optimal policy as defined above the changes in equilibrium values are equal to the changes given in Table 4.4 for the planned economy.

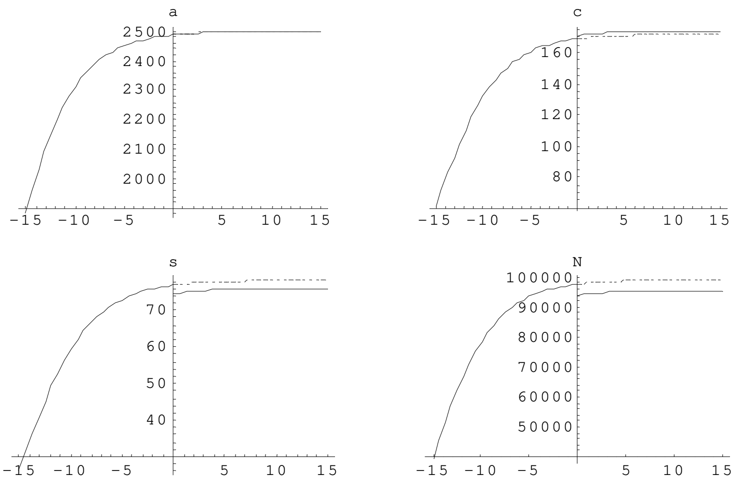

Figure 4.13: Change of α from 0.74 to 0.75 with optimal policy: assets, consumption, environmental expenditures and environmental quality

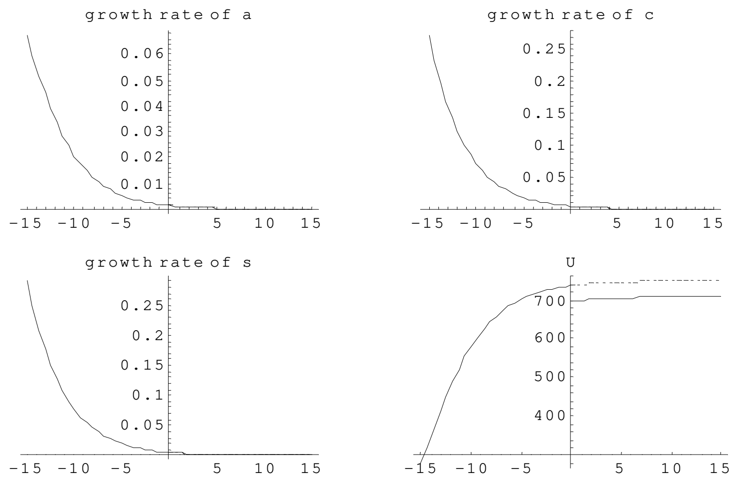

Figure 4.14: Change of α from 0.74 to 0.75 with optimal policy: growth rate of assets, consumption and environmental expenditures, and utility level

[15] See Figure 4.14 in comparison to Figure 4.8 for the planned economy and Figure 4.2 for the market economy.

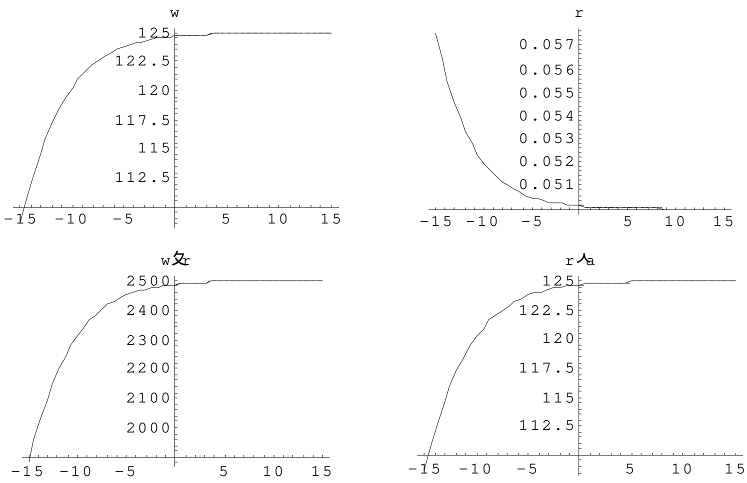

Figure 4.15: Change of α from 0.74 to 0.75 with optimal policy: wage rate, interest rate, relation between wage and interest rate, and capital income

Table 4.5: Percentage change of variables in t = 0 following a change of preferences with an optimal policy

$\Delta\alpha$	Δc	Δs	ΔN	ΔU
$0.74 \rightarrow 0.75$	1.254	−2.848	−3.678	−5.511
$0.70 \rightarrow 0.75$	6.632	−12.799	−15.986	−25.033
$0.60 \rightarrow 0.75$	23.238	−30.670	−36.190	−59.212
$0.50 \rightarrow 0.75$	46.476	−42.578	−48.485	−78.666

As in the models with greening preferences the budget cash flow is almost negligible. As can be expected the changes of tax revenue, the subsidy expenditures and the budget cash flow in $t = 0$ have the same dimension but the opposite algebraic sign.

