MANAGING WATER DEMAND IN EUROPE

Price elasticity assessment of agricultural water demand

June 2017

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1. Methodology

The estimation of price-demand elasticity has some particularities in the case of agricultural water use. The reason for this is that the price or charge of agricultural water is rarely determined in the market. Instead it is set by government agencies and rarely varies from year to year or conditioned on the water supply. Their main, and almost always unique, goal is to recuperate part or all of the water supply and delivery costs (Molle & Berkoff, 2007). In Australia and Chile (Donoso et al. 2014) available water markets data has permitted estimating irrigation water demand elasticities using direct observations of prices and quantities (Zuo et al 2016).

Thus, the hypothetical effectiveness of pricing as a demand management tool needs to be derived from modeling exercises, starting from production functions and setting up the farmer's optimization problem. The literature in this field provides numerous examples of studies using Mathematical Programming Models to obtain or derive water demand functions, from which demand elasticities can be obtained. Briefly explained, in these models, available water volume for irrigation is parameterized at different levels and model runs. The optimized solution includes the amount used for irrigation (demanded) and the shadow price or opportunity cost of the water (the amount of money the farmer would be willing to pay for an extra unit of resource). If the parameterized price level is high enough, the 'representative farm' would not use any of it, and the shadow price would be 0. In between this high level that chokes demand off, and a price at or near zero, the model runs will provide pairs of prices and demanded amounts, from which a demand curve can be obtained. The plotted demand curve enables estimating the elasticity of demand. This procedure has been used in tens of articles. Lacking information on individuals' explicit water demand implies that estimates of elasticity have only considered average prices paid (e.g., Schoengold, Sunding, and Moreno 2006).

Other techniques, such as the econometric techniques or field experiment techniques, are less common in the literature on elasticity of agricultural water (Scheierling et al. 2006). During the 1970s and early 1980s, estimates of irrigation water demands were also developed from statistical crop-water production functions, based on data from field crop experiments conducted at state experiment stations (Scheierling et al. 2006). These types of studies relate agronomic models with economic production function analysis. Production functions are estimated by statistically relating plant yield to water application and, in some cases, fertilizer application and weather. From this, water inverse demand functions can be estimated. More recent analyses have used stated and revealed preference data (Zuo et al. 2016).

This can be explained by the fact that in irrigation districts, and generally in all cases where water is priced or taxed, the price or charge is not used as a water allocation mechanism. As a consequence, water price does not vary with the amount consumed or serviced. Allocation is generally made using centralized rationing systems and sometimes market institutions.

Setting up and calibrating Mathematical Programming Models are complicated tasks and very demanding in terms of data and time. They require using field data, which makes them highly time-consuming and costly. Field data enables calibrating models that otherwise would be irrelevant or completely detached from reality. Given our limited resources, we have disregarded conducting quantitative economic analysis. Instead, we have derived water demand elasticity from models already implemented and published. In cases where irrigation water response curves are available, we have estimated the price elasticity using this simple formula:

$$E = \frac{\left[\frac{Q_2 - Q_1}{(Q_1 + Q_2)/2}\right] \times 100}{\left[\frac{P_2 - P_1}{(P_1 + P_2)/2}\right] \times 100} \quad [1]$$

Where the numerator is the percentage change in water consumption and the denominator is the percentage change in water price. Q_2 is water consumption in step 2; Q_1 is water consumption in step 1; P_2 is water price in step 2; P_1 is water price in step 1.

2. Case study overview

The unit of analysis in cases that focus on agriculture water use is the irrigation district. Irrigation districts, sometimes called 'Irrigation Communities' (ICs) (e.g., in Spain), are independent users of public water (surface and groundwater) with important competences in water distribution, establishment of water use tariffs, control and conflict resolution.

Using the ICs as the main unit of analysis, an in-depth study on water price elasticity has been undertaken for 11 ICs in Spain and several in France, Italy and Portugal. The selection of the ICs has been based on data availability and the following criteria: location/River Basin; year of establishment (old/modern); total irrigated land and crop distribution; number of irrigators; source of water (surface water/groundwater/mixed); infrastructure ownership (public/private); average water consumption; irrigation technology; water distribution system (on demand/by turn…); water tariffs; participation in modernization programs; and costs (O&M, investments); revenues.

In Spain, we have selected 5 ICs located in the Guadalquivir River Basin, 2 in the Guadiana River Basin, 3 in Duero River Basin and 1 in the Ebro River Basin. Figure 1 shows a map of the River Basins in Spain to help identify locations. Table 1 summarizes the main characteristics of the ICs following the selection criteria mentioned above.

Figure 1. River Basins in Spain

Source: Based on MAGRAMA

Table 1. Description of selected Irrigation Communities in Spain

IC	Vegas de Saldaña y Carrión	Canal del Duero	Virgen del Aviso	Manzanares	Tomelloso	Genil Cabra	Huetor Tajar y Villanueva de Mesía	Bembézar
River Basin	Duero	Duero	Duero	Guadiana	Guadiana	Guadalquivir	Guadalquivir	Guadalquivir
Region/Province	Castilla y León (Palencia)	Castilla y León (Valladolid)	Castilla y León (Zamora)	Castilla-La Mancha (Ciudad Real)	Castilla-La Mancha (Ciudad Real)	Cordoba (Andalucía)	Granada (Andalucía)	Córdoba (Andalucía)
Year of establishment	1942	1972	1957	1988	1992	1979	1958	1967
Surface (ha)	11966	5000	1902	17896	4739	37000	1512	4000
Main crops	Maize, sunflower, barley, sugar beet	Wheat, maize, barley	Maize, sunflower, wheat, sugar beet	Barley, melon, pea, vineyard	Mainly vineyard		Onion, alfalfa, wheat, sunflower, maize, asparagus and potatoes	Orange tree, cotton, maize, olive tree, garlic and wheat
Nº Irrigators	3300	2000	786	850	403	1600	900	160
Water source	Surface water (Carrión river)	Surface water (Duero river)	Surface water (Duero river)	Groundwater (La Mancha Occidental Aquifer)	Groundwater (La Mancha Occidental Aquifer)		Surface water (Genil river)	Surface water (Bembezar river)
Infrastructure ownership	Public	Private	Public	Private	Private	Pivate	Private	Private
Water allotments (m^3/ha)	4600	5100	4200	Depending on farm size (on the order of 2000 for arable crops	Depending on farm size (on the order of	4013	4500	2700

