Economic Growth, Environment Quality and Pollution Abatement

Gareth D. LEEVES
University of Queensland
Department of Economics
Brisbane, Qld, 4072
Australia
email: g.leeves@economics.uq.edu.au

Ric D. HERBERT
Modelling and Simulation Group
University of Western Sydney
Hawkesbury
Richmond, NSW, 2753
Australia
email: r.herbert@uws.edu.au

Abstract The importance of the rate of change of the pollution stock in determining the damage to the environment has been an issue of increasing concern in the literature (Nordhaus, 1991; Nordhaus, 1992; Tahvonen, 1995). The paper uses a three sector (economy, population and environment) non-linear model to examine the control through taxes, of accumulating damage from pollution flows. The model explicitly links economic growth to the health of the environment. The stock of natural resources is affected by the rate of pollution flows, through their impact on the regenerative capacity of the natural resource stock. This can shed useful insights into pollution control strategies, particularly in developing countries where environmental resources are crucial for production in many sectors of the economy (Rosendahl, 1996). Simulation exercises suggested that, under plausible assumptions, there might be an optimal tax rate in the trade off between economic growth and maintenance of the stock of natural capital. In addition, early implementation of environmental taxes is important in order to avoid unsustainable growth paths.

1. INTRODUCTION

In a recent paper, Tahvonen (1995) considered the implications for intertemporally efficient pollution control under conditions where pollution damage occurs as a result of accumulation in the stock of pollution and the time derivative of the pollution stock. The latter reflects the importance of the rate of change of pollution stock in determining the damage to the environment. There are a number of dimensions to the relationship between the rate at which pollution flows occur and their impact on the environment's ability to cope and provide a flow of economic resources. At the aggregate level, increases in the rate of pollution accumulation can potentially increase the rate of biodiversity loss (Weitzman, 1992) and reduce the environment's future economic value. On the other hand, species can adapt to conditions of increasing rates of pollution (Taylor *et al.*, 1991) and mitigate adverse effects. Dasgupta and Mäller (1995) produce evidence to suggest that the environment's resilience diminishes when the environment deteriorates. Hence, adverse effects on output from environmental damage may increase above some critical rate of pollution flow, other things being equal (Smulders, 1995). This paper seeks to examine how the control of pollution through taxation might be achieved under conditions where pollution accumulation (or rather where the reduction in the rate of pollution accumulation) is unsustainable, with different assumptions about the regenerative capacity of the stock of environmental resources.

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2. THE MODEL

We use an extension of the four sector model developed by Sanderson (1994). The stock of natural capital is determined by the rate of flow of pollutants and the speed of the regenerative process. Each section of the model will be presented below. All variables are described in Table 1 and the

Variable	Description
Y	output
I	net output
B	the crude birth rate
D	the crude death rate
N	the population
F	the flow of pollutants
K	the natural capital stock
C	the pollution control expenditure
P	the quantity of pollution
τ	environmental tax rate

Table 1. Model Variables

parameters set out in Table 2.

2.1 Economy

$$Y_{t+1} = Y_t\left[1+\gamma-(\gamma+\eta)(1-K_t)^{\lambda}\right] \quad (1)$$

$$I_t = Y_t - C_t \quad (2)$$

Equation 1 defines the economy's output, Y, to grow exponentially, depending on its own previous level and the stock of natural capital, K. The value of natural capital can vary between the values 0 and 1. If the stock value is 1 then all natural resources are undiminished by pollution. If the environment is totally polluted then it takes the value 0. The lower the stock of natural capital the lower the rate of growth. The second equation in the economic section, Equation 2, states that net output, I, is the difference between output and expenditures on pollution control, C.

The lower the stock of natural capital, the lower the rate of growth (Equation 1). This is a reasonable assumption, especially for a developing natural resource dependent economy. De Franco *et al.* (1993), quoted in Rosendahl (1996), estimated gross domestic production and private consumption in Nicaragua were reduced by 14% and 13% respectively over a period of ten years, through soil erosion, compared to a scenario without agricultural productivity loss induced by erosion.