Table 4.6: Tax revenues, subsidies and budget cash flow over time and change after shock in absolute values

$\Delta\alpha$	$\int_{-15}^{15} T$	$\int_{-15}^{15} S$	$\int_{-15}^{15} B$	$\Delta T\|_{t=0}$	$\Delta S\|_{t=0}$	$\Delta B\|_{t=0}$
$0.74 \rightarrow 0.75$	2078.22	2068.47	9.755	−2.184	−2.186	0.00185
$0.70 \rightarrow 0.75$	2234.36	2226.28	8.086	−10.933	−10.942	0.00852
$0.60 \rightarrow 0.75$	2606.36	2601.25	5.108	−32.947	−32.968	0.02165
$0.50 \rightarrow 0.75$	2964.42	2961.03	3.385	−55.205	−55.236	0.03177

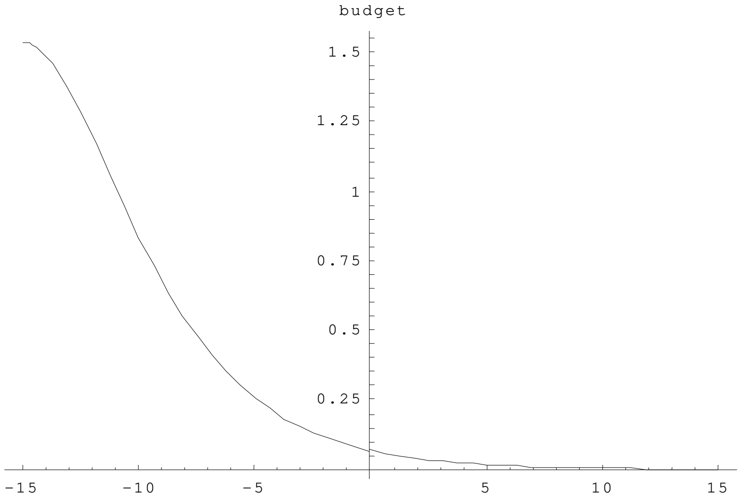

Figure 4.16: Change of α from 0.74 to 0.75 with optimal policy: budget cash flow

A closer look at the case with a change of the preference parameter from 0.50 to 0.75 shows that the trajectories in the model with an optimal policy bear a striking resemblance to the trajectories in the model of the planned economy - except for the growth rates. As a consequence the economy converges faster if constant taxes and subsidies are used to internalize the external effects.[16]

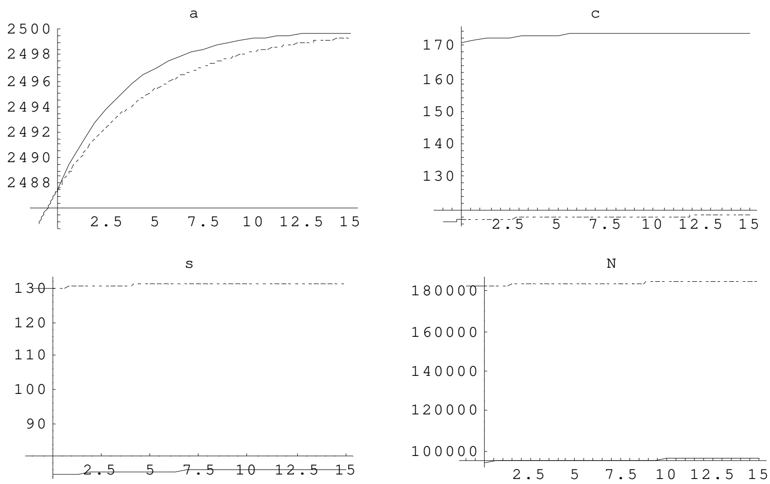

Figure 4.17: Change of α from 0.50 to 0.75 with optimal policy: assets, consumption, environmental expenditures and environmental quality

[16] Compare especially Figure 4.11 and Figure 4.18.

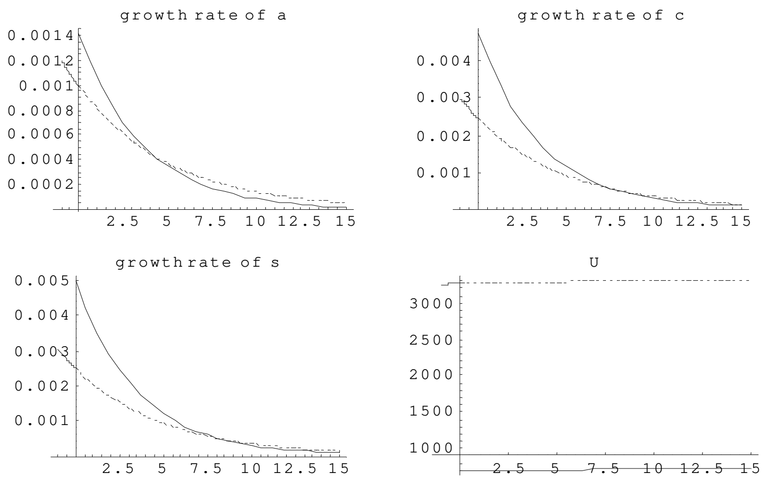

Figure 4.18: Change of α from 0.50 to 0.75 with optimal policy: growth rate of assets, consumption and environmental expenditures, and utility level

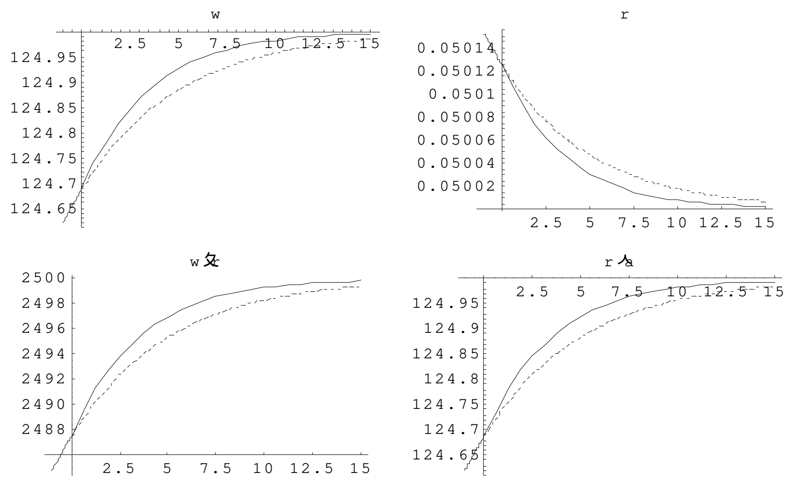

Figure 4.19: Change of α from 0.5 to 0.75 with optimal policy: wage rate, interest rate, relation between wage and interest rate, and capital income

5 Big Sleep: A Delay in the Adjustment of Policy Measures

In contrast to most theoretical models the adjustment process in the real world usually takes time. First, a change of preferences does not happen over night.[17]

[17] An exception are accidents that can change preferences in no time at all.

