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Analysis of Water Pricing Policy Effects in a Mediterranean Basin Through a Hydroeconomic Model

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Abstract

This paper explores the impacts of water pricing as a demand management policy, at a regional level (or basin-sector). To this aim, a hydro-economic model for the Guadalquivir River basin (southern Spain) is proposed here. This basin constitutes a perfect example of a Mediterranean basin subject to frequent and long drought periods, where challenges related to water scarcity are increasing, leading to social conflicts among water users. Moreover, this basin is characterised by a closure state meaning that all available water resources are already allocated among users. In this context, water pricing policy may act as an effective tool to reduce water demand by encouraging changes of behaviour in water users. In particular, those who perform irrigation practices in the agricultural sector. This paper focuses on the irrigation sector since it is the main water user in the basin (87%). Additionally, alternative water-availability scenarios have been used to test the effect of water pricing under drought conditions. The hydro-economic model presented here has been sectorized into four basin sectors with common characteristics (hydro and economic). This enables the analysis of alternative price scenarios in the agricultural sector, in terms of water used, crop patterns and gross margin. Results show that water pricing policy should consider the regional characteristics at the basin-sector scale to gain effectiveness and equity at the river basin scale. Moreover, it has been found that both water availability and the crop pattern at the basin-sector scale have an effect on the reduction of water used (and therefore in gross margin.

Keywords Tariff · Water · Resources · Management · Basin

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1 Introduction

Irrigated agriculture plays a very significant role in terms of social-welfare maintenance in water-scarce regions, but it also represents the largest user of water resources (FAO 2014). This is the case in Mediterranean river basins, most of them characterized by a closure status (or are about to reach a closing point), where supply cannot further satisfy the growing water demand. Moreover, pressures on water resources from alternative uses are increasing in this part of the world due to increasing water scarcity, changing climatic conditions, and poor governance models leading to increasing conflicts among users (Portoghese et al. 2021). Water demand-driven policies aim to maximize the amount of water available by relocating resources to achieve efficient water use and social well-being. One such policy is pricing, which is also an economic instrument explicitly acknowledged by the European Water Framework Directive (WFD) (Sapino et al. 2020): "Water pricing policies provide adequate incentives for users to use water resources efficiently, and thereby contribute to the environmental objectives of this directive" (Art. 9, WFD).

Water pricing[1] has been generally identified in the recent literature as a valid water demand instrument to help solve problems of water scarcity and competition (Al-Rubaye 2019; Bierkens et al. 2019; Gallego-Ayala et al. 2011; Portoghese et al. 2021; Upadhyaya et al. 2022). Molle and Berkoff (2007) offer a review of concepts and experiences in irrigation water pricing, identifying practical gaps and constraints of alternative irrigation pricing policies. The work of Molle and Berkoff (2007) highlights the multiple effects that water charges have on the irrigation sector, such as promotion of conservation and water-saving technologies, changes in crop patterns towards less-water demanding crops, reallocation of water to high-value agriculture, and enhancement of water quality through the reduction of agricultural pollution. Nevertheless, water pricing policy in the irrigation sector is often not so effective as expected (to achieve the previously mentioned outcomes). This is due to the particular features of each sector, not being possible to simply extrapolate water pricing schemes from other sectors. In this sense, Upadhyaya et al. (2022) argue that there is no uniform set of principles for fixing water tariff in the irrigation sector: "a multiplicity of factors is followed, such as the capacity of irrigators to pay, recovery of water cost, crop water requirement, sources of water supply and its assurance". Cooper et al. (2014) consider that in order to achieve effectiveness (reduction of water consumption) and social equity (minimizing regional disparity in terms of negative economic effects), the pricing scheme should comply with the following principles: i) economic efficiency (tariffs should reflect the cost of service provision); ii) revenue adequacy (costs are recovered over the life of any assets, including operating and maintenance costs); iii) administrative simplicity (practical to implement); iv) flexibility (capacity to accommodate changing supply and demand) and v) equity (ability to pay by vulnerable consumers). Similarly, Albiac et al. (2020) discuss the conditions for an effective water pricing policy in the context of the EU WFD, highlighting the importance of collective action of all involved stakeholders.

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[1] Water pricing constitutes a demand-side economic instrument. Concepts, such as tariff and rates, are usually found in the literature together with water pricing. Specifically, a water tariff (or water rate in the United States and Canada) refers to the price assigned to water supplied by a public utility through a piped network to its customers. Tariff schemes may have different designs depending on social and political factors. For sake of simplicity, this paper uses the economic concept of 'water pricing' as instrument to affect water demand and model water management at river basin scale.

The use of water pricing for irrigation demand management has been a widely discussed topic in economic literature. Contributions from Johansson et al. (2002), Tsur et al. (2004), Montilla-López et al. (2017), and Berbel and Expósito (2020) conclude that an analysis of multidimensional impacts (regional, hydrologic, etc.) should be considered, before adopting specific water pricing policies. This is especially relevant in the irrigation sector since farmers' responses and environmental impact may significantly differ depending on their crop patterns and location in the river basin. To date, the assessment of regional impacts at river basin level is still scarce and the development of hydro-economic models to carry out such an assessment is limited to a few studies. Examples are Kahil et al. (2016) and Greve et al. (2018).

Hydro-economic models are a suitable instrument to analyse regional impacts along a river basin (Alamanos et al. 2020; Harou et al. 2009; Mirzaei and Zibaei 2021; Sherafatpour et al. 2019; Ward and Pulido-Velazquez 2008). According to Medellín-Azuara et al. (2012), economic and societal benefits from specific water policies should be analysed on a case-by-case basis, considering specific regional characteristics.

