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**State Dependent Pollution Control and the
Choice of Policy Instruments**

by

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ABSTRACT

The paper examines the role of policy instruments aiming at the control of environmental problems. If there is a complex relationship between economic activities and environmental effects, the use of indirect economic measures such as environmental taxes may be inefficient compared with direct abatement measures. Moreover, an optimal tax can not be assessed if the level of abatement efforts is sub-optimal. This calls for an integrated approach to the analysis of environmental policy, including cost-benefit analysis of abatement measures. It is shown that cost-benefit evaluations of abatement should include a shadow price on environmental qualities that is likely to increase over time. The effect of this increase may outweigh the effect of discounting, thus making environmental benefits of present abatement measures in the far future count even with a high discount rate.

1 Introduction ¹

During the past decades, economists have contributed substantially to environmental policy making by emphasising the importance of efficiency in the use of natural as well as economic resources. To mitigate severe environmental problems may be very costly. Economic instruments have therefore played an increasing role in environmental policy making both within countries and in policy processes dealing with global environmental problems. Cost efficiency does not only minimize the conflict between material growth and environmental sustainability. It also makes environmental measures easier to carry out.

The rationale for using economic instruments is to make the polluter pay for the damage he causes. He thereby gets incentives to reduce his polluting activities, and to substitute towards less polluting technologies. By aiming environmental policy at initiation of "environmental friendly" behaviour on a decentralized level, the task for the central authorities is radically simplified. The most well-known economic instruments are environmental taxation, tradeable quotas and deposit-refund systems. To reduce anthropogenic emissions to air, taxation has been suggested frequently and some countries have already carried out such a policy.

To assess an appropriate tax level is, however, not straight forward. Hoel and Isaksen (1993) show that the weights of the contribution to global warming from different greenhouse gases depend considerably on the economic assumptions. The success of environmental taxation as a policy instrument has also caused warnings from economists, see e.g. Alfsen *et al.* (1992). It has been stressed that activities subject to taxation may cause several environmental problems. If a CO_2 -tax is imposed on fossile fuels, for instance, one will benefit from reductions in the emissions of SO_2 , NO_x and other pollutants as well. It has been argued, therefore, that in order to achieve the correct tax-level, *all* the effects should be examined, not only those from the reduced emissions of CO_2 .

It is true that one activity may cause several problems, but it is also true that a problem is normally caused by several activities (Aunan *et al.*

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(1994)). In a simple economic model structure, activities are defined as the use and production of specified goods and services. However, environmental problems are scarcely proportionately related to economic activities. Different pollutants react with each other in different manners and with different time lags. To forecast the effect of a given set of pollutants, one will have to model the chemical processes in the atmosphere and try to assess the effects of changes in air quality.

What may seem optimal in an economic model which focuses the control of emissions may be far from optimal in the real world, simply because the economic model will usually be unable to identify "what to tax" properly. This paper suggests a way to model economic efficient instruments in which the complexity of environmental effects is taken into account. It aims at integrating dose and response-functions in an aggregated dynamic economic growth model similar to that of Ramsey, and discusses the sensitivity in the use of efficient instruments, here limited to environmental taxation and abatement costs.

Although this paper emphasises the methodology, it has also got a message. It is shown that environmental taxes cannot be assessed optimally unless the level of abatement costs, for instance investments in cleaning equipment, is optimally assessed. The optimal choice between abatement costs and taxation depends critically on chemical processes affecting the state of the environment. Normally, it is impossible to relate environmental problems directly to specific economic activities, because the severeness of the problems depends *inter alia* on the composition of emission components, dispersion of pollutants and the lifetime of specific chemical materials. This enhance the importance of abatement activities such as investments. Private investments in abatement as a response to environmental taxation may, as a consequence, be far from sufficient to secure an optimal combination of taxation and abatement. Thus, public investments in abatement may be desirable to secure cost efficiency of taxation. Moreover, I show that investments in abatement measures may be extremely profitable because the shadow price of environmental quality is likely to increase over time.

