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Design and assessment of an efficient and equitable dynamic urban water tariff. Application to the city of Valencia, Spain

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Abstract

Water pricing policies have a large and still relatively untapped potential to foster more efficient management of water resources in scarcity situations. This work contributes a framework for designing equitable, financially stable and economically efficient urban water tariffs. A hydroeconomic simulation model links the marginal value of water, which reflects water scarcity given its competing uses, to water supply reservoir levels. Varying reservoir levels trigger variations in the second block of the proposed two-block increasing-rate tariff; these variations then reflect water's value at that time. The work contrasts the two-block scarcity tariff with a constant volumetric rate for the city of Valencia, Spain, and the drought-prone Jucar basin, where most of 430,000 households are equipped with smart meters. Results show urban consumption is reduced by 18% in the driest years, lowering basin-wide scarcity costs by 34%.

Keywords: *dynamic tariff, urban water management, water pricing, marginal value of water, hydroeconomic modelling*

1. Introduction

Growing pressure on existing water resources from rising demand and uncertain supply underline the value of efficient management strategies. Although urban water conservation is often achieved through prescriptive regulation, the use of prices to manage water demand can be more cost effective than non-price conservation programs (Olmstead, 2009). The potential of water pricing to foster more efficient management of available water resources has been recognized in regulatory frameworks such as the EU Water Framework Directive (EC, 2000). This European regulation promote pricing as a way to pursue several objectives such as cost recovery for water suppliers, economic efficiency and environmental preservation by factoring in not only the financial but also the environmental and resource costs (Heinz et al., 2007; Pulido-Velazquez et al., 2008; Brouwer et al., 2009) .

A pricing policy is economically efficient if the prices charged correspond to the total marginal cost of water (Rogers et al., 2002). In economic terms, efficient water management abides by the equimarginality principle, whereby the benefit forgone by allocating an additional unit of water to any consumer – also known as marginal resource opportunity cost (MROC),(Pulido-Velazquez et al. 2008 and 2013a; Macian-Sorribes et al., 2015) – is the same regardless of the consumer. In lay terms, to achieve the greatest return from existing water resources a supplemental unit of water should be valued equally by different consumers. Yet, even though water pricing can in theory pursue several objectives at once including economic efficiency, its practical implementation can prove challenging because other objectives might have to considered for price design. This is the case for urban water rates that are expected to meet some basic functions (Hanemann, 1998; Griffin, 2006; Barberan and Arbues, 2009). Cost recovery is a priority, as the selected tariff has to provide sufficient revenues to allow the utility to recover the cost of supply and meet its financial obligations, in both short-run and long-run conditions. Other objectives of urban water tariffs refer to the way costs should be allocated among consumers. Water rates should ideally be perceived as affordable, fair and equitable by the consumers. Finally, the proposed rates should be easily understood by clients and utilities and legally acceptable. An example of residential urban tariff design that considers efficiency, equity, financial cost recovery, public acceptability and transparency is proposed by Garcia-Valiñas (2005). The method characterizes the urban water demand using an econometric approach, and the costs of water supply through a Cobb-Douglas function. A variety of tariffs was then evaluated in terms of welfare effects, using the consumer surplus as indicator. The approach assessed economic efficiency and financial considerations but only at the consumer and utility levels, whereas the consequences of urban tariffs on consumption have repercussions on water availability and scarcity for all consumers in a river basin.

Rate design is also constrained by the metering technology, which determines how regularly consumption can be measured. For instance, without water meters, customers are charged a fixed rate, which provides no incentive for consumers to know their consumption (Whittington et al., 2002). With ordinary meters, water can be charged at a volumetric rate. Flat rates can be efficient if well-designed (Garcia and Reynaud, 2004; Dige, 2013). Decreasing block rates, which lead to high volume consumers paying lower average water prices, has gradually fallen out of favor (Whittington et al., 2002). In contrast, increasing block rates (IBR) that penalize heavy consumers have become widely implemented, because they are seen as fairer and more economically efficient (e.g., Martins and Fortunato, 2007; Chen and Yang, 2009; Madhoo, 2011; Ward and Pulido-Velazquez, 2009). Yet, these merits of IBR have been questioned (Boland and Whittington, 2000; Strong and Goemans, 2014; Whittington et al, 2015), suggesting that when metering technology constrains rate design, pricing schemes may not always achieve their stated objectives. One option is seasonal IBR, that aims at reining in consumption during summer months in places where high summer use puts a strain both on scarce water resources and/or on the distribution infrastructure (e.g. Hoque and Wichelns, 2013; Molinos-Senante, 2014). New smart metering technologies, with their frequent and automated consumption measurements, enable dynamically varying tariffs, i.e., water pricing policies that changes over time. This includes seasonal pricing, but also peak-pricing strategies within a day (Rouge et al., in press). Sharing this information with customers could help manage residential demand (Rizzoli et al., 2014; Cardell-Oliver et al., 2016). Through real time information on water consumption, consumers can get learn about their water use and its associated cost, which has been shown to lower consumption (Gaudin, 2006; Strong and Goemans, 2015). Through real time information on water consumption, consumers know how much water they are using and how much they are going to pay, and how far are them from moving to the next block. Furthermore, prepayment water meters can be considered as a tool to manage water resources that benefit both consumers and utilities. These water meters allow reducing financial and operational costs for the utilities; and allocating the resources more efficiently. However, their implementation could be difficult for low income consumers (Casarin and Nicollier, 2010).