A comprehensive economic analysis of the impacts of water pricing on the irrigation sector should also consider the well-known 'spillover effects' on the rest of the economy. Although this assessment constitutes a complex task, several studies such as Howitt et al. (2015), Rodríguez-Chaparro (2013), Gómez-Ramos and Pérez (2012) and Bhattarai et al. (2001) have made important contributions in this field, in different parts of the world. To mention some examples, Howitt et al. (2015) estimated an overall spillover effect of 1.49 in the case of California, close to the case of southern Spain (1.40) given by Gómez-Ramos and Pérez (2012). Greater quotes have been elicited by Bhattarai et al. (2001) (around 3.1 in the case of India) and Rodríguez-Chaparro (2013) or Mainar-Causapé et al. (2017) (around 3.4 in the case of Spain). In this study, spillover effects on the rest of the economic sector are considered with the aim to assess the overall economic impact at river basin scale. Due to the limited literature available on the regional (basin sector) impacts of water pricing strategies along a river basin, and the need to design regional-tailored pricing policies to achieve effectiveness and equity principles, this paper aims to explore how water pricing affects agricultural production and water use at the river basin scale, considering regional differences in crop patterns and water flows. In order to achieve this, we have developed a hydro-economic model for the Guadalquivir River basin (southern Spain) which aims to provide adequate water pricing strategies to minimize negative impacts on agricultural production and regional equity, while promoting efficiency and water conservation. This basin constitutes an example of a typical Mediterranean basin subject to frequent and long drought periods and where challenges related to water scarcity are increasing. Moreover, this basin is characterised by a closure state, which means that all available water resources are already allocated, Expósito and Berbel (2019) describe drivers and impact of closure for Guadalquivir.

This present work aims to explore the effectiveness of water pricing policy to reduce water demand, while assessing economic impacts on the irrigation sector. The hydro-economic model also explores the specific responses in four basin sectors with common agronomic characteristics, thus allowing the analysis of the territorial and social impacts of alternative price scenarios on the agricultural sector, in terms of changes in water use, crop patterns and gross margin. To do so, basic sectors water demand functions have been estimated.

In summary, our specific objectives are threefold: i) to develop and apply an integrated hydro-economic model to a closed river basin in order to describe the hydro-economic dynamics of the basin at regional (or subbasin) level; ii) to assess the responses of the irrigation sector along the river basin through modeling local (subbasin) water demand functions; and iii) to explore the regional impacts on water use, crop patterns, and agricultural gross margins (including the spill-over effect) with the aim to provide useful information for effective water pricing policy.

The novelties of the paper are several. On the one hand, the water pricing policy is applied in a water supply deficient basin, where the response to pricing is expected to be lower than in other basins. On the other hand, an analysis is carried out by regions with different crop distribution patterns that will have an effect on the redistribution of water due to water pricing. One last novelty lies in relaxation effects of the environmental restriction in the last gauge before the river estuary.

The rest of the paper is structured as follows. The Method section describes the case study and the developed hydro-economic model. Results are shown in Section 3. Finally, a brief discussion of the results and some concluding remarks are offered in Section 5.

2 Material and Methods

In this section, the Guadalquivir River basin study area is described, along with the hydro-economic model used to assess the regional impacts of water pricing, under different scenarios.

2.1 Case Study Area: The Guadalquivir Basin

The Guadalquivir basin extends over an area of 57,527 km^2 and supports the economic activities of a population of more than 4.2 million people. Available renewable resources exceed 7,000 hm^3/year. Water abstraction exceeds 50% of the renewable resources and reaches 3,830 hm^3/year (surface water 2,903 hm^3/year and groundwater 927 hm^3/year) (CHG 2021). The largest consume of water in the basin is attributed to agriculture (87%).

The River Basin Authority (RBA), *Confederación Hidrográfica del Guadalquivir*, is responsible for water management in the basin. This RBA coordinates the participation of those user groups and administrations involved in the management of water. Rainfall variability is high, and hence the allocation of water to users is not guaranteed. The local authority assigns each farmer an amount of water as “an administrative concession” or as “water rights”.

As shown in Fig. 1, the river basin has been divided in 4 basin sectors with the aim to analyse the different regional impacts of water pricing.

Crops are well-defined in terms of their geographical distribution. The upper basin sector accounts for 48% of the perennial crops present in the basin (Table 1). This area is close to mono-cropping since olive trees account for more than 85% of the total cultivated area. In the middle basic sector (from Marmolejo to Puente Genil) there is a weak diversification of crops with the incorporation of extensive winter crops and vegetables (mainly in the Genil area). Almond and orange trees are also found here, among the perennial crops in this area. Close to the Guadalquivir estuary, other crops predominate, such as rice (12% of the total cultivated area), wheat, sunflower and cotton (43%).

Table 2 shows the baseline cultivated area (total and per irrigation method), water use, and gross margins per basin sector in the baseline scenario. Under normal climatic conditions, the gross margin of the whole basin amounts to 1,099 M EUR and the total agricultural water used is 3,127 hm^3, irrigated land covers 856,429 ha of crops, 68%

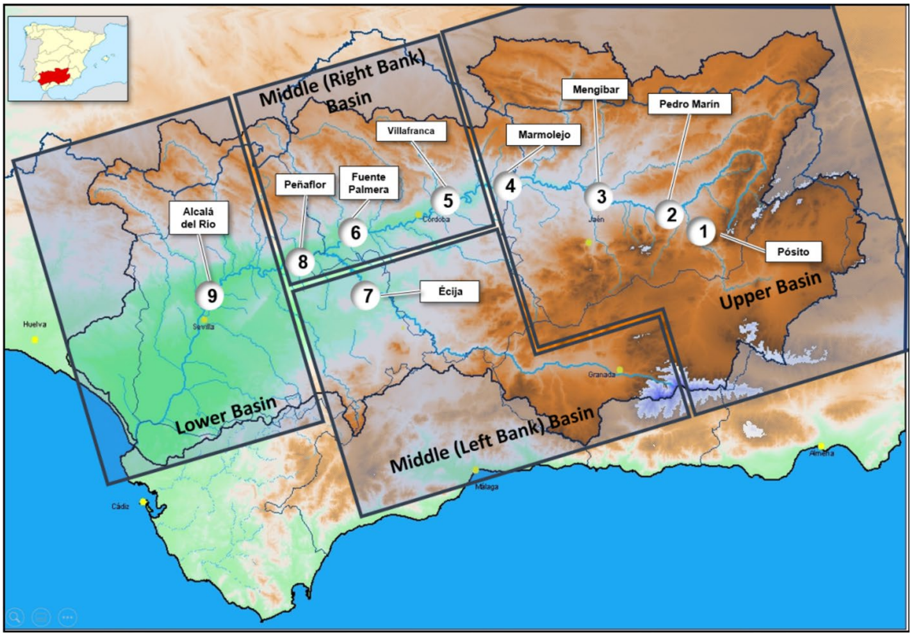

Fig. 1 Guadalquivir basin illustration with main gauges (Source: CHG (2021); CHG (2022))

