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Is Growth Bad for the Environment?

Pollution, Abatement, and Endogenous Growth

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and
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In what circumstances, if any, do economic growth and environmental quality go hand in hand?

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Van Marrewijk, van der Ploeg, and Verbeek investigate the implications of pollution as a byproduct of production and analyze how environmental concern affects the optimal rate of economic growth and optimal government policy.

The government must levy taxes on income to finance both productive government spending *and* abatement activities. It must levy an optimal tax. Too high a tax rate harms prospects for growth and too low a tax rate is bad for the environment.

Van Marrewijk, van der Ploeg, and Verbeek distinguish between two approaches to incorporate the environment into the model stock approach and the flow approach. The flow approach assumes that the level of environmental quality changes instantly if production or abatement levels change (this is relevant for analyzing externalities associated, for example, with noise). The stock approach assumes that pollution and abatement *indirectly* influence the environment by affecting the rate of change in the environment over time (this is more relevant for analyzing problems of acid rain).

They conclude that:

- "Win-win" situations (in which improvements in economic growth and environmental quality go hand in hand) cannot arise under the flow approach, but can arise under the stock approach — if and only if the intertemporal elasticity of substitution exceeds unity.

- Maximizing the economy's growth rate is never optimal unless consumers care nothing about the environment.

Is Growth Bad for the Environment? Pollution, Abatement, and Endogenous Growth

by

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CONTENTS

1. INTRODUCTION

Mankind's concern with the quality of the environment dates back at least to 450 BC when Artaxerxes I attempted to restrict cutting Lebanese cedar.[1] This concern has recently been expressed by the UNCED conference in Rio de Janeiro (1992) and the World Bank Report on Development and the Environment (1992). Both emphasize two points in particular: (*i*) the presence of "win-win" situations, indicating that care of the natural environment requires economic growth, while economic growth in turn cannot take place without taking proper care of the environment, and (*ii*) the importance of modeling the environment as influencing directly the health level and the (economic) well-being of the individual. It is a challenge to provide a solid economic theory underpinning these points of view. Naturally, there is a vast literature on the economics of (non)renewable resources, where the environment is used as an input in the production function.[2] In that literature, however, the environment does not *directly* influence the economic well-being of the individual which therefore fails to take care of the second point mentioned above.[3] Neither is there a trade-off between a better quality of the environment and a higher rate of

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[1] For a lucid overview of the roots of environmentalism in the western world, see Grove (1992).

[2] See Withagen (1991) for a recent overview.

[3] Withagen (1992) takes one of the first steps in this direction, see also Bovenberg and Smulders (1993) and Ligthart and van der Ploeg (1993).

economic growth. Van der Ploeg and Withagen (1991), on the other hand, investigate what happens to capital intensity and the rate of economic growth when the environment influences the utility level of the individual. Their neoclassical model, however, compares different steady states in which extra care for the environment always harms the *level* rather than the *rate of growth* of production, so they do not find "win-win" situations.

In this paper we take as given point (*ii*) above, *i.e.* the benefits from the environment are reflected in economic well-being, while our main objective is to investigate under which conditions "win-win" situations can arise.[4] In particular we show, in contrast to Bovenberg and Smulders (1993) and Ligthart and van der Ploeg (1993), that "win-win" situations can arise even if the environment does not play a productive role. We depart from neoclassical growth theory which takes the long-run growth rate as exogenous and use the insights of the new endogenous growth theory, pioneered by Romer (1986), instead. We also analyze, within a context of endogenous growth the interaction between production externalities (productive government spending, see Barro (1990) and Alogoskoufis and van der Ploeg (1990)) and the environment and derive the optimal tax rule. To this end we extend a popular model of endogenous growth in which productive government spending is a public good, developed by Barro (1990), by incorporating the welfare effects of the

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[4] A similar question, the double dividend hypothesis, is examined in a static context by Bovenberg and de Mooij (1993) and Bovenberg and van der Ploeg (1992).

environment, government abatement activities and the negative external effects of pollution associated with production. Our attention is restricted to balanced growth paths.[5] The task of the government is twofold: on the one hand it acts as a growth-catalyst by investing in productive government spending and on the other hand the government must act as caretaker of the environment.

The remainder of the paper is organized as follows. In section 2 we briefly discuss the results of Barro's (1990) theory of productive government spending, distortionary taxation and endogenous growth. In section 3 we drop productive government spending and focus attention on the environmental externality. The two basic ways in which pollution affects environmental quality, namely on the level and the rate of change of environmental quality, are investigated separately. In section 4 we investigate the interactions of productive government spending as a public good and the environmental externality. We analyze both the command optimum and the decentralized market economy. However, the outcome for the decentralized market economy coincides with the command optimum if there is only one externality, so that we will only explicitly distinguish between the command and market outcomes if both externalities are present. Sections 3 and 4 also provide examples. Section 5 concludes the paper.

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5 There is no need to investigate dynamic convergence to the balanced growth path, since in all cases the economy will immediately jump to this path.

2. Productive government spending, public finance and endogenous growth

To put our results in a proper perspective we briefly discuss the results of Barro (1990). The representative consumer maximizes instantaneous utility, U(c(t)), over an infinite time horizon using the positive and constant time preference rate (or subjective discount rate) ρ. The utility function has a constant intertemporal elasticity of substitution (equal to σ).[6] The representative consumer, therefore, solves the following problem

$$max \int_0^\infty exp(-\rho t)\ U(c(t))\ dt \qquad \text{with } U(c(t)) = \left[\frac{c(t)^{(1-1/\sigma)} - 1}{1 - 1/\sigma}\right] \tag{1}$$

subject to the consumer budget constraint[7]

$$\dot{a} = r(t)a(t) + w(t)l(t) - c(t) \tag{2}$$

where $r(t)$ is the interest rate, $w(t)l(t)$ is income from labor, $c(t)$ is private consumption and $a(t)$ is the stock of non-human wealth, all evaluated at time t. Consumption is proportional to human plus non-human wealth, because

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6 This is the only utility function compatible with balanced growth paths, see King, Plosser and Rebelo (1988).