				and 1000 for vineyard)	2000 for arable crops and 1000 for vineyard)			
Irrigation technology	Gravity	Sprinkler	Gravity, sprinkler, drip	Sprinkler, drip	Sprinkler, drip	Sprinkler, drip	Private	Private
Water pricing	Fix (€/ha)	Fix (€/ha)	Fix (€/ha)	Mix (€/ha and €/m^3)	Mix (€/ha and €/m^3)	Mix (€/ha and €/m^3)	Mix (€/ha and €/m^3)	Mix (€/ha and €/m^3)

IC	Fuente Palmera	San Rafael	Bardenas
River Basin	Guadalquivir	Guadalquivir	Ebro
Region/Province	Córdoba (Andalucía)	Córdoba (Andalucía)	Zaragoza (Aragón)
Year of establishment	1976	1956	1992
Surface (ha)	5299	1104	16700
Main crops	Olive tree, maize, cotton, cereals, sunflower	Maize, Sugar beet, wheat, sunflower, Cotton	Alfalfa, maize, rice, cereal, sunflower
Nº Irrigators	890	184	1100
Water source	Surface water (Guadalquivir river)	Surface water (Guadalquivir river)	Yesa Dam (Bardenas Chanel)
Infrastructure ownership	Private	Private	Private
Water allotments (m^3/ha)	4000	4500	8390
Irrigation technology	Private	Private	Gravity, drip
Water pricing	Mix (€/ha and €/m^3)	Mix (€/ha and €/m^3)	Mix (€/ha and €/m^3)

3. Results: elasticity assessment in agricultural case studies

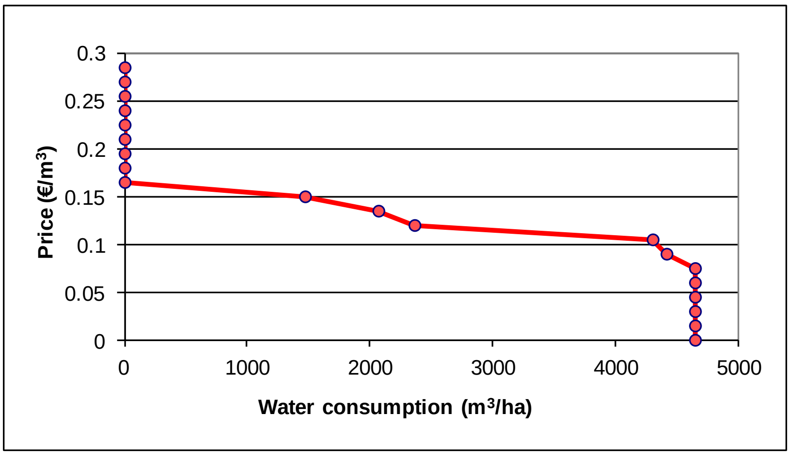
3.1. Spain

Duero river basin

- **IC of Vegas de Saldaña y Carrión**

Blanco and Varela (2007) analyzed the irrigators' response to water pricing policies using a mathematical programming model that allowed the simulation of farmers' behavior following distinct risk aversion to climate as well as market price variations. Empirical application of the model was carried out in two different Irrigation Communities which represent the agriculture in Castilla-Leon region in the northern central plateau of Spain: Vegas de Saldaña y Carrión and Canal del Duero. In both cases, the current fixed pricing system (area tariff) was changed into a binomial pricing system (two-part tariff), in which a progressive volumetric tariff of 0.015 €/ m^3 for 20 price levels was added to the area-based system now in place. The effects of price changes on water consumption for the IC of Vegas de Saldaña y Carrión are shown in Figure 2.

Figure 2. Irrigation water demand curve in Vegas de Saldaña y Carrión



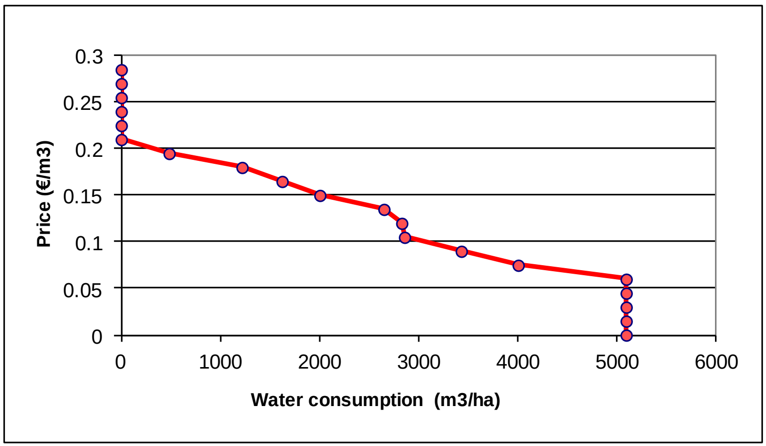
Source: Blanco and Varela (2007)

On the basis of these results and using the equation 1 (see the methodology section) we have estimated the price elasticity of irrigation water demand. As expected, water demand is inelastic when prices are low. Prices ranging from 0 to 0.075 €/m^3 do not make any change in water demand values, i.e. the water demand curve is perfectly inelastic (price elasticity is equal to 0). For mid price rates from 0.09 and 0.105 €/m^3, price elasticity ranges between -0.28 and -0.17. It means that water demand is inelastic (the percent change in demand is less than the percent change in price). This trend is finally reversed for high prices. From 0.12 to 0.165 €/m^3 water demand is elastic (demand is affected to a greater degree by changes in price), with price elasticity values greater than one, in the order of -3.5. Water prices higher than 0.165 €/m^3 turn water demand perfectly inelastic again.

