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Projecting and valuing domestic water use at regional scale: A generic method applied to the Mediterranean at the 2060 horizon

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ABSTRACT

The present work focuses on the demand side of future water scarcity assessment, and more precisely on domestic water demand. It proposes a quantitative projection of domestic water demand, combined with an original estimation of the economic benefit of water at large scale. The general method consists of building economic demand functions taking into account the impact of the level of equipment, proxied by economic development. The cost and the price of water are assumed to grow with economic development.

The methodology was applied to the Mediterranean region, at the 2060 horizon. Our results show the evolution of water demand and value, measured by surplus, over time. As long as GDP per capita and water price remain low, demand per capita increases along with economic development, and surplus per capita increases with demand. As demand approaches saturation, the combined negative effects of water cost and price increase on surplus grow stronger, and surplus per capita begins to decrease.

The developed methodology is meant to be used for large-scale hydroeconomic modelling, in particular for regions with heterogeneous levels of development and low data-availability.

1. Introduction

Pressure on water resources is a major issue in the Mediterranean region. More than half of the world's "water-poor" population is located in the region, which concentrates 7.3% of the world's population for only 3% of its water resources [23]. Global changes are expected to exacerbate this pressure on resources in the following decades: on the one hand water demand will increase with demographic growth and economic development, while on the other hand climate change is predicted to reduce water availability and intensify droughts around the Mediterranean [7].

Spatially contrasted situations, with some basins more affected by water scarcity than others, could foster water related interactions between basins such as water transfers, activity relocations and, indirectly, migrations. Such interactions could particularly arise in the case of the Mediterranean, which has a history of exchanges and migrations between rims [9].

In such a context, it is important to anticipate future water scarcity issues and identify basins at risk, in order to inform management strategies and policies. Traditionally, water management policies focused on adapting supply to demand, by mobilizing new water resources. But as resources become increasingly scarce and costly, policy makers have developed demand side management aiming at reducing water wastage.

In the present work we concentrate on the demand side of the water scarcity issue, and more precisely on domestic water demand. Irrigation is the largest water use sector in the Mediterranean, representing 63% of total water use [23], and its projection is a research field of interest [10]. However, its share in total water use is decreasing [23]. Moreover, domestic demand, while accounting for a lower share of demand, is critical in terms of needs. Indeed, irrigation needs can be adjusted to some extent by virtual water trade, water scarce areas having the possibility of importing food rather than producing it themselves [4]. Domestic needs cannot be adjusted in that way. In addition, domestic uses such as

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consumption, food preparation and hygiene are essential to human life.

Some projections of domestic water use in Mediterranean countries exist, but they are not homogeneous between countries in terms of time horizons, methods and scenarios. In most cases they rely on simple trend prolongations [23]. When looking at the whole region, a global projection methodology applicable to the different countries, taking into account sociodemographic changes to come and simulating comparable scenarios across countries, is pertinent.

Generic global scale modelling of domestic water use is covered extensively in the literature [2,3,17,34,35]. The general principle is to model and project a unitary water use intensity per capita, that is to be multiplied by the projected number of inhabitants. In the WaterGAP methodology [1], the per capita water use intensity is modelled to evolve with the level of economic development (relationship statistically estimated at country scale) and decrease over time with technological improvement (represented by a fixed rate of improvement). In the Total Runoff Integrating Pathways (TRIP) model, future levels of domestic water use per capita in developing countries have been modelled either to converge towards that of present developed countries as economic growth continues [32,19], or independent of economic growth [17]. Other authors consider the impact of additional factors: Hughes et al. [21] statistically estimate municipal water use per capita as a function of climatic variables and GDP per capita; Ward et al. [35] estimate municipal water demand as a function of GDP per capita and urbanisation rate, taking into account regional dummies and country characteristics as fixed effects.