7 In the sequel a dot above a variable will denote its change over time. Naturally, the no-Ponzi game restriction is also employed.

there is a constant intertemporal elasticity of substitution. In the sequel we shall abstract from population growth and assume that producers all have access to the same technology. This allows us to treat the production sector as if there is only one representative producer. The inputs in production are labor, private capital goods and productive government spending. The production function is of the Cobb-Douglas type:

$$y(t) = Ak(t)^{(1-\beta)}g(t)^{\beta} \tag{3}$$

where $0 < \beta < 1$, y is output per worker, l is the supply of labor per worker, k is the representative producer's quantity of capital and g productive government expenditure per worker. There is no government debt so that the capital stock is the only asset that is held by the household, hence $a = k$. The constant A is a shift parameter incorporating the effect of labor in the production function. This can be done because the supply of labor is exogenous and does not change over time. The productive technology is of the 'endogenous' type as the rate of economic growth can be chosen optimally, and is not an exogenously determined constant, since there are constant returns to scale in k and g together (but diminishing returns in k and g separately). We draw attention to a peculiar aspect of the specification of the production function, namely the power of the government to instantaneously stop all production in the private sector by setting productive government spending (g) equal to zero. In reality the government does not have this power and it would be better to specify the model by outlays on productive government spending (a flow) affecting the level of productive government spending (a stock). Should the government cease investment at any moment in time, the production level would slowly fall over time as the stock of productive government spending depreciates. The specification of the production function in equation (3), taken from Barro (1990), is therefore a modelling shortcut taken for convenience, see also the 'flow' approach to the environment in the sequel. It is possible to also allow for knowledge spill-overs in production; for example, by replacing k by $k^{\gamma}\bar{k}^{(1-\gamma)}$ where $\bar{k}$ denotes the economy wide capital stock per worker and $0<\gamma\leq 1$. The smaller the value of γ the larger the productive externality. Such an externality arises when there are no effective patent markets. In a decentralized market economy the government can correct for this with the aid of a capital subsidy. In this paper we abstract from such issues.

The representative producer maxizimizes net wealth taking prices and productive government expenditures as given ($R(t)$ is cumulative interest):

$$max \int_0^{\infty} exp(-R(t))[(1-\tau_g)y(t) - w(t)l - \dot{k}]dt \qquad (4)$$

subject to the production technology (3), where τ_g is the (constant) tax rate on production and $\dot{k}$ is investment undertaken by the representative producer. For simplicity, and without loss of generality, there is no depreciation of the capital stock. The government spends its entire income on productive government spending (g). It finances this spending by levying a distortionary tax τ_g on production, so that the budget constraint for the government is:

$$g = T = \tau_g y = \tau_g A k^{1-\beta} g^{\beta} \tag{5}$$

where T are total taxes paid by the representative producer. Barro derives the following results:[8] (*i*) the outcome of the decentralized market economy coincides with the command optimum, (*ii*) the optimal tax rate equals the national income share of productive government spending ($\tau_g = \beta$), and (*iii*) maximization of the growth rate of the economy (π, say) is equivalent to maximization of social welfare. Result (*i*) requires that there are no knowledge spill-overs in production (*i.e.* γ=1). Results (*ii*) and (*iii*) depend on the Cobb-Douglas specification for the production function.

3 Environmental externalities, abatement and endogenous growth

The analysis of section 2 is modified to incorporate utility from environmental quality, pollution and abatement. To focus attention on the

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[8] All conclusions and derivations in this paper are conditional on the boundedness of utility, which basically amounts to assuming that the rate of time preference is large enough.

environment, we abstract here from productive government spending as a public good in the production function, *i.e.* $\beta = 0$, see Rebelo (1991), so:

$$y(t) = Ak(t) \tag{3'}$$

The environment (the quality of which is denoted by e) enters the instantaneous utility function U of the households in the following non-separable fashion:

$$U(c,e) = \left\{\frac{[c^{\alpha}e^{1-\alpha}]^{(1-1/\sigma)} - 1}{1 - 1/\sigma}\right\} \equiv [u(c,e)-1]/(1-1/\sigma) \qquad \sigma \neq 1,\ 0<\alpha<1 \tag{6}$$

where $u(c,e)$ is defined for convenience and α represents the importance of consumption relative to environmental quality in generating instantaneous utiltity. A decrease in α is shift of preferences toward a higher environmental quality. Pollution enters as a by-product of production and negatively affects the quality of the environment. Both households and firms are atomistic and do not take into account the damage they impose on the environment.

The government can positively influence the quality of the environment by financing expenditures (s) to be spent on abatement policies to clean up the environment and to be used for direct investment into the environment itself. A good example is the "San Bei" project in China which started in 1978 and is expected to last into the second half of the next century. It entails the building of a giant 'Green Wall' in the north of China[9] by planting bushes and trees to halt and reverse the desertification process. Taxes are again levied on production, so the government budget constraint is

$$s = T = \tau_s y = \tau_s A k \tag{7}$$

Two basic approaches to model the impact of pollution and abatement on the environment can be identified in the literature. We will call them the 'flow' approach, see *e.g.* Forster (1973) and Gruver (1976), and the 'stock' approach, see *e.g.* Keeler, Spence and Zeckhauser (1972) and Becker (1982).

The *flow approach* assumes that the flow of pollution and abatement affects the level of environmental quality, hence its name. The best example of such an environmental externality is, perhaps, noise. We get

$$e = E(y,s) \quad \{= E(1,s/y) \equiv e(\tau_s)\};\ E_y < 0,\ E_s > 0 \tag{8}$$

where we have put in between brackets the assumption that the function $E(.)$ is homogeneous of degree zero. We will use that assumption throughout the remainder of the paper for two reasons. First, we cannot investigate balanced growth paths unless the function $E(.)$ is homogeneous of degree γ, which of course implies $\dot{e}/e = \gamma\ (\dot{y}/y)$. Second. if γ is positive (negative)

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[9] San Bei stands for the three norths, *i.e.* northwest, north and northeast.

environmental quality can only improve if the economy slows down (speeds up). This implies a rather restrictive treatment of stock effects, a more general treatment of which is discussed below. Assuming that $\gamma = 0$ enables balanced growth paths of the economy at a stable level of environmental quality (to be chosen optimally), provided investments in environmental quality and abatement policies grow at the same rate as the economy.

The *stock approach*, on the other hand, assumes that the flow of pollution and abatement *in*directly influence the quality of the environment by affecting the rate of change of the environment over time

$$\dot{e}/e = F(y,s) \quad \{= F(1,s/y) \equiv f(\tau_s)\};\ F_y < 0,\ F_s > 0,\ e(0) \text{ given} \tag{9}$$

A good example of this is acid rain and the associated deterioration of the ozone layer. To enable balanced growth paths, we have put in between brackets the assumption, which we will henceforth make, of zero homogeneity of the function $F(.)$. This does not imply that the environment changes over time proportional to production, see above. It merely states that the rate of change of the environment is positively influenced by an increase in the national income share of investment in the environment and abatement policies (τ_s). If $f(.)$ is negative for all values of τ_s, this implies we can only influence the speed with which the environment deteriorates over time. If there is a critical value, $\bar{\tau}_s$ say, such that $f(\tau_s)$ is positive if $\tau_s > \bar{\tau}_s$, then it is possible, along a balanced growth path, that the environment improves indefinitely. This implies, in particular, that there is no upper bound for the quality of the environment. If e is interpreted in a physical sense this is obviously not possible since there is a limit to the number of trees one can plant on the earth. The same problem arises if production is interpreted in a physical sense in a one-sector neoclassical growth model. One should, therefore, under these circumstances interpret e as the value of the environment.[10] Otherwise, one would have to look for turnpike theorems. In any case, these differences of interpretation do not affect the results derived below.