- **IC of Canal del Duero**

Looking at the results for the IC of Canal del Duero (see Figure 3), we can see that water demand is perfectly inelastic for water prices ranging from 0 to 0.6 €/m^3 and from 0.21 to 0.285 €/m^3. Thus, only with considerable increases in water prices up to 5 to 6 times, farmers would develop a thrifty behaviour in relation to water consumption. Water demand is elastic with prices ranging from 0.06 to 0.105 €/m^3 and from 0.135 to 0.21 €/m^3. In those price ranges, price elasticity can vary between -1.1 and -4.4. In the middle of the curve, from prices that go from 0.105 to 0.135 €/m^3, demand is inelastic (price elasticity is about -0.5).

Figure 3. Irrigation water demand curve in Vegas de Saldaña y Carrión



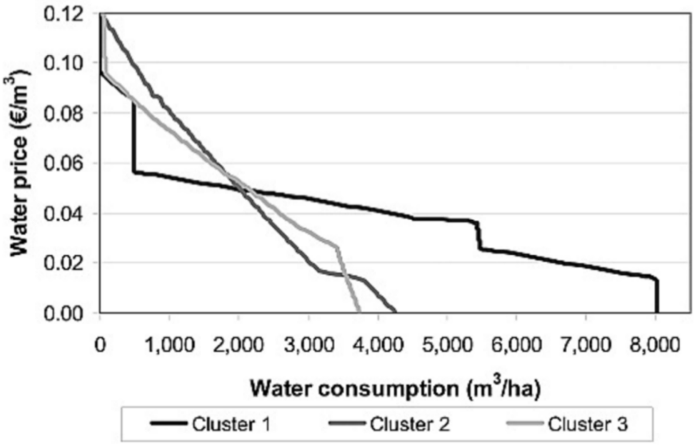
Source: Blanco and Varela (2007)

If we compare the ICs analyzed in the Duero River Basin, we can observe that water demand is more elastic in the old irrigation district of Vegas de Saldaña y Carrión than in Canal del Duero. As explained in Blanco and Varela (2007), this may be due to the fact that Vegas de Saldaña y Carrión has more room to save water. This can provide larger water savings by changing its old irrigation systems to more modern ones.

- **IC Virgen del Aviso**

Gomez-Limón and Riesgo (2004) used a cluster analysis in Virgen del Aviso irrigation district where each cluster of farmers has a set of variables, representing the binomial crop-irrigation technology. Obtained demand curves for each cluster are collected on Figure 4.

Figure 4. Irrigation water demand curve in Virgen del Aviso



Source: Gómez-Limón and Riesgo (2004)

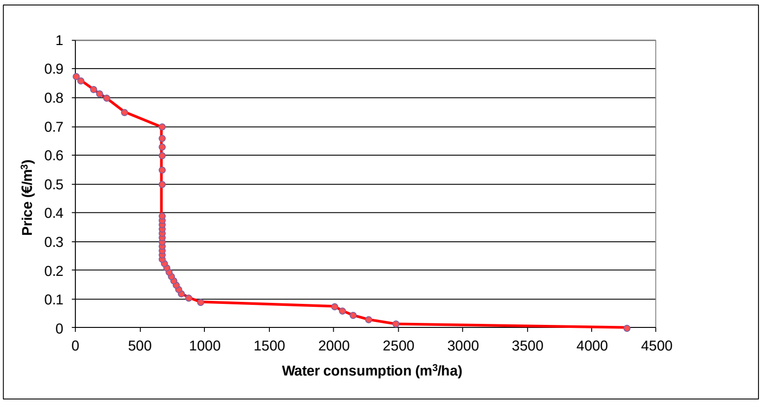
In their results, they pointed out that changes in water demand in the different clusters can be justified by the existence of segments with different slopes for each price interval (i.e., elasticities of demand) that can be distinguished within each group's demand curve. In all cases, the segments of the water demand curves with high slopes (relative low elasticities) coincide with prices for which the farmers are insensitive to resource price increases, maintaining their usual crop mixes and irrigation techniques without any substantial change. On the other hand, the segments with lower slopes (relative high elasticities) correspond to those water tariffs that encourage farmers to replace their current crops with others with lower water requirements and/or to improve their irrigation systems (water use efficiency) by adoption sprinkler techniques.

Guadiana river basin

- **IC of Manzanares**

Using also a mathematical programming model, Esteve (2007) simulates a reoccurring increase of 0.015 €/m^3 in the price of water in several ICs located in the Upper Guadiana Basin, within the aquifer of La Mancha Occidental. Here we analyzed the results obtained for two representative ICs: Manzanares and Tomelloso. Figure 4 shows the irrigation water demand curve of Manzanares.

Figure 5. Irrigation water demand curve in Manzanares



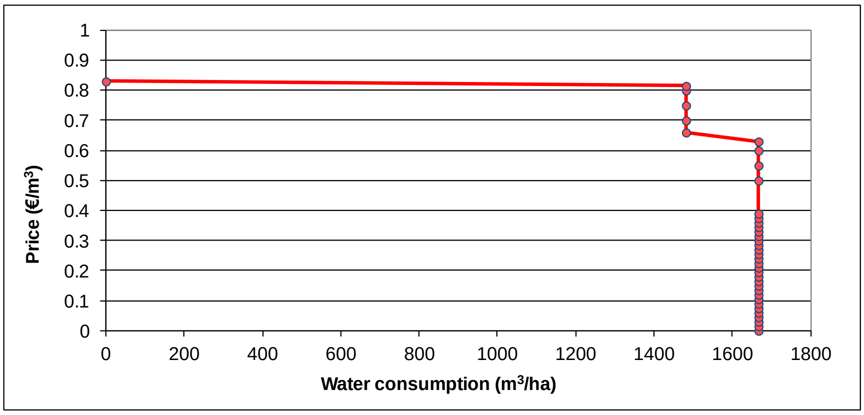
Source: Esteve (2007)

As we can see in Figure 5, water demand is highly elastic at low prices. From 0 to 0.015 €/m^3 water demand is almost perfectly elastic. An increase of 0.015 €/m^3 produces a decrease of 53% in water consumption. Water demand is also very responsive to price increases for water prices ranging from 0.075 to 0.09 €/m^3. When prices rise above 0.09 €/m^3, water demand shows an inelastic behaviour. In fact, price elasticity values between 0.09 and 0.24 €/m^3 are about -0.2 and -0.4, reaching even 0 above 0.24 €/m^3 (between 0.24 and 0.7 €/m^3).