of which are perennial, mainly olive trees. The financial results due to the agricultural activity (gross margin) closely resemble those of the allocation of water. The upper basin accounts for 20% of the irrigation water used and 19% of the gross margin of the whole basin. The middle and lower basin use 28% and 53% respectively of the irrigation water used in the basin and account for 31% and 50% of the gross margin obtained by the basin.

Regarding efficient systems in the use of water, in the last 20 years the basin has undergone a process of technological transformation, replacing traditional production systems with higher intensity systems with more efficient irrigation techniques. For example, the subsurface drip irrigation area now represents 78% of the basin as a whole and reaches 92% of use in the upper basin (near Marmolejo). Further down the basin, the use of drip methods is gradually being replaced by sprinkler technology, reaching 61% of the cultivated area in the lower basin. An exception to this precision technology is the use of surface irrigation in those rice farms located at the mouth of the river.

Table 1 Crop distribution along the basin (ha). Percentage of total irrigated area in the basin

	Olive		Other perennials		Cereals		Other crops		Total	
Upper	248,189	56%	12,775	13%	14,484	11%	17,013	9%	292,461	34%
Middle (SW)	53,471	12%	20,105	21%	19,173	14%	20,651	11%	113,399	13%
Middle (SE)	88,902	20%	9,218	9%	22,830	17%	40,327	22%	161,277	19%
Lower	54,781	12%	55,893	57%	76,611	58%	95,468	53%	282,753	33%
Basin	445,343	100%	97,991	100%	133,097	100%	179,998	100%	856,429	100%

Table 2 Irrigated land, water allocation, and gross margin in the baseline scenario

Basin region	Cultivated area per irrig. technology (ha)				Water allocation (hm^3; %)		Gross Margin (M EUR; %)	
	Flood	Sprinkler	Drip	Total				
Upper	21,623	1,511	269,326	292,461	617	20%	206	19%
Middle (RB)	2,997	14,932	95,470	113,399	365	12%	113	10%
Middle (LB)	22,491	14,741	124,045	161,277	503	16%	230	21%
Lower	82,638	30,259	176,395	289,292	1,642	53%	549	50%
Basin	129,750	61,444	665,236	856,429	3127	100%	1099	100%

2.2 The Hydro-economic Model

A hydro-economic model has been developed combining both hydrological and economic components for the entire river basin. Figure 1 describes this model differentiating four basin sectors, which were further subdivided into smaller sectors named demand units. Figure 2 shows the outline of the hydro-economic modelling process.

2.2.1 Hydrological Component

The hydrological component is a network of nodes and links, based on the model developed by Kahil et al. (2016) and Kahil et al. (2018), where the model is further specified. In this component, nodes stand for the basin water supply and demand units while links show the flow relationships between these nodes (Fig. 3). The model is a reduced-form hydrological model of the Guadalquivir basin, calibrated with the observed flows by using the hydrological principles of mass balance and river flow continuity. Data obtained at selected gauging points in the basin by CHG (2021) and CHG (2022) allowed to establish the modelling of the flow rates at each node and the spatial distribution of the available water among the different units. For the purpose of the model, the basin has been further split into 18 agricultural demand zones in