3.1 *Flow of pollution affects environmental quality*

As stated in the introduction and will become clear in the next section the outcome for the decentralized market economy coincides with the command optimum in the presence of only one externality, as long as the government sets the income tax rate appropriately. For brevity only the latter will be discussed here. Under the flow approach to the environment, equation (8), and in the absence of productive government spending, equation (3'), we can define the current value Hamiltonian

$$H_1 = U(c,e(\tau_s)) + \lambda_1[Ak-c-s] \tag{10}$$

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[10] Note that we refer to e as the quality of the environment.

where λ_1 denotes the social marginal value of capital. The first-order conditions are:[11]

$$\alpha u(c,e)/c = \lambda_1 \tag{11}$$

$$(1-\alpha)[u(c,e)/e](e'/y) = \lambda_1 \tag{12}$$

Let $\tilde{\alpha} = \alpha/(1-\alpha)$, *i.e.* $\tilde{\alpha}$ is the importance of consumption relative to environment in the instantaneous utility function, and let $\varepsilon(\tau_s) = \tau_s e'(\tau_s)/e(\tau_s)$, *i.e.* ε is the elasticity of environmental quality with respect to abatement, then we derive from equations (11) and (12) the following relation between the national income share of private consumption $c/y \equiv \tau_c$ and the share invested in public abatement policies τ_s:

$$\tau_c = (\tilde{\alpha}/\varepsilon)\tau_s \tag{13}$$

It follows from equation (13) that an increase in τ_s increases τ_c.[12] This necessarily implies that an increase in abatement policies reduces investment in physical capital, which reduces the growth rate of the economy:

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[11] In deriving the first-order conditions, here and in the sequel, one should keep in mind that terms like τ_s depend on s and y, the latter of which in turn depends on k or on k and g.

[12] This requires $\varepsilon > \tau_s e''/e'$, which holds if e is concave.

$$\pi = \dot{k}/k = A(1-\tau_c-\tau_s) \tag{14}$$

We therefore conclude that "win-win" situations cannot arise if the flow approach is used, *i.e.* higher growth is always bad for the environment.

Let, for notational convenience, $\bar{\sigma} \equiv \alpha + (1-\alpha)\sigma$, *i.e.* $\bar{\sigma}$ is the weighted average between the intertemporal elasticity of substitution and one, which is the elasticity of substitution between consumption and the environment in the instantaneous utility function. Differentiating equation (11) with respect to time gives

$$\dot{c}/c = (\sigma/\bar{\sigma})(-\dot{\lambda}_1/\lambda_1) + [(\sigma-1)(1-\alpha)/\bar{\sigma}](\dot{e}/e) \tag{15}$$

from which immediately follows an important observation. The growth rate of private consumption (which in equilibrium equals the growth rate of the economy) is *independent* of the growth rate of the environment if either (*i*) the environment does not enter the instantaneous utility function ($\alpha = 1$), (*ii*) the intertemporal elasticity of substitution equals unity, or (*iii*) the environment itself does not grow. The latter is the case here so that equation (15), using $\dot{\lambda}_1/\lambda_1 = \rho\lambda_1 - \partial H_1/\partial k$, reduces to

$$\dot{c}/c = (\sigma/\bar{\sigma})[A(1-\tau_s)-\rho] \tag{15'}$$

This unambiguously shows that any increase in τ_s reduces the growth rate of the economy. Combining equations (14) and (15'), and using that in equilibrium $\dot{c}/c = \dot{k}/k$, and equation (13) gives a relation from which the optimal tax rate τ_s can be solved[13]

$$(\rho\sigma/\bar{\sigma})-[\alpha(\sigma-1)/\bar{\sigma}]A(1-\tau_s)=(\tilde{\alpha}/\varepsilon)A\tau_s \tag{16}$$

As an example take lim $\sigma \rightarrow 1$, *i.e.* logarithmic utility, and $e(\tau_s) = B\tau_s^{\varepsilon}$ for $B > 0$ and $0 < \varepsilon < 1$, which implies $e/e' = \tau_s/\varepsilon$, then equation (16) gives

$$\tau_s = \varepsilon\rho/\tilde{\alpha}A \tag{16'}$$

and therefore the share of income spent on abatement policies increases if the rate of time preference (ρ) increases, the importance of environmental quality in social welfare (1-α) increases, the effectiveness of abatement activities (ε) increases or productivity (A) decreases and is independent of B. The effects of 1-α and ε are straightforward. One may wonder why an increase in the rate of time preference would increase investment in abatement policies. However, under these circumstances τ_s directly affects environmental quality. An increase in ρ increases the weight given to this initial consumption of the environment. Similarly, an increase in A makes investment in physical production more attractive which (in this case) always implies a decrease in

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[13] The equilibrium is unique for concave $\epsilon(.)$ if $\sigma \leq 1$.

investment in abatement policies.

In concluding we note that (*i*) the command optimum coincides with the outcome for the decentralized market economy, (*ii*) maximization of the growth rate is not optimal, and (*iii*) "win-win" situations are not possible. Point (*i*) implies that the first-best oucome can be replicated in a competitive market economy.

3.2 *Stock of pollution affects environmental quality*

When there is only one externality we can restrict attention to the command optimum as this then coincides with the decentralized market outcome. If there is no productive government spending, equation (3'), the current value Hamiltonian under the stock approach, equation (9), is:

$$H_2 = U(c,e) + \lambda_2[Ak-c-s] + \mu_2 f(\tau_s)e \tag{17}$$

where λ_2 and μ_2 are the social marginal values of capital and environmental quality, respectively. This gives the first-order conditions:

$$\alpha u(c,e)/c = \lambda_2 \tag{18}$$

$$\mu_2 f'e/y = \lambda_2 \tag{19}$$

Equation (18) is equivalent to equation (11) and states that λ_2, which is the shadow price of capital, equals the marginal utility of private consumption. Differentiation again leads to equation (15) which reduces to

$$\dot{c}/c = (\sigma/\bar{\sigma})[A(1-\tau_s)-\rho] + [(\sigma-1)(1-\alpha)/\bar{\sigma}]f(\tau_s) \tag{20}$$

It is now immediately evident from equation (20) that "win-win" situations are possible under the flow approach if and only if the intertemporal elasticity of substitution (σ) is larger than one, since only then is the growth rate of the economy maximized for a *positive* level of τ_s (provided the limit of f' if τ_s approaches zero exceeds $\sigma A/[(\sigma-1)(1-\alpha)]$).[14] If it is relatively easy to substitute future consumption of goods and the environment for current consumption (if $\sigma > 1$), it pays to invest heavily in physical capital as well as in the environment today in order to enjoy higher levels of consumption of goods and the environment tomorrow. However, if the elasticity of intertemporal substitution is high enough and there is no saturation in the growth of environmental quality growth may be good for environmental quality.