2 Optimal growth with feed-backs

In later years, economists have increasingly emphasised the feed-backs on economic activities of environmental deterioration. Integrated modelling is

a rather new branch of research, and employs mainly those with access to large computable models (see e.g. Hope *et al.* (1994), Alcamo *et al.* (1994), Manne *et al.* (1994) and Peck and Teisberg (1994)). These are often quite detailed in their description of activities and components, but most of them have a rather simple structure, both with respect to economic relations and to environmental linkages. Their complexity is related to the level of disaggregation. To understand what really goes on in these “black boxes” is often quite difficult. To explain the role of economic instruments in environmental policy making, I will describe a simplified economic growth model in this section. The aim is to show how the “conventional wisdom” about the use of environmental policy can be explained. A more comprehensive analysis of a similiar growth model with environmental effects is given in van der Ploeg and Withagen (1991). Later the model is extended to include a more complex set of environmental relations in order to analyse to what extent the conventional wisdom is still valid.

Consider an economy which produces one commodity that is used for consumption (c_t), activities preventing or cleaning environmental damage (abatement), a_t , and two kinds of capital, k_1 and k_2 . Denote by $\Psi(k_{1t}, k_{2t}, m_t)$ the macro production function. Total capital formation, ($\dot{k}_t = k_{1t} + k_{2t}$) is

$$\dot{k}_t = \Psi(k_{1t}, k_{2t}, m_t) - c_t - a_t \quad (1)$$

The output of the economy is produced by input of the two capital goods but is also dependent on an environmental variable, m_t which may be interpreted as physical “damage”. The two different types of capital, produced in the same manner, or representing capital equipment in two sectors, are equal as regards the allocation of products. The production function has the conventional properties with respect to both categories of capital, i.e. $\Psi'_{k_i} > 0$ and $\Psi''_{k_{ii}} < 0$, ($i = 1, 2$), while $\Psi'_m < 0$.

The distinction between the k_{1t} and k_{2t} is that the latter causes emissions with environmental consequences while k_{1t} is “clean”. Apart from being dependent on the size of k_{2t} , m_t can also be reduced by abatement. Assume that there exists a “damage function”,

$$m_t = g(k_{2t}, a_t), \quad (2)$$

for which $g'_k > 0$, $g''_{kk} > 0$, $g'_a < 0$ and $g''_{aa} > 0$. No doubt, this function is very difficult to assess, and will be subject to considerable uncertainty. The

reason for including it is, however, that in order to arrive at an optimal environmental policy, one cannot discard the fact that environmental damage occurs. To simplify the interpretation of the results, we assume that the macro production function can be separated into a somewhat more conventional one, where production in the private sector depends only on the two types of capital whereas the damage only shows up in the social aggregate of production. Thus, the productive part of $\Psi(\cdot)$ describes the aggregate of production functions as reported from private enterprises, while the damage part includes the indirect effects. Then, capital formation can be written

$$\dot{k}_t = f(k_{1t}, k_{2t}) - g(k_{2t}, a_t) - c_t - a_t \quad (3)$$

This model is radically simplified compared with computable macro-economic models in most respects, but it includes important relations that are absent from many of them. Static models have been applied to evaluate carbon taxes to mitigate climate change (Moum (1992)). Other frequently cited works on the cost of carbon emission control such as those of Fankhauser (1992) Nordhaus (1992), Manne and Richels (1992), Jorgenson and Wilcoxon (1991) do not include feed-back mechanisms. The above model “convolutes” the main properties of macro-economic models describing emissions and integrated models, and is sufficient to show why environmental taxation has achieved so high confidence among economists.

Optimal growth is found by maximization of discounted welfare over the time horizon:

$$\max_{c_t} \int_0^T w(c_t) e^{-\delta t} dt, \quad (4)$$

where $w(c_t)$ is the temporal welfare function with the standard properties, and δ is the pure rate of time preference (rate of impatience). The “static” first order conditions becomes:

$$\frac{f'_{k_1}}{f'_{k_2}} = 1 - \frac{g'_k}{f'_{k_2}}, \quad (5)$$

$$-g'_a = 1. \quad (6)$$

(5) determines the relationship between the two categories of capital. The marginal social productivity of the two should be equal. Without environmental effects, i.e. $g'_k = 0$, we get $f'_{k_1} = f'_{k_2}$. If environmental effects are

present, environmental damage from the use of k_2 causes an adjustment which corresponds to the marginal damage per unit of marginal contribution to the output from k_2 .

(6) simply states that the marginal effect of abatement should equal 1. This is because abatement according to (3) is measured directly in terms of units of output. Thus, an extra unit of abatement near optimum should yield the same amount in return.

