ECOLOGICAL ECONOMICS 68 (2009) 1020–1031

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METHODS

The shadow price of assimilative capacity in optimal flow pollution control

Marc Leandri

Department of Economics, Ecole Polytechnique, Route de Saclay - 91128 Palaiseau, France

ARTICLE DATA

Article history:
Received 22 December 2007
Received in revised form
15 November 2008
Accepted 15 November 2008
Available online 29 December 2008

Keywords:
Pollution control
Assimilative capacity
Ecosystem services

JEL classification:
Q51; Q53; H23

ABSTRACT

We present a model of optimal flow pollution control considering explicitly the dynamics of the corresponding assimilative capacity. We focus first on the degradation of this assimilative capacity triggered by pollution excesses and determine the intertemporal efficient pollution path, taking into account this ecological feedback. Our analysis shows that a minimum level of initial assimilative capacity is necessary to prevent its optimal extinction. We then allow for the restoration of assimilative capacity and characterize the conditions under which this option frees the optimal policy from the dependency on the initial conditions. In both cases our results call for environmental standards based on the shadow price of assimilative capacity that are stricter than the static optimum commonly used in flow pollution control.

1. Introduction

The assimilative capacity of an ecosystem receiving pollution can be defined as the ability "to receive a determined level of residues, to degrade them and to convert them in non-damaging and even beneficial products" (Pearce and Turner, 1990, p.38). This environmental sink function is at work in both stock and flow pollution. The assimilation of CO2 by oceans and forests and the protection of watercourses from lixiviated nutrient flows[1] by riparian buffer zones (Correll, 1996) illustrate these respective cases[2]. The level of assimilative capacity is not constant over time and depends either on the current stock of pollution (the concentration of greenhouse gases in the atmosphere) or on the "history" of pollution flows (periodic emissions of nitrates originating from fertilizers).

These dynamics are all the more important in flow pollution problems in that the level of assimilative capacity reflects the maximum amount of pollution that does not cause any social damage and that does not trigger any permanent alteration of the ecosystem functions. For instance, as long as the flows of lixiviated nitrates remain below the assimilative capacity threshold of riparian buffer ecosystems, no social damage is sustained and this capacity remains unaffected for future use. If the emissions exceed this threshold, not only will there will be contamination of the watercourses but the riparian buffers' assimilative capacity will be impaired by temporary nitrogen saturation (Hanson

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E-mail address: marc.leandri@polytechnique.edu.

[1] In this setting, flow damages consist in increased costs of artificial purification for drinking water, health problems, temporary loss of recreational amenities and commercial benefits due to the temporary clogging of estuaries by seaweed.

[2] Noise can be considered as another example of flow pollution involving assimilative capacity. In that case the assimilative capacity at work is the human ability to cope with noise without suffering from stress.

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doi:10.1016/j.ecolecon.2008.11.019

et al., 1994; Fromm, 2000). Therefore a merely static economic analysis of optimal flow pollution control will prove inappropriate when assimilative capacity is involved. Since the pollution optima serve as theoretical landmarks for environmental regulation, an economic instrument such as a pigouvian tax can lead to the extinction of the assimilative capacity if it is not calibrated properly. Indeed, if the static optimal level of pollution exceeds the assimilative capacity, it will cause damage and lower the threshold at which this social damage occurs in the future. At the next period, the same constant amount of pollution will thus be even more in excess of the assimilative capacity and will cause even more social damage and more degradation of assimilative capacity. This vicious cycle, first highlighted by Pearce (1976), can continue until the assimilative capacity is extinguished[3]. That is why it is crucial to carry out the economic analysis of flow pollution with assimilative capacity in an adequate dynamic framework.