Differentiating equation (19) with respect to time along a balanced growth path gives the rather elegant equation

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[14] It should be noted at this point that estimating the intertemporal elasticity of substitution by using the inverse of the rate of risk aversion leads to biased estimates in a more general context that allows for uncertainty, see Selden (1978) and van der Ploeg (1992).

$$\dot{\lambda}_2/\lambda_2 + \dot{k}/k = \dot{\mu}_2/\mu_2 + \dot{e}/e \qquad (21)$$

Hence, the capital gains of investment in capital plus its growth rate must be balanced against the capital gains of investment in the environment plus its growth rate. Using $\dot{\lambda}_2/\lambda_2 = \rho\lambda_2 - \partial H_2/\partial k$ and $\dot{\mu}_2/\mu_2 = \rho\mu_2 - \partial H_2/\partial e$ equation (21) reduces to

$$f'(\tau_s) = \tilde{\alpha}A \qquad (21')$$

which determines the optimal tax rate τ_s. Most importantly, this tax rate is *independent* of the rate of time preference and the intertemporal elasticity of substitution. This is intuitively appealing in view of the symmetric treatment of production and the environment both in the instantaneous utility function and in the investment functions under the stock approach. The optimal tax rate and national income share of abatement increases if productivity (A) decreases (see 3.1) or if the importance of environmental quality ($1-\alpha$) increases.

In concluding we note that (*i*) the command optimum coincides with the decentralized market outcome, and can thus be replicated in a market economy, (*ii*) maximization of the growth rate is not optimal,[15] and (*iii*) given that there is no saturation of environmental quality, "win-win" situations are possible if and only if the intertemporal elasticity of substitution exceeds

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[15] This is because maximization of π in equation (20) does not lead to equation (21').

unity.

4. Productive government spending and the environment

Finally, we evaluate the interactions between the productive government spending externality discussed in section 2 and the environmental externality analyzed in section 3. Throughout this section, therefore, the production function corresponds to (3), while instantaneous utility is given by (6). In the presence of two externalities the government must simultaneously act as caretaker of the environment and as growth catalyst. Its budget constraint is given by

$$(\tau_g+\tau_s)y = T \tag{22}$$

where $\tau_g = g/y$ and $\tau_s = s/y$.

4.1 *Productive government spending and the flow of pollution*

4.1.1 *The decentralized market economy*

Under the flow approach the level of environmental quality is given by (8). The outcome of the household's maximization of utility and the producer's net wealth optimization then leads to the following differential equations (where use has been made of the fact that e does not change over time along a balanced growth path)

$$\dot{c}/c = (\sigma/\bar{\sigma})[(1-\beta)(1-\tau_g-\tau_s)\left[A\tau_g^{\beta}\right]^{\frac{1}{1-\beta}}-\rho] \qquad \{= \pi\} \tag{23}$$

$$\dot{k}/k = (1-\tau_g-\tau_s-\tau_c)\left[A\tau_g^{\beta}\right]^{\frac{1}{1-\beta}} \tag{24}$$

Given the government choice of tax rates τ_g and τ_s, the growth rate of the economy π is determined by equation (23). Equation (24) then determines the concomitant share of consumption τ_c. Given $k(0)$ this determines $c(0)$ and hence the welfare level, W say, associated with τ_g and τ_s:[16]

$$W = \frac{\left(c(0)^{\alpha} e^{1-\alpha}\right)^{(1-1/\sigma)}}{(1-1/\sigma)[\rho - \alpha(1-1/\sigma)\pi]}, \text{ with} \qquad e = e(\tau_s) \tag{25}$$

$$c(0) = k(0)[(1-\tau_g-\tau_s)\left[A\tau_g^{\beta}\right]^{\frac{1}{1-\beta}} - \pi];$$

Where π follows from (23). The objective for the benevolent government is to maximize W given the initial capital stock, $k(0)$, and the changes of c and k over time by using the instruments τ_g and τ_s. Maximizing welfare with respect to τ_g leads to the condition that $\partial\pi/\partial\tau_g = 0$, which gives the following optimal taxation rule:[17]

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16 We drop the constant $-1/(1-1/\sigma)\rho$ in W.

17 Maximization of the growth rate of the decentralized market economy,

$$\tau_g = \beta(1-\tau_s) \tag{26}$$

The optimal share of productive government spending in national income (τ_g) is *smaller* than its marginal productivity β because of the detrimental effects of production on the environment and crowding out when there is positive investment in abatement activities, *i.e.* when $\tau_s > 0$. Hence, a higher share of abatement activities, which reduces pollution and improves the environment, is accompanied by a lower share of investment in growth-promoting productive government spending, such that the total tax rate rises less than proportionally. Maximization of W with respect to τ_s, using the optimal taxation rule $\tau_g = \beta(1-\tau_s)$, shows that $\partial\pi/\partial\tau_s \neq 0$ due to the term e in the numerator of W. The growth rate of the economy is therefore maximized with respect to τ_g, but not with respect to τ_s.

4.1.2 *The command optimum*

When we allow for productive government spending and the externality arising from the flow of pollution the current value Hamiltonian is

$$H_3 = U(c,e(\tau_s)) + \lambda_3[Ak^{1-\beta}g^{\beta}-c-s-g] \tag{27}$$

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equation (23), also leads to the optimal tax rule (26). In particular, under the flow approach this growth rate is maximized if $\tau_s = 0$, and hence $\tau_g = \beta$.

with first-order conditions

$$\alpha u(c,e)/c = \lambda_3 \tag{28}$$

$$[(1-\alpha)u(c,e)/e]\beta\tau_s e' = \lambda_3(\beta y-g) \tag{29}$$

$$[(1-\alpha)u(c,e)/e](e'/y) = \lambda_3 \tag{30}$$

Equation (28) is by now familiar. Equation (29) immediately shows that putting $\tau_g = \beta$ cannot be optimal, while combining equations (29) and (30) gives the same optimal tax rule as for the decentralized market economy in the presence of both externalities, see equation (26).

$$\tau_g = \beta(1-\tau_s) \tag{31}$$

Similarly, combining equations (28) and (30) leads to the same relation between the share of consumption and investment in abatement in the absence of the productive government spending externality, see equation (13).

$$\tau_c = (\tilde{\alpha}/\varepsilon)\tau_s \tag{32}$$

Hence, the optimal tax rule is rcbust with respect to the decentralized market outcome and command optimum, and with respect to the presence of productive government spending (since $\tau_g = 0$ if $\beta = 0$), while the relation between consumption and investment in abatement under the flow approach is robust to allowing for productive government spending