- **IC of Tomelloso**

The IC of Tomelloso presents a very inelastic irrigation water demand curve. Figure 6 shows that water demand is perfectly inelastic (price elasticity equal 0) between prices that go from 0 to 0.6 €/m^3 and from 0.66 and 0.815 €/m^3. Only at very high prices, above 0.815 €/m^3 water demand react to the price increase, showing a very high price elasticity.

Figure 6. Irrigation water demand curve in Tomelloso



Source: Esteve (2007)

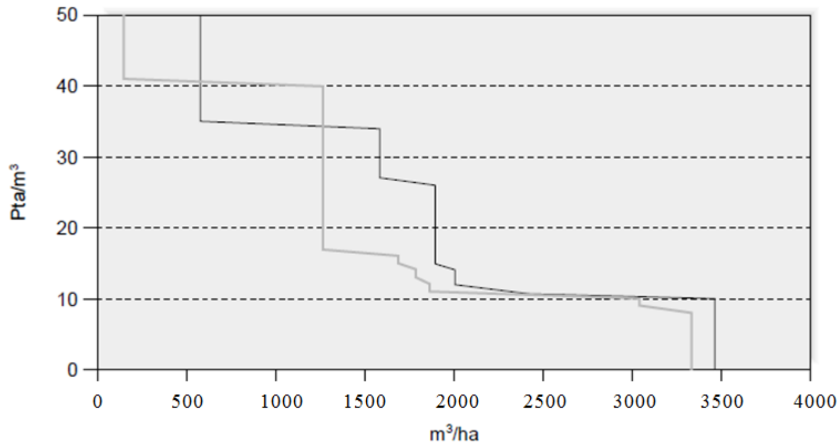
The reason for such inelasticity is the large number of vineyards grown in this IC that takes water from the Western La Mancha Aquifer. The IC of Tomelloso is dominated by profitable monoculture vineyards with low water consumption (in the order of 1500-1700 m^3/ha), but highly unresponsive to increases in water price. Farms in the IC of Manzanares are larger and more diverse, which is why they show a higher capacity of response and resilience given water shortages and price rises.

Guadalquivir river basin

- **IC of Genil-Cabra (Southern Spain)**

Jiménez et al. (2001) have carried out some economic analysis to study water demand in different irrigation districts, which included Genil-Cabra. Figure 7 shows the irrigation demand curve obtained in Genil-Cabra by means of two different methodologies. These methodologies follow the classical linear programming model that maximizes just one objective as well as the multi criteria programming model that attempts to maximize several objectives.

Figure 7. Irrigation water demand curve in Genil-Cabra



Source: Jiménez *et al.* (2001)

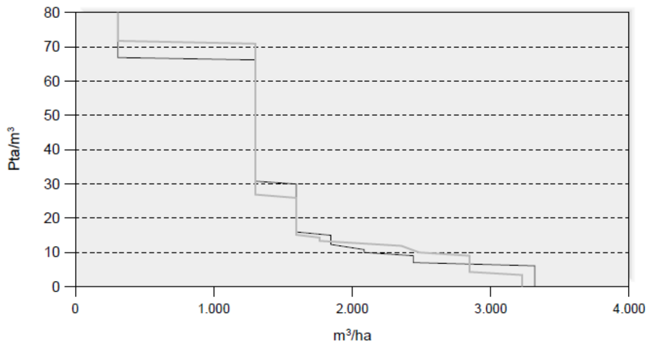
TheGuadalquivir River Basin Authority also carried out some economic analysis to study the Genil-Cabra irrigation district (CHG, 2001) obtaining a water demand curve similar to those obtained by Jiménez et al. (2001) shown in Figure 7.

As shown in Figure 7, irrigation water demand is rather inelastic below 0.10 €/m3 and elastic beyond it. A water tariff of more than 0.18 €/m3 does not induce a reduction in water demand. Other authors (Berbel and Rodriguez, 1998; Feijoó et al., 2000; Gómez-Limón and Berbel, 1999; Gómez-Limón and Riesgo, 2004; Sumpsi et al., 1998) also suggest that water demand elasticity in Genil Cabra is very low. To induce a reduction in water demand, considerable price increases are required.

- **Zona Regable de Huetor Tajar y Villanueva de Mesía**

Jiménez et al. (2001) also studied Huerto Tajar and Villanueva de Mesía irrigation districts, the water demand curve was obtained following the same methodology than in the Genil-Cabra irrigation district. Water demand for this irrigation district is represented in Figure 8.

Figure 8. Irrigation water demand curve in Huetor Tajar y Villanueva de Mesía



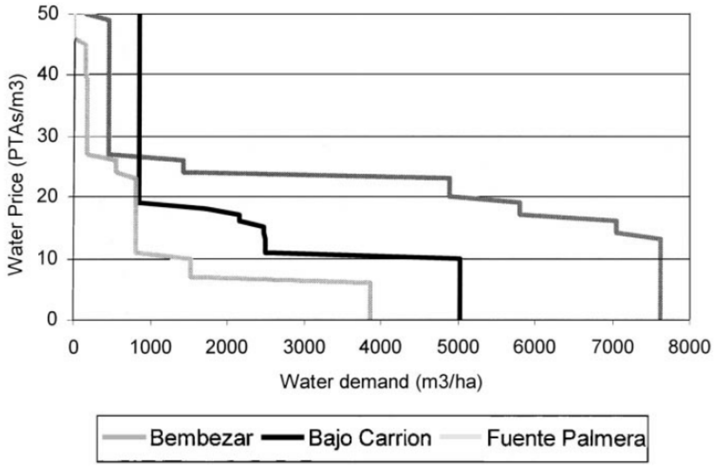
Source: Jiménez *et al.* (2001)

As shown in Figure 8, the water demand curve for Huetor Tajar y Villanueva de Mesía has the same shape as the previously analyzed irrigation districts and can also be split into three segments according to elasticity.

