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Pigouvian taxes and payments for environmental services in an economic model restricted by the resilience of a body of water☆

David Tobón Orozco [a,*], Carlos Molina [a], John Harvey Vargas Cano [b]

[a] Universidad de Antioquia, Department of Economics, Calle 67 No. 53-108, Medellin, Colombia
[b] Universidad de Antioquia, Institute of Mathematics, Calle 67 No. 53-108, Medellin, Colombia

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ABSTRACT

This paper introduces a general equilibrium model to analyze the influence of the polluting sector on (1) a body of water's capacity for resilience, (2) the provision of drinking water and (3) social welfare. Since this capacity for resilience is uncertain, a probability distribution is defined that takes into account the growing loss of resilience when pollution goes from a prudent state to an imprudent one. The paper also finds that expected Pigouvian taxes are insufficient to maintain resilience due to the unaccounted cumulative effect of pollution, and that society would prefer a prudent tax. Furthermore, we introduce the transaction of payments for environmental services between the sector that provides drinking water and the polluting sector. This analysis reveals a redistribution of resources that very much favors the polluting sector, and thus there are no incentives to invest in these payments unless the affected sector has additional objectives to maximize its private benefit.

1. Introduction

The effects of extraction and the assumption that the degradation of resources that reduce natural systems' capacity for regeneration, and the opportunity cost produced when economic activity is regulated, have generated a growing concern about the importance of establishing restrictions on production. Particularly, Climate change (CC), which threatens human survival, mass extinctions of species and a potential drop in economic activity, is considered a key concept to understand such trade off [1,2].

Ref. [3] discusses whether society is willing to accept stricter environmental policies in order to reduce pollution and CC even if these policies have a negative impact on the economy, based on probability distributions of predicted medium- and long-term temperature changes. He finds that there are no strong incentives for society to considerably reduce its economic activity for reasonable values of risk aversion and intertemporal preference rates.

The relationship between natural systems and economic activity is important, because in the last 50 years the development of technology and the spread of mass production have generated changes in environmental conditions and the planet's natural resources [4]. For instance [5], calculates that based on current trends, Earth's temperature will increase by 4.3 °C, which would increase the risk of extinction of species by nearly 8%.[1]

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* Corresponding author.
E-mail addresses: david.tobon@udea.edu.co (D. Tobón Orozco), ca.molina11@uniandes.edu.co (C. Molina), harvey.vargas@udea.edu.co (J.H. Vargas Cano).

[1] See Ref. [37] for historical evidence of the incidence of temperature changes on ecosystems and the conflictive displacement of species and economic activities.

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A common conclusion in the field is that CC will threaten water availability [6]. Ref. [7] predict that by 2050, 59% of the world population will face blue water shortages (rivers and aquifers), and 36% will face green water shortages (naturally infiltrated rain). However, they suggest that managing local green water resources can help build water resilience [8] remark that three events are quite likely to happen simultaneously: future improvements in water resource reliability due to increased winter rainfall, reductions in resource resilience and an increased vulnerability to drought. In some regions, high-yield improvements in agricultural research and development should be required, because doubling irrigation development will not be sufficient to reverse the negative effects of CC [9].

Natural systems' *resilience* refers to their capacity to absorb shocks and changes when faced with degradation and pollution in order to ensure the supply of goods and services that are essential for economic functioning [10,11]. Yet it is difficult to quantify a system's level of resilience or capacity to respond. The Intergovernmental Panel on Climate Change concluded in 2007 that the effects of CC are quite uncertain due to the relationship between the planet's physical and chemical conditions [4].[2] Ref. [12] suggest several ways of modeling CC, and assert that the parametric uncertainty due to climate sensitivity is more complex than the specification of the uncertainty found in different reviewed models.