Differentiating equation (28) with respect to time and using $\dot{\lambda}_3 = \rho\lambda_3 - \partial H_3/\partial k$ and the first order conditions, we get the following differential equations for the command economy.

$$\dot{c}/c = (\sigma/\bar{\sigma})[(1-\beta)(1-\tau_s)\left[A\tau_g^{\beta}\right]^{\frac{1}{1-\beta}}-\rho] \tag{33}$$

$$\dot{k}/k = (1-\tau_g-\tau_s-\tau_c)\left[A\tau_g^{\beta}\right]^{\frac{1}{1-\beta}} \tag{34}$$

If we compare the evolution of the market economy and the command economy we note that the technical relations are the same, equations (24) and (34), but the optimal consumption relations differ. In particular, we immediately note the absence of the term τ_g in equation (33) if compared to equation (23). This implies, for given values of τ_g and τ_s, that the market economy grows more slowly, due to crowding out, than the command economy. Maximization of the same welfare function under different conditions leads to different outcomes, so the private optimum does not coincide with the command optimum. It is also clear that in the presence of only one externality, implying either $\tau_g = 0$ or $\tau_s = 0$, equations (23) and (33) coincide, so the private and command optimum are identical.

Combining equations (33) and (34), while using equations (31) and (32), leads to an equation from which the optimal tax rate τ_s (and hence τ_g) can be solved (this equation reduces to equation (16) if $\beta = 0$):

$$(\rho\sigma/\bar{\sigma}) - (\alpha(\sigma-1)/\bar{\sigma})(1-\beta)[A\beta^{\beta}(1-\tau_s)]^{\frac{1}{1-\beta}} = (\tilde{\alpha}/\varepsilon)\tau_s[A\beta^{\beta}(1-\tau_s)^{\beta}]^{\frac{1}{1-\beta}} \tag{35}$$

4.1.3 *An example*

To illustrate some of the aspects of the interaction between productive government spending and the environment we assume that the elasticity of environmental quality with respect to abatement is constant, *i.e.*

$$e(\tau_s) = B\tau_s^{\varepsilon} \qquad \text{with } B > 0,\ 0 < \varepsilon < 1 \tag{8'}$$

With this specification a typical plot of the welfare level of the market economy as a function of the share of income used for abatement (using the optimal tax rule) is unimodal, provided the welfare level is bounded, see footnote 8. In the sequel the optimal outcomes for the command economy and the decentralized market economy will be identified using subindex c (for command) and m (for market) respectively. Let τ_s* denote the value of τ_s, the share of income used for abatement policies, that maximizes the growth rate of the decentralized market economy (equation 23) after substitution of the optimal tax rule (equation 26), see footnote 18. Our representative base scenario has parameter values: $\sigma = 2$; $\alpha = .7$; $\beta = .15$; $\varepsilon = .3$; $\rho = 1$; $A = 2$; and $B = 1$, which leads to:

$$\tau_s^* = 0 < \tau_{sc} = .069 < .074 = \tau_{sm}$$

$$\tau_{gc} = .140 > .139 = \tau_{gm}$$

$$c(0)_c = .858 < 1.152 = c(0)_m$$

$$\pi_c = .405 > .104 = \pi_m$$

$$W_c = 1.959 > 1.940 = W_m$$

Hence, we find that the optimal share of income used for abatement in the decentralized market economy is *higher* than in the command economy and therefore the concomittant share of income used for productive government spending is *lower* in the market economy than in the command economy.[18] This somewhat unexpected result follows from the fact that for a given choice of government tax rates the decentralized market economy grows more slowly than the command economy, due to crowding out, which makes it easier, and hence more attractive, to clean up the environment in a market economy. In that sense crowding out is beneficial to the environment and, from a purely environmental point of view, the decentralized market economy can be preferred to the market economy. Since the command economy grows more quickly than the market economy, which requires higher investments in physical capital, the initial consumption level is lower in the command economy than in the market economy. Since "win-win" situations cannot occur under the flow approach the share of income used for abatement policies that maximizes the growth rate of the decentralized market economy is zero. Obviously, the welfare level in the

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18 That is, we were unable to come up with a counterexample to this observation.

command economy (the first best solution) exceeds the welfare level of the decentralized market economy (the optimal second best solution).

The influence of the parameters on some of the optimal variables is listed in table 1. The qualitative responses for the market economy and the command optimum are identical. Less environmental concern (higher α) or a smaller effectiveness of abatement policies (lower ε) boosts the share of growth promoting government spending and depresses the share of abatement policies. As a result the rate of economic growth is higher while environmental quality deteriorates and the initial level of private consumption falls (see section 3.1). In fact, a more patient society (lower ρ), easier intertemporal substitution (higher σ) or a higher level of physical productivity (higher A) induce the same effects (also see section 3.1).

A larger role for productive government spending (higher β) boosts both the share of growth-promoting public spending and the share of abatement policies. The severity of the externality associated with productive government spending increases and therefore requires an increase in the share of income used to fight this externality. This increase in the tax rate reduces the growth rate of the economy which in turn makes it easier to clean up the environment through an increase in abatement policies.

List of symbols

a	*non-human wealth*
A	*physical productivity parameter*
B	*environmental productivity parameter*
c	*consumption*
^{c}	*command*
e	*environmental quality*
$e(.)$	*environmental flow function*
$E(.)$	*environmental flow function*
$f(.)$	*environmental stock function*
$F(.)$	*environmental stock function*
g	*productive government spending*
H	*Hamiltonian*
k	*stock of private capital*
l	*labor*
^{m}	*market*
r	*interest rate*
s	*government spending on abatement*
R	*interest factor*
t	*time*
T	*total tax*
$U(.)$	*instantaneous utility*
$u(.)$	*monotone transformation of instantaneous utility*
w	*wage rate*
W	*welfare level*
y	*production*
α	*relative importance of consumption in instantaneous utility*
α	$= \alpha/(1-\alpha)$
β	*productivity of productive government spending*
ε	*elasticity of environmental quality with respect to abatement*
λ	*shadow price of capital*
μ	*shadow price of the environment*
ρ	*rate of time preference*
σ	*intertemporal elasticity of substitution*
$\bar{\sigma}$	*weighted average of* 1 *and* σ
τ_g	$= g/y$
τ_s	$= s/y$
τ_s^*	*rate of* τ_s *that maximizes the market economy growth rate*
τ_c	$= c/y$
π	*growth rate of the economy*
$\cdot$	*over a variable denotes rate of change over time*

Table 1 Growth and the Rate of Pollution ($e = B\tau_s^{\varepsilon}$)

Changes in Environmental concern (basecase: α=.7)