The flow pollution control models found in the economic literature are either set in a static framework (Perman et al., 2003, p.171) or they do not allow for actual ecological dynamics (Schou, 2002). Meanwhile, the seminal articles on optimal stock pollution acknowledge the role played by assimilative capacity and its evolution over time (Forster, 1975). A survey of the different representations of assimilative capacity in the literature can be found in Pezzey (1996). Recently some authors such as Cesar and de Zeeuw (1994), Tahvonen and Salo (1996), Tahvonen and Withagen (1996), Toman and Withagen (2000), Chevé (2002), Hediger (2006) and Prieur (in press) have improved the specification of the assimilative capacity in various models of stock pollution control. However these contributions neither address the case of flow pollution nor allow for assimilative capacity restoration. The latter can provide a useful tool to a society that wishes to offset the degradation of assimilative capacity. For instance, CO_2 assimilation can be increased by afforestation while the assimilative capacity of riparian ecosystems can be restored through expansion and revegetation of buffer strips (Anderson and Ohmart, 1985; Goodwin et al., 1997). Although there exist significant work on environmental quality restoration (Phillips and Zeckhauser, 1998; Keohane et al., 2007) little attention has been paid specifically to the restoration of assimilative capacity (d'Arge, 1971; Pearce and Common, 1973) and to our knowledge this policy option has never been represented in a stylized model.

We therefore propose to build an optimal flow pollution control model, based on an intuition of Pearce (1976) extended later by Pezzey (1996) and Godard (2006), that takes into account the role and dynamics of assimilative capacity. We treat this assimilative capacity as an autonomous state variable that follows its own dynamics. This dynamic flow pollution model allows for a more comprehensive view of the economy–ecology interactions at stake and enables us to consider explicitly the option of restoring the assimilative capacity. After specifying in Section 2 our original pollution control model, we characterize in Section 3 the optimal pollution path and compare it to the static optimum. We introduce in Section 4 the possibility of restoring the assimilative capacity and we determine the new optimal path corresponding to this enhanced version of the model. In Section 5 we discuss the policy applications of our set of results. Section 6 concludes and points out potential extensions of our model.

2. The modified flow pollution model

As in most social optimization problems, we use a discounted utilitarian framework with a social welfare function including both the private benefit and the environmental damage with δ, $\delta \in]0,1[$, the social discount rate, supposed constant. We adopt a simplified pollution control model without capital accumulation similar to Ulph and Ulph (1994). The social planner problem amounts to

$$\max_{p} W = \int_{0}^{+\infty} U(p(t), A(t)) e^{-\delta.t} dt = \int_{0}^{+\infty} (f(p(t)) - D(p(t), A(t))) e^{-\delta.t} dt \quad (1)$$

subject to $\dot{A}(t) = -h(p(t), A(t))$ and $A(0) = A_0$
where $U(p(t), A(t))$ is the utility derived from an economic activity emitting a flow of pollution[4] $p(t)$ while benefiting from a level $A(t)$ of assimilative capacity and $h(p(t), A(t))$ is the degradation function of the assimilative capacity. A_0 denotes the initial level of assimilative capacity supposedly known. U is an concave function that can be separated into the private benefit function from polluting activity f and the socio-environmental damage D function triggered by this flow of pollution such that $U(p(t), A(t)) = f(p(t)) - D(p(t), A(t))$.

We work with a private-benefit function characterized by the standard properties of the literature: f positive, non-decreasing, concave, defined over R^+, $f_p \geq 0$, $f_{pp} \leq 0$. As we assume that the polluting firm ignores the externality it imposes on society, its private pollution optimum x_p is such that $f_p(x_p) = 0$. We exclude the possibility of a technical change that would allow to yield the same benefit while polluting less. There is no particular need to give an essential dimension to this production, the benefit function should thus not impose an "infinite penalty" on a zero level of production, and therefore we shall reject the Inada conditions (see Heal, 2000, p.37). In particular, if the environmental conditions are such that any strictly positive level of emissions will have negative welfare effects, then the economy will switch to any backstop production solution yielding positive welfare effects:

$$\lim_{p \to 0} f_p(p) < +\infty \quad and \quad f(0) = 0 > -\infty.$$

We use a flow damage function $D(p(t), A(t))$ that depends not only on the level of emissions $p(t)$ but also on the level of assimilative capacity $A(t)$. Indeed, when there is a neutralizing assimilative capacity at work in the ecosystem, the environmental damage is nil for any flow of pollution below the current assimilative capacity level. Conversely, the higher the

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[3] A similar cycle degrades soil productivity when farmers fail to consider the intertemporal impact of their activity on soil quality (Barbier, 1990).

[4] Pollution is an input in production, and the firm must necessarily increase its polluting emissions if it wants to increase its profit, through either a greater production of goods or a reduction of its pollution control costs.