The literature that studies the effects of exogenous shocks on a system frequently incorporates uncertainty to account for the impossibility of determining the actual effect of a given shock, since in the natural system, the “point of no return”—or the step towards another stationary state of a less biodiverse system—cannot be exactly determined. Ref. [13] shows that the effects of uncertainty must be understood when studying the relationship between natural and economic phenomena, because these effects can be even more representative than intertemporal-related effects.

Following the idea of representing resilience endogenously [11], the critical point (*cp*)—or the concavity change of a function that represents a natural system's capacity for resilience—represents the point of no return. Uncertainty could be modeled by maintaining the trend of the function and making a random displacement so that the level of resilience and the *cp* vary based on the production of a representative polluting sector. Unlike [14]; who point out that resilience directly affects the probability of remaining in a determinate state, this paper evaluates the complete transmission channel when a shock to the level of activity of a polluting sector affects the provision of a public service such as drinking/usable water and. Such a shock increases the probability of being at a more critical level as the polluting sector's production increases. This paper utilizes a continuous distribution to capture a multiplicity of possible states faced with a shock, agreeing with the asymmetric nature system's characteristics.

In addition, researchers must address the interaction between a natural system and an economic system and the different consequences of economic production, including a loss of resilience, the effects on the drinking water supply, the value of economic production and social welfare. To do so, we implement a General Equilibrium Model (GEM) to account for this interaction and the overall effects of environmental regulations.

We use a GEM that includes two representative economic sectors—a representative consumer and a natural system (body of water) as a supplier for the economy—in a two-period life cycle. Property rights regarding the body of water are quite well defined and used to provide drinking water, so it is fundamental to maintain the natural system's capacity for resilience. Furthermore, the effects of pollution on resilience are not known, nor are the effectiveness of economic environmental regulations.

From an economic perspective, an optimal tax policy in a world of uncertainty is based on planners' knowledge of the distribution of stochastic variables, such as pollution and nature's reaction to such pollution. Furthermore, in a dynamic environment, agents continuously adjust their knowledge in order to formulate such policies [15–17]. To understand the characteristics of bodies of water and establish suitable policies, it is necessary to bear in mind that natural systems also have cumulative factors that could influence the design of environmental taxes. This study shows that an optimal tax, in accordance with the expected value of the effects, may not be sufficient to maintain resilience because of the cumulative effect of pollution, which is exacerbated by general equilibrium effects. This suggests that it is mandatory to be prudent when implementing environmental taxes, in accordance with the belief in a low level of resilience. This research also studies the effectiveness of Payments for Environmental Services (PES), a private initiative of the drinking water producing sector that intends to invest in this protection to encourage the polluting sector to reduce its level of activity and its emissions, in order to generate an environmental benefit and to guarantee profits for the drinking water sector in the future.

The remainder of the article is organized as follows. Section 2 presents the literature review and the framework of the study. Section 3 proposes the GEM and discusses its scenarios and the results of the various simulations. The last section highlights the main conclusions and limitations of the present study and suggests areas for future research.

2. Modeling of a natural system in an economic context

The economic literature has emphasized that natural systems are different from economic systems in important ways, and these differences must be considered when modeling the former (see Refs. [18–20]. For example [20], argues that economic systems are simpler in the sense that it is possible to rigorously study the partial balance of their properties. By contrast, since natural systems are highly interconnected, it is difficult to independently analyze their characteristics.

Therefore the difference between modeling an economic system and a natural system is the inclusion of these individual characteristics.Ref. [21] provide a useful characterization of the properties of ecosystems and their relationship with endogenous phenomena, such as climatic change and its effects. However, their study does not address economic systems. Ref. [13] examines the economic impact of various catastrophic events and shows that the omission of both ecosystem restrictions in economic systems and dynamics tends to underestimate the effects of climatic aspects. Ref. [22] study how abrupt shifts in ecological systems—cascading ecological

[2] In this line [3], models the expected temperature using a gamma (fat-tailed) distribution allowing by greater probabilities of extreme outcomes.