One background for proposing policy measures is provided by a comparison of the results of this model with the solution in a perfectly competitive market. In such a market the relative marginal productivity of different categories of capital equals the relative price between the capital goods. If the relative price between k_1 and k_2 is $(1 - g'_k/f'_{k_2})$ in the competitive market, the social optimum is attained. The only difference between the two categories of capital in the model is their impact on the environment. To the private enterprises, the two are equal. A non-interrupted perfect market would therefore yield the same price for the two. To achieve social optimum one should impose a tax on k_2 equal to g'_k/f'_{k_2} .

As for the optimal abatement concerns, the intuition of the cost-benefit rule applies: Abate if total marginal benefits, $-g'_a$, exceed total costs. Note that the damage function can be limited to the damage imposed on other actors only, i.e. it prescribes indirect effects. Productivity losses caused by own activities are supposed to be reflected in the production function, $f(\cdot)$. The abatement activity presumes that someone takes the lead in carrying out the correct amount of abatement. The government may do this, or they may subsidise abatement carried out by those who happen to suffer from environmental degradation. Since the subsidies finally result in a net social return, they might be carried out without conflicts.

On the other hand, the abatement have to be financed at the expence of the disposable income to the private sector. This may have effects on the income distribution and cause political difficulties in obtaining an optimal amount of a_t . In the public debate, therefore, we often hear that abatement activities should be financed from the income of the environmental taxes, and conversely that the income from environmental taxation should be "ear-marked" environmental abatement activities. This would require that income taxes were sufficiently high to assure that the optimal level of abatement were feasible.

If the only tax income in a competitive market were derived from these

taxes, we would have to require that the tax rate was equal to $g'_k/f'_{k_2} = a_t/k_2$. As this equation does *not* follow from the optimal solution, it means that a new constraint is introduced. Consequently, one cannot do better than without it. Even if the social welfare function included some concern for the income distribution, the above condition would be arbitrary from the point of view of income distribution. The final solution would be affected in a non-positive direction. Therefore, economists warn against “ear-marking” of environmental taxes. There is no unambiguous relation between the amount of abatement and the level of emission charges.

Another problem is to assess the total marginal benefits of abatement. The model above abstracts from these problems by assuming that the damages are known and can be measured directly in terms of a loss in output. However, the discussion of optimal abatement addresses exactly the question how easy this is. For instance, if we cannot separate production and damage, such as in equation (3), the marginal effect of abatement in optimum shifts from 1 to Ψ'_m from the general production function (1). The optimal tax rate shifts from g'_k/f'_{k_2} to $-g'_k/(\Psi'_{k_2}g'_a)$. In other words, the level of abatement affects the optimal tax rate directly: A suboptimal level of abatement will lead to a suboptimal tax level.

Till now, only the static conditions of the dynamic problem has been commented. Denote by ρ the social return on capital. If the static conditions are fulfilled, we have $\rho = f'_{k_1} = f'_{k_2} - g'_k$, or if the more general production function in (1) is applied:

$$\rho = \Psi'_{k_1} = \Psi'_{k_2} - \frac{g'_k}{g'_a} \quad (7)$$

Optimal growth is characterized by the familiar Ramsey rule (see e.g. Blanchard and Fisher (1989)):

$$\rho = \delta + \mu \frac{\dot{c}}{c} \quad (8)$$

\dot{c}/c is the optimal rate of consumption growth, and $\mu = -c_t u''_{cc}/u'_c$ denotes the marginal elasticity of intertemporal substitution. μ characterizes the intertemporal properties of the welfare function. The higher μ is, the more attention is paid to future generations. In other words, nothing changes from the conventional wisdom. As for costs and benefits of abatement measures that have consequences beyond “one year”, future amounts can be discounted

with the ordinary choice of a social discount rate, provided of course that k_1 and k_2 are correctly priced.

The implication of this is that in principle, there is no reason why it is more important to pursue environmental taxation rather than abatement activities to attain cost efficiency. On the contrary, the two cannot be assessed separately. Moreover, cost-benefit rules applies for the assessment of optimal abatement in this macroeconomic context. Some economists exhibit scepticism against cost-benefit evaluation of projects because project evaluation fails to take market effects of large projects into account. On the other hand, vague and unidentified notions of environmental effects of economic activities may be an equally, or even a more important obstacle for attaining the best policy. Apart from this, the economic approach to choices among environmental policy measures applies: Carry out abatement measures which yields net social benefits, and impose an indirect tax on polluting activities which cause market distortions.