2.2 Population

$$B_t = \beta_0\left[\beta_1-\left(\frac{e^{\beta I_t}}{1+e^{\beta I_t}}\right)\right] \quad (3)$$

$$D_t = \alpha_0\left[\alpha_1-\left(\frac{e^{\alpha I_t}}{1+e^{\alpha I_t}}\right)\right]\left[1+\alpha_2(1-K_t)^{\theta}\right] \quad (4)$$

$$N_{t+1} = N_t\left[1+\left(\frac{B_t-D_t}{1000}\right)\right] \quad (5)$$

Population growth is represented by Equations 3 to 5. Growth in population, N, is measured as the difference between the crude birth rate, B, and death rate, D. Increases in net output lead to decreases in the birth and death rates. The death rate is also influenced by the stock of natural capital, whereby decreases in the stock cause the death rate to rise.

One of the characteristics of this model of the population is that if the stock of natural capital is complete ($K = 1$), then for a constant level of economic output, the population will grow exponentially. Further, in this situation, in the extreme case when the economy completely collapses ($Y = 0$), then the population will still grow given the parameters in Table 2.

2.3 Environment

$$F_t = N_t Y_t P_t - \kappa\left(\frac{e^{\epsilon C_t N_t}}{1+e^{\epsilon C_t N_t}}\right) \quad (6)$$

$$K_{t+1} = \nu\left[\frac{e^{\ln\left(\frac{K_t}{1-K_t}\right)+\delta K_t^{\rho}-\omega F_t}}{1+e^{\ln\left(\frac{K_t}{1-K_t}\right)+\delta K_t^{\rho}-\omega F_t}}\right] \quad (7)$$

$$C_t = \phi(1-K_t)^{\mu}Y_t \quad (8)$$

$$P_{t+1} = \chi P_t \quad (9)$$

The environment is modelled by four equations. The first, Equation 6, describes the annual flow of pollutants, F. These are determined by the population, output, per unit pollution and the amount spent on pollution control measures. The flow also depends on the effectiveness of pollution control measures denoted by the parameter κ.

Equation 7 specifies the interaction between the flow of pollution and the stock of natural capital. Obviously, natural capital is adversely affected by a higher pollution flow. However, the equation allows for natural capital to regenerate itself and offset the pollution flow of earlier periods. The speed of natural resource regeneration is governed by the parameter ν ($0 \leq \nu \leq 1$). This representation ensures that regeneration can never be complete. Some of the flow of productive services provided by natural resources are lost for ever after a period of stock reduction, this occurs through biodivirisity loss and the elimination of the more productive natural resources.

It is assumed (in Equation 9) that over time the technologies associated with production are gradually improving, in terms of pollution per unit of output at some rate χ. For example, developing countries gain access to improved technology of more developed countries and reduce pollution per unit of output but not necessarily the overall flow of pollution.

Parameter	Value	Section
γ	0.04	Economy
η	0.04	Economy
λ	2	Economy
α	0.09	Population
α_0	10	Population
α_1	2.5	Population
α_2	2	Population
β	0.08	Population
β_0	40	Population
β_1	1.375	Population
θ	15	Population
κ	1	Environment
δ	1	Environment
ϵ	0.02	Environment
ρ	0.2	Environment
ω	0.1	Environment
ν	0.8	Environment
ϕ	0.5	Environment
μ	2	Environment
χ	0.96	Environment
γ_0	0.05	Economy

Table 2. Model Parameters (for Sustainable Scenario)

Pollution control expenditure, C, is related to two variables. Firstly, deterioration in the state of the environment. Note that the expenditure is related to the condition of the stock of natural capital and not the current level of pollution flow. Thus, whilst the latter is important for the state of the countries environmental resources in the future, it is the former that prompts environmental action. The second variable affecting pollution control expenditure is an increase the level of output. This reflects pollution control expenditure being related to the general standard of living.

3. POLLUTION ABATEMENT

It is interesting to explore the possibility for the use of taxation measures to avoid unsustainable paths and the implications for the natural resource stock of the economy. Taxes are modelled in the following manner. Firstly, they will have an adverse impact on output, this is illustrated in the equation below

$$Y_{t+1} = Y_t \left[1 + \gamma - (\gamma + \eta)(1 - K_t)^{\lambda} - \frac{\gamma_0 \tau}{1 - \tau} \right] \quad (10)$$