Scarcity pricing has its origin in the fact that, unlike in power networks, water distribution systems rely on largely climate-driven natural supplies. As water becomes scarce, its marginal value increases, and scarcity pricing aims to reflect this. When the supply is abundant, this value is essentially zero and water price at the tap only reflects the treatment and delivery costs. When water becomes scarce, scarcity pricing adds the opportunity costs in the allocation of the scarce water to the price of water at the source that promotes an economically efficient allocation (Pulido-Velazquez et al. 2013a; Riegels et al. 2013 and Griffin 2006). This efficient scarcity price at source is the same for all other sectors, such as agriculture, industry, etc.

However, water scarcity pricing has been very rarely implemented. In California, the 2012-2016 drought spurred the implementation of economic tools such as drought surcharges and penalties to reduce residential water use. 29% of water utilities used drought surcharges (Mitchell et al, 2017): an increase in the unit price of water triggered by low water supply levels. During the same period, up to 79 % of utilities used penalties: fines charged to those that do violate water restrictions. These instruments have served to decrease water use while increasing revenues in periods when lower water use reduce revenues considerably, functioning as economic and financial tools at the same time. Mitchell et al. (2017) found that drought surcharges were significant in reducing per capita water use and complying with conservation targets. Previous studies have analysed the impacts of applying temporary drought pricing (e.g. Sahin et al. 2015 and 2016) on urban systems. These pricing policies are only applied during drought periods, and the escalation of the baseline price schedule is based on the storage (price increased in a percentage with respect to the normal price, based on certain critical storage levels). But those prices are not linked to the marginal economic value of water in the system.

In this paper we present a novel method for the design and assessment of economically efficient, equitable and financially-stable urban water rates considering a scarcity price, based on the estimation of water's value at basin scale over time. Rates are dynamic in the sense that they vary every year according to the estimated marginal value of water, which is linked to water scarcity and water demand. The urban water tariff is designed to transfer marginal water values at river basin scale to consumers, while considering the required conditions of urban water rates. As such, they are a first step towards exploiting the combined use of economic basinwide water resources assessment and urban smart metering technologies for designing economically efficient water tariffs.

2. Methods

2.1. General overview

The proposed three-staged framework aims to design a dynamic urban water tariff considering the changing value of water (throughout the river basin and over time) for achieving more efficient water use. The first stage consists of obtaining a scarcity-based step pricing policy at river basin scale via use of time series of water value estimated throughout the basin. The second stage is the design of a baseline water tariff at consumer level taking into account the revenue sufficiency and equity criteria. Finally, the third stage is the dynamic urban water tariff using as a basis the scarcity-based pricing policy at river basin scale (stage 1) and the baseline water tariff at consumer level (stage 2). An increase block rate has been chosen to design the dynamic urban water tariff.

2.2. Marginal value of water at source

The marginal value of water is used to get the scarcity-based water pricing policy. It can be estimated using hydro-economic models (HEMs) that use willing-to-pay estimates (‘demand curves’) for each water user within the water resource system. HEMs allow for an integrated analysis of water supply, demand and infrastructure management at basin scale (Pulido-Velazquez et al. 2008 and 2014; Harou et al. 2009; Heinz et al., 2007; Bauer-Gottwein et al., 2016).

In this work, time series of marginal value of water at different reservoirs in the system were determined through a priority-based simulation model that accurately reproduces complex system features, such as priorities in water allocation and system operating rules. The model was developed using the Decision Support System (DSS) SIMGAMS, a generic tool for developing hydroeconomic simulation models (Pulido-Velazquez et al., 2013b; Lopez-Nicolas, 2014) programmed in GAMS. The model solves a priority-based simulation model that estimates water allocation on a monthly basis following existing rules. Rules include targets for demands, storage, minimum environmental instream flows, etc., allocation priorities and reservoir operating rules (Fig.1). The model incorporates groundwater and stream-aquifer interaction, thus allowing conjunctive use simulation. The river basin must be characterized in terms of topology of the flow network, available infrastructure, hydrology, stream-aquifer interaction and economic data. HydraPlatform (Knox et al., 2015) and Microsoft Excel were used as auxiliary tools for pre-processing all the data. HydraPlatform is an open-source software platform for network (node-link) model that allows input, storage, display and export model data, including the connectivity matrix of the system (which represents the relations between nodes and links).