However, the optimal dose of different measures and the balancing between them may critically depend on environmental effects. One may suspect that a strongly simplified description of environmental effects, for instance that needed to assess the "damage function" $g(k_{2t}, a_t)$, may lead to a systematic bias in proposals for a cost efficient environmental policy. In the remainder of this paper, we examine how dependent such proposals may be on arbitrary assumptions about physical and chemical relations, necessary to establish simplified "damage functions".

3 A frame for modelling environmental processes

The structure of the model is as follows: Economic activities generate emissions in addition to goods and services. Emissions to air is an example. The emissions contribute to changes in air quality, which we assume can be represented by state variables. How the states develop over time depends on the composition of emissions and the interaction between the different state variables, which are subject to chemical processes in the atmosphere. Finally, a change in the air quality has an impact on the economic production feasibilities. These changes are described by shifts in individual's probability of being affected by the change in air quality, the environmental risk. These effects include for instance respiratory diseases, cancer or a more rapid capital

depreciation. In other words, the responses to changes in air quality are described by binary variables: One is either be affected or not.

Emissions from economic activities are supposed to depend on economic output, x_t , and abatement activities a_t :

$$e_t = \eta(x_t, a_t) \quad (9)$$

We may think of e_t as a $1 \times m$ -vector, where each element e_{it} denotes a primary pollutant, such as emissions of CO_2 , SO_2 or NO_x . To link emissions to activities in this manner is a quite common practice in economic analysis of environmental problems, but is clearly a simplification. Emissions will also depend on to what puposes the commodities such as fossile fuels are used, and what technology they enter. These problems are quite familiar to those who make estimates of emissions because such estimates require a very detailed knowledge about economic activities. As this paper aims at a very general level, this assumption is probably one of the smaller camels we will have to swallow.

The state of the environment is represented by a $1 \times n$ -vector S_t . n is the number of description variables, for instance the number of indecies necessary for a relevant description of air quality. The concentration of greenhouse gases provides another example of "the state". The description variables would then include concentrations of e.g. CO_2 , CH_4 and ozone in the stratosphere and the troposphere. Yet another example is the thickness of the ozone layer, for which description variables include e.g. chlorines, bromides, ozone and particles. Assume that the state of the environment develops according to a known stochastic process:

$$dS_t = [\Pi(S_t) + g(e_t)]dt + \sigma(S_t, t)dz \quad (10)$$

The function $\Pi(S_t)$ represents the expected change in the state of the environment for given levels of environmental quality, provided no man-made distortions, i.e. the nature's own ability to recover. $g(e_t)$ is the impact on environmental states from the current vector of emissions, and dz is a standardized stochastic term with zero expectation, and $\sigma(S_t, t)$ is the standard deviation of the process between t and $(t + \Delta t)$ as $\Delta t \rightarrow 0$.

This implies some assumptions that need a comment. The stochastic evolution of states indicated above describes a Brownian motion. Thus, I

assume that the history does not add any information of relevance to the development of environmental states. All information of relevance is embodied in S_t . However, environmental effects of human actions typically occur at later points of time, in some cases much later, than the action took place. In this sense, the history of emissions is of great importance to the description of the present state of the environment. So how can we defend to use a Brownian motion in this context?

To answer one has to make clear whether the utility function depends only on the current state, e.g. consumption, at each point in time, or if the utility at some t is directly affected by the future expected consequences of present actions. In the first case, the model given above is sufficient to reflect the future effect, because the intertemporal utility function includes the future consumption level which is affected by the development of environmental states by equation (10). In the next section, we will deal with this assumption.

However, the construction of Brownian state processes may also allow for the latter utility structure to be represented if we define states partly by "vintages". Assume that each element in S_t , s_{it} causes a constant change in the development of element s_{jt} , independent on their levels. Then, we can define a $n \times n$ -matrix α with elements α_{ij} , which describes the unit contribution to the development of state i from state j . α is then an "input-output" matrix of environmental states. S_t may be further divided into submatrices, each containing states of relevance for the description of the overall environmental state for a given "vintage", and the set of submatrices will refer to different "vintages" of states. Say for instance that it takes four years from a given initial set of emissions till they have an effect in terms of economic consequences. Then, there are four sets of states included in S_t which describe the state in each future year. In addition there are sets of cross-effects which indicate the effect of physical and chemical processes between the "vintages".