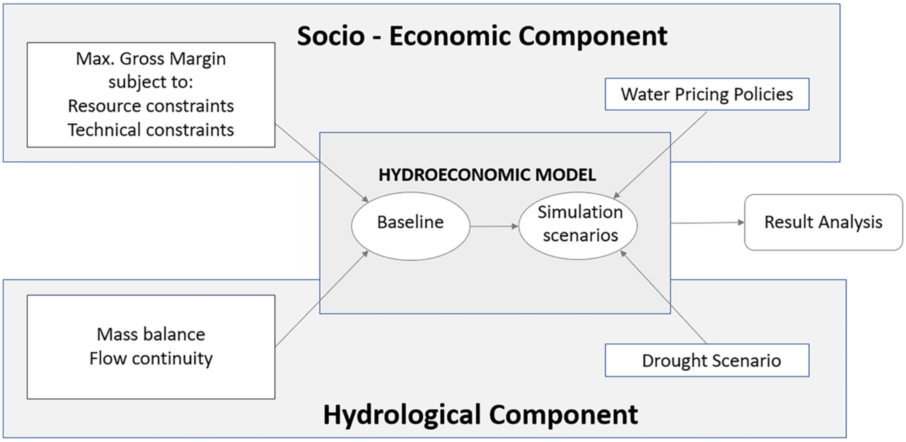

Fig. 2 Modelling Framework

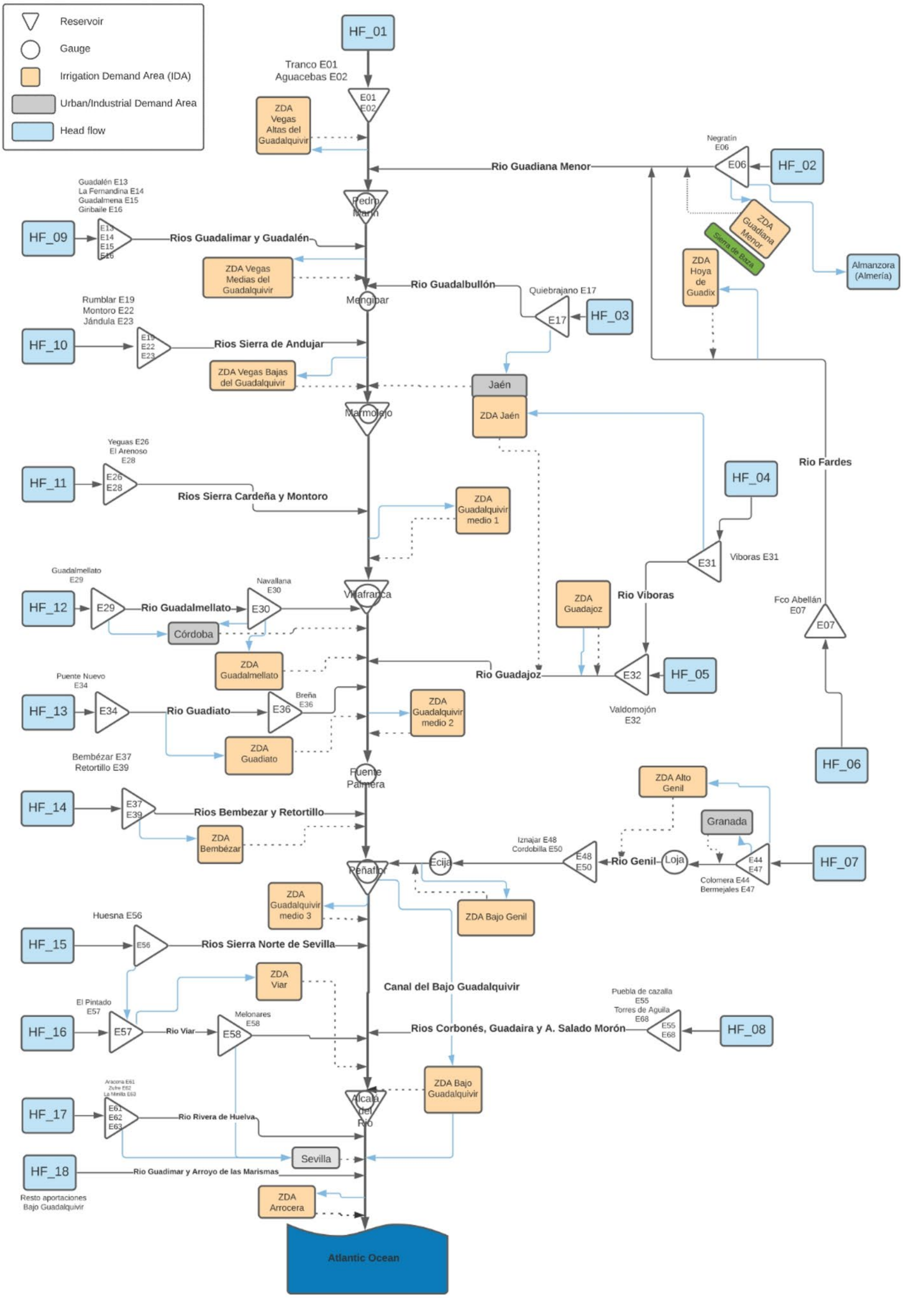

Fig. 3 Guadalquivir Basin Flowchart

order to calculate the irrigation water used. Urban and industrial demand has also been included as nodes withdrawing water from the system.

The streamflow, X_v, at each river gauge v (a subset of i) is equal to the sum of the flows at any upstream node i, whose activities affect that flow. These flows include headwater inflow, river gauges, diversion, return flows and surface flows. We define the non-negative streamflow at each river gauge as follows:

$$X_v = \sum_i b_{i,v} * X_i,\ \forall v \tag{1}$$

where $b_{i,v}$ is a vector relating the flow nodes v given to nodes i.

A diversion limit of surface water is required to ensure that the total available flow at each diversion node d (a subset of i) is greater than the diverted flow X_d:

$$X_d \leq \sum_i b_{i,d} * X_i,\ \forall d \tag{2}$$

where $b_{i,d}$ is a vector of coefficients that links flow nodes, i, to diversion nodes, d.

The applied water at each application node a (a subset of i) is defined as follows:

$$X_a \leq \sum_d b_{d,a} * X_d,\ \forall a \tag{3}$$

where $b_{d,a}$ is a vector of coefficients that links application nodes to diversions.

Equation (4) defines the total irrigation water applied at each agricultural node X_a^{ag}:

$$X_a^{ag} = \sum_{j,k} b_{a,j,k}\left(\sum_d b_{d,a} * L_{d,j,k}\right),\ \forall a \tag{4}$$

where:

j crops.

k irrigation technologies.

$b_{a,j,k}$ water application per ha.

$L_{d,j,k}$ irrigated area.

$b_{d,a}$ binary matrix to set nodes.

Water consumption,X_c, at each node c (a subset of i), is the amount of water consumption through crop evapotranspiration (ET) in irrigation. In urban networks it is defined as the proportion of the urban water supply that is not returned through the sewer system.

Return flows, X_r, at each return flow node r (a subset of i), is a proportion of water applied, X_a, that returns to the river system. Water applied must equal water consumed plus water returned.

A set of slack variables for each river section are used to achieve the calibration of the hydro-economic model, allowing the model to replicate the real observed flows.

2.2.2 Socio – Economic Component

The agricultural activity of the basin has been divided into 10 Irrigation Demand Areas (IDAs) to develop the optimisation model. The allocation of areas un each IDA is based on the Irrigable Zones defined by CHG (2021). The prices and costs used in the model are constant and the growth functions are linear and decreasing with crop expansion. A penalty for fallowing perennial land has been included in the objective function to quantify the potential future yield losses if farmers decide to fallow perennial land. Positive mathematical programming (PMP) was used in the calibration of the crop model to obtain the observed water and land use solution in the baseline scenario (Howitt 1995). PMP stands out for its smooth change output as a result of the use of new management policies (Gohar and Cashman 2016). The PMP variant used is the one of Dagnino and Ward (2012).This variant enables the estimation of the parameters for a linear yield function which follows the Ricardian rent principle whereby the yield of a crop decreases as its scale of production increases.