The representation of taxes (τ) in the output equa-

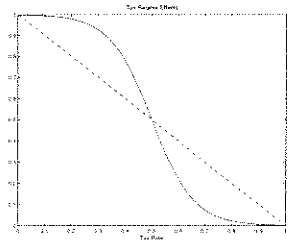

Figure 1. Response of P to Environmental Tax

tion assumes that a higher rate of tax will have a proportionally greater adverse effect on output as firms less able or less committed to reducing pollution outflows attempt to adopt environmentally friendly technologies and processes. Such firms will not respond to lower rates of environmental taxes, which consequently may relatively less effect on output. Similar assumptions are incorporated into the equation that models the pollution output effect of taxation:

$$P_{t+1} = \left[\frac{\tanh(-2\pi(\tau - \frac{1}{2})) + 1}{2} \right] \chi P_t \quad (11)$$

A low tax rate has a relatively small impact on the use of production technology and methods to reduce pollution output but this increases as tax rates rise. However, at higher tax rates the pollution reduction effects start to reduce as readily available technologies have been exploited. The behavioural response of pollution reduction to tax effects is illustrated in Figure 1. It is worth noting that there is a double effect on the flow of pollutants from the imposition of taxes. Taxes reduce output (Y) and pollution per unit of output (P), both of which reduce the flow of pollutants (F). Reducing the flow of pollutants permits for faster regeneration of capital.

4. MODEL SCENARIOS

In all simulations, the initial values of the economy, population and pollution production technology are set at unity. The stock of natural capital, K, is set at 0.98 giving a near complete stock. Note that the rate of the regenerative process of natural capital (ν) is set at 0.8. The time horizon used in all simulations is 200. Before taxes are introduced into the model we present some results to illustrate sustainable and unsustainable growth paths for the environment and the economy, which helps to portray some of the main features of the model and the context in which environmental taxes would be employed.

Environmental parameters are important for determining the evolution of the states. Particularly, we concentrate on the effect of variations in the

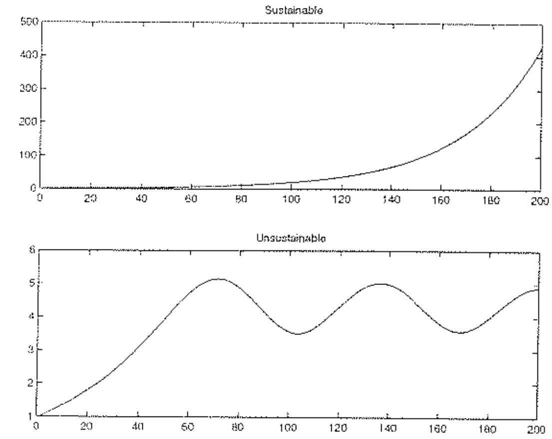

Figure 2. The Economy – Output (Y).

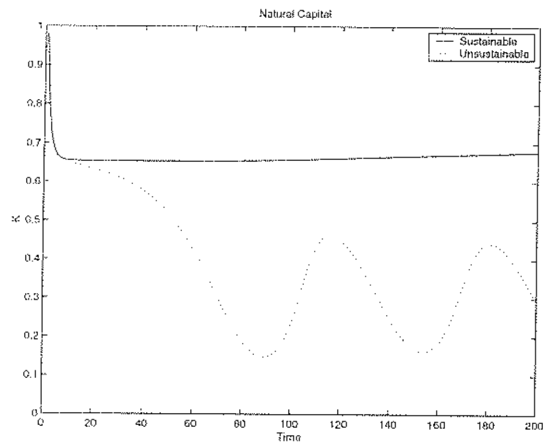

Figure 3. The Environment – Natural Capital (K).

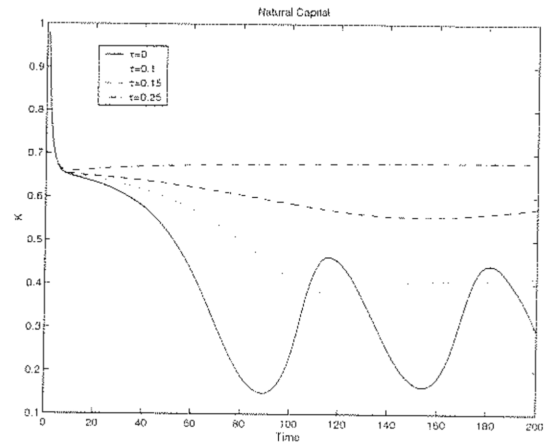

Figure 4. Natural Capital (K) under the differing tax rates.