I will assume that $\Pi(S_t) = \alpha S_t$ in the sequel, but will *not* interpret α by vintages, because this would require additional assumptions about the utility function. Now, S_t contains all information of relevance, and the development of states can be simplified to

$$dS_t = [\alpha S_t + g(e_t)]dt + \sigma(S_t, t)dz \quad (11)$$

which in spite of the fact that α is constant provides a rather flexible description of environmental development. Note that if S_t contains vintages, the emissions will affect the "first" sub-vector only.

Responses. Damage caused by changes in the state of the environment is expressed in terms of probabilities

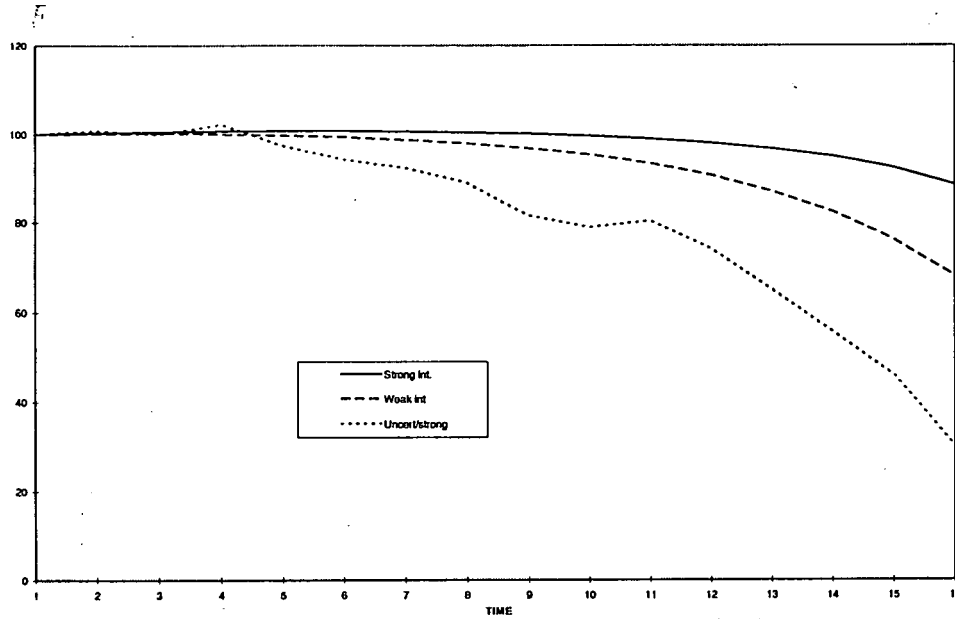
$$p_t = F(S_t) \quad (12)$$

As for e_t and S_t also p_t may represent a vector where each element depends on more than one state: The frequency of e.g. cancer depends on the concentration of particles and of the thickness of the ozone layer for instance. The use of probabilities indicates that uncertainty is taken into account, but in the context of the present model this is not so. There are no uncertainties related to the responses, except those originating from the development of states. One may e.g. interpret p_t as the probability for a given person to catch a given disease caused by environmental degradation. She does not know whether she will catch the disease or not, but on a macro level assume that we can tell with reasonable accuracy how many people that will be affected by environmentally caused diseases if the states of the environment are known. The attitude towards this risk may be included directly in the economic model, which is outlined in the sequel.

The difference between direct control of emissions and concern about the effects of environmental changes is illustrated in Figure 1. Three alternative paths of the state-variables with the same, slightly increasing, emissions path are displayed. The "strong interaction" and "weak interaction" paths represents the evolution of one out of five interactive description variables under certainty. "Strong" means that the absolute values of the elements of the α -matrix are higher than in the "weak" alternative. One see that stronger interaction not necessarily has a negative impact on the evolution of states. It also turns out that small changes in the coefficients of the α -matrix may have considerable effects on the evolution of states: In this illustration the values of the coefficients are reduced by 5 percent in the "weak interaction" alternative. This resulted in a 15 to 20 percent reduction of the state-measure within 15 years.

The third alternative is a randomly drawn development in the "strong interaction" case. Again, there is a vast impact on the state description variable. If the response depends on the description variable displayed in the

Figure 1. Alternate development of states with similar emissions



figure, it is clear that an optimal policy will differ considerably in the three cases. Therefore, it may be far from optimal to base environmental policy on emissions rather than the effects.