The methodology to calculate the spill over effect is based on the Input/Output (I/O) accounts. The I/O accounts follow the Leontief model, which applies the use of two indicators called backward linkage and forward linkage. Based on Muñoz-Repiso et al. (2013) the spill-over effect estimator used in this study is 1.8252 (i.e., an increase of 1 EUR in the primary sector generates an increase of 0.8252 EUR in the rest of the economy due to the spill-over effect). This value is in line with those mentioned in the introduction of Howitt et al. (2015), Gómez-Ramos and Pérez (2012) or Rodríguez-Chaparro (2013) (values ranged from 1.49 to 3.43). The agricultural production multipliers cited have a range between 1.40 and 3.43. Hence, 1.825 will be used as an estimate of the spill-over effect proposed by Muñoz-Repiso et al. (2013) as a mean value between both extremes and supported by the I/O table methodology.

2.3 Baseline, Drought Scenario and Water Pricing Definition

2.3.1 Baseline Scenario and Calibration

The baseline scenario represents the water inflows and gauges recorded in the 2015/16 rainfall year (from October to September), with an average recorded rainfall of 532 mm (CHG 2022). The mean annual rainfall in the basin is 573 mm, with a range between 260 and 983 mm (standard deviation of 161 mm). This baseline scenario is used to calibrate the model and perform a preliminary analysis of the application of water management policies based on water pricing, under normal conditions.

2.3.2 Drought Scenarios Definition

The impacts of a climate change scenario projected by CEDEX (2012) are estimated as an average reduction in water resources of 36% for the Guadalquivir basin, with an increase in the frequency of droughts as the twenty-first century progresses. Therefore, with the aim to analyse the water pricing policy under alternative water-availability scenarios, a severe drought scenario is proposed with a 40% reduction in water inflows to

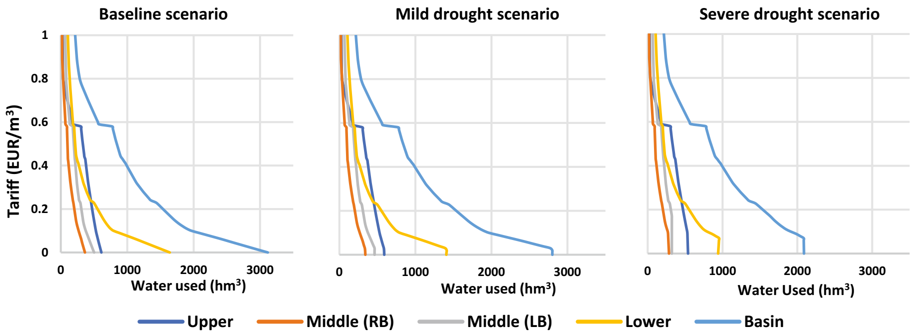

Fig. 4 Water used vs Water pricing (Tarriff)

the basin, compared to the baseline scenario. In addition, a mild drought scenario has also been proposed (with a 20% reduction of water inflows).

2.3.3 Water Pricing Definition

Water pricing involves a progressive increment in the water price through an increase of 0.01 EUR per m^3 of water used, up to a maximum increase of 1 EUR/m^3. Water pricing is applied to the three scenarios outlined above, baseline, mild drought, and severe drought by letting the model freely allocate the water used for agricultural irrigation in all cases, instead of proportionally, as established in the current RBA drought management protocol.

3 Results

Although the model considers 10 sectors within the GRB (as explained in Section 2.1), these have been aggregated in 4 more extensive areas (or basin-sectors) which share similar agronomic and hydrological characteristics (Upper, Middle Right Bank, Middle Left Bank and Lower Basin, as shown in Fig. 1). We believe that this sectorisation facilitates the assessment of the analysed impacts, as well as the understanding of the findings.

Overall results show that water management policies based on water pricing are a useful tool for water savings in a normal scenario. At the basin level, there is a first stage in which the water consumption used for irrigation is very sensitive to price increases (see Fig. 4), with reductions of about 4% of the water used for each 0.01 EUR/m^3 applied, up to 0.10 EUR/m^3. In addition, a price of 0.02 EUR/m^3 (equivalent to the Financial Cost-Recovery price estimated by Borrego-Marín et al. 2020), results in a saving of 7% of the water used in the basin whereas a price of 0.09 EUR/m^3 reduces water used by 33%. A second price range (from 0.10 EUR/m^3 to 0.44 EUR/m^3), shows water savings between 1 and 2% for each 0.01 EUR/m^3 increase. Finally, from 0.44 EUR/m^3 onwards, we find a very inelastic performance, with savings of less than 1% of the water used for each 0.01 EUR/m^3 increase. In this last price range, it should be noted that for a price of 0.59 EUR/m^3, survival irrigation is no longer viable, and therefore, at this price level, there is a 6% decrease in water consumption due to the definitive withdrawal of most of the perennial crops. As shown in Fig. 4, this pattern of performance prevails in both drought scenarios. The main difference in the drought scenarios compared to the baseline is that in the first stage (the most elastic) water pricing loses its effectiveness

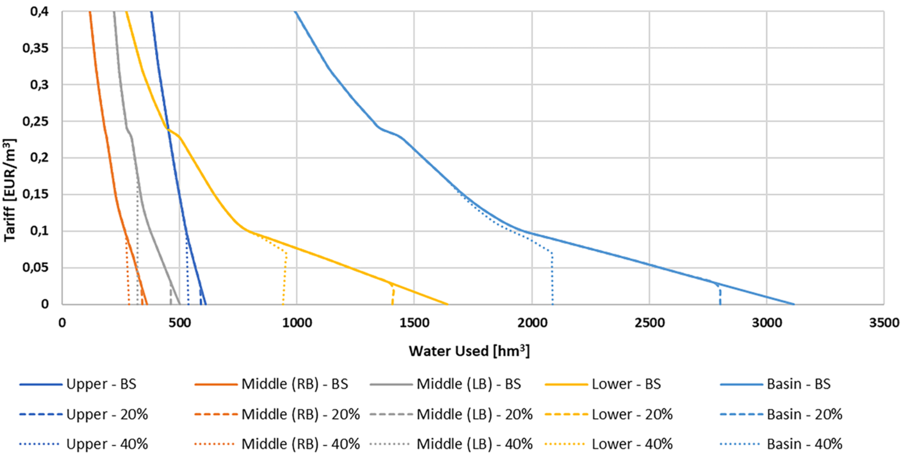

Fig. 5 Convergence of the water use curves in different drought scenarios

because of the drought event itself. Water pricing does not achieve savings of water used up to a price of 0.03 EUR/m^3 in the mild drought scenario and 0.09 EUR/m^3 in the severe drought scenario respectively.