- **CR Bembézar - CR Fuente Palmera - CR Bajo Carrión**

Berbel and Limón (2000) simulated the impact a policy based upon price of water could have on agricultural production and therefore, on irrigation water demand. To do this, they developed a methodology based upon a simple linear programming model. This model was tested on 3 ICs belonging to Guadalquivir river basin, Bembézar, Fuente Palmera and Bajo Carrión, located on the Duero river basin. The Bajo Carrión study case has already been analyzed above, based on the work performed by Blanco and Varela (2007) and is shown in Figure 4. The model was designed with the aim of reflecting the viewpoint of the individual farmer as a member of an IC. The objective and the constraints of the model are equal, as in Cañas et al. (2000). Results obtained from the model are shown in Figure 9.

Figure 9. Irrigation water demand curve in San Rafael



Source: Cañas *et al.* (2000)

Demand curves obtained from the model are classic, as in former studied ICs. Differences among the curves are due to local conditions such as climate, soil and technical environment. As seen in previous cases, demand curves can be divided into three segments according to elasticity. Limit values between these segments are shown in Figure 10.

Figure 10. Demand segments limits in San Rafael

Demand segments (PTAs/m^3)

	CR Bembézar	CR Fuente Palmera[a]	CR Bajo Carrión
Segment A (inelastic)	0–13	0–6	0–10
Segment B (elastic)	14–26	7–27	11–18
Segment C (inefficient)	>26	>27	>18

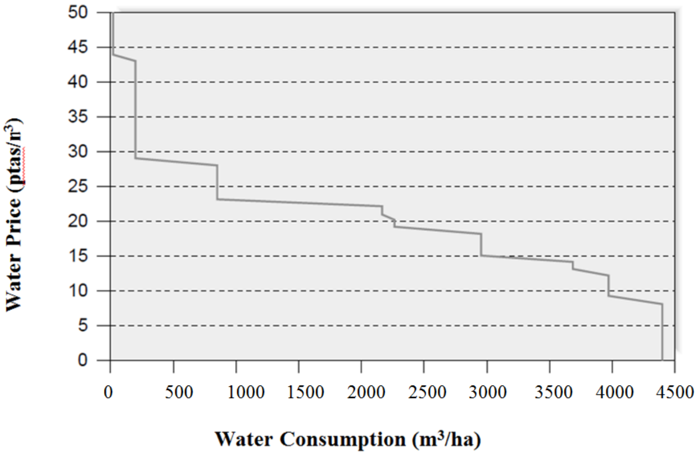
Source: Cañas *et al.* (2000)

In the first segment, that is inelastic, the farmer makes very small or zero responses to price increases. The middle segment is elastic in all cases and thus the farmer responds to price increases by reducing water consumption. In the third segment, water demand is again inelastic and there is no response to water price shifts.

- **IC San Rafael:**

Cañas *et al.* (2000) obtained the irrigation water demand curve for simulated water tariff policies using a mathematical multi criteria model. Farmer's income maximization and risk minimization were the objectives of the model and surface, measures linked to the EU Common Agricultural Policy and traditional crop rotations were the model restrictions. This model was applied on San Rafael IC, obtaining irrigation water demand curve as shown in Figure 11.

Figure 11. Irrigation water demand curve in San Rafael



Source: Cañas *et al.* (2000)

San Rafael IC water demand curve can be split into three parts according to water price evolution. In the first one, when price increases from 0 till 8 pta/m^3, water demand is inelastic. When water reaches 9 pta/m^3, demand turns elastic and each water price increase is corresponded with a decrease in water consumption. The last part of the curve begins when water price is equal to 44 pta/m^3 point where water demand shifts and shows an inelastic demand again.

Ebro river basin

- **IC of Bárdenas**

The last Spanish case study relates to the IC of Bárdenas, located in the Ebro River Basin in Northeast Spain. Relevant data on water consumption and water prices have been collected from the annual reports of Bárdenas IC for the period 2002-2014 (see Table 2). This IC applies a two-part tariff, where a volumetric tariff is combined with a fixed charge. The fixed part includes general irrigation district expenses, a dam regulation canon, amortization of dams and major canals, and energy expenses.

Table 2. Water consumption and water prices in the IC of Bárdenas (Ebro Basin) from 2002 to 2014.

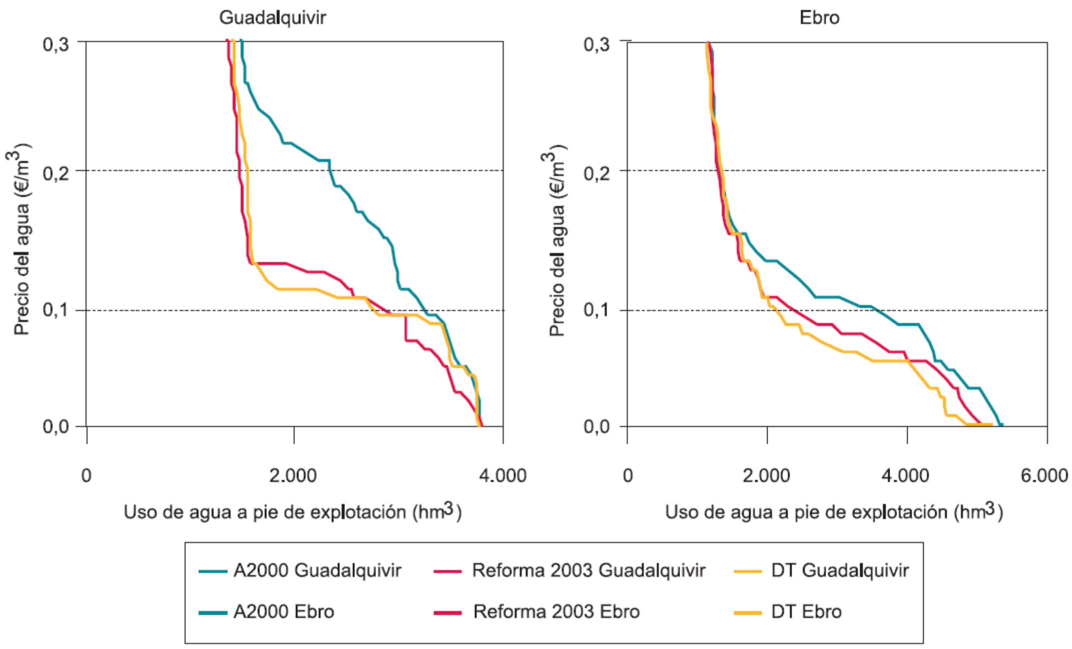
Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Water consumption (m^3/ha)	5000	7000	6282	6047	6255	6100	6100	6955	8144	7036	6523	5604	6463