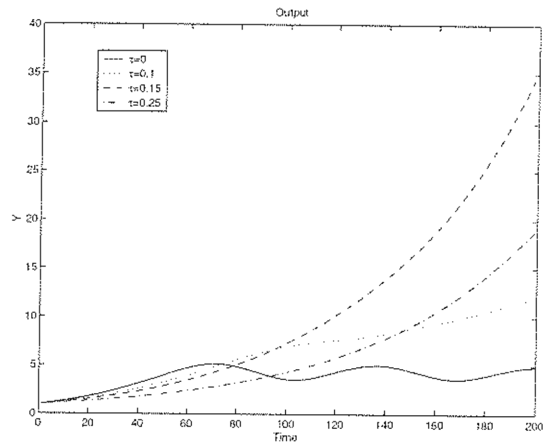

Figure 5. The Economy (Y) under the differing tax rates.

value of χ, the rate at which pollution per unit of output declines. In the first instance this parameter is set at 0.96, a rate of decrease of 4% per period (all other settings are as shown in Table 2). In the second instance it is set at 0.99. The time paths of the output and natural capital are shown in Figures 2 and 3. If $\chi = 0.96$, we observe that output grows continually (Figure 2) and the environment settles to a stable path, which is approximately 70% of the complete stock (Figure 3). Clearly, this scenario is sustainable. The change to $\chi = 0.99$ is sufficient to create unsustainable conditions. Output grows for the first sixty periods and then enters a cyclical pattern thereafter, without any further growth. The lack of growth in output is reflected in per capita output (not shown), which declines as output stops growing as the population rate continues to increase. Natural capital stock initially declines until it reaches 15% of the complete stock and then recovers, through regeneration, to about 40%; after which it enters a cyclical pattern centred round a stock level of 30%. Note that the cyclical pattern in output appears to lag that of natural capital. Thus, the pollution flow effect on natural resource stocks eventually dominates the evolution of output after the initial period of growth. The results obtained are consistent with a theoretical model proposed by Rosendahl (1996) and the empirical observations he cites of Schramm and Warford (1989), where externalities from the environment directly impinge on productive activity. The next section explores the effects of taxes aimed at reducing pollution output if the economy is following the unsustainable scenario described above.

4.1 Pollution Taxes and Unsustainable Outcomes

The effects of the tax regime described in Section 3 are presented in Figures 4 and 5. Only Natural Capital and Output figures are presented as they are the two key variables of interest. The tax regime is implemented from the outset of the simulation period. The various trajectories depict a range of tax rates from 0 (for comparison purposes) to 25%. A tax rate of 10% eliminates the cyclical fluctuations in output and natural capital but the natural capital stock remains significantly depleted settling at a steady-state of 40% complete and the growth rate of output is negligible.

If the tax rate is increased to 15% then we observe a significant improvement in output levels and it appears to be on a sustainable growth path. However, this is still considerably below the levels achieved after 200 periods in the sustainable scenario of Figure 2, where $\chi = 0.96$. The natural resource stock is gradually reduced to just under 60% of its complete amount. Clearly, a tax rate of 15% is better for the economy and the environment than lower rates.

However, if the tax rate is increased to 25% the situation is less clear. The stock of natural capital is now maintained at approximately 70% of its complete state and suffers no diminution due to the slower reduction in pollution flows as it is at the level attained in the sustainable scenario (Figure 3). This has to be set against a reduction in the growth rate of output compared to that achievable with a tax rate of 15%. Output levels are 50% of those achieved with a tax rate of 15% after 200 periods. Thus, there is in this latter case a trade-off between preservation of the environment and output. Unreported simulations indicated that a tax rate of 44% lead to falls in output similar to those observed in the no tax case.

In sum, optimal economic development requires maintenance of environmental quality. However, as Anderson (1987) notes, although the environment and economic growth may be positively linked, the high rate of time preference, especially in developing countries, and the temporal aspect of resource degradation may preclude an optimal result. There is a lag between the felling of trees and the time soil loses its fertility. We can observe in Figure 5 that in the first 60 periods economic growth is higher without any tax in place than if one is imposed. Withagen (1995) considered optimal growth and pollution effects using an endogenous growth framework based on the Rebelo (1991) model. Pollution was assumed to be proportional to production and the regeneration process exponential and the stock of pollution generates a negative externality. With a linear abatement technology, it is optimal to forego some small amount of consumption initially in order to approach the original growth rate implied by the mode, in later periods.

