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Optimal adaptation strategies to face shocks on groundwater resources

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ABSTRACT

We consider an exogenous and reversible shock to a groundwater resource, namely a decrease in the recharge rate of the aquifer. We compare optimal extraction paths and the social costs of optimal adaptation in two cases: under certainty, i.e. when the date of occurrence of the shock is known, and under uncertainty, when the date of occurrence of the shock is a random variable. We show that an increase in uncertainty leads to a decrease in precautionary behavior in the short run and to an increase in precautionary behavior in the long run. We apply our model to the particular case of the Western la Mancha aquifer in Spain. We show that, in this context, it is advantageous for the water agency to acquire information on the date of the shock, especially for high-intensity and intermediate-risk events.

1. Introduction

Periods of low precipitation may lead to insufficient filling of groundwater resources and pose challenges for existing management rules (see Amigues et al., 2006; Zilberman et al., 2003). This problem may become even more acute in the context of global warming. Moreover, the evolution of the natural system may be subject to abrupt changes that can be qualified as "regime shifts". Adaptation to such shifts hinges crucially on the available information about the nature of the change, such as its date and its intensity. In this paper, we address the problem of regime shifts in the context of groundwater management and identify the circumstances in which information on the date and intensity of the shock is particularly important for a water manager.

We examine a case in which a common groundwater resource, used by several farmers for irrigation, is subject to dry periods. We use a simple groundwater model, the Gisser and Sanchez (1980) model (for similar model frameworks, see for example Cummings, 1971 or Roseta-Palma, 2003, 2002), in which we introduce a sudden change in the dynamics of the resource. Such a shock may occur due to a decrease in mean precipitation that leads to a decrease in the recharge of the aquifer, or it may correspond to the abstraction of a certain amount of water that is dedicated to other uses in the case of a drought, such as filling drinking water reservoirs.[1] The aquifer is managed by a social planner, the water agency, who wishes

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[1] In reality, such changes would not occur at a precise date but rather over some period of time. In addition, a decrease in the recharge rate requires a period of time in order to have a real impact on the aquifer. For simplicity, we consider here that the effect of the shock is immediate.

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to adapt as well as possible to these shocks. We characterize both the hydrological and the economic consequences of the shock by comparing short and long-run levels of resource stocks and social welfare.

In particular, we are interested in discussing the effect of information knowledge on the optimal management of the water resource. To this end, we introduce two types of shocks in our model: a deterministic shock at a given date and a random shock that may occur with a certain probability. This allows us to discuss the impact of uncertainty on precautionary behavior and management efficiency.

First, when the date of the shock is known, intuitively, one might think that the water agency would prepare for the event by applying a more careful extraction strategy. However, our results contradict our intuition and more water is extracted in the short term. Such a result can already be found in the literature (see Di Maria et al., 2012), in the context of polluting resources, where the phenomenon is known as the "announcement effect" or the "abundance effect". However, using a numerical example, we show that non-monotonic extraction behavior is possible in the short term, when the value of the shock is important and when it takes place later in time. Second, when the date of the shock is a random variable, some hints about possible solutions can be derived from the literature on catastrophic events, in the context of groundwater resource management (see Tsur and Zemel, 2014, 2004, 1995) and pollution control (see Brozovic and Schlenker, 2011; Clarke and Reed, 1994; de Zeeuw and Zemel, 2012; Tsur and Zemel, 1996; Zemel, 2012).

In Tsur and Zemel (2014), review the literature on the variety of forms in which uncertainty enters resource management problems. They distinguish two types of uncertainties: ignorance uncertainty, due to the limited knowledge of certain parameters of the resource (for example the recharge or instantaneous benefit may undergo an abrupt shift when the stock process crosses some unknown threshold) and exogenous uncertainty due to random environmental elements (for example weather variability)[2]. Depending on the type of uncertainty considered, the relationship between precautionary behavior and an increase in uncertainty can vary. Some studies show that an increase in uncertainty leads to non-monotonic changes in precautionary behavior (see Brozovic and Schlenker, 2011; Clarke and Reed, 1994; Zemel, 2012), while others show that an increase in uncertainty leads to a decrease in precautionary behavior (see Tsur and Zemel, 2004, 1995). Still others conclude that an increase in uncertainty leads to an increase in precautionary behavior (see de Zeeuw and Zemel, 2012; Tsur and Zemel, 2004). For example, Brozovic and Schlenker (2011) and Zemel (2012) found a non-monotonic relation when several sources of uncertainty are combined. Tsur and Zemel (2004) proved that an increase in uncertainty leads to more intensive extraction in the case of irreversible exogenous events.[3] In contrast, they showed that more precautionary behavior is applied in the long run in the case of reversible exogenous events or endogenous events. Moreover, in de Zeeuw and Zemel (2012), proved that the introduction of a random jump in the damage function of a pollution control model leads to more precautionary behavior, both in the case of endogenous events and irreversible exogenous events.

In this paper, we study reversible exogenous events and analyze the relationship between the characteristics of the shock and adaptive behavior in the short run and in the long run. We are especially interested in the exogenous uncertainty of the time parameter T, when T is a random variable whose realization marks the occurrence of an event. In this case, Tsur and Zemel argue that, compared with the risk free situation,[4] the optimal policy entails more aggressive exploitation in the short term and more conservative extraction after the occurrence of the event. We show that although our results correspond to the solutions found by Tsur and Zemel (2014), our paper differs from theirs in several ways: First, Tsur and Zemel analyze catastrophic events (such as saltwater intrusion) which render further use of the resource impossible (unless restoration is undertaken). We focus on an event that does not hinder further exploitation. Second, we add to the exogenous uncertainty of the time parameter, an abrupt shift in the dynamics of the resource, and not in the objective function.[5] Third, we compare optimal adaptation behavior for different uncertainty scenarios, and do not only compare the risk-free and the uncertainty situation. Finally, we illustrate the economic implications of the shock with a numerical example.

We apply our model to the Western la Mancha aquifer in the South of Spain. In this area, the state of groundwater resources has significant implications for the future provision of important ecosystem services (see Esteban and Albiac, 2011; Esteban and Dinar, 2012 for details). The average annual groundwater recharge in this aquifer is 360 million cubic meters. In recent decades, the aquifer has been subject to numerous droughts. Since 1999, the recharge rate has decreased by approximately 100 millions cubic meters, leading to an estimated decrease of 3000 million cubic meters over the past three decades (see López-Gunn, 2012). In the numerical simulations, we analyze the impact of such shocks, considering variations in the recharge rates of the same magnitude as past variations (and not possible future variations caused by climate change). We thus analyze a lower benchmark problem. Even though we assume that the water agency does its best to adapt to these shocks, we show that the costs to society are high, and may reach several million Euros. In addition, we wish to know whether or not the water agency should try to forecast the date of the shock. We show that it is always advantageous for the water agency to acquire additional information about the date of the shock. Moreover, this information is more useful when the shock is more intense and when it takes place in the medium run. Finally, we confirm that it is always better for the water agency to be prepared to adapt, with or without knowledge of the date of the shock, than not to prepare for the shock at all.

[2] Similar concepts are those of endogenous and exogenous events used by Tsur and Zemel (1995) in Tsur and Zemel (1995).

[3] In Tsur and Zemel (2004), they define that an event is irreversible when its occurrence renders the resource obsolete, and is reversible when restoration is possible at a cost.

[4] The risk-free situation corresponds to our initial groundwater problem in the absence of shock.

[5] In Tsur and Zemel's articles, for reversible events, a penalty function is added to take into account restorations costs.