The possible reasons mentioned in the introduction are connected to slow processes of knowledge creation, distribution, acquisition and processing. Second, the changed preferences are not immediately reflected in a changed policy. Sometimes only an election provides an opportunity for a modification of the political orientation. And even a new government is generally not able to change very much very fast. The delayed adjustment of policy after a preference change is especially important if we look at the *introduction* or *abolition* of policy instruments. Nevertheless, this is a bit mitigated if we discuss the adjustment of instruments that are already established. Usually this adjustment can be realized more easily and at a faster pace. But there is still time necessary to change the preferences of a large proportion of the population after an initial start-up. Last but not least we should point out that also the administrative implementation of policy measures takes time.

The previous paragraph shows that there is no qualitative difference between models dealing with different dimensions of shocks. Therefore, in the following the point of time of the shock will be "earlier": We assume a change of the preference parameter if the assets attain 95% of the equilibrium value. The only motive behind this modification of the model used in the previous chapters is to make the consequences of policy measures better visible. We abstain from an extensive discussion of the case of a change of preferences towards more consumption since in the previous chapter we have shown that this case is more or less a mirror image of greening preferences.

Note that long-dashed trajectories correspond to a reference scenario without preference change, the short-dashed trajectories to a reference scenario with preference change but without adjustment of the policy instruments.

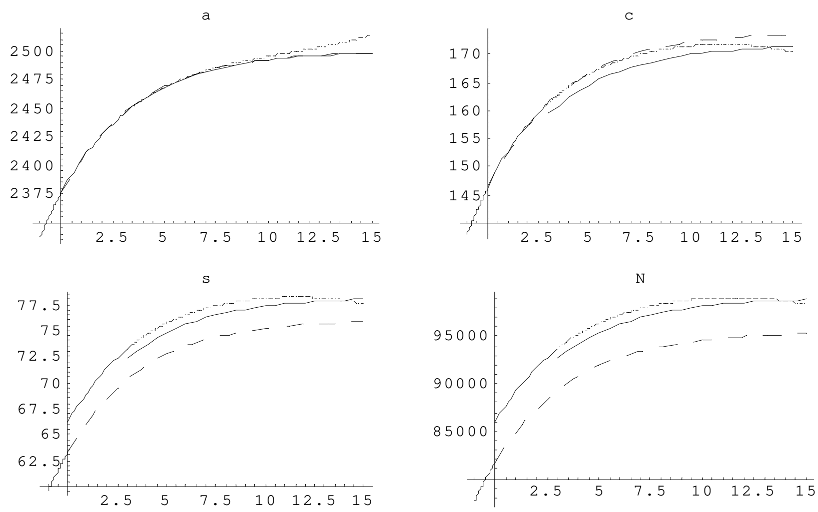

Figure 5.1: Change of α from 0.75 to 0.74 with optimal policy and a lagged adjustment after 3 periods: assets, consumption, environmental expenditures and environmental quality

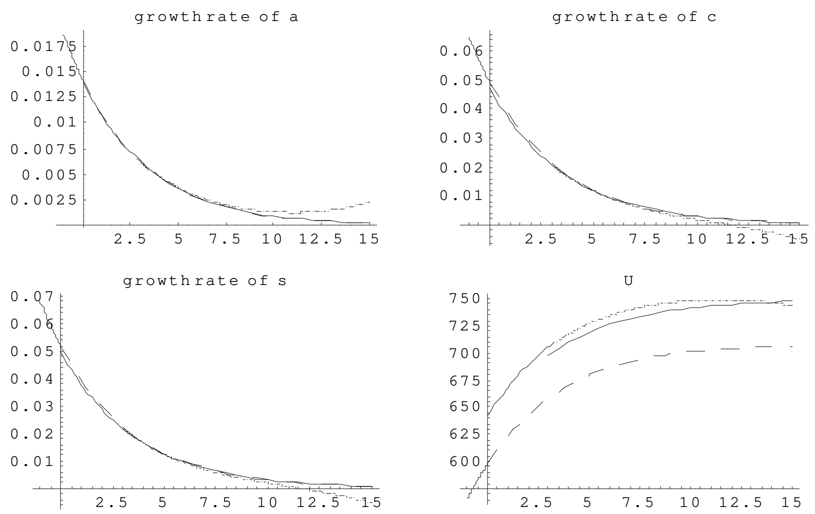

Figure 5.2: Change of α from 0.75 to 0.74 with optimal policy and a lagged adjustment after 3 periods: growth rate of assets, consumption and environmental expenditures, and utility level

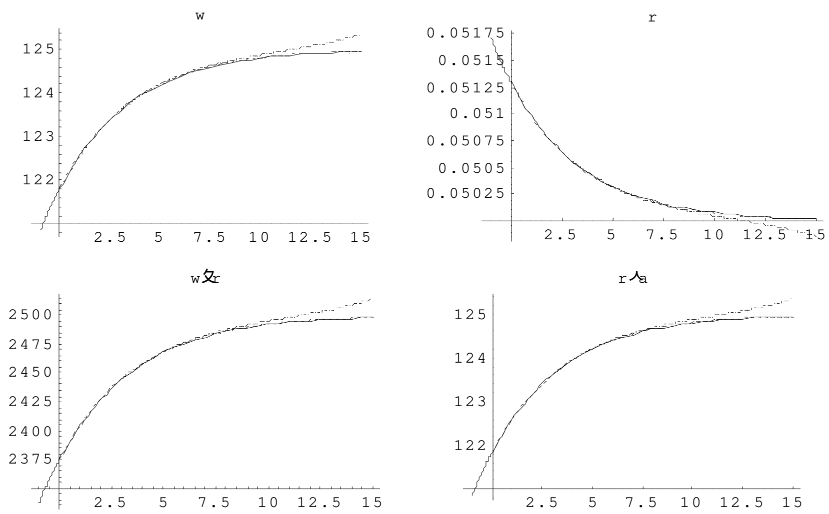

Figure 5.3: Change of α from 0.75 to 0.74 with optimal policy and a lagged adjustment after 3 periods: wage rate. interest rate, relation between wage and interest rate, and capital income