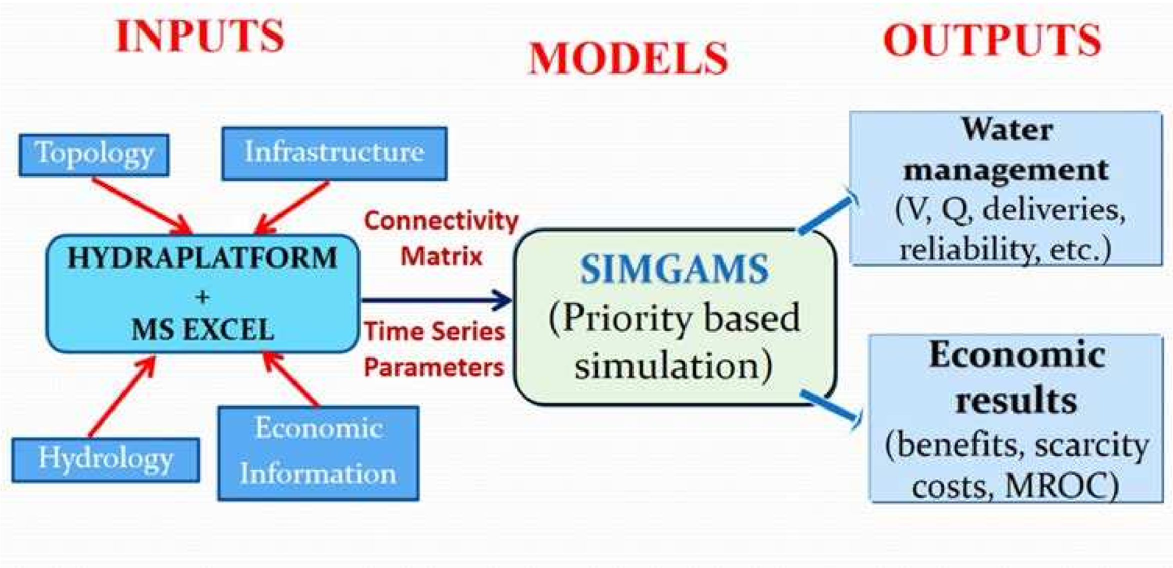

Figure 1. General flowchart to estimate time series of water´s value at river basin scale

The main results are allocation decisions such as storages or deliveries, and economic results such as water scarcity cost and the value of water at selected surface reservoirs. SIMGAMS also evaluates the associated water scarcity cost for each consumer of the system through the economic demand functions that relate the quantity of water consumed to its marginal value.

From the baseline simulation run, the value of water at a given date *t* and a given specific reservoir node is obtained by the following procedure (Pulido-Velazquez et al., 2008 and 2013a):

- Step1: addition of a small quantity of water at this date and reservoir.

- Step 2: simulation of the system from t onwards with this additional water; the initial condition at t is exactly the same as the situation at that date in the baseline run.
- Step 3: the marginal value of water at the date and node is approximated by the change in benefit with respect to the baseline scenario due to the extra water resources, divided by the marginal increase of the resource.

Time series of marginal water values are obtained by iterating this procedure for all monthly time steps of the simulation, for all the reservoirs for which they must be obtained.

2.3 Stage 1: scarcity-based step pricing policy at river basin scale

The scarcity-based water pricing policy at river basin level will be obtained through the time series of marginal water values (referred to hereafter simply as ´water value´). Then, the impacts of this pricing policy will be evaluated at river basin scale in order to verify its effectiveness.

The water values, which have been obtained through the simulation DSS tool SIMGAMS (section 2.2), are used to design the efficient scarcity-based step pricing function, which defines a price of water associated to a storage range in reservoirs. This procedure follows the following subsequent steps (Pulido-Velazquez et al. 2013a):

  - To plot water values as a function of the storage for each time step.
  - To lump the values in different groups using as thresholds predefined storage levels.
  - To obtain the scarcity-based step pricing policy based on the average value for each group.

The rationale behind this method is that high levels of water storage reflect low water scarcity, and therefore a low value of water. Consumers are assumed to react to price changes according to microeconomic theory. The change in water use due to a price change will be given by the corresponding economic demand function for each consumer (Fig. 2). When water reserves in the system are scarce, a high price will lead to a reduction in the target demand for each use (Pulido-Velazquez et al. 2013a). The effectiveness of the scarcity-based step pricing function can be quantified in terms of reduction of the water scarcity cost.

Each scarcity price corresponds to a target reduction of water use with respect to the initial target demand—which is the base water use without any price intervention. Scarcity price and target reduction are linked by the price elasticity of demand. Ultimately, reservoir levels and associated water values, determined at basin level, are linked with scarcity pricing and target reductions at the water consumer level as we describe in section 2.5, for achieving a more efficient use of water.

