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Modeling sustainable groundwater management: Packaging and sequencing of policy interventions

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ABSTRACT

Of the many studies estimating effectiveness of policy reforms most have been considering various types of policy reforms in isolation from each other. Such pattern has also been the case in water resource regulations. In the case of groundwater almost all policy interventions considered in the literature have been implemented individually, without taking into account the possible interactions and impacts among them. In this paper, we focus on two policy instruments: water quota and uniform water tax. The paper demonstrates how packaging and sequencing sets of policy interventions, with possible triggers to initiate their time of implementation, may be more effective in achieving a sustainable groundwater management than single policies when environmental externalities exist. The policy instruments are applied to the Western la Mancha aquifer in Southeast Spain, a major aquifer that is managed by a command and control approach.

1. Introduction

"…determining the appropriate sequencing of policy reforms is thus an inescapable practical issue for policy-makers, and may have a considerable bearing on the success of any adjustment program" (Montiel and Angor, 1996:500). The recognition of a need to consider packaging and sequencing of policy interventions (reforms) as a mean for success of adjustment programs is seen in an increasing number of studies, mainly addressing macro-level reforms (e.g., Bevan, 1999; Gelan, 2002; Roe et al., 2005; Saleth and Dinar, 2009). In this paper we compare the performance of individual policy interventions to packaging and sequencing of these policy interventions in the case of groundwater, which becomes an acute resource in need of regulation. The sequencing of policy interventions in the case of groundwater has much less studied in the past.

Groundwater represents the main source of fresh water worldwide (Koundouri, 2004). Like other water bodies, groundwater resources suffer overexploitation that reaches critical levels in many of the aquifers across the world. Overexploitation combined with mismanagement regimes that govern groundwater lead to aquifer disasters in many countries (McGuire, 2007; Tiwari et al., 2009). This situation calls for regulatory intervention.

There are a large number of environmental norms and regulations that can be implemented, which include quotas, taxes, subsidies, tradable permits, voluntary agreements, or liability rules. One of the main problems in regulating the environment is the choice of the best policy instrument to achieve an environmental objective. Another hindrance is the "principal-agent problem"[1] (Grossman and Hart, 1983; Siebert, 2005; Xepapadeas, 1991) in which the policy maker wants to achieve an environmental target and tries to influence the decisions of the agents. The objective is to find the correct institutional arrangement to lead the agents to reach the environmental goal; it is a case of incentive compatibility (Siebert, 2005).[2] Sometimes one isolated policy will not achieve the environmental objective of the agency and a combination of policies may be required to protect the resource.

In this paper, we analyze an aquifer that is used mostly for irrigated agriculture. Under no regulation, farmers extract more water than the social optimal level due to not internalizing all the external costs of their activity. Farmers usually ignore two types of

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[1] The "principal-agent problem" designs all the situations where one party (principal) depends on the acts of other party (agent). The principal does not have full information and depends on the agent. The "principal-agent problem" is the typical example of asymmetric information among the parties.

[2] To solve the problem, Siebert suggests that the policy maker (principal) maximizes the social welfare function, in which all externalities are included. Social welfare is defined as the net benefits of the environmental objective (or policy) restricted by the reaction function of the agent (that restriction reflects the agent behavior).

externalities generated by their activity: (1) extraction costs externality, and (2) environmental externality. Extraction cost externality is defined as the increase in the cost of groundwater pumping due to a decrease in the water table level. Environmental externality is defined as the damage to ecosystems connected to the aquifer from a reduction in the water table level.

The paper offers the concept of packaging and sequencing of policy interventions (instruments) for groundwater regulation. The usefulness of these two concepts is demonstrated using a hydro-economic model that was developed for the Western la Mancha aquifer in Southeast Spain (Esteban, 2010; Esteban and Albiac, 2011). The model evaluates the effect of these policy interventions on the net present value of the users' private profits, on the stock of water in the aquifer at the end of the planning period (30 years), and on the net present value of the regional social welfare. The main conclusion is that when policies are packaged and sequenced with triggers that dictate their implementation, there is an increase in efficiency (higher benefits, welfare, and water stock) compared with the policies implemented separately.

2. Literature review: the regulation of groundwater extractions

Agriculture operations affect water resources quality and quantity. These effects are especially important in the case of groundwater resources, due to being the main source of fresh water in the world. A large bundle of instruments can be implemented to control groundwater resources (such as taxes, subsidies, quotas, permits, voluntary agreements, or liability rules). Tax instruments penalize the use of water, or the decrease in the water table level. Subsidies are positive incentives to farmers for reducing their water extraction or production levels. With water quotas, a maximum quantity of water extraction or a minimum water table level is set. With market-based instruments, such as water tradable permits, users are assigned a quantity of water (permits) and they have the option to sell them to or to buy from other users (private market rules). Liability rules assign responsibilities for the damages that users cause due to their extractions. Voluntary agreements are mechanisms that users undertake by themselves (sometimes through incentives) to reduce the extractions and protect the resource (Madani and Dinar, 2011a,b, 2012).