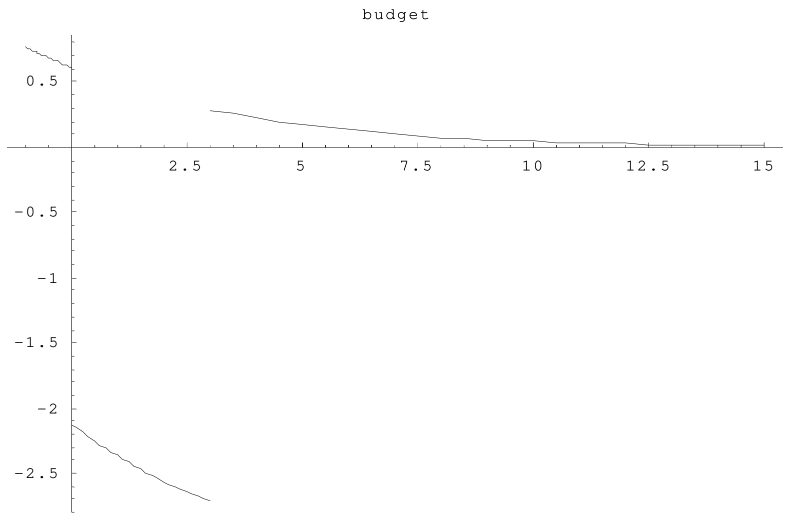

Figure 5.4: Change of α from 0.75 to 0.74 with optimal policy and a lagged adjustment after 3 periods: budget cash flow

The figures show the consequences of the adjustment of the policy instruments. The changes right after the shock are similar to the changes in the case of an unregulated economy (see Section 3). But the adjustment after three periods is accompanied by a perceptible decrease of consumption and environmental expenditures as well as natural quality. Consequently, utility decreases, too. Therefore, incentives to delay or prevent necessary adjustments of policy measures exist even if politicians are only slightly myopic.[18]

In the long run, adjustment ensures a sustainable path. Without adjustment, overaccumulation of capital takes place and the utility level decreases. Due to the distortions induced by incorrect tax and subsidy rates the system is no longer on a stable path towards a steady-state equilibrium.[19]

6 On the Edge: Errors in the Adjustment Process

In the previous section, the adjustment after a preference change was delayed. There is another possible consequence of the unpredictability of changes of preferences. Errors in the determination of the necessary extend of tax and subsidy changes are unavoidable if there are certain difficulties in the process of obtaining and processing of information.[20] Due to these errors the economy will not reach the new optimal steady state. In the following we assume an error in the determination of the optimal tax rate. However, the government is able to determine the subsidy rate that guarantees a balanced budget in the long run. This implies either different types of difficulties in the determination of tax rates and subsidy rates or a higher flexibility in the determination of expenditures than in the determination of revenues. Table 6.1 shows the equilibrium values after a change of the preference parameter α to 0.6 depending on the seize of the percentage error ε in the determination of the optimal tax rate. Note that the equilibrium of the capital stock is - as is always in this model - unaffected by the preference change and the tax rate. As in the previous section we leave out the case of a change of preferences towards higher consumption.

Table 6.1: Equilibrium values after a greening of preferences to $\alpha = 0.6$ and an error ε in the determination of the tax rate

[18] This supports results from a previous study about consequences of delayed adjustments in the case of productivity shocks (Barthel, 2007).

[19] Note that in this section the deviation from the optimal tax is much bigger than the assumed error in Section 6. Therefore, the distortion is big enough to cause the unstability. However, the rather small deviation of at most ±5% results in a stable equilibrium in the sorrounding of the optimal equilibrium.

[20] The problem of the determination of the correct tax and subsidy rate is also discussed in Barthel (2005).

ε in %	c	s	N	U
−5.0	143.873	106.127	144216	1729.74
−2.5	142.285	107.715	146746	1730.26
−1.0	141.350	108.650	148236	1730.40
−0.1	140.794	109.206	149120	1730.42
±0	140.732	109.268	149218	1730.42
+0.1	140.671	109.329	149315	1730.42
+1.0	140.121	109.879	150190	1730.40
+2.5	139.213	110.787	151633	1730.27
+5.0	137.726	112.274	153993	1729.81

An error in the determination of the tax rate of −5% - implying a tax rate that reaches only 95% of the optimal tax - results in an increased consumption by +2.232% and reduced environmental expenditures by −2.874%. And although natural quality is reduced by −3.352%, utility decreases only by −0.039%. Similarily, a tax rate that is too high (+5%) leads to lower consumption by −2.136% and increased environmental expenditures by +2.751%. Consequently, natural quality is higher than in the optimal point by +3.200%. Again, utility decreases by only −0.035%. The utility loss due to reasonable errors is rather small. This is caused by the compensation within the system. The utility loss due to too much pollution as a result of a tax rate below the optimal level is nearly compensated by the utility gain caused by higher consumption. If the tax rate is too high the decreased consumption is compensated by the lower pollution. As in the model discussed in Barthel (2007a), the utility gains due to the introduction of environmental taxes are remarkably higher than utility gains by an adjustment of environmental instruments. That implies low incentives to adjust such a system if transaction costs are high. On the other hand the utility changes are small even for noticeable changes of the tax rate. If the transaction costs are low the incentives to adjust the tax rates are not diminished by considerations with regard to a possible decrease of consumption.