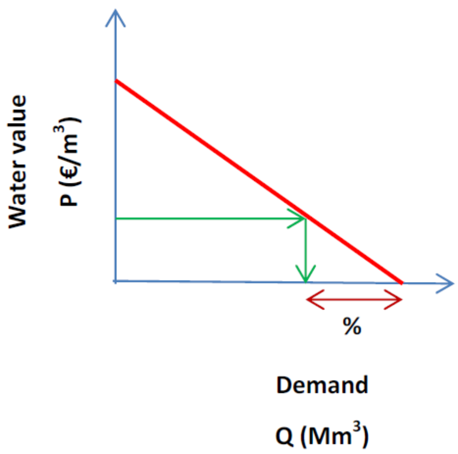

Figure 2. Economic demand function showing willingness to pay as a function of water use

2.4 Stage 2: dynamic increasing block urban tariff. Design of the baseline

We assume a simple two-tier increasing block price structure. The tariff should fulfill the objectives of revenue sufficiency (cost recovery) and equity, in addition to economic efficiency. According to the revenue sufficiency criterion, the revenues, R (M. € / year), should be equal to the summation of costs for each source of water for urban supply, Cs (M. € / year):

$$R = \sum_{s=1}^{m} C_{\ s} \qquad [1]$$

In the two-block tariff, the revenue is given by:

$$R = \lambda_1 \cdot \sum_{i=1}^{6} V_i + \lambda_2 \cdot \sum_{j=1}^{6} V_j + FI \qquad [2]$$

λ_1 is the marginal price for the first block (€/m^3) and λ_2 is the marginal price for the second block (€/m^3), *FI* is the revenue from fixed charges (M.€ / year) due to service and maintenance services; and V_i and V_j are the supplied volume of water for the first and the second block respectively (m^3/bi-monthly). The cost for each source is expressed as:

$$C_s = FC + \sum \frac{V_i}{E} \cdot VC \qquad [3]$$

Where *s* represents each water source, *FC* are the fixed costs (M. €/ year), *E* is the efficiency parameter of the distribution network that defines the water losses from each source, and *VC* represents the variable costs associated with water treatment and distribution (€/m^3). Substituting equations 2 and 3 into equation 1 and assuming the value of λ_1 ,(considering expert consultation), the value of λ_2 can be obtained.

The second block penalizes large uses, especially during water scarcity periods, and therefore uses water pricing to enhance water use efficiency and promote water conservation. As a result, the first block improves equity among consumers in the sense that large consumers subsidize the basic uses for everybody with their second-block payments as the water tariff for the first block will remain constant even during scarcity situations.

2.5 Stage 3: dynamic increasing-block urban tariff. Design of the dynamic component

The second block is designed to achieve the economic efficiency target by transferring the impact of the step scarcity-based pricing function at river basin level (stage 1) to the consumer´s level, assessing the demand reductions with respect to the initial target demand.

The charges for each block coming from stage 2 and the percentages of demand reductions, with respect to the baseline target demand (section 2.3), are the basis for developing the new dynamic urban water tariff. This IBR will be dynamic, since the volumetric rate will depend on the storage available in the main reservoirs for each year, used as a proxy of water scarcity in the basin, as the scarcity price depends on the storage (section 2.3).As a result, consumers get to know those prices beforehand, and react accordingly. The rate of the first block remains constant due to equity conditions, whilst for the second block each water rate will be obtained as the minimum price of water that allows achieving the reductions of the demand that come from the river basin level analysis.

3. Case study and material

3.1. Water supply to the city of Valencia from the Jucar river

The case study is the supply to the city of Valencia from the Jucar river system, a complex water resources system located in Eastern Spain within the Jucar river district (Fig. 3).

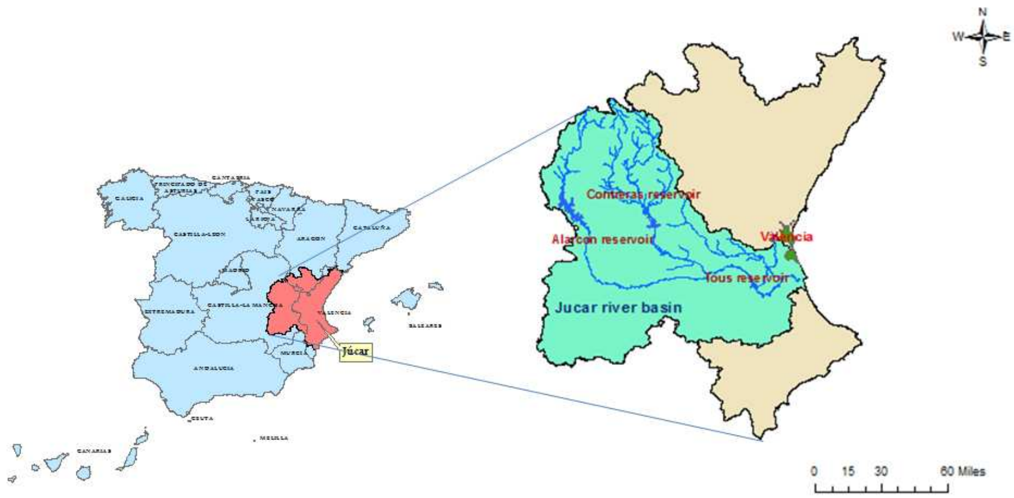

Figure 3. Jucar river district / Jucar river basin

The Jucar river system is the largest part of that water resources district (22378 km^2), and comprises the Jucar river basin and the area supplied by the Jucar-Turia canal. The basin is highly regulated, and almost 84% of its water supply is consumed for crop irrigation, and 13 % goes to urban use. Water demand totals 1397 Mm^3/year, whilst the average water resources availability is estimated as 1517 Mm^3/year from 1940/41 to 2011/12 (CHJ, 2015a). The municipality of Valencia receives water from two water treatment plants, “La Presa” and “El Realón” (45 % and 55 % of the total demand respectively) and from 2 main sources: the Jucar river (through the Jucar-Turia canal for inter-basin transfer; 75% of the supply on average) and the Turia river (25%) (CHJ, 2015a).

