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Avoiding an ecological regime shift is sound economic policy

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ABSTRACT

We extend the shallow lake model by adding the capital stock of an industry. A government can mitigate the effects of pollution arising from industrial activities by imposing the requirement to abate emissions. Within this framework two scenarios are examined: in the social optimal benchmark, the social planner optimally allocates investment. In the competitive equilibrium, market forces determine the investment in capital, but the government can still abate emissions. We find that irreversible environmental regime shifts are avoided in the competitive equilibrium by means of a static level of abatement when it is socially optimal to do so.

1. Introduction

Ecological studies show that a wide variety of systems (lakes, coral reefs, oceans, forests, arid lands) do not respond to gradual change in a smooth way (Scheffer et al., 2001). In particular, these systems may be prone to catastrophic shifts, where a small change in external conditions can drastically alter the steady state of the ecosystem. The paradigmatic model for catastrophic shifts in ecosystems is the so-called shallow lake (Scheffer, 1998). In its pristine state, a shallow lake exhibits clear water, rich submerged vegetation and a high number of fish. The alternative steady state is one with turbid water, a high concentration of algae and almost devoid of fish. The external factor that determines the steady state is the inflow of phosphorus. The state of the lake (i.e. its turbidity) seems almost completely unresponsive to the inflow of phosphorus except near a threshold value where, due to biological feedback mechanisms, the turbidity suddenly jumps from low to high. If the lake ecosystem is very fragile, the jump is irreversible. But even in less fragile lakes, the inflow of phosphorus has to be lowered far below the threshold value to make the lake jump back to a clear state.

The problem of optimally managing shallow lakes, introduced by Mäler et al. (2003), is important to environmental economics for two reasons. First, it captures a basic trade-off. To increase the returns to agriculture more fertiliser has to be employed, which leads to an increase in the phosphorus level of the lake, decreasing the returns to fishery. Therefore more intensive agriculture has a detrimental effect on fishery. The question then is how to optimally manage the lake taking into account the returns to agriculture and fishery as well as the dynamics of the lake. In more general terms, the model can be

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used to discuss the trade-off between consumption and the state of the environment. The inclusion of this basic trade-off is a common feature of the models used in environmental economics.

Second, and perhaps more importantly, by incorporating a positive feedback mechanism the shallow lake model allows to move beyond simple linear descriptions of the environment. In particular, issues of irreversibility, hysteresis, and regime shifts can be studied; this has been the focus of a number of recent papers (Tahvonen and Salo, 1996; Brock and Starrett, 2003; Mäler et al., 2003; Wagener, 2003; Dechert and O'Donnell, 2006; Kossioris et al., 2008; Kiseleva and Wagener, 2010). In the shallow lake model, the optimal policy depends on the initial state of the lake. In certain cases, if the initial phosphorus level is below a certain threshold, it is optimal to move towards a clean lake; if above, to let the lake become more polluted.

One of the drawbacks of the shallow lake problem is that, by taking the stock of pollution as the only state variable, it implies a highly stylised model of the economy. In particular, at any moment in time any positive level of consumption can be reached. We therefore extend the shallow lake model by adding industrial capital as a second state variable, assuming that the inflow of pollution is proportional to the installed base of capital. Consumption is then constrained by the requirement that it cannot exceed output.

We present two extensions of the model of Mäler et al. (2003). The benchmark extension is that of a social planner managing both the industry and the lake. This is then contrasted to a competitive industry, where the externalities of pollution are not properly taken into account. As the capital stock of the industry is polluting the environment, we examine the effect of forcing the industry to abate pollution. Specifically, the industry is taxed and proceedings from this tax are used to clean a fixed proportion of the pollution flow; this is different from the situation in Mäler et al. (2003) where the tax was returned lump-sum to society. The level of abatement is fixed over time: this reflects the fact that dynamic policies are hard to implement, although we investigate one instance where the level of abatement can be adjusted once over the planning horizon.

The model presented in this paper is related to that of Bovenberg and Heijdra (1998, 2002) and to a lesser extent to those of Tahvonen and Kuulivainen (1993) and Economides and Philippopoulos (2008). These studies analyse a non-linear externality problem by considering small deviations from the steady state and then performing a linearisation of the model. We take a different approach, as in non-linear systems that feature history dependence local analysis is in general not sufficient. In particular, we investigate the dependence of the system on two parameters: the initial stock of pollutant and the fixed level of abatement. These parameters determine which of the steady states is reached in the long-run; our contribution is to provide a global analysis.

We focus on the case where the ecological system features an irreversible tipping point. That is, there is a critical level of the stock of pollutant such that if the stock level surpasses this, it can never return to lower, 'cleaner' levels. The main result of this paper is that when using a time-independent abatement level optimally, government policy avoids catastrophic regime shifts into the polluted regime in the competitive equilibrium, if it is socially optimal to do so. More elaborate abatement schemes improve welfare only marginally. In particular, we find that government policy is crucial to avoid large welfare losses by adverse ecological regime shifts in the competitive case. Additionally, we find that if policy measures are taken that are sufficient to avert these regime shifts, the differences between the social planner benchmark and the competitive case are marginal.

Some recent papers explore similar issues. Ranjan and Shortle (2007) also add capital dynamics to the shallow lake model of Mäler et al. (2003) and find environmental Kuznets curves. Wirl (2004) provides a global analysis of a modified version of Bovenberg and Heijdra (1998), focusing on thresholds and cycles. However, these papers do not examine the case of a competitive industry (with corrective taxation/abatement).

Prieur (2009), extending John and Pecchenino (1994), adds non-linear environmental dynamics to a Diamond-type overlapping generations model. In contrast to the approach of this paper, he only considers the case of a competitive equilibrium. He finds that John and Pecchenino (1994)'s result, that abatement is sufficient for environmental quality to improve, does not hold when environmental dynamics are non-linear.

Our results complement the results in Ranjan and Shortle (2007) and Prieur (2009). As Ranjan and Shortle (2007) observe, the basin of attraction of the clean steady state is smaller in the competitive equilibrium than it is in the social planner benchmark. We show that by using a simple state-dependent abatement scheme, where the government switches from full abatement to the optimal static level of abatement, the basin of attraction of the clean steady state can be increased substantially over a situation where an everywhere constant abatement scheme is used. Our state-dependent scheme should occupy the middle ground between being practically feasible, yet being sophisticated enough to replicate the social planner outcome at least at the steady state.

Prieur (2009) shows that, without government interference, current generations may invest too little in abatement to prevent an irreversible shift to high levels of pollution. In our analysis, we argue that it is optimal for the government to enforce investment in abatement to prevent such a shift.

Greiner and Semmler (2005) and Greiner et al. (2010) investigate an economy whose emissions contribute to global warming, which in turn affects the production function adversely. That is, capital and environmental dynamics are interdependent on the dynamic level, and the agents are only interested in maximising consumption. This can be contrasted to our model, where the capital dynamics influences the environmental dynamics, but not the other way round, and where the welfare also depends on the state of the environment. Both papers compare the outcome under social planning against a competitive economy. The first paper focuses on the stationary growth paths; in the second paper, the dynamics under