Price – Fixed part (€/ha)	59.17	61.42	56.86	45.04	68.10	71.12	81.00	84.10	85.30	84.42	93.23	102.10	96.00
Price- Per-unit volume charge (€/m3)	0.013	0.023	0.024	0.024	0.024	0.025	0.026	0.026	0.026	0.023	0.027	0.023	0.026

The data collected confirms that water price does not vary from year to year with the amount of water consumed or serviced. In other words, the price is not used as a water allocation mechanism; it is only used to recover the costs of water services. Luque et al. (2014) used a mathematical programming model to simulate a water market and maximize the irrigators' added benefit in the IC of Bárdenas. The water market was simulated under different water allocation reductions of 12 % and 25 %. The results indicate that when water allocations were reduced from 6860 m^3/ha to 5803 m^3/ha, water price increased from 0.0115 €/m^3 to 0.0273 €/m^3, showing also a rather inelastic response. However, if we compare the impact of a water pricing increase in the IC of Bárdenas and the IC of Genil Cabra, we find that water demand is more sensitive to price increases in the water abundant IC of Bárdenas (Ebro Basin) than in the water scarce IC of Genil Cabra (Guadalquivir Basin). The same results were obtained by Gutiérrez and Gómez (2009), who studied how water demand responded to price changes in the Guadalquivir River Basin and the Ebro Basin.

Figure 12 shows the aggregated water demand curves of the Guadalquivir River Basin and the Ebro River Basin.

Figure 12. Irrigation water demand curves in the Guadalquivir River Basin and the Ebro River Basin under different agricultural policy scenarios.



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Source: Gutiérrez and Gómez (2009)

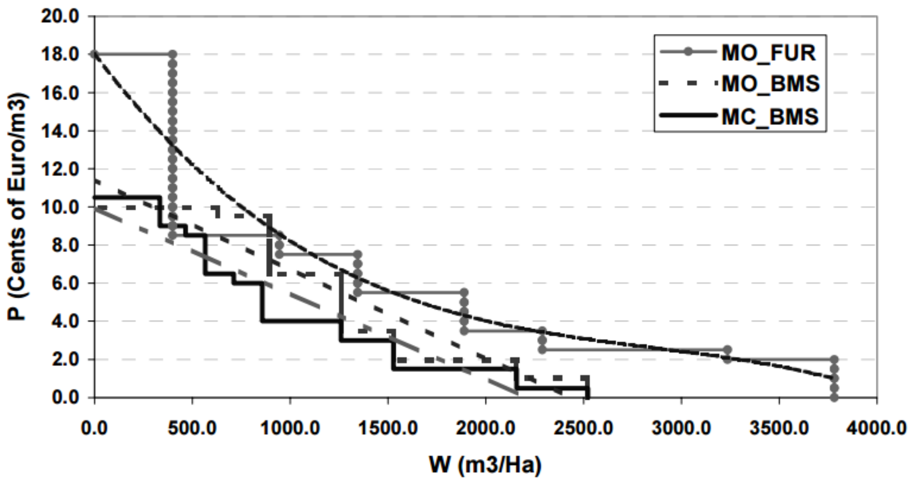
As we can see in Figure 12, water demand in the Ebro River Basin is very sensitive to increases in water prices. Water demand can be reduced by more than half (from 5500 Hm^3 to 2000 €/m^3) when water prices increase from 0 to 0.10 €/m^3. The same increase in water prices in the Guadalquivir River Basin (from 0 to 0.10 €/m^3) only reduces water demand by 1000 Hm^3.

3.2. Italy

- **Consorzio di Bonifica del Canale Emiliano Romagnolo**

Bazzani (2003) followed the methodology developed by Sumpsi et al. (1996) and improved by Amador et al. (1998) in the Po river valley in the irrigation districts known as Consorzio di Bonifica del Canale Emiliano Romagnolo. The model was simulated taking into account different irrigation systems: Furrow irrigation (FUR) and self-moving sprinkler (BMS); and farmers behavior: a profit maximizing behavior (MO), and a more balanced one (MC); with a utility function that depends on net income, labor and complexity. Figure 13 represents water demand curves obtained in this study. The three curves present similar decreasing pattern but different shapes and intercepts.

Figure 13. Irrigation water demand curve in San Rafael simulating different irrigation systems and farmer behavior



Source: Gutiérrez and Gómez (2009)

While FUR and BMS are approximated by linear and non-linear curves of different shapes, the multicriteria objective function (MC) shifts the curve to the left. In more detail, the external curve describes FUR: maximum water consumption is 3781 m3 /ha at zero price. Technological innovation represented by BMS drastically reduced water consumption to 2500 m3 /ha (-28.6%). The intercept with the vertical axes, that identifies the point where irrigation stops, is also different: from 0.18 €/m3 in the FUR, drops to around 0.10 €/m3 when BMS is adopted. At zero cost of water the optimum crop mix is always composed by maize and sugar beet, fully irrigated in a ratio 3/1, due to rotation, plus the set aside requirement (10 %). In all cases, response to water price increase is quite strong in a first phase which ends at a price of 0.06 €/m^3. This price level could reduce water demand to around 1000 m^3/Ha (-60 %). Maize production is the first to leave the field to rain fed wheat. At higher prices, the curves become steeper for the higher water marginal productivity on sugar beet, at medium and low irrigation levels. When MC is adopted at a water price of 0.04 €/m^3 soya-bean becomes profitable for the lower labour requirements.