The dynamic behavior of the system is shown in the next figures. We assume a change of the preference parameter α from 0.75 to 0.60 and an error in the determination of the tax rate of −5%.[21] Again we leave out the time path of the variables for the periods between −15 and −1.

[21] This implies an increase of the tax rate by only 68.735% instead of 77.615% (compare Section 3.3)

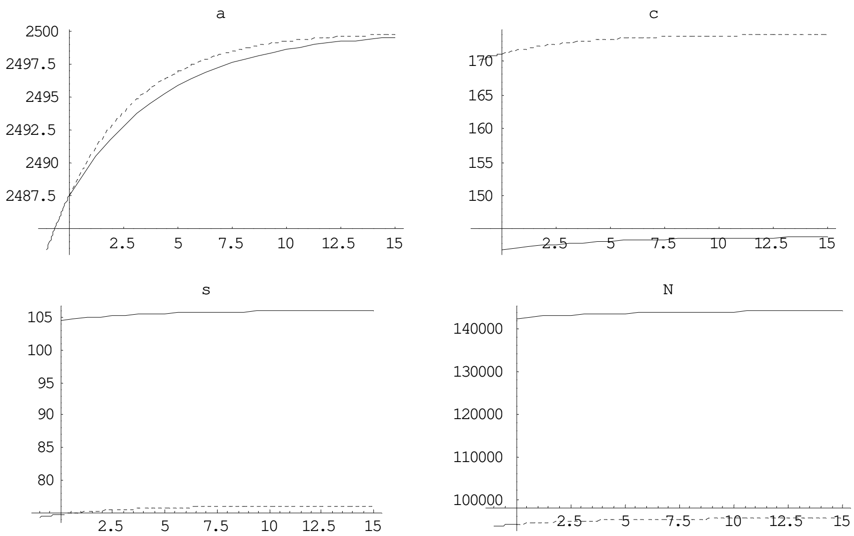

Figure 6.1: Change of α from 0.75 to 0.60 with an error in the adjustment of the tax rate of -5%: assets, consumption, environmental expenditures and environmental quality

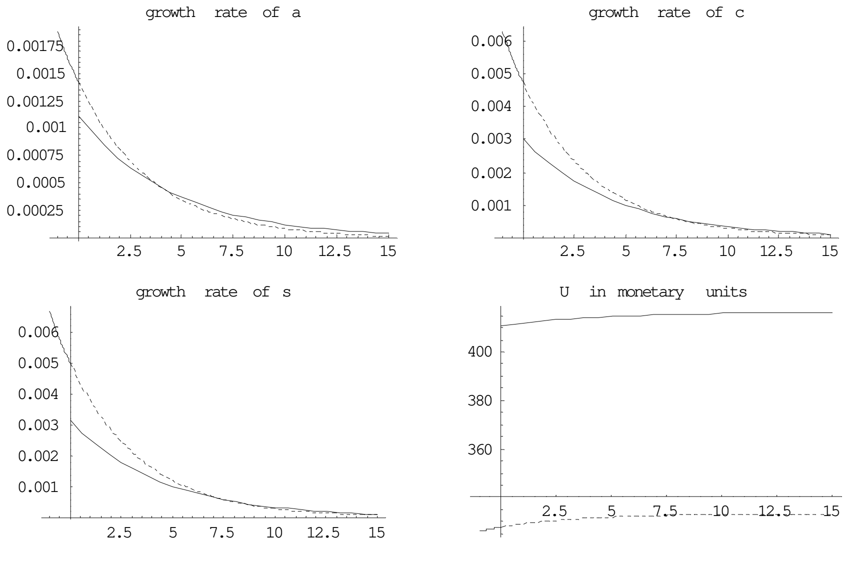

Figure 6.2: Change of α from 0.75 to 0.60 with an error in the adjustment of the tax rate of -5%: growth rate of assets, consumption and environmental expenditures, and utility level

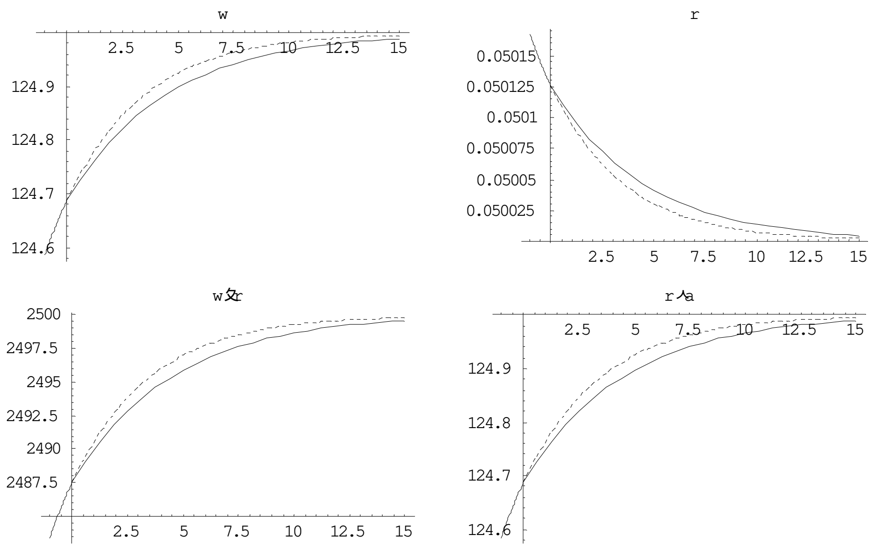

Figure 6.3: Change of α from 0.75 to 0.60 with an error in the adjustment of the tax rate of -5%: wage rate, interest rate, relation between wage and interest rate, and capital income