While evaluating water quantities at stake is essential, it is also relevant to have an idea of the economic benefits associated with water uses and the potential economic losses associated with water shortage. Economic valuation can be an indication on how to manage at best the available resource and allocate it between competitive uses when water is scarce. In hydroeconomic models, instead of considering water demands as fixed requirements, water is allocated to its different uses based on the economic benefits it generates: the economically optimal allocation is the one that maximises the aggregated economic value of the water used [18].

However, economic valuation of domestic water, as well as methods to project changes in water value, is absent from the large-scale literature. Because markets are absent or inefficient for the water sector, it is not possible to observe directly the economic value of water. It is necessary to develop alternative non-market valuation techniques to reveal and estimate water's value [37]. For the domestic sector, water is valued using willingness to pay and deriving economic surplus from econometric estimations of price-elasticity and demand functions [37]. Such a method requires much data, which could be among the reasons explaining why hydroeconomic models have been developed mainly at an infra-national geographical scale [18].

To account for changes in both demands and economic benefits, in a region with heterogeneous data-availability, we develop an original generic method. We build an economic demand function, analogous to the demand function modelling approach used in hydroeconomic models of smaller scale [28], which enables water valuation. In order to take into account the link between water use and economic development, a methodology similar to WaterGap [1] is used.

This paper first describes the methodology developed to build generic demand functions that project both quantities and economic values of future domestic water demands at large scale and at a time horizon enabling to picture global changes (cf. diagram in Appendix A). Then it proposes an application to countries of the Mediterranean rim, from Western and Eastern Europe, Middle East and North Africa (cf. map of Mediterranean countries in Appendix B).

2. Building generic demand functions taking into account structural change

2.1. Overview

Our approach is to build simple three-part inverse demand functions (Fig. 1), in which the willingness to pay for water decreases with quantity [18]. Each part of the demand function corresponds to a different category of use. The first category corresponds to basic water requirements for consumption, food and hygiene, which are very highly valued (e.g. hand washing). The second category corresponds to intermediate needs, including additional hygiene (regular laundry, showers, etc.), less valued than uses of the first category. The last category corresponds to least-valued supplementary consumption, such as further indoor uses (e.g. leisure bath) or outdoor uses (lawn watering, pool, fountain, etc.).

To build a demand function for each country, we determine the bounds of the demand blocks corresponding to these three categories: their respective volume limits (noted *Q*) and the marginal willingness to pay (noted *V*) for those volumes.

Hence, the first step of the methodology is to determine the volume limits of the demand blocks, taking into account that demand will be impacted by economic development processes. The second step is to determine the willingness to pay for water at those volumes of reference, in order to value water. This second step also makes it possible to take into account the possible impact of water price on demand.

2.2. Volumes of the demand blocks: taking into account structural change

Following Alcamo et al. [1] and their “structural change” modelling, we want to take into account that average domestic water demand per capita grows along with economic development, proxied by GDP per capita, in order to take into account equipment effects. Indeed, as their income increases households get more water-using appliances (washing machines, dishwasher, etc.) and use more water; eventually they reach equipment saturation and water use stabilises whilst income continues to grow. To take into account structural change, we consider that the volumes of the blocks of our demand function evolve over time following economic development.

We assume that only non-essential uses are sensitive to this equipment effect, so we consider that the volume of the first block of our demand function is fixed. Following Gleick [16] and Howard and Bartram [20] (Table 1), we set the volume limit of the first demand block to 50 l/c/d, which meets needs for consumption, food and personal hygiene.

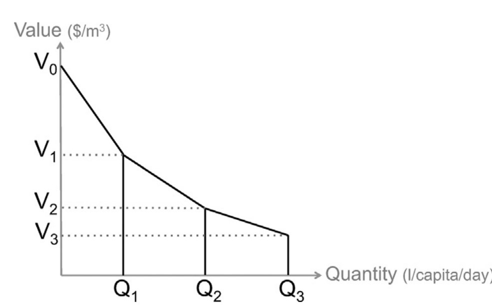

Fig. 1. General structure of the three-part inverse demand function (with volumes *Q* and willingness to pay *V*).