- **Relevant farming systems**

Bartolini *et al.* (2007) performed a study where five irrigated agricultural systems have been selected: a cereal system – Mantua Lombardy region, Northern Italy (RIB Fossa di Pozzolo); a rice system – Ferrara, Emilia Romagna region, Northern Italy (RIB I Circondario Polesine di Ferrara); a fruit system – Ravenna, Emilia Romagna region, Northern Italy (RIB Romagna Occidentale); a vegetables system – Foggia, Apulia region, Southern Italy (RIB Capitanata); and a citrus system – Syracuse, Sicily region, Southern Italy (RIB Piana di Catania). They analyzed these study cases by means of a hierarchical cluster algorithm (Ward method) (Ward, 1963) which was applied to each area database employing standardized variables, while ANOVA was used to test the significance of each dependent variable (crop mix and farm size). Once clusters were formed, each cluster was modeled separately and the results were aggregated at a later stage (step 6). The methodology adopted for modeling was based on multi-criteria mathematical programming as seen above in Bazzani (2003).

Figure 14. Main features of study areas

Main features of the five study areas

	Agricultural system				
	Cereal	Rice	Fruit	Vegetables	Citrus
Water supply	Po River	Po River	Emilia Romagna Canal	Dams, Ofanto River, private wells	Dams, Simeto River, private wells
Water distribution system	Open canals	Open canals	Pressure pipes, open canals	Pressure pipes	Pressure pipes
Irrigation system	Mobile wings, sprinklers	Flood system, infiltration	Drip irrigation	Drip irrigation	Drip irrigation, sprinklers
Water price	0.12 euro/m³	0.016 euro/m³	0.15 euro/m³	0.09 euro/m³	0.31 euro/m³
Prevailing tariff system	Area based	Volumetric	Volumetric	Volumetric	Volumetric
Agricultural area in the RIB (ha)	48,137	91,085	193,359	143,000	98,000
Agricultural area of the system (ha)	27,919	11,582	21,675	25,740	14,700
Main crops	Maize, soy, sugar beet	Maize, soy, sugar beet, rice	Peach, nectarine, wine grape	Durum wheat, tomato, broccoli	Orange

Source: Bartolini *et al.* (2007)

Obtained results showed that water pricing will have, in most cases, slight effects. As far as water use is concerned, only the cereal, rice and citrus systems show reactions to water prices. The water demand curve is less reactive to price increases than agricultural markets, and policy scenarios and pricing could here play the role of satisfying full cost recovery, unless prices become so high that they lead to the abandonment of the main crops.

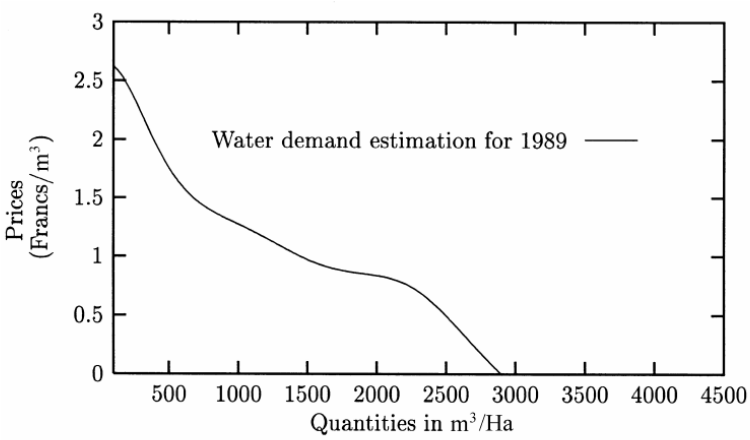
Bartolini et al (2007) found a broad spectrum of situations: completely inelastic demand (vegetables) and very elastic (citrus in Sicily); but the actual water prices range from 0.016 for rice to 0.31 in Sicily, so the doubling effect is very different across situations and contexts.

3.3. France

- **South west of France**

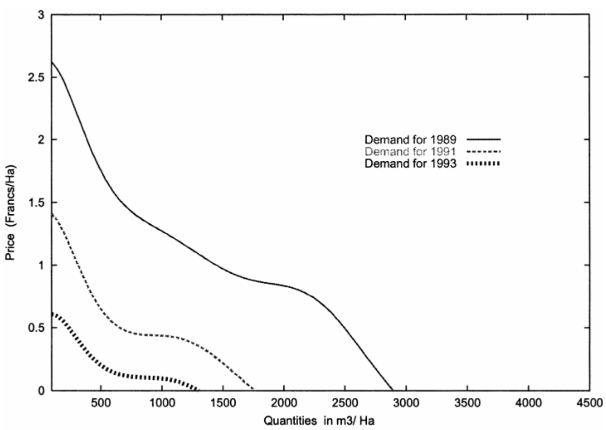
The demand function estimations performed by Bontemps and Couture (2002) in irrigated areas of the South west of France are directly derived from the estimated profit functions, as shown in Figure 15. The results of the demand estimates in Figure 16 show clear differences in water demand for the three weather conditions. The drier the weather, the greater the irrigation water demand. However, these curves present the same shape and trends. These three demand functions are decreasing and nonlinear. Water prices being set at the range of 0.6 to 2.61 F/m3, depending on weather conditions, induce a zero water demand. From the water quantity available, equal to 2900 m3 per hectare in dry year, to 1700 m3 per hectare in average year, and to 1350 m3 per hectare, it is not in the farmer's interest to irrigate. The differences between these maximum quantities can be very important. Note that this water quantity increases twofold from the wet year to the dry one. These differences are due to precipitation; water demand will be higher when precipitation is low. Another interesting feature is that the estimated water demand functions have inflexion points and can be decomposed into areas. At low water prices, irrigation water demand seems to be inelastic. However, demand appears more and more elastic as price increases. The price levels at which the changes in price-responsiveness appears depend on weather conditions and are ranging from 0.30 F/m3 in wet year to 1.60 F/m3 in dry year. Up to these prices the variations in water consumptions, with respect to the change in prices, appear quite significant. These results are confirmed by existing studies using programming methods in the literature on irrigation water demand (Montginoul and Rieu, 1996; Iglesias et al., 1998; Varela-Ortega et al., 1998).