	Command Solution				Market Solution		
	α=.65	α=.7	α=.75		α=.65	α=.7	α=.75
τ_{sc}	.090	.069	.051	τ_{sm}	.096	.074	.056
τ_{gc}	.136	.140	.142	τ_{gm}	.136	.139	.142
$c(0)_c$	.889	.858	.825	$c(0)_m$	1.165	1.152	1.137
π_c	.340	.405	.467	π_m	.056	.104	.148
W_c	1.908	1.959	2.018	W_m	1.893	1.940	1.994

Changes in the role of productive government spending (basecase: β=.15)

	Command Solution				Market Solution		
	β=.1	β=.15	β=.2		β=.1	β=.15	β=.2
τ_{sc}	.061	.069	.076	τ_{sm}	.063	.074	.083
τ_{gc}	.094	.140	.185	τ_{gm}	.094	.139	.183
$c(0)_c$	.782	.858	.917	$c(0)_m$	1.000	1.152	1.275
π_c	.622	.405	.236	π_m	.400	.104	-.133
W_c	2.068	1.959	1.883	W_m	2.054	1.940	1.860

Changes in effectiveness of abatement (basecase: ε = .30)

	Command Solution				Market Solution		
	ε=.20	ε=.30	ε=.40		ε=.20	ε=.30	ε=.40
τ_{sc}	.045	.069	.095	τ_{sm}	.048	.074	.101
τ_{gc}	.143	.140	.136	τ_{gm}	.143	.139	.135
$c(0)_c$	.837	.858	.880	$c(0)_m$	1.139	1.152	1.165
π_c	.465	.405	.342	π_m	.158	.104	.047
W_c	2.045	1.959	1.887	W_m	2.023	1.940	1.870

Changes in the rate of time preference (basecase: ρ =1)

	Command Solution				Market Solution		
	ρ=.9	ρ=1	ρ=1.1		ρ=.9	ρ=1	ρ=1.1
τ_{sc}	.056	.069	.083	τ_{sm}	.061	.074	.087
τ_{gc}	.142	.140	.138	τ_{gm}	.141	.139	.137
$c(0)_c$	.693	.858	1.024	$c(0)_m$	.992	1.152	1.312
π_c	.592	.405	.218	π_m	.285	.104	-.078
W_c	.007*	1.959	-.057*	W_m	-.025*	1.940	-.070*

Changes in the level of productivity (basecase: A = 2)

	Command Solution				Market Solution		
	A=1.5	A=2	A=2.3		A=1.5	A=2	A=2.3
τ_{sc}	.124	.069	.049	τ_{sm}	.128	.074	.054
τ_{gc}	.131	.140	.143	τ_{gm}	.131	.139	.142
$c(0)_c$	1.087	.858	.716	$c(0)_m$	1.282	1.152	1.071
π_c	-.248	.405	.812	π_m	-.448	.104	.447
W_c	1.725	1.959	2.170	W_m	1.719	1.940	2.129

Change in intertemporal substitution (basecase: σ = 2)

	Command Solution				Market Solution		
	σ=1.5	σ=2	σ=3		σ=1.5	σ=2	σ=3
τ_{sc}	.074	.069	.061	τ_{sm}	.078	.074	.068
τ_{gc}	.139	.140	.141	τ_{gm}	.138	.139	.140
$c(0)_c$	.922	.858	.758	$c(0)_m$	1.169	1.152	1.124
π_c	.333	.405	.519	π_m	.081	.104	.141
W_c	-.048*	1.959	-.030*	W_m	-.063*	1.940	-.057*

Base scenario: σ = 2; α = .7; β = .15; ϵ = .3; ρ = 1; A = 2; B = 1

* The welfare changes of σ and ρ also take into consideration changes in the constant $-1/(1-1/\sigma)\rho$, which for the base scenario results in W_c = -.041 and W_m = -.060. An increase in B does not affect τ_{sm}, τ_{sc}, τ_{gm}, τ_{gc}, $C(0)_m$, $C(0)_c$, π_m or π_c, but positively influences both the quality of the environment and the welfare level.

To conclude we note that (*i*) the command optimum does *not* coincide with the private optimum, *i.e.* the first-best outcome cannot be sustained in a decentralized market economy, (*ii*) maximization of the growth rate is not optimal, (*iii*) "win-win" situations are not possible, and (*iv*) the optimal tax rule is $\tau_g = \beta(1-\tau_s)$ in both private and command optimum. Clearly, we are in the realms of second-best problems of public finance.

4.2 *Productive government spending and the stock of pollution*

4.2.1 *The decentralized market economy*

Under the stock approach the level of the environment is given by (9). The outcome of the household's maximization of utility and the producer's net wealth optimization then leads to the following differential equation for private consumption.[19]

$$\dot{c}/c = (\sigma/\bar{\sigma})[(1-\beta)(1-\tau_g-\tau_s)\left[A\tau_g^{\beta}\right]^{\frac{1}{1-\beta}}-\rho] + [(\sigma-1)(1-\alpha)/\bar{\sigma}]f(\tau_s) \qquad (36)$$

Given the government choice of national income share of productive government spending and abatement (τ_g and τ_s), the growth rate of the economy π is determined by equation (36). Equation (24) then determines the

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[19] Maximization of the growth rate of the decentralized market economy under the stock approach also leads to optimal tax rule (31).

concomitant national income share of private consumption (τ_c). Given $k(0)$ this determines $c(0)$ and hence the welfare level W associated with τ_g and τ_s. It can be shown, see Verbeek (1993), that maximization of W by the benevolent government implies that π is maximized with respect to τ_g, but not with respect to τ_s, and again leads to the optimal taxation rule $\tau_g = \beta(1-\tau_s)$, see equations (26) and (31). It is also apparent from equation (36), even taking into account the optimal taxation rule, that the growth rate of the economy is maximized for *positive* levels of investment in abatement, and hence "win-win" situations occur, if and only if the intertemporal elasticity of substitution exceeds unity.