3.2. Hydroeconomic simulation model of the Jucar river system

The Jucar river model has been developed using as main sources the data from the Jucar river basin agency and previous studies and simulation models of the Jucar basin developed using SIMGES (Andreu et al. 1996), applied in the development of the river basin management plan of the Jucar district (CHJ, 2015a). The schematic of the model's network is shown in Fig. 2 in supplementary material.

The main reservoirs of the basin are Alarcon (1112 Mm^3 of capacity), Contreras (440 Mm^3 of useful capacity, 852 Mm^3 of total capacity) and Tous (378 Mm^3 of useful capacity). Alarcon and Contreras are located in parallel in the upper basin, whilst Tous is located downstream. The Jucar river basin agency sets the system operating rules considering Alarcon and Contreras as the main over-year storage facilities. Tous reservoir is mainly used for flood control and for regulation during the irrigation season.

The most important irrigation infrastructures are the Jucar-Turia and the Acequia Real canals. The Jucar-Turia canal delivers water to the metropolitan area of Valencia and to the city of Sagunto, and to the Jucar-Turia irrigation district. The Acequia-Real canal supplies water to the Ribera Alta irrigation district in the lower basin, mainly for rice crops and fruit trees, such as oranges and persimmon. The main gross urban demands are Valencia (74.3 Mm^3/year, (70 % corresponds to residential uses; Ayuntamiento de Valencia, 2014)), Albacete (13.3 Mm^3/year), Sagunto (8.8 Mm^3/year), and Mancha-Manchuela (10.9 Mm^3/year).

The exploitation of the Eastern Mancha aquifer (in the upper basin) is one of the key management challenges in the basin (CHJ, 2015b), since the increase in groundwater abstractions has inverted stream-aquifer interaction, moving from a winning to a losing river. The model allocates water based on the current priorities and operating rules for the 2012 water demands.

3.3. Urban water supply in the city of Valencia

The city of Valencia has around 800,000 inhabitants, and most of the 430,000 households are equipped with smart water meters, making the implementation of a dynamic scarcity tariff feasible. Table 1 shows the distribution of households per block water rate under the current IBR tariff. More than 30% of the clients have a low consumption (between 0 and 8 m^3/2 months). The distribution of the type of meters, according to the diameter, is needed for assessing the total fixed cost. 97.5% are less than 15 mm and 1.75% is 20 mm; the remaining 0.75% is over 20 mm (EMIVASA, 2016).

Table 1. Percentage of households per block tariff (Source: EMIVASA,2016)

Percentage of households per block tariff	
Consumption (m^3/2 months)	**%**
0 - 8	37.65
8- 12	18.65
12 - 25	33.98
25 - 40	7.28
> 40	2.44

Using an econometric approach, Garcia-Valiñas (2004; 2006) obtained a price-elasticity of demand of -0.64 for the city of Valencia. The urban water demand, excluding urban municipal and agricultural uses, was estimated using a log-linear functional form. With the average annual per capita volume of water (m^3) as independent variable, the model incorporates the following explanatory variables: price (average cost in euros), revenue per capita (in euros), percentage of single-family homes, percentage of vacation homes, a binary variable to identify coastal homes, and two variables for identifying industrial and tourism activities.

The point expansion method (Jenkins et al., 2003) has been used to extrapolate this price-elasticity estimate to compute the consumers' response to different water tariffs. It uses a Cobb-Douglas function with constant price elasticity (See Fig. 3 in supplementary material for the economic function of Valencia).

4. Results

4.1 Water values and scarcity-based step pricing policy

In order to get the step scarcity-based water pricing policy, the marginal value of water is estimated at the Tous reservoir considering the total storage in the 3 main surface reservoirs of the system (Alarcon, Contreras and Tous reservoirs). Although the main carryover storage is kept in the 2 main upstream reservoirs, Tous is the reservoir from which surface water is derived for the main demands of the basin.

Figure 4 shows the time series of Tous reservoir marginal value of water versus the total storage. As expected, it increases when the storage get lower, and is maximal during the drought periods (e.g. from 2005 to 2008).