Figure 15. Irrigation water demand curve in the South west of France in a dry year



Source: Bontemps and Couture (2002)

Figure 16. Irrigation water demand curve in the South west of France for 'dry', 'medium' and 'wet' year



Source: Bontemps and Couture (2002)

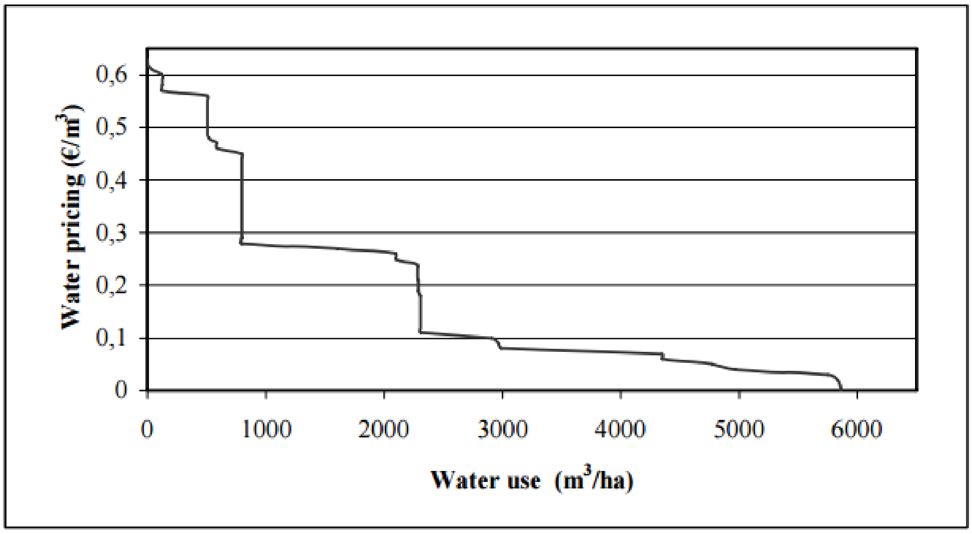
3.4. Portugal

- **Irrigated area of Odivelas (Alentejo)**

The irrigated area of Odivelas located in the Portuguese region of Alentejo was studied by Noéme and Fragoso (2004). To do so, they used a sequential discreet stochastic programming model, based on the studies developed by Fragoso (1996; 2001), Jacquet et al (1997), Keplinger et al (1998) and Blanco (1999). In Figure 17 the expected results of the water demand are presented. The demand of water is shown as the water use by hectare of potential irrigated area. The water use by hectare, when the water price is zero is about 5900 m3. That consumption does not change significantly for low water price (0.02

€/m3). Higher prices lead to a progressive decrease of the water use, some stabilization being seen around 2300 and 795 m3/ha in the price gap between 0.11-0.24 €/m3 and 0.28-0.47 €/m3, respectively. Those gaps, such as the gap of 0-0.02 €/m3 correspond to the inelastic segments of the water demand function.

Figure 17. Irrigation water demand curve in Irrigated area of Odivelas (Alentejo)



Source: Noéme and Fragoso (2004)

4. Discussion and conclusions

The results obtained show that irrigation water demand is rather inelastic, especially in those ICs where water is scarce or permanent crops are predominant (e.g., ICs in the Guadalquivir Basin in the South of Spain and the IC of Tomelloso with vineyard crops in the Guadiana Basin). Scheierling, Loomis, and Young (2006) reviewed 24 studies in the US of price elasticity of demand for temporary irrigation water and report estimates ranging from −0.001 to −1.97, with a mean of −0.48. Zhou et al (205) obtained an irrigation water demand of -0.55 in the Heihe River basin, northwestern China. Hendricks and Peterson (2012) estimated a demand elasticity for irrigation water in the High Plains of -0.10, also highly inelastic. Davidson and Hellegers (2012) obtained the overall own-price elasticity of irrigation water, −0.64 in irrigated areas in the Musi basin in India. Mullena et al (2009) concluded that in US State of Georgia row crop producers' water demand is modestly affected by water price (with elasticities between −0.01 and −0.17). These are just a selection of studies that found generally inelastic water demand for irrigation. Reasons for finding generally inelastic irrigation demand are:

- With regard to groundwater use, the number of wells and pumping rights are constrained due to water rights.

- Low elasticity of substitution of water inputs with other inputs, either because crop technologies are of Leontieff nature (fix proportions) or because climate conditions are very arid, limiting the substitution of crops.
- Very often elasticity varies along the demand curve: in regions with abundant and cheap water the elastic segment will be found at lower prices, followed by more inelastic segments in the upper price range. A contrary situation is found when price is costly and resources are limited (many situations of groundwater or semi-arid areas): the demand is inelastic at the relatively lower prices, up to a point where demand is completely choked off. This is the point where water use becomes completely unprofitable.
- Long-term estimations, considering variable capital scenarios, will in general reveal more elastic water demand. But this does not mean that the price signal will necessarily stimulate capital investment in irrigation. Other reasons may explain the investment: reduced management costs, more precise applications and water control, better crop yields and quality.
- In most circumstances, the amount of water use is constraint by entitlements or rights. Therefore, if farmers tend to use them in full, and water prices are low, then demand will be in general inelastic. If lower used volumes are identified, this may be due to reduced deliveries instituted to cope with drought situations.

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