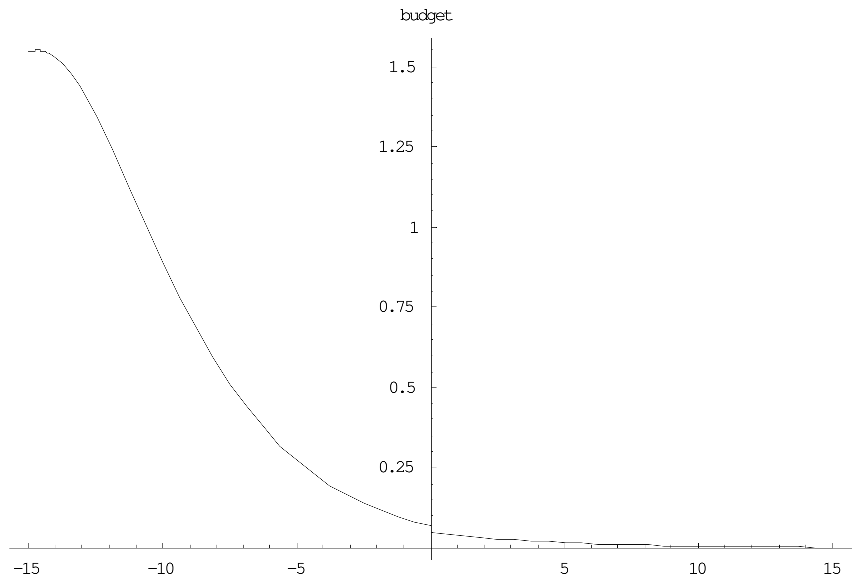

Figure 6.4: Change of α from 0.75 to 0.60 with an error in the adjustment of the tax rate of -5%: budget cash flow

A comparison with the figures in the third section shows that there is no qualitative difference in the trajectories between the model with correct and the model with incorrect tax rates. Of course, the initial changes in $t = 0$ and the equilibrium are different. Table 6.2 shows the initial changes in dependence of the adjustment error.

Table 6.2: Percentage change of variables in t = 0 after a greening of preferences to $\alpha = 0.6$ and an error ε in the determination of the tax rate

ε in %	Δc	Δs	ΔN	ΔU
−5.0	−17.044	40.090	51.464	145.077
−2.5	−17.960	42.186	54.121	145.150
−1.0	−18.500	43.422	55.685	145.169
−0.1	−18.821	44.156	56.614	145.172
±0	−18.856	44.238	56.716	145.172
+0.1	−18.892	44.318	56.819	145.172
+1.0	−19.209	45.045	57.737	145.167
+2.5	−19.733	46.243	59.251	145.149
+5.0	−20.590	48.207	61.730	145.083

The deviations from the optimal initial change correspond closely to the deviations of the equilibrium values of the variables. With an error of −5%, consumption in $t = 0$ is +2.232% higher than without this error, environmental expenditures are −2.876% lower. Consequently, natural quality is −3.351% lower, but again the utility level is nearly unaffected and decreases by −0.039%. Similarly, a tax exceeding the optimal rate by +5% results in initial consumption −2.137% below the optimal level, increased environmental expenditures by +2.752%, consequently a natural quality +3.199% above the optimal value and a decrease in utility by −0.036%. This implies a nearly unchanged speed of convergence.

The comparison with the path without the preference change shows the same pattern of deviations as can be seen in section 3.[22] Therefore we can apply the same arguments as discussed in Section 3.1.

7 Summary

The present paper builds on previous work. In Barthel (2005) the impact of the elasticity of substitution was in the focus of the analysis. Different environmental policy instruments were examined in a similar model. In a follow up, consequences of productivity shocks and capital depreciation are investigated (Barthel, 2007). Here we concentrate on shocks due to changes of preferences of the individuals.

In a model with pollution as a side effect of consumption, preferences of households shift over night. The changes are caused by exogenous shocks and

[22] Compare Figures 3.10-3.12 with Figures 6.1-6.3.

can induce "greener" or "blackened" expenditure patterns. Models of an unregulated economy, an economy controlled by a benevolent planner and regulated by a system of taxes on consumption and subsidies on environmental expenditures are calculated. The combination of taxes and subsidies internalizes the negative external effect caused by consumption and the positive external effect induced by environmental expenditures. Furthermore, we have assumed that the budget of the government is balanced in the long run. In another set of models the policy measures are adjusted with a delay. This delay is caused by the time-consuming political and administrative processes.

"Greening" of preferences is modeled as a sudden unanticipated change of the preference parameter of the utility function in favor of environmental quality. In an unregulated economy, consumption and environmental expenditures increase. The reason is a perceptible decrease of the growth rates. The higher pollution is compensated by the relatively dominating increase in environmental expenditures; consequently quality of nature and, hence, utility increase. In the not-really-long run, the growth rates are slightly higher than in the reference case without preference changes. Naturally, all growth rates approach zero in the steady state - the really long run - since we have no growth if the assets - and therefore the capital stock - attain the exogenously determined steady state level.

In a planned economy and in the case of optimal environmental policy we can observe the similar pattern of variable changes. The main difference is the speed of convergence - the planned economy and especially the economy regulated by taxes and subsidies converge faster. In the case of the combination of optimal taxes and subsidies, the budget cash flow is small and approaches zero in the long run.

An increase of the preference parameter induces a higher preference for goods consumption. Consequently, the observable variable changes are different. Expenditures decrease after the shock in favor of a higher speed of convergence. A more prominent decrease of environmental expenditures induces a lower environmental quality despite the decreasing pollution due to less consumption. Hence, the utility level decreases. Again, regulation implies a higher speed of convergence to the new steady state.

If the political and administrative processes take time, the adjustment of policy measures may be lagged. The effects of changes in the preference structure are then separated highly visible from the impact of the adjustment of tax and subsidy rates. Hence, the incentives to prevent the adjustment are apparent. However, in the long run adjustment ensures sustainability of the environmental policy.