4.2.2. *The command optimum.*

Under the stock approach and with productive government spending as a public good the current value Hamiltonian is

$$H_4 = U(c,e) + \lambda_4[Ak^{1-\beta}g^{\beta}-c-s-g] + \mu_4 f(\tau_s)e \qquad (37)$$

with first-order conditions

$$\alpha u(c,e)/c = \lambda_4 \qquad (38)$$

$$\beta\tau_s\mu_4 ef' = \lambda_4(\beta y-g) \qquad (39)$$

$$\mu ef'/y = \lambda_4 \qquad (40)$$

Equation (38) is familiar, while equation (40) coincides with equation (19), which shows that the relation between production and the shadow prices of the environment and capital does not depend on allowing for productive government spending. Differentiation of this relation with respect to time along a balanced growth path then obviously results again in equation (20) on the necessity to balance the capital gains of investment in capital plus its growth rate against the capital gains of investment in the environment plus its growth rate. Combining equations (39) and (40) once more leads to the optimal tax rule $\tau_g = \beta(1-\tau_s)$. Using this optimal tax rule, $\dot{\lambda}_4/\lambda_4 = \rho\lambda_4 - \partial H_4/\partial k$ and $\dot{\mu}_4/\mu_4 = \rho\mu_4 - \partial H_4/\partial e$ equation (20) leads to

$$f'(\tau_s) = \tilde{\alpha}\left[A\beta^{\beta}(1-\tau_s)^{\beta}\right]^{\frac{1}{1-\beta}} \tag{41}$$

which reduces to equation (21') if $\beta = 0$. As in section 3.2 the optimal tax rates τ_s and τ_g are *independent* of the rate of time preference and the intertemporal elasticity of substitution. The discussion on the divergence between the decentralized market economy and the command optimum is analogous to section 4.1.2 above.

4.2.3 *An example*

Finally, we illustrate the above analysis by assuming that the elasticity of the growth rate of environmental quality with respect to abatement is constant, *i.e.*

$$\dot{e}/e = B\tau_s^{\varepsilon} \qquad \text{with } B > 0,\ 0 < \varepsilon < 1 \tag{9'}$$

The base scenario, using parameter values $\sigma = 2$; $\alpha = .7$; $\beta = .1$; $\varepsilon = .3$; $\rho = 1$; $A = 1.6$; $B = 1$, leads to:

$$\tau_s^* = .009 < \tau_{sc} = .037 < .038 = \tau_{sm}$$

$$\tau_{gc} = .096 \geq .096 = \tau_{gm}$$

$$c(0)_c = .846 < 1.019 = c(0)_m$$

$$\pi_c = .281 > .107 = \pi_m$$

$$W_c = 2.230 > 2.221 = W_m$$

As in the example discussed in section 4.1.3 the share of income used for abatement (productive government spending) is higher (lower) in the decentralized market economy than in the command economy. This confirms the results in the static model of Bovenberg and de Mooij (1993) who find that an increase of environmental taxes toward their Pigovian level, which fully internalizes the social costs of pollution, may no longer be welfare improving if the government requires distortionary taxes to finance its spending, see also Oates and Schwab (1988). Again, as under the flow approach, the growth rate of the market economy is lower and hence the initial consumption level is higher. In contrast to the flow approach, the share of income used for abatement policies that maximizes the growth rate of the economy is *positive* (since in our example $\sigma > 1$). Hence up to that point the interests of the economy and the environmentalists coincide. The influence of the parameters on some of the optimal values is listed in table 2. The qualitative responses of the share of income used for abatement activities are identical for the decentralized market economy and the command economy, with the exception of changes in the intertemporal elasticity of substitution (σ) and the rate of time preference (ρ) on the tax rates τ_s and τ_g. As explained above the command optima τ_{sc} and τ_{gc} are independent of the levels of ρ and σ. In contrast, changes in these parameters lead to, in general rather miniscule, changes in the optimalmarket economy tax rates τ_{sm} and τ_{gm}. The qualitative responses of the share of income used for abatement policies that maximizes the growth rate of the economy and the share of income used for abatement policies that maximizes the welfare level of the decentralized market economy are identical.

The qualitative impact of most parameters on the economic variables under the stock approach coincides with their impact under the flow approach, so we restrict attention here to the points where they diverge. Most obviously, a stronger growth in environmental quality (higher B) now *does* affect τ_{sm}, τ_{sc}, τ_{gm}, τ_{gc}, $c(0)_m$, $c(0)_c$, π_m or π_c, and again positively influences the growth rate of environmental quality and the welfare level. A shift of preferences to environmental quality (an increase in $1-\alpha$) increases the share of income used for abatement and reduces the growth rate of the economy both under the stock approach and the flow approach. Under the stock approach, however, investment in the environment is similar to investment in physical capital and therefore requires a decrease in the initial consumption level. The effectiveness of

Table 2 **Growth and the Stock of Pollution** $(\dot{e}/e = B\tau_s^{\varepsilon})$

Changes in Environmental concern (basecase: α=.7)

	Command Solution				Market Solution		
	α=.65	α=.7	α=.75		α=.65	α=.7	α=.75
τ_s*	.012	.009	.007**	τ_s*	.012	.009	.007**
τ_{sc}	.051	.037	.026	τ_{sm}	.052	.039	.026
τ_{gc}	.095	.096	.097	τ_{gm}	.095	.096	.097
$c(0)_c$	.842	.846	.849**	$c(0)_m$	1.006	1.019	1.031**
π_c	.267	.281	.293	π_m	.101	.107	.109
W_c	2.247	2.230	2.216**	W_m	2.239	2.221	2.206**

Changes in the role of productive government spending (basecase: β=.15)

	Command Solution				Market Solution		
	β=.1	β=.15	β=.2		β=.1	β=.15	β=.2
τ_s*	.008	.009	.011**	τ_s*	.008	.009	.011**
τ_{sc}	.033	.037	.039	τ_{sm}	.033	.039	.041
τ_{gc}	.048	.096	.144	τ_{gm}	.048	.096	.144
$c(0)_c$	.764	.846	.908	$c(0)_m$	.863	1.019	1.140
π_c	.521	.281	.100	π_m	.422	.107	-.134
W_c	2.383	2.230	2.129	W_m	2.379	2.221	2.117

Changes in effectiveness of abatement (basecase: ε = .30)

	Command Solution				Market Solution		
	ε=.20	ε=.30	ε=.40		ε=.20	ε=.30	ε=.40
τ_s*	.009	.009	.009**	τ_s*	.009	.009	.009**
τ_{sc}	.033	.037	.034**	τ_{sm}	.034	.039	.035**
τ_{gc}	.097	.096	.097**	τ_{gm}	.097	.096	.096**
$c(0)_c$	.812	.846	.870	$c(0)_m$	.986	1.019	1.044
π_c	.319	.281	.260	π_m	.144	.107	.085
W_c	2.289	2.230	2.189	W_m	2.279	2.221	2.181

Changes in the rate of time preference (basecase: ρ =1)

	Command Solution				Market Solution		
	ρ=.9	ρ=1	ρ=1.1		ρ=.9	ρ=1	ρ=1.1
τ_s*	.009	.009	.009**	τ_s*	.009	.009	.009**
τ_{sc}	.037	.037	.037**	τ_{sm}	.038	.039	.037**
τ_{gc}	.096	.096	.096**	τ_{gm}	.096	.096	.096**
$c(0)_c$	.692	.846	1.000	$c(0)_m$	.865	1.019	1.173
π_c	.435	.281	.127	π_m	.260	.107	-.047
W_c	.318*	2.230	-.182*	W_m	.303*	2.221	.176*