4.2 Pollution Taxes and Timing

It is of interest to consider the implications of a delay in implementing the tax regime if the economy is on an unsustainable growth path scenario. In Figures 6 and 7 Natural Capital and the

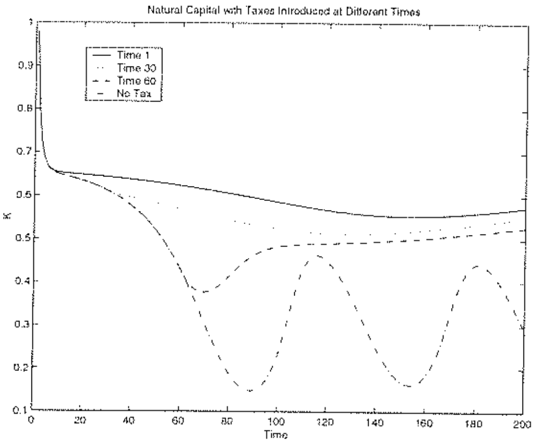

Figure 6. Natural Capital (K) with the tax rate introduced at differing times. ($\tau = 0.15$).

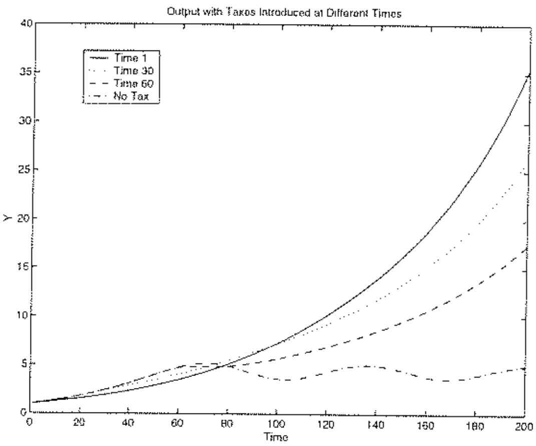

Figure 7. The Economy (Y) with the tax rate introduced at differing times. ($\tau = 0.15$).

Economy projections for two later implementation dates, period 30 and 60, are illustrated. The former equates to a reaction to the first noticeable signs of resource stock depletion, the latter to a period when the resource loss is greater than 50% of the initial stock. The figures include no tax and introduction in the first period for comparisons with the results in the previous section. A tax rate of 15% has been selected, as this appeared to be the optimal rate of those examined in the previous section. It would be expected that a delay would adversely effect the long-term outcome for both the economy and natural capital. In the case of output, a delay of 60 periods delays the commencement of sustainable growth and output levels, after 200 periods, are half those achieved if the tax had been implemented from the outset. A 30 period delay results in proportionally less reduction in output growth

The relatively quick transition to sustainable growth in output, even with a delay in tax implementation appears to arise from the dynamics of natural capital adjustment. In a relatively short period of time after the tax is implemented, fluctuations in the stock are removed and it approaches a steady-state level marginally lower than if taxes were implemented from the first period (6% lower in the case of a 60 period delay and 3% lower in the case of a thirty period delay). In sum, even a delay until pollution flows have severely reduced the natural resource stock is not, in the long-term sufficient to stop the tax putting the economy back on to a sustainable path.

5. CONCLUSION

This paper examined the impact of a pollution taxation policy in a model where there is a positive association between economic growth and environmental quality. It was argued that this model might be particularly relevant to resource industry dependent developing countries. Certain plausible assumptions were made about the response of producers to the imposition of taxes and the resultant effect on output and pollution emission. It was shown that when the economy was following an unsustainable growth path, taxes could be beneficial for the environment and sustain economic growth. However, beyond a certain level higher taxes promoted the sustainability of natural resources at the expense of lower rates of economic growth. To implement taxation that rectifies unsustainable development paths implies some sacrifice in living standards for current generations, in order to bring substantial benefits for future generations. Thus, according to the results in this paper, the government would be justified in taking a paternalistic stand towards its inhabitants. Especially if the social discount rate is lower than the private discount rate (Sen, 1982).

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