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Nonlinear dynamic pollution under uncertainty and binding targets

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Abstract

In this paper, we study the effects of environmental regulation which establishes binding targets to pollution accumulation. Pollution follows a geometric Brownian motion. Inside the targets, pollution behaves as if it were freely floating until it hits one of the two limits. The model provides three main results. First, we show that targets can affect pollution accumulation even when they are slack at the current time. Solutions of the model show that pollution becomes an *S*-shaped locus of the fundamentals. Second, we show that binding targets will lead to more stable pollution rate determination within the boundaries, than free floating. Finally, stabilization of pollution stock is related to the credibility of the regulator in defending the targets.
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Keywords: Pollution targets; Optimal stochastic control; Uncertainty

1. Introduction

Over the last fifteen years the world economic system shifted from a regime of unregulated pollutant emissions, to a new and more regulated system of rules in which authorities committed themselves to keep emissions within broad targets. The most prominent agreement was the Kyoto protocol (1997). Later on, there were many other international commitments whose aim was the defense of the climate and environment. Nonetheless, the recent Copenhagen negotiations (2009) did not bring the waiting game initiated by the Kyoto protocol, and the lack of binding commitments for 2020 stands in contrast with the promises for 2050. But, what are the consequences to delay agreements? And, what is the role of credible commitments in controlling pollution?

This paper investigates these questions by means of a dynamic model of pollution accumulation with uncertainty and constraints. Our aim is twofold. We show that (1) without binding targets economies pollute too much in the meantime, and that (2) the lack of credibility of authorities reduces the implicit cost to respect commitments at the present time.

We are well acquainted with the tragedy of the commons. Free riding and non-cooperative behavior reduce the incentive to preserve environment. International authorities and governments operate to design regulations whose aim is the control of polluting emissions. Such a design builds on principles usually based on price coherency, incentive-compatible rules, target setting, accountability, monitoring and enforcement. Notwithstanding, some critical

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aspects of environmental regulations remain unexplored on the theoretical and factual grounds. For example, little research has been done on how such regulations would operate in practice when uncertainty and constraints affect the global pattern of emissions. Actually, this issue is investigated in some papers using a deterministic framework [18,15,23,13,8,22]. But, for many environmental issues the assumption of deterministic setup is unrealistic. An example is the achievement of a policy aimed at controlling the uncertain flow of emissions. In this scenario, any active policy will require to take into account that the future is uncertain even when pollution approaches the targets. Consequently, a crucial role in controlling emissions is played by expectations of economic agents. These expectations affect not only the current economic decisions, but also the associated flow of emissions and the effectiveness of policies at the current time. This is the focus of the paper.

Accordingly, to investigate the issue we present a stochastic model of pollution determination in continuous time with binding targets which emphasizes dynamic nonlinearities. Optimal regulation of Brownian motion is a topic, in the theory of the stochastic optimal control, which has found several applications in economics and finance [12,28,6,29,19,20]. Then, over the last two decades, the formalities of stochastic control have been applied in the field of environmental economics. New results are in [30,16,17,11,3,26,1,9,10,2,21]. All these authors derive conditions for optimal timing of policies whose aim is to regulate emissions of pollutants to maximize social welfare and/or discounted private utility and profits. Nonetheless, the manner in which future targets affect current emissions still remains an open question.

We assume that pollution is a by-product of aggregate output. Then, the optimal pollution control will take the form of two threshold targets. Inside the targets, emission behaves as if it was freely floating until it hits one of the two bounds. There are two reasons why we assume the existence of two targets. First, in the context of uncertainty, characterizing the present model, there may be immense difficulties in identifying economically efficient targets. Second, regulators are likely to have multiple objectives. Efficiency matters, but it is not the only thing that matters. Therefore, targets are often chosen in practice on the basis of a mix of objectives. The mix may include technology or health considerations, regulation and welfare. Nonetheless, we may simplify the analysis removing the lower target. This change does not alter the properties of the model. Basically, the questions at the heart of the paper is: can binding targets affect emissions even when boundaries are slack at the current time? This is a crucial issue for regulation, because if the answer to this question is positive then the stabilization of polluting emissions can take place even when the regulator is not actively defending the binding targets.

We get three results. First, we show that binding targets can affect the pollution dynamics even when the boundaries are currently slack. Solutions of the model state that pollution emissions become an S-shaped function of the fundamentals, with the potential targets exerting a global effect on the pollution dynamics. Second, we show that targets will lead to more stable pollution rate determination within the boundaries, than free floating. Finally, stabilization of pollution emissions are related to the growth rate and volatility of fundamentals, to the sensitivity to expected changes of pollution rate and to the credibility of the agreements in defending the targets.

The paper is organized as follows. In Section 2 we sketch the properties of a discrete-time representation of our problem where pollution is a by-product of economic activity. The first part of Section 3 deals with a deterministic version of our model to highlight the constrained problem of pollution accumulation over time. Then, in the second part of the same section, we study the stochastic version of the problem and derive the second order differential equation which describes the dynamics of pollution as long as it is strictly between the binding targets. Section 4 derives the solution at the binding targets. Section 5 outlines the conclusions of the analysis.

2. The model

In environmental economics there are different ways to model the process characterizing pollution accumulation and its effects on economic variables [31]. Some authors argue that pollution is a by-product of production or consumption process taking place during economic activities [4,27,24]. In other works, it is assumed that emissions affect the flow or the accumulation of pollution in the environment [25,5,14]. Finally, pollution can have detrimental effects on utility of individuals and productivity of inputs [24,7,3,21].

To be as simple as possible, we begin sketching the properties of a discrete-time representation of our problem where pollution is a by-product of output. Precisely, let us assume that in any period the level of pollution $P(t)$ depends on output $x(t)$. Further, suppose that stochastic variations (Δ) in output affect the pattern of pollution at the current

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