Changes in the level of productivity (basecase: A = 2)

	Command Solution				Market Solution		
	A=1.5	A=2	A=1.7		A=1.5	A=2	A=1.7
τ_s*	.011	.009	.009	τ_s*	.011	.009	.009
τ_{sc}	.041	.037	.033	τ_{sm}	.042	.039	.034
τ_{gc}	.096	.096	.097	τ_{gm}	.096	.096	.097
$c(0)_c$	.888	.846	.804	$c(0)_m$	1.048	1.019	.990
π_c	.156	.281	.406	π_m	-.005	.107	.219
W_c	2.161	2.230	2.305	W_m	2.154	2.221	2.294

Change in intertemporal substitution (basecase: σ = 2)

	Command Solution				Market Solution		
	σ=1.5	σ=2	σ=3		σ=1.5	σ=2	σ=3
τ_s*	.005	.009	.014**	τ_s*	.005	.009	.014**
τ_{sc}	.037	.037	.037**	τ_{sm}	.037	.039	.038**
τ_{gc}	.096	.096	.096**	τ_{gm}	.096	.096	.096**
$c(0)_c$	.913	.846	.750	$c(0)_m$	1.060	1.019	.961**
π_c	.214	.281	.377	π_m	.066	.107	.165
W_c	.217*	2.230	.249*	W_m	.210*	2.221	.236*

Change in Growth of Environmental Quality (basecase: B = 1)

	Command Solution				Market Solution		
	B=.8	B=1	B=1.2		B=.8	B=1	B=1.2
τ_s*	.007	.009	.012**	τ_s*	.007	.009	.012**
τ_{sc}	.023	.037	.048	τ_{sm}	.027	.039	.049
τ_{gc}	.097	.096	.095	τ_{gm}	.097	.096	.095
$c(0)_c$	.862	.846	.828	$c(0)_m$	1.038	1.019	.999
π_c	.278	.281	.284	π_m	.102	.107	.112
W_c	2.202	2.230	2.261	W_m	2.193	2.221	2.251

Base scenario: σ = 2; α = .7; β = .15; ε = .3; ρ = 1; A = 2; B = 1

* The welfare changes of σ and ρ also take into consideration changes in the constant $-1/(1-1/\sigma)\rho$, which for the base scenario results in W_c = .230 and W_m = .221.

** These results are different from the flow approach and note that τ_s* is always equal to zero in the flow approach.

abatement activities (ε) on the optimal tax rates is ambiguous because if it is easier to clean up the environment it is also more attractive not to do so since, other things being equal, an increase in e increases the marginal utility of consumption, which therefore makes it more attractive to consume.

To summarize: (*i*) the command optimum does *not* coincide with the outcome of the decentralized market economy, and it is thus not possible to sustain the first-best optimum in a market economy, (*ii*) maximization of the growth rate is not optimal,[20] (*iii*) "win-win" situations are possible if and only if the intertemporal elasticity of substitution exceeds unity, and (*iv*) the optimal tax rule is $\tau_g = \beta(1-\tau_s)$ in both the decentralized market economy and

[20] On this see Verbeek (1993).

the command optimum.

5. Conclusions

Recently, the importance of environmental and economic "win-win" situations has been stressed, indicating that care of the environment requires economic growth, while economic growth in turn cannot take place without taking proper care of the environment. We generalize a popular endogenous growth model with constant returns to scale in a broad measure of the capital stock, by making consumers care not only about current and future consumption levels, but also about the current and future quality of the environment, to see under what circumstances "win-win" situations can arise. The capital stock is decomposed into private capital and productive government spending. Production of goods and services causes pollution which is detrimental to the environment. The government can invest in abatement processes to clean up the environment and in productive government spending by taxing production (= income). There is, therefore, both an environmental externality and a public good, *i.e.* productive government spending. This brings us within the realms of second-best economics. We investigate the decentralized market economy as well as the command economy. Two approaches to model the environment can be distinguished in the literature: the stock approach and the flow approach. The flow approach assumes that the level of environmental quality changes instantaneously if the production level changes or if the level of abatement changes and is particularly relevant for analysing the environmental externality associated with noise. The stock approach, on the other hand, assumes that pollution and abatement *in*directly influence the environment by affecting the rate of change of the environment over time and is more relevant for analyzing the problems of acid rain. Some of the conclusions we derive are:

"Win-win" situations cannot arise under the flow approach, but can arise under the stock approach if and only if the intertemporal elasticity of substitution exceeds unity. This holds even though the natural environment does not play a productive role.

Maximization of the growth rate of the economy is never optimal, unless consumers do not care at all about the environment.

The command economy can be sustained in a decentralized market economy if and only if there is *either* an environmental externality *or* productive government spencing as a public good, indicating that one tax instrument can be used for one task only. Otherwise, for given tax rates, the market economy grows more slowly than the command economy due to crowding out.

It is always optimal to set the share of income used for productive government spending equal to the productivity of government spending after correction for the share of income spent on abatement policies. This optimal tax rule, therefore, reflects the fact that investment in productive government spending must be smaller than its marginal product (the positive externality) to correct for the negative externality of pollution associated with production. Maximization of the growth rate of the decentralized market economy is characterized by the same optimal tax rule.

The growth rate of the economy is independent of the change over time of the environment if the intertemporal elasticity of substitution is unity - *i.e.* if the utility function is loglinear over time.

Under the stock approach the optimal tax rates of the command optimum do *not* depend on the intertemporal elasticity of substitution and the rate of time preference.

In our two examples we found that under either the stock or flow approach the share of income used for abatement is higher, and therefore the natural environment is cleaner, in the optimal decentralized market economy than in the command economy. This follows from the distortionary taxes needed to finance government spending which, through crowding out, leads to a lower growth rate of the market economy. This, in turn, makes it easier, and hence more attractive, to clean up the environment in a decentralized market economy. This is of course due to the interaction between the two distortions. The distortionary taxation with the purpose of financing public investment lowers the growth rate more in a decentralized market economy and hence lowers the opportunity cost of abatement. This is generally true when a market failure affects the dynamics of the economy.[21] Also, less environmental

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21 Some types of externalities, however, can have opposite affects. See Aghion

concern, a smaller effectiveness of abatement policies and a higher level of productivity depress the national income share of abatement policies and boost the share of growth-promoting public spending, hence the rate of economic growth rises while environmental quality worsens independent of whether the rate of pollution affects the level or the rate of change of environmental quality. A higher effectiveness of productive government spending raises, however, both the national income share of productive government spending and of abatement policies and improves environmental quality while depressing the rate of economic growth.

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and Howitt (1992), where innovation can cause higher growth, as the innovators do not take into account the premature obsolence of existing products. Here a market failure raises growth but would harm the the environment. We thank Bill Easterly for this observation.

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