4 Optimal development

The previous set of environmental relations allows for a more specific description of the “damage function” (2) introduced in the economic framework given above. Instead of translating this damage into loss in terms of productivity, effects of environmental degradation should be given in terms of responses. To be simple about this, we assume that the response is given as a reduction in work-days for the labor-force. Let \bar{n} denote the total labor force and n_t those available for production. Then we have

$$n_t = \bar{n}[1 - F(S_t)]. \quad (13)$$

Rather than dealing with the production function in (1) which includes “damage”, we can now use the more familiar one

$$x_t = \Phi(k_{1t}, k_{2t}, n_t). \quad (14)$$

The responses can of course be included in a number of ways, and the above is the more simple one. One may extend the number of effects, and if focus is on diseases one might introduce a health service sector in which the activity is endogenously determined by the number of people affected. This is of interest if the aim is to recommend policy for practical implementation. Here, however, the scope is limited to outline the method and to point at some principles about policy choices.

To sum up, we recall the statement of the problem:

$$\max_{c,a} \int_0^T w(c_t) e^{-\delta t} dt$$

s.t.

$$dk_t = (\Phi(k_{1t}, k_{2t}, \bar{n}[1 - F(S_t)]) - c_t - a_t) dt$$

$$dS_t = (\alpha S_t - g(a_t, k_{2t})) dt + \sigma(S_t, t) dz$$

where the effect on environmental states from emissions is represented by $g(a_t, k_{2t})$. This problem can be solved by dynamic programming. Define

$$V(k_t, S_t) = \max_{c,a} \int_t^T u(c_s) e^{-\delta s} ds \quad (15)$$

under the constraints given above. Then the Hamilton-Jacoby-Bellman-equation is:

$$0 = \max_{c,a} E\{u(c_t) e^{-\delta t} + V_t' dt + V_k' dk_t + V_S' dS_t + \frac{1}{2} V_{SS}'' dS_t^2\} \quad (16)$$

Inserting for $E(dk_t)$ and $E(dS_t)$, and noting that under the present assumptions $E(dS_t)^2 = \sigma(S)^2/2$, we obtain the first order "static" maximum conditions for this problem:

$$V_k' = u_c' e^{-\delta t} \quad (17)$$

$$V_S' = -\frac{u_c'}{g_a'} e^{-\delta t} \quad (18)$$

V'_S and V'_k can be interpreted as shadow prices similiarly to that of the Hamiltonian problem under certainty. By differentiation of (16) wrt. k_1 and k_2 , we also find the same relation between optimal use of the two as before:

$$\frac{\Phi'_{k_1}}{\Phi'_{k_2}} = 1 + \frac{g'_k}{g'_a} \quad (19)$$

In economic terms, this implies that the relation between the optimal use of different cathegories of captial still is to be controlled by a unit tax on k_2 assessed by the relative marginal effect on emissions between capital and abatement costs. From now on we use k_1 as the “numeraire” for capital. However, also the state of the environment is to be controlled in the present case. The optimal control of the state variables can be evaluated by expanding (17) and (18) by Dynkin’s formulae. Together with the derviatives of (16) wrt. to the state variables we obtain the following expressions for the expected change in the shadow prices over time:

$$\frac{\partial}{\partial t}(V'_{k_1}) = V'_{k_1} \Phi'_{k_1} \quad (20)$$

$$\frac{\partial}{\partial t}(V'_s) = V'_{k_1} \Phi'_n \bar{n} F'_S - \alpha V'_S - \sigma \sigma'_S V''_{SS} \quad (21)$$

Inserting for (17) and (18) and some manipulations we obtain the expected rate of change in these shadow prices over time, $\rho(t)$ and $\pi(t)$ respectively

$$\rho = \Phi'_{k_1} \quad (22)$$

$$\pi = -(\alpha + g'_a \Phi'_n \bar{n} F'_S + \sigma \sigma'_S [\frac{g''_{as}}{g'_a} - \frac{u''_{cs}}{u'_c}]) \quad (23)$$

ρ is the rate of discount. Thus, we achieve the same rate as for a perfect competitive economy, namely that the rate of discount is to be equal to the marginal return on capital. Recall that this return is measured in terms of k_1 , i.e. “clean” technologies. The optimal distribution of k_1 and k_2 is given from (19). From the point of view of environmental policy decisions, (23) is of greater interest. It points at an important property of social cost-benefit analysis of environmental measures, namely that also future effects of abatement are to be differently priced over time. This answers the “problem” of

discounting future environmental effects in cost-benefit analysis: The problem is not discounting, but that the price of the state of the environment is unknown if environmental states are left out of the study.