Therefore, it has been found that drought impact in reducing water use is offset by the impact of water price. As Fig. 5 shows, the use of water in the different drought scenarios converges with the baseline scenario because of the water price. This means that, regardless of the drought scenario, above a certain price threshold, water is reduced not because of the drought, but because of the water price increase. Thus, for the moderate drought scenario, the price effect exceeds the drought effect from 0.03 EUR/m^3, at which point the curves become elastic (coinciding thereafter with the baseline water demand curve). In the moderate drought scenario and for the basin, this convergence appears at 0.17 EUR/m^3, although in almost all sectors (except Middle (LB)), the convergence occurs below 0.10 EUR/m^3.

It is important to highlight that Figs. 4 and 5 clearly show an intra-basin territorial impact, since the response is unequal in the four basin regions (or subbasins). Upper and middle regions (highly specialized in perennial crops) have a lower response to price variation than the lower basin. This is explained by the dominance of perennials which shows distinctive characteristics, having different water requirements. Firstly, the value of water is significant higher in perennials (i.e., mainly olive, almond, citrus) compared to commodities (i.e., herbaceous such as rice, cotton, maize). Additionally, water demand response is significantly more inelastic when deficit irrigation becomes a common practice, as it is the case for a majority of perennial crops in the GRB. Secondly, the inclusion of a minimum water allocation (Survival Irrigation) that allows them to keep the trees alive during drought periods while waiting for rainfall in the coming years also plays a significant role. The Lower basin, however, widely planted with other annual crops such as cotton, wheat, rice, or sunflower, is much more sensitive to water price increases, since farmers may choose not to irrigate, giving up the crop without assuming additional economic losses to those of the loss of production of the current season. Certain crops in this basin sector even slightly increase their cultivated area up to a price of 0.07 EUR/m^3 as their gross margin allows them to do so.

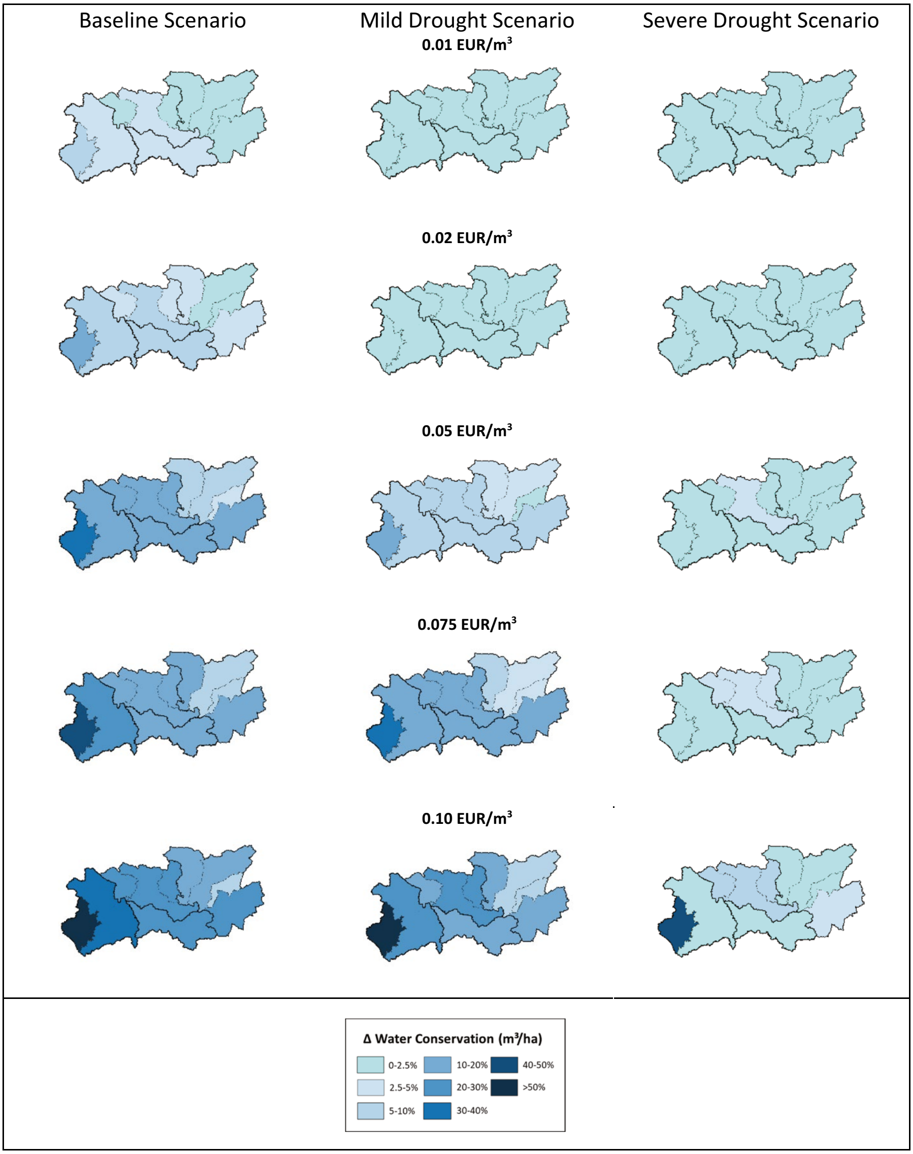

Fig. 6 Water pricing. Spatial water savings display. Baseline and Drought scenarios

Figure 6 graphically summarises the information above: the uneven distribution of water savings across regions, when water prices increase and the low response to water increases in drought scenarios for prices below 0.10 EUR/m^3. As observed, impacts on water savings are uneven distributed along the territory in the three scenarios analysed.