To round off the analysis we provide an investigation of consequences of errors in the adjustment process. As long as the error is of reasonable size, the trajectories of variables are shifted. A tax rate that exceeds the optimal level results in higher environmental expenditures and natural quality but lower consumption. If the tax rate is too low, consumption is higher than in the optimum and environmental expenditures and natural quality are lower. However, in both cases the utility level remains nearly unaffected.

8 Appendix

8.1 Solution of the Household's Optimization Problem in the Basic Model

The Hamiltonian for the household i is:

$$J_H = U\left(c_i, N\left(E\left(S\right), P\left(C\right), \overline{N}\right), \phi\right) + \theta_{(a)} \cdot \left(r \cdot a + w - c_i - s_{(N)_i}\right) \tag{28}$$

The first-order conditions are:

1. $\frac{\partial J}{\partial c_i} = 0$
$$U_c + U_N \cdot N_P \cdot P_C = \theta_{(a)} \tag{29}$$

2. $\frac{\partial J}{\partial s_{(N)_i}} = 0$
$$U_N \cdot N_E \cdot E_S = \theta_{(a)} \tag{30}$$

3. $\frac{\partial J}{\partial a} = \rho \cdot \theta_{(a)} - \dot{\theta}_{(a)}$
$$\rho \cdot \theta_{(a)} - \dot{\theta}_{(a)} = \theta_{(a)} \cdot r \tag{31}$$

The transversality condition[23] is given by:

$$\lim_{t \to \infty} \left[\theta_{(a)} \cdot a\right] = 0$$

which is equivalent to:

$$\lim_{t \to \infty} \left[e^{-\rho \cdot t} \cdot a\right] = 0$$

From the conditions (29) and (30) we can derive:

$$U_c = U_N \cdot (N_E \cdot E_S - N_P \cdot P_C)$$

Derivation of the conditions (29) and (30) with respect to time yields:

$$\begin{aligned} \frac{\dot{\theta}_{(a)}}{\theta_{(a)}} &= \xi_1 \cdot \dot{c} + \xi_2 \cdot \dot{s} \\ &= \xi_3 \cdot \dot{c} + \xi_4 \cdot \dot{s} \end{aligned}$$

with

$$\begin{aligned} \xi_1 &\equiv \frac{\begin{array}{c} U_{cc} + U_N \cdot n \cdot \left(N_P \cdot P_{CC} + P_C^2 \cdot N_{PP}\right) \\ +U_{cN} \cdot P_C \cdot N_P \cdot (n+1) + U_{NN} \cdot P_C^2 \cdot N_P^2 \cdot n \end{array}}{U_N \cdot N_E \cdot E_S} \\ \xi_2 &\equiv \frac{\left(\left(U_{NN} \cdot N_E \cdot N_P + U_N \cdot N_{EP}\right) \cdot P_C + U_{cN} \cdot N_E\right) \cdot n}{U_N \cdot N_E} \\ \xi_3 &\equiv \frac{\left(U_{NN} \cdot N_E \cdot N_P + U_N \cdot N_{EP}\right) \cdot P_C \cdot n + U_{cN} \cdot N_E}{U_N \cdot N_E} \\ \xi_4 &\equiv \frac{\left(U_N \cdot E_{SS} \cdot N_E + U_{NN} \cdot E_S^2 \cdot N_E^2 + U_N \cdot E_S^2 \cdot N_{EE}\right) \cdot n}{U_N \cdot N_E \cdot E_S} \end{aligned}$$

[23] See Barro and Sala-i-Martin (1995, 503-508).

Therefore, the control variables change according to:

$$\begin{aligned}
\dot{c} &= \frac{\xi_4 - \xi_2}{\xi_1 \cdot \xi_4 - \xi_3 \cdot \xi_2} \cdot (\rho - r) && (32)\\
\dot{s} &= \frac{\xi_1 - \xi_3}{\xi_1 \cdot \xi_4 - \xi_2 \cdot \xi_3} \cdot (\rho - r) && (33)
\end{aligned}$$

8.2 Solution of the Planner's Optimization Problem

The Hamiltonian can now be written as:

$$J_P = U\left(c, N\left(E\left(S\right), P\left(C\right), \overline{N}\right), \phi\right) + \theta_{(a)} \cdot \left(f\left(a\right) - c - s_{(N)}\right) \qquad (34)$$

The first order conditions are:

1. $\frac{\partial J}{\partial c} = 0$
$$U_c + U_N \cdot N_P \cdot P_C \cdot n = \theta_{(a)} \qquad (35)$$

2. $\frac{\partial J}{\partial s_{(N)}} = 0$
$$U_N \cdot N_E \cdot E_S \cdot n = \theta_{(a)} \qquad (36)$$

3. $\frac{\partial J}{\partial a} = \rho \cdot \theta_{(a)} - \dot{\theta}_{(a)}$
$$\rho \cdot \theta_{(a)} - \dot{\theta}_{(a)} = \theta_{(a)} \cdot f_a \qquad (37)$$

From equations (35) and (36) follows:

$$U_c = U_N \cdot n \cdot (N_E \cdot E_S - N_P \cdot P_C)$$

Derivation of conditions (35) and (36) with respect to time yields:

$$\begin{aligned}
\frac{\dot{\theta}_{(a)}}{\theta_{(a)}} &= \xi_1 \cdot \dot{c} + \xi_2 \cdot \dot{s}\\
&= \xi_2 \cdot \dot{c} + \xi_3 \cdot \dot{s}
\end{aligned}$$

with:

$$\begin{aligned}
\xi_1 &\equiv \frac{U_{cc} + \begin{bmatrix} U_N \cdot \left(N_P \cdot P_{CC} + P_C^2 \cdot N_{PP}\right) \\ +U_{NN} \cdot N_P^2 \cdot P_C^2 \end{bmatrix} \cdot n^2 + 2 \cdot U_{cN} \cdot P_C \cdot N_P \cdot n}{U_N \cdot N_E \cdot E_S \cdot n}\\
\xi_2 &\equiv \frac{U_{cN} + U_{NN} \cdot N_P \cdot P_C \cdot n}{U_N} + \frac{N_{EP} \cdot P_C \cdot n}{N_E}\\
\xi_3 &\equiv \frac{U_{NN} \cdot N_E \cdot E_S \cdot n}{U_N} + \frac{N_{EE} \cdot E_S \cdot n}{N_E} + \frac{E_{SS} \cdot n}{E_S}
\end{aligned}$$