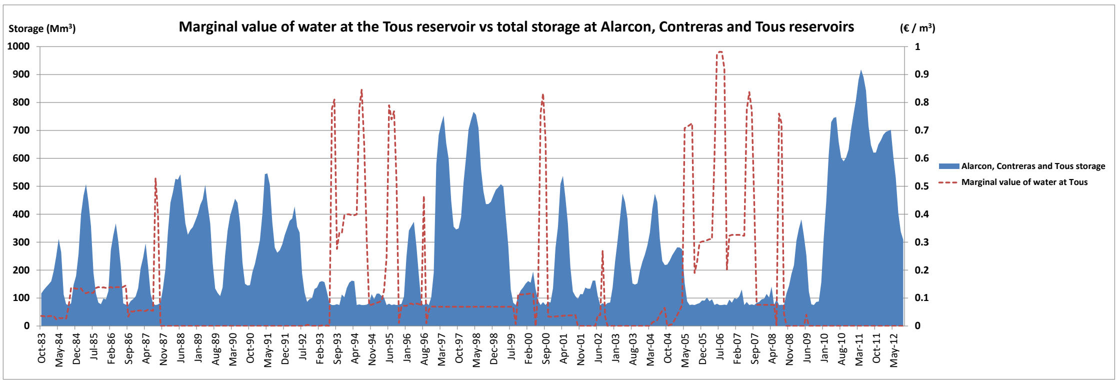

Figure 4. Marginal value of water vs total storage (Alarcon, Contreras and Tous reservoirs)

The annual scarcity-based step pricing function of the Jucar river basin has been obtained considering estimated water value at Tous vs. the total storage of Alarcon, Contreras and Tous reservoirs. The storage represented corresponds to the beginning of May, since 1) by then most of the rainfall of the hydrologic year has occurred, and 2) is the starting of the irrigation season. Therefore, May storage represents the available volume at the beginning of the most critical period of water supply within the year. The water value at May 1st is obtained as the average value for the corresponding hydrological year. The storage thresholds for defining each step of the pricing schedule were set as 160, 367 and 507 Mm^3 respectively (Fig.5). The final step-pricing function was defined by taking the mean of the annually averaged marginal water values at each of the 4 storage intervals (Fig.5).

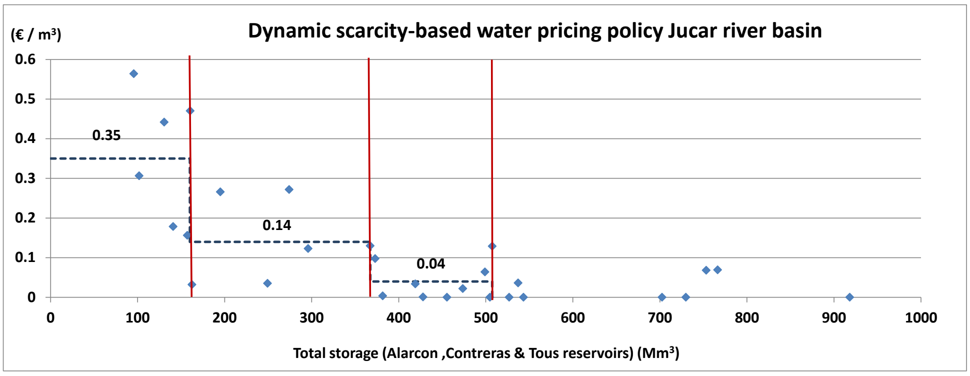

Figure 5. Scarcity-based step pricing function at the Jucar river basin

4.2 Impact of the step scarcity-based pricing policy

Once the scarcity-based step pricing function has been obtained, the next step is to evaluate the impact of this water pricing policy at river basin scale by using the DSS SIMGAMS.

Figure 6 shows the water scarcity cost in the historical drought periods for both the baseline scenario (without pricing policies) and the scarcity-based water pricing policy scenario. The results demonstrate the benefit of applying this step water pricing policy for all the competing consumers, with a significant reduction of the water scarcity cost when applying these policies (34 % during the latest drought period).

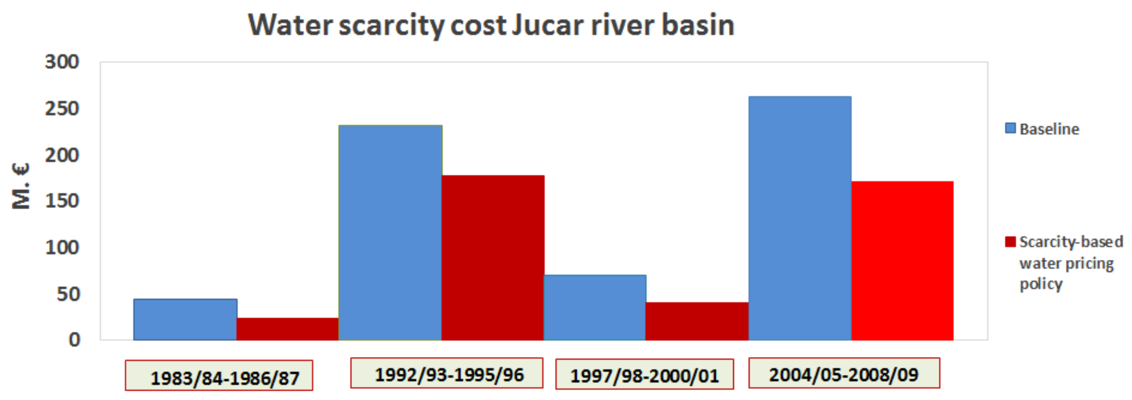

Figure 6. Impacts of scarcity-based water pricing policy at river basin scale

Once we had simulated the economic efficiency of the scarcity pricing at river basin scale, we calculated the reduction of the demand, with respect to the target demand, for the urban supply of the city of Valencia using its economic function and the scarcity pricing function. The reductions of the annual target demand are 18 %, 8% and 3 % for a scarcity price of 0.35 €/m^3, 0.14 €/m^3 and 0.04 €/m^3 respectively. These values are used for developing the dynamic component of the urban water tariff.