A review of instruments available for managing groundwater (Koundouri, 2004) highlights the main advantages and disadvantages of most of these regulations. A tax instrument seems to be an effective policy intervention to control the level of groundwater extractions. However, the problem resides in the implementation of the optimal regulation or setting the tax rate (Pigouvian regulation); the heterogeneity among farmers and the incomplete information on stochastic factors affecting groundwater produce multiple optimal tax rates. Thus, frequently, the lack of information and the existence of high administrative and transaction costs render the execution of the tax regulation impractical. Other instrument like water quotas could also control groundwater extractions, however, water quotas are not always economically efficient instruments; furthermore, and similarly to tax regulations the optimal quota is not unique and different quotas should be implemented with the associated transaction costs. Subsidies are not economically efficient and can generate distortions. Market-based instruments need the existence of an institution enabling the assignment of water rights and establishing some operational rules. These instruments are efficient mechanisms because the market establishes the optimal prices and quantities. However, the problem is the necessity of having capable institutions to manage the rights and setup the rules. Voluntary agreements are efficient instruments, due to reducing farmers' extractions, but usually require the creation of incentives for farmers to collaborate and monitoring costs to prevent cheating. Most works, though, focus on the comparison between taxes and quotas; we provide a short review of the finding regarding their effectiveness.

Bredehoeft and Young (1970) analyzed the effects of two policy instruments – a tax and a quota – implemented to reduce the level of extractions in a hypothetical basin. An unrestricted equilibrium is compared with the results of the two policy regulations implemented separately. The results suggest that both instruments (tax and quota) yields similar results, the improvement in the social welfare when each regulation is implemented is relatively small (not justifying the intervention).

Likewise, Feinerman and Knapp (1983) empirically analyzed the magnitude of the benefits from groundwater management through the analysis of two instruments: pumping taxes and groundwater quotas. The results suggest that groundwater users prefer water quotas over pumping taxes. Similarly to Bredehoeft and Young, the results also suggest that the increase in social welfare with each of the policy interventions is not large enough to justify regulation.

In a theoretical work, Weitzman (1974) analyzes the advantages and disadvantages of taxes and quotas. This author highlights how under uncertainty neither taxes nor quotas yield satisfactory results. The characteristics of the benefit and cost's functions determine the suitability of the best instrument. Weitzman concludes that under some situations the best instrument is a combination of policies, mixing taxes and quotas will yield the highest social welfare.

Choi and Feinerman (1995) empirically analyze the effectiveness of first-best taxes and quotas to reduce groundwater pollution in Israel.[3] In the case of groundwater pollution, these authors show that both first-best taxes and first-best quotas are efficient measures to achieve a target level of emissions.

Brozovic et al. (2004) analyzed the convenience of using second-best taxes or second-best quotas in a context of pollution with heterogeneous firms. The main finding is that under some assumptions, a quota further decreases the pollution loads compared with a uniform tax. Sorensen and Herbertsson (1998) compare the application of two types of taxes: a Pigouvian tax versus a tax on the total amount of water (using a non-optimal rate).[4] Both regulations increase the social welfare, but the preferred instrument is the Pigouvian tax. The main problems arise in the calculation of the optimal tax rates, which, due the lack of information on the natural resource, is a difficult or even impossible task.

As previous literature suggested, the individual application of quotas and taxes will not normally yield a 'first best' results (Weitzman, 1974). So, several studies have also analyzed the feasibility of applying a combination of instruments (mainly taxes and quotas) in order to achieve better social welfare levels.

Maddock and Haimes (1975) implemented a combined instrument to preserve groundwater resources reducing the extraction cost externality. These authors mix two instruments: a quota and a tax/subsidy. A quota, or maximum quantity of extractions, is established and a tax/subsidy will be implemented depending on whether or not the quota is exceeded. If farmers extract above the quota, the tax is applied; if farmers extract below the quota then the subsidy is applied. The main conclusion is that the combination of instruments is an efficient mechanism to reduce extractions.

Costello and Karp (2004) compared dynamic taxes and quotas when asymmetric information exists between the regulator and

[3] The first-best tax and the first-best quota are implemented alone and not as combined instruments.

[4] In the work of Sorensen and Herbertsson, the Pigouvian tax changes over the time, so the optimal rate is different each period. A tax on total water is a constant quantity tax throughout the entire planning horizon.