Regarding the crop pattern, Table 4 shows the crop distribution for all scenarios without taking into account the increase in water price (extended tables of crop distribution for different water prices can be found in the annex). Water savings in the

Table 4 Crops distribution (Tariff = 0 EUR/m^3)

Crops **1000 ha**	**Baseline**	**Mild drought**	**Severe drought**
Upper Basin			
Peren. Normal Irr	257	250	232
Peren. Survive Irr	4	11	29
Peren. Total	261	261	261
Rice	0	0	0
Vegetables	7	7	7
Cereals and Others	24	20	10
Total Crops	292	288	278
Middle (RD) Basin			
Peren. Normal Irr	73	71	67
Peren. Survive Irr	1	2	5
Peren. Total	74	74	73
Rice	0	0	0
Vegetables	5	5	4
Cereals and Others	35	29	16
Total Crops	113	108	93
Middle (LD) Basin			
Peren. Normal Irr	97	94	79
Peren. Survive Irr	1	4	18
Peren. Total	98	98	97
Rice	1	1	0
Vegetables	17	17	16
Cereals and Others	45	37	11
Total Crops	161	153	123
Lower Basin			
Peren. Normal Irr	109	108	102
Peren. Survive Irr	1	2	5
Peren. Total	111	111	108
Rice	36	26	9
Vegetables	19	19	18
Cereals and Others	124	105	59
Total Crops	289	260	194
Total Basin	856	856	688

elastic phase of the baseline scenario curve (from 0.01 to 0.10 EUR/m^3) result mainly from the shift of perennial crops to survival irrigation in the whole basin and from the reduction of annual crops and rice in the lower part of the basin. Survival irrigation is a feasible choice for adaptation to the new conditions, up to an increment of 0.59 EUR/m^3. As mentioned above, increases above this price cannot be supported by farmers. Horticultural crops withstand water price increases better than other crops, due to the high gross margins they provide. Hence, farmers are able to maintain their farms, despite the higher costs resulting from water price increases. Finally, results in the drought scenarios show that increasing water scarcity has a larger effect on water use

Table 5 Water Used vs Gross Margin for selected tariffs. Baseline Scenario

Water Used (hm^3)	**Tariff (EUR/m^3)**			
	0,00	**0,01**	**0,05**	**0,10**
Upper Basin	611	-1%	-7%	-14%
Middle (RD) Basin	363	-3%	-13%	-26%
Middle (LD) Basin	502	-3%	-13%	-25%
Lower Basin	1640	-5%	-25%	-52%
Total Basin	3117	-4%	-18%	-37%
Gross Margin	**Tariff (EUR/$m^{3)}$**			
(M EUR)	**0,00**	**0,01**	**0,05**	**0,10**
Upper Basin	207	-3%	-14%	-27%
Middle (RD) Basin	113	-3%	-15%	-28%
Middle (LD) Basin	230	-2%	-10%	-19%
Lower Basin	550	-3%	-13%	-22%
Total Basin	1099	-3%	-13%	-23%

than water pricing measures, thus minimizing (or even offsetting) the impacts of rising prices (Table 4).

The economic impact of this water management policy on the agricultural system of the basin is lower than the impact produced on the water used. For example, a price of 0.02 EUR/m^3 would produce a decrease of 7% of the water used in the baseline scenario. However, that same price level would result in a 5% decrease in the gross margin earned by the agricultural sector in the entire basin (Table 5).

Gross margin loss is partially compensated by the total revenue collected by the RBA. Therefore, although there is a private loss for farmers, society is much less affected. Figure 7 shows how the total revenue collected by the RBA and the agricultural gross margin loss evolved for each level of price applied. In the baseline scenario, the revenue collected by the RBA offsets these losses in the gross margin of the system at prices lower than 0.03 EUR/m^3. However, for higher tariffs, there is a loss of economic

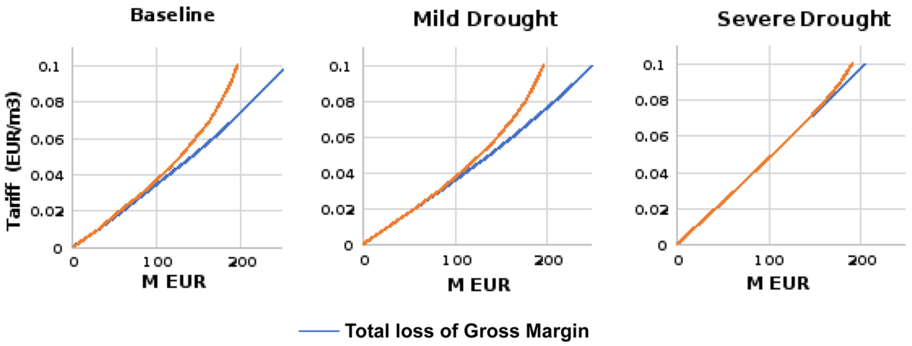

Fig. 7 Revenue collected by the River Basin Authority (RBA) vs. Agricultural Gross Margin loss for each water tariff

Table 6 Spillover and Total impacts in gross margin lose due to the decrease in agricultural activity

Tariff (EUR/m^3)	Baseline		Mild Drought		Severe Drought	
	Spillover Impact (MEUR)	Total Impact (MEUR)	Spillover Impact (MEUR)	Total Impact (MEUR)	Spillover Impact (MEUR)	Total Impact (MEUR)
0.00	0	0	0	0	0	0
0.01	-25	-56	-23	-51	-17	-38
0.02	-50	-110	-46	-102	-34	-76
0.05	-117	-258	-113	-250	-86	-190
0.07	-157	-347	-153	-339	-121	-267
0.10	-210	-464	-206	-456	-170	-377

efficiency since the gross margin losses in the agricultural sector are far higher than the amount collected by the RBA. However, the loss of gross margin due to water pricing in the drought scenarios is lower than in the baseline scenario since the droughts itself already causes gross margin losses of 0.4% in the case of mild drought and 4.52% in the case of severe drought scenario. The initial inelasticity in the water demand curve in the drought scenarios (due to no change in cropping pattern) makes the loss of gross margin equal to the RBA revenue until high prices are reached.