4.3 Baseline component of the urban water tariff

The baseline water tariff has been designed with an equity objective (large volume consumers are subsidizing other consumers' basic uses though the 2-tier price schedule), as well as with the condition of revenue sufficiency for the utility that provide the service (equations 1, 2 and 3). So, we assess the total cost (fixed and variable components) and the fixed component of the revenues in order to obtain the water rate for each block. With respect to the cost, the total cost has been estimated as 72.14 M. €/year, with a volumetric variable cost of 0.472 €/ m^3, using data provided by the Valencia water utility (EMIVASA, 2016) and the official water rates for 2016 (DOCV, 2015). With respect to the revenue, the total fixed revenue per year has been estimated as 47.91 M. €/ year, using the percentage of households per block tariff (Fig. 1 in supplementary material), the distribution of clients per type of meter (EMIVASA, 2016) and the official water rates for 2016 (DOCV, 2015) . So, the values of λ_{1b} and λ_{2b} can be obtained by substituting these data into equations 1, 2 and 3.

The baseline water rate has been obtained by maintaining the official current rate for the 1st block, λ_{1b}, at 0.44 €/m^3, and applying equation 2 to obtain a value of λ_{2b} of 0.56 €/m^3 for the second block. In this way, the threshold for the first block, 12 m^3, has been set based on the basic quantity of water that people need for survival in healthy conditions. According to the World Health Organization 100 l/day/person (Howard and Bartram, 2003) is a minimum requirement of per capita water use. Moreover, 60 % of the households have 2 or less persons. Thus, the consumption for households of 2 persons corresponds to 12 m^3 per 2 months.

4.4 Dynamic component

The dynamic urban water tariff is designed with 2 blocks. The rate of the first block remains the same based on the equity conditions, whilst the rate of the second block depends on the storage, as explained in section 2.5. So, the dynamic urban water tariff for the city of Valencia consists of 4 different rates for the second block, as the step scarcity-based pricing policy for the Jucar river basin has 4 different possibilities. These rates have been calculated considering the demand reductions during scarcity periods, using the economic demand function for the city of Valencia and the scarcity-based pricing policy at the Jucar river basin scale (see table 2). In this way, we link the impact of scarcity-based water pricing policy at river basin level with water tariffs at consumer's level.

Table 2. Dynamic urban water tariff

Water value (€/m^3)	λ_1 (€/m^3)	λ_2 (€/m^3)	% Annual demand reductions
0.35	0.44	0.78	18%
0.14	0.44	0.66	8%
0.04	0.44	0.60	3%
0	0.44	0.56	-

Then, we test the impact of the dynamic urban water tariff considering the historical storage time series (from 1980 to 2012). Figure 7 shows the annual demand reductions

(%) versus the total storage at May 1st, the highest demand reductions are obtained as expected during drought periods. Demand reductions from pricing applied early in drought periods increase the availability of water resources later on.

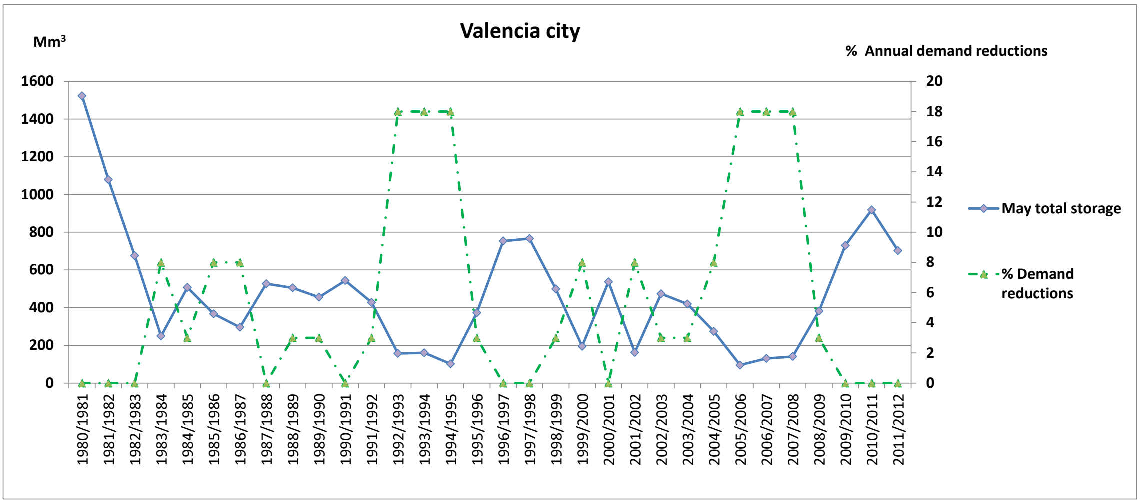

Figure 7. Demand reductions from applying the dynamic urban water tariff

Table 3 shows the revenue coming from the fixed and variable rate structure of the dynamic water tariff. The results show that certain extra revenue (up to 1% of the annual revenue in the baseline conditions) is expected in those years in which scarcity pricing is applied.

