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Dynamic management of water transfer between two interconnected river basins☆

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ABSTRACT

This paper analyzes the dynamic interaction between two regions with interconnected river basins. Precipitation is higher in one river-basin while water productivity is higher in the other. Water transfer increases productivity in the recipient basin, but may cause environmental damage in the donor basin. The recipient faces a trade-off between paying the price of the water transfer, or investing in alternative water supplies to achieve a higher usable water capacity. We analyze the design of this transfer using a dynamic modeling approach, which relies on non-cooperative game theory, and compare solutions with different information structures (Nash open-loop, Nash feedback, and Stackelberg) with the social optimum. We first assume that the equilibrium between supply and demand determines the optimal transfer price and amount. We show that, contrary to the static case, in a realistic dynamic setting in which the recipient uses a feedback information structure the social optimum will not emerge as the equilibrium solution. We then study different leadership situations in the water market and observe that the transfer amount decreases toward a long-run value lower than the transfer under perfect competition, which in turn lays below the social optimum. In consequence, the water in

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the donor's river-basin river converges to a better quality in the presence of market power. Finally, we numerically compare our results to the Tagus-Segura water transfer described in Ballestero (2004). Welfare gains are compared for the different scenarios. We show that in all dynamic settings, the long-run transfer amount is lower than in Ballestero's static model. Further, we show that the long-run price settles at a lower level than in Ballestero's model, but is still higher than the average cost-based price determined by the Spanish government.

1. Introduction

This paper analyzes the interaction between two neighboring regions with different water inflows and water productivity. If the river-basin in one region receives more rainfall while the water productivity is higher in the other (for example: higher fertility of the irrigated soil, or demand for water for highly productive activities like tourism), then the existence of a transfer infrastructure that enables the transfer of water from the former to the latter would increase overall productivity (see for example Dinar and Wolf, 1994).[1] Independently of whether the two river-basins are located in the same or in two adjacent countries, using such an aqueduct to transport the water from the donor to the recipient would help increase efficiency, and can therefore be regarded as a good decision (by a central government) or agreement (between the two parties), from an economic point of view.

Because water inflows in the donor basin are large, after covering the demands from households and industrial activity in this region, there will be a water surplus. As long as the water transfer does not exceed the water surplus, it will not harm the donor's economy. Nevertheless, the water transfer reduces the water level in the donor's river-basin, causing environmental degradation, and hence reducing the welfare of the donor. The water transfer improves productivity in the recipient basin but also increases the environmental constraint in the donor basin (for environmental effects of water transfers, see, for example Kumar, 2006). A transfer payment must thus be set up to compensate the donor for forgone benefits from holding on to the water resource.

The payment of the water transfer can be settled by a central planner (who has to determine how to share the gains from cooperation), or through a bargaining process between the two regions which may take place in a water market. Although some kind of cooperation is needed between the regions to set up the market (see Bhaduri et al., 2011), we consider that each region acts non-cooperatively within the market and hence we use non-cooperative game theory to explain the strategic interactions occurring (for a literature review on different non-cooperative solution concepts in game theory see Madani, 2010; Madani and Hipel, 2011). We first investigate the Nash equilibrium that occurs in the market (see Nash, 1951). We consider a bilateral monopoly with a single water seller and a single water buyer, like in Lekakis (1998). The transfer price will be determined in a demand-supply setting in the market (see for example Ballestero, 2004). Alternatively, we study the solution when one of the players can make a take-it-or-leave-it offer to its counterpart, which is represented in a Stackelberg game. In this case, the price and quantity of the transfer is not determined by the market clearance. The donor (resp. the recipient) chooses the price in order to maximize welfare taking into account the demand for water (resp. the supply of water) made by its opponent. In the following, we will refer to the player who makes the take-it-or-leave-it offer as the player who has the "market power".

Addressing water scarcity through inter-basin water transfer is just one possibility for the recipient. Water-savings, water recycling, or the production of fresh water by desalination plants are alternative ways to increase the supply of usable water that should be considered when long-term

[1] Water trade between two regions is mutually beneficial when one region is characterized by a relatively less binding water constraint and the other by a relatively efficient water-use technology, see Dinar and Wolf (1994).