In addition to the direct loss of gross margin in the agricultural sector, indirect effects have to be taken into account. Table 6 summarizes the annual estimated spillover impact on the river basin economy, based on the I/O accounts as outlined in the methodology section using a multiplier of Muñoz-Repiso et al. (2013).

4 Discussion

This paper assesses the effectiveness of water pricing as an economic instrument to enhance water-use efficiency (thus, leading to water savings to achieve environmental objectives), while analysing the economic impacts, as measured by agricultural gross margins and spill-over effects, at basin-sector and basin scales. The logic behind water pricing as an environmental tool is based on the classic economic assumptions of the Pigouvian tax that internalize the social and environmental cost of resource use. The difficulty with pricing is that it may be inconsistent with a water budget defined as a maximum allowable water use. Similarly, in the field of climate policy, Catalano and Forni (2021) compare the effectiveness of different fiscal policy instruments concluding that carbon pricing is not sufficient to achieve sustainability as it would lead to significant energy price increases that would be recessionary. In a similar way, the model shows that water pricing, as a single policy instrument on the Guadalquivir River, will reduce farmers' income and have a large economic impact on the regional economy. Therefore, the goal of reducing water consumption to achieve system sustainability requires a combined use of several policy instruments (e.g., prices, quotas, markets).

Water pricing is a favoured policy to induce water savings in irrigation (Berbel et al. 2019). Additionally, water pricing policies have shown to be a valuable solution to achieve higher efficiency in water consumption, specially under water scarcity scenarios (e.g., drought periods) (Pulido-Velazquez et al. 2013). Conversely, Davidson et al. (2019) argue that the introduction of pricing instruments may lead to unexpected negative outcomes, not showing the expected changes in water-consumption behaviours (e.g., water savings) and deploying negative side effects, which are often neglected or simply not analysed (e.g., spill-over economic effects derived from changes in irrigated agriculture). As also highlighted by Cortignani et al. (2018), the general evidence on water pricing policies is that meeting the environmental objectives while limiting intense social and economic negative impacts is not a straightforward issue. In practice, prices of irrigation are usually set below supply cost (Berbel et al. 2019; Molle 2009) and subsidies from public funds are common. In fact, this situation has led to the opposite outcomes, in terms of environmental deterioration and unsustainable use of scarce water resources (Renzetti et al. 2015).

Analysis of environmental instruments such as water pricing, require a system analysis that considers the interdependencies of economic and natural systems. In order to assess other environmental policy domains, such as climate policy from the early 1990s, researcher have relied on integrated assessment models (Nordhaus 2018). Concerning water policy, the system boundaries are better defined by the geography of the river basin and the regional economy. In some cases, however, the regional/state water infrastructure is interconnected, as it happens in California, where the State general water management is represented by the State/regional level. Here,, State hydro economic models such as CALVIN has been used to model policy options (Howitt et al. 2015) or evaluate drought impacts (Howitt et al. 2015).

Another negative effect of water pricing is the loss of economic efficiency. As shown by the results, the loss of gross margin is higher than the tariff collection by the basin authority. This loss is known as excess burden of taxation. Excess burdens can be measured using the average cost of funds or the marginal cost of funds (MCF). In the first case it would be calculated as the total cost of the distortion (loss of gross margin) divided by the total revenue collected by the authority. In the second case it would be measured in marginal terms, so that the higher the tax rate, the greater the divergence between loss and revenue. This principle holds true in the case-study here analysed, where the higher the tariffs, the higher the losses, as has been reflected in other works such as Garcia and Reynaud (2004) and van Heerden et al. (2008). A limitation of our model is that it focuses on the agricultural sector (85% of demand), as water for industry and urban use is at a higher level of priority and it is not generally affected by drought protocols. Although the abstractions and return flows of non-agricultural users are already included in the proposed hydrological model, no economic analysis has been done (see Borrego-Marín et al. (2020) for a simplified all-sector model of the Guadalquivir river). In conclusion, our model has focused on the agricultural sector (85% of water use), is based on a detailed system analysis which estimates the direct and indirect impact on the economic performance of the agricultural system, while quantifying the influence of the environmental flow constraints.

5 Concluding Remarks

Water scarcity have increasing become a central issue in European water policy. In the EU some reduction of abstraction pressures has been achieved and definition of environmental flow is progressing adequately, but there is large uncertainty on return flows and basin balance. Therefore, there is a need for the use of hydro economic models to assess the impact of water policies, such as water pricing, which has been the focus of this paper. The

European Green Deal and the EU Strategy on Adaptation to Climate Change request quantitative water management aimed to improve sustainability and climate resiliency.

Our results show that impacts at basin-sector scale differ in terms of reduction of water used, and this caused differences in farmer gross margin as a function of local crop pattern. As crop specialization is linked to spatial characteristics defined by soil, climate and socio-economic conditions, this differential impact will produce differences in areas. According to Spanish Water Law, tariffs should be designed to achieve full cost recovery, and this is done at subsystem level; defined as subbasin of territories that share a common infrastructure (catchments, dams, transfers). Concerning the Guadalquivir basin, 95% of territory is managed centrally and all infrastructure is interconnected, so that a common tariff should be applied for water users under the same management subsystem. It will not be possible, under current Spanish legislation, to stablish differentiated tariffs for users included in the 'general system' as they face the same cost recovery. Therefore, we have applied a unified water pricing increase that is both legally and politically acceptable.

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Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics Approval This paper has not been published or is being considered for publication elsewhere.

Consent to Participate The authors declare that they are aware and consent to their participation in this paper.

Consent for Publish The authors declare that they consent to the publication of this paper.

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