Table 3. Fixed and variable revenue components of the dynamic urban water tariff

λ_2 (€/m^3)	Fixed Revenue (M. € / year)	Variable Revenue (M. € / year)	Total Revenue (M.€ / year)	Increased revenue (M.€ / year)
0.78	47.91	24.95	72.86	0.72
0.66	47.91	25.00	72.91	0.77
0.60	47.91	24.61	72.52	0.38
0.56 (baseline)	47.91	24.23	72.14	-

We have analysed a hypothetical scenario considering a price elasticity of the demand of -0.4 instead of -0.64. We have tested the benefit of applying the step water pricing policy for all the competing consumers, considering the -0.4 price elastic of demand for urban consumers, obtaining also a significant reduction of water scarcity cost at river basin scale (20 % during the latest drought period). Finally, the annual percentage of urban demand reduction ranges from 1.7 to 11 %, percentages lower than those in table 2 obtained for a price-elasticity of -0.64, as expected.

5. Discussion and conclusions

The proposed framework enables the design of a dynamic water tariff considering the role of water pricing as a tool for efficient management of water demand during scarcity periods. This is done by integrating a scarcity price component in the rate without modifying the reduced price considered for equity reasons and keeping the revenue sufficiency condition. A hydroeconomic simulation model of the river basin is used to estimate the changing marginal value of water at river basin scale. This requires estimated economic demand curves for water consumers throughout the basin and assessing the costs of water service for water utilities and characterising the supply (e.g., number of blocks or household distributions per block rate). The proposed scarcity-based pricing policy sends a scarcity signal to water users because the price varies with water availability.

A dynamic water tariff considers the economic value of the resource when water is scarce thereby promoting efficient water use by moderating consumption. This requires the ability to measure consumption accurately over well-defined periods. New smart meter technologies allow utilities to track consumption remotely and accurately over specific time-periods (e.g. Cominola et al., 2016). The case study is the urban water supply to the city of Valencia, which is almost fully equipped with smart meters where volumetric consumption is charged on a bimonthly basis but where prices do not currently vary over time. The dynamic water tariff is set for each year, since the Jucar river basin suffers from multiyear droughts. Although dynamic pricing could be applied to shorter periods, we choose to demonstrate the concept in a way a less removed from current practice as possible. Changing tariffs once a year in our case enables substantial efficiency gains whilst minimising little regulatory change and business planning changes for water users. Because May storage levels are representative of water availability that year (at the beginning of the irrigation season and little further rain is expected), it acts as a good proxy of water scarcity in the basin.

The dynamic water tariff sends water consumers a water scarcity signal via the increase of water price for the second block (the initial price for low consuming users is kept constant for equity reasons), ranging from 0.60 €/ m^3 to 0.78 €/m^3 when the scarcity price of water is considered (the baseline rate is 0.56 €/m^3). Higher water rates allow reducing water use between 3 % and 18 % during scarcity situations (according to our estimate price-elasticity of demand). Despite the reduction in water use, there will be an increase in utility revenue from 0.38 to 0.72 M €/ year, due to the higher water rates. So, a high water price could soft the expected revenue decrease due to the demand reductions. This is consistent with the findings in the international literature. For example, Sahin et al. 2016 found that temporary drought pricing would generate additional revenues in the case study of the Australia´s populated South-east Queensland region than can fund water supply infrastructures. Furthermore, Garcia-Valiñas 2005 found that the proposed optimal water tariffs, based on Ramsey (1927) and Feldstein (1972) theories, lead to welfare improvements, using Seville as case study.

The excess revenue generated during the scarcity periods (partially compensated by a lower demand) could generate additional resources for increasing water security investments. Since urban tariffs are usually designed for revenue neutrality for the utility, the additional revenue could be assigned to either increase the security of urban water supply (e.g. reducing leakage) or to investments that promote a more efficient and sustainable use of water in the basin, and in that case the extra revenue could be managed by the river basin authority.

There is also a significant uncertainty on the average behaviour of the users for scarcity pricing (prices higher than the current prices based on the reliability of the price elasticity estimate). Nevertheless, we would like to highlight that higher water tariffs during water scarcity periods provide an incentive for reducing water use with respect to initial target demands. This is evaluated by assessing the impact of scarcity pricing on the demand of water through the economic demand functions for each consumer.

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