It follows:

$$\begin{aligned}
\rho - f_a &= \xi_1 \cdot \dot{c} + \xi_2 \cdot \dot{s}\\
&= \xi_2 \cdot \dot{c} + \xi_3 \cdot \dot{s}
\end{aligned}$$

Here, the growth rates are given by:

$$\begin{aligned}
\dot{a} &= f(a) - c - s_{(N)} && (38)\\
\dot{c} &= \frac{\xi_2 - \xi_3}{\xi_2^2 - \xi_1 \cdot \xi_3} \cdot (\rho - f_a) && (39)\\
\dot{s} &= \frac{\xi_2 - \xi_1}{\xi_2^2 - \xi_1 \cdot \xi_3} \cdot (\rho - f_a) && (40)
\end{aligned}$$

Using the specifications the short hand equations simplify to:

$$\begin{aligned}
\xi_1 &\equiv \frac{U_{cc} + \left(U_{NN} \cdot P_C^2 - U_N \cdot P_{CC}\right) \cdot n^2 - 2 \cdot U_{cN} \cdot P_C \cdot n}{U_N \cdot E_S \cdot n}\\
\xi_2 &\equiv \frac{U_{cN} - U_{NN} \cdot P_C \cdot n}{U_N}\\
\xi_3 &\equiv \frac{U_{NN} \cdot E_S^2 + U_N \cdot E_{SS}}{U_N \cdot E_S} \cdot n
\end{aligned}$$

8.3 Solution of the Household's Optimization Problem with Repayment of Tax Revenues as a Subsidy

The Hamiltonian for the household i is:

$$\begin{aligned}
J_H &= U\left(c_i, N\left(E(S), P(C), \overline{N}\right), \phi\right) && (41)\\
&\quad + \theta_{(a)} \cdot \left(r \cdot a_i + w_i - (1+d) \cdot c_i - (1-p) \cdot s_{(N)_i}\right)
\end{aligned}$$

The first-order conditions are:

1. $\frac{\partial J}{\partial c_i} = 0$

$$U_c + U_N \cdot N_P \cdot P_C = \theta_{(a)} \cdot (1+d) \qquad (42)$$

2. $\frac{\partial J}{\partial s_{(N)_i}} = 0$

$$U_N \cdot N_E \cdot E_S = \theta_{(a)} \cdot (1-p) \qquad (43)$$

3. $\frac{\partial J}{\partial a} = \rho \cdot \theta_{(a)} - \dot{\theta}_{(a)}$

$$\rho \cdot \theta_{(a)} - \dot{\theta}_{(a)} = \theta_{(a)} \cdot r \qquad (44)$$

Again, we can derive:

$$U_c = U_N \cdot \left(\frac{1+d}{1-p} \cdot N_E \cdot E_S - N_P \cdot P_C\right)$$

From the derivation conditions (42) and (43) with respect to time follows:

$$\begin{aligned}
\frac{\dot{\theta}_{(a)}}{\theta_{(a)}} &= \xi_1 \cdot \dot{c} + \xi_2 \cdot \dot{s} + \xi_3 \cdot \dot{d}\\
&= \xi_4 \cdot \dot{c} + \xi_5 \cdot \dot{s} + \xi_6 \cdot \dot{p}
\end{aligned}$$

with:

$$\begin{aligned}
\xi_1 &\equiv \frac{\begin{array}{c} U_{cc} + U_N \cdot n \cdot \left(N_P \cdot P_{CC} + N_{PP} \cdot P_C^2\right) \\ +U_{NN} \cdot P_C^2 \cdot N_P^2 \cdot n + U_{cN} \cdot N_P \cdot P_C \cdot (n+1) \end{array}}{\frac{1+d}{1-p} \cdot U_N \cdot N_E \cdot E_S} \\
\xi_2 &\equiv \frac{\left(\left(U_N \cdot N_{EP} + U_{NN} \cdot N_E \cdot N_P\right) \cdot P_C + U_{cN} \cdot N_E\right) \cdot n}{\frac{1+d}{1-p} \cdot U_N \cdot N_E} \\
\xi_3 &\equiv -\frac{1}{1+d} \\
\xi_4 &\equiv \frac{\left(U_N \cdot N_{EP} + U_{NN} \cdot N_E \cdot N_P\right) \cdot P_C \cdot n + U_{cN} \cdot N_E}{U_N \cdot N_E} \\
\xi_5 &\equiv \frac{\left(U_N \cdot N_E \cdot E_{SS} + U_{NN} \cdot N_E^2 \cdot E_S^2 + U_N \cdot N_{EE} \cdot E_S^2\right) \cdot n}{U_N \cdot N_E \cdot E_S} \\
\xi_6 &\equiv \frac{1}{1-p}
\end{aligned}$$

This can be rewritten as:

$$\begin{aligned}
\dot{c} &= \frac{(\xi_5 - \xi_2) \cdot (\rho - r) - \xi_3 \cdot \xi_5 \cdot \dot{d} + \xi_2 \cdot \xi_6 \cdot \dot{p}}{\xi_1 \cdot \xi_5 - \xi_4 \cdot \xi_2} \\
\dot{s} &= \frac{(\xi_1 - \xi_4) \cdot (\rho - r) + \xi_3 \cdot \xi_4 \cdot \dot{d} - \xi_1 \cdot \xi_6 \cdot \dot{p}}{\xi_1 \cdot \xi_5 - \xi_4 \cdot \xi_2}
\end{aligned}$$

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