The rate of change in the price of the environment includes three terms. The first refers directly to the natural forces, while the second represents marginal responses of environmental change. Finally, the third term, which relates to the uncertainty, expresses the implicit substitution between the state of the environment and the control variables, abatement and consumption.

π and ρ can also be expressed in terms of the rate of growth. The relationship between consumption growth and the discount rate is given by the ordinary Ramsey rule

$$\rho = \delta + \mu_c \frac{\dot{c}}{c} \quad (24)$$

while the price of the environment is related to the discount rate in the following way:

$$\pi = \rho + \mu_g \frac{\dot{a}}{a} \quad (25)$$

where $\mu_g = -ag'_a/g''_{aa} > 0$.

The model prescribes conventional economic wisdom for the traditional consumption saving decision: Projects without environmental impacts should be discounted by the rate of return on productive capital, while input of capital with environmental effects are to be charged for these impacts. The optimal consumption/saving ratio is determined such as to equate the social marginal rate of return on capital with the rate of change in the marginal utility of consumption along the optimal path.

The difference between the present result and the conventional one is that the rule for initiation of abatement activities differs. In the conventional case environmental achievements must be compared with discounted net costs of abatement *ex post*, without any guidance as to how environmental benefits in distant future are to be treated. In the present case the discounted benefits include an explicit shadow price of the environment. This shadow price is related to the rate of discount, and is equal to the "overall" social return on a marginal reduction in consumption. Thus, under constant abatement, $\pi = \rho$.

The social return on abatement activities emerges because the environment is defined as a state variable, just as capital.

We emphasise again that pi_t is related to the environmental states, not emissions, nor the effects, which are determined by the probabilities p_t . These probabilities are, however, decisive for the abatement level which is determined in (23). Thus, from an empirical point of view, π can be assessed with two alternative points of departure, similar to the assessment of ρ . One may either assume that the increase in the level of abatement is optimal, and then assess π from (25). If one believes that the abatement efforts are sub-optimal, the shadow price of the environment may be assessed from (23), but this, of course, requires solution of the whole model.

5 Final remarks and further analysis

Economists frequently emphasise the importance of cost efficiency in the choice of environmental policy instruments. These are usually understood as indirect economic measures which aim at giving correct incentives to the decision makers at a decentralized level. Partly as a consequence of the view that indirect measures are "better" than direct environmental policy measures, one also regards macroeconomic ("top-down") models as a more appropriate analytical tool than micro-studies ("bottom-up").

In this paper, I try to show that the above position rests on a rather narrow view on the aim of environmental policy, namely to restrict a given activity with unpleasant consequences. With such a vague notion of environmental effects it is not likely that one ends up with recommendations for an optimal environmental policy. By including more well-defined environmental relations I show that the views on cost efficient measures and appropriate choice of analytical tools become more complex.

First, abatement costs, for instance investments payed by central authorities or even direct control of activities, may be appropriate if the environmental problem cannot easily be revealed from an economic activity. This does not mean that environmental taxation or creation of environmental markets are inefficient. The point is that direct abatement measures should be introduced along with indirect measures in optimum.

Second, the choice of abatement costs will normally be subject to project evaluation ("bottom up"-analysis), in which discounted benefits and cost are

compared. As pointed out already by Arrow and Kurtz (1970), the choice of a discount rate should ideally rest on a comprehensive evaluation of *all* effects of the project. The choice has been subject to a long debate (see e.g. Lind (1984) and Hanley (1992)), especially when environmental effects concerns, because benefits from abatement may not occur before long. The frame given above suggests one way to analyse abatement measures.

One important result is that the shadow price of the environmental may turn out to be considerable. For instance, a constant abatement level implicitly reflects a shadow price of the environment that increases with a rate equal to the discount rate. This means that the increase in the price of the environment outweighs the effect of discounting in a cost-benefit approach, and thereby makes the future benefits of abatement count even with the use of a high discount rate. Several authors have claimed that cost-benefit analysis does not apply for environmental abatement measures because the main benefits becomes negligible. This view rests on the misunderstanding that the value of environmental benefits can be revealed from a description of economic relations alone, without explicit integration of environmental relations.

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