Ramsey pricing for cost recovery applied to reservoir infrastructure in Andalucia

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Abstract

The Water Framework Directive requires Member States to apply water pricing policy in order to achieve the efficient use of resources. This ruling requires that they recover the costs of water-related services. Our intention in this paper is twofold: firstly we propose an alternative calculation of the annual depreciation charge for the investment in water infrastructure to that currently made by public administration, and then we apply the Ramsey contribution to the calculation of the price or regulatory tariff charged in 2009 by the Guadalquivir River Basin Authority (Andalucia, Spain) for providing water for urban supply and irrigation. The idea of these quasi-optimum Ramsey prices is to recover the costs of water services whilst maximizing social welfare. The results show that the River Basin Authority should charge a tariff of 0.07 €/m^3 instead of the 0.06 €/m^3 that it currently charges. According to Ramsey's formula, the urban water supply should bear 74.9% of this tariff whilst 25.1% should be paid by irrigators. Thus its greatest effect is felt by domestic users, whose demand is relatively inelastic, compared to those whose demand is for agricultural purposes.

Key words: Ramsey pricing; Water Framework Directive; water economics; water regulatory tariff.

JEL Classification: H21; D04; D42; D61; Q25

INTRODUCTION

Community Directive 2000/60/CE of the European Parliament establishes a community framework for action within the sphere of water policy[1] and introduces criteria for economic rationality in the management of this resource based upon the principal of cost recovery, in such a way that the users – industries, farmers and households – pay a price that covers the costs of exploiting and maintaining the water supply and also the depreciation of the outlay made on infrastructure.

Within this context of economic analysis and recovery of the costs of water services, the prime aim of this paper is to assess whether Spanish water-pricing policies follow the economic criteria of efficiency and recovery of costs demanded by the Directive. In fact, the level of cost recovery for the provision of water services as a whole falls within the range of 65% to 96%, depending upon the service, the users and the basin in question (Ministry of the Environment, 2007).

The integration of responsibilities as far as water management is concerned is particularly complicated in Spain, bearing in mind the powers entrusted to each of the administrative bodies involved, because apart from the state and regional governments, local corporations and user communities also have a say in certain aspects of the matter. A distinction should be made between the higher reaches of the water system, carrying the water from the large, initial storage sites such as reservoirs, treatment plants and channelling it to local deposits, and water management at the tail end, piping it from the local deposits to the end users (urban, industrial and agricultural) and then collecting and recycling sewage and other waste waters (Sánchez-Martínez *et al.,* 2012).

This work focuses on one case in point, that of the prices charged for water at the Quéntar and Canales reservoirs in Granada (Andalucia), both managed jointly by the Guadalquivir Water Confederation, to the firm responsible for supplying water to the city of Granada, to other neighbouring municipalities and to the irrigation groups in the plain surrounding the city. Although we shall use mainly the terms "price" or "cost" of water, the term used by the Guadalquivir Water Confederation is regulatory tariff, which means the cost charged at the

[1] The Water Framework Directive: hereafter "the Directive".

reservoir - in euros per cubic metre provided for urban use, or per hectare for irrigation purposes.

For our assessment we propose an alternative calculation to the tariff actually charged by the Guadalquivir Water Confederation for both urban and irrigation use. Our proposed tariff takes into account, on the one hand, a reasonable calculation of the outlay on infrastructure, and on the other, introduces Ramsey's formula (1927) for optimum tariff systems. As far as depreciation of investment is concerned, we correct the annual depreciation charge, given that the Water Confederation calculates it in nominal rather than real terms, whilst the "Ramsey", or "quasi-optimum" prices, charged by a natural monopoly, such as these reservoirs controlled by the Guadalquivir Water Confederation, allows the provider to cover its costs whilst the loss of social welfare remains as low as possible. If Pareto prices were applied, which obey the criterion of a price equal to the marginal cost, social welfare would be maximized but losses would be incurred due to the fact that in natural monopolies the marginal cost is lower than the average cost.

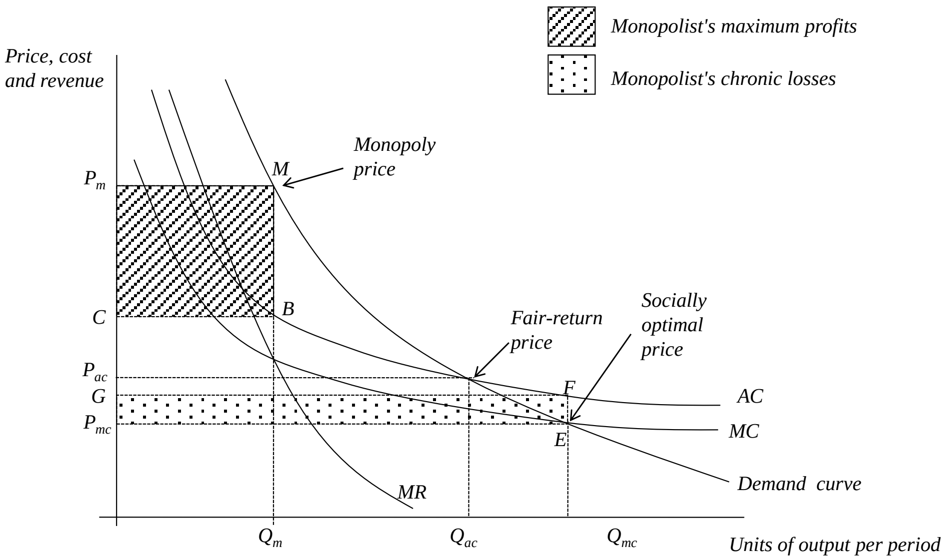
This paper is organised in the following way; in the second section we cover the most relevant theoretical bases for our calculations; in section three we describe the regulatory tariff charged by the Guadalquivir Water Confederation and offer our newly calculated proposal for the annual depreciation charge; in the following section this newly calculated depreciation charge is introduced into Ramsey's formula to obtain the new regulatory tariff that would allow the Guadalquivir Water Confederation to recover the costs of water provision whilst at the same time maintaining any loss of social welfare to a minimum; and in the final section we present our conclusions to this economic investigation.

2. Economic analysis of the water charges

2.1. Pricing options for a natural monopoly

In a natural-monopoly market for the provision of water supplies (Figure 1) the supplier will fix a level of production, Q_m, for which the marginal revenue, *MR,* is equal to the marginal cost, *MC*, which will result in a price, P_m; that is to say, a lower quantity at a higher price than a competitive firm. The monopolist's profit is given by the area P_mMBC. Nevertheless, the efficient assignment of the resource demands price regulation. The principle of charging according to marginal cost derives from the necessary conditions of optimality obtained from the model of general equilibrium of the economy under ideal conditions (first best). In Figure 1, P_{mc} is the optimum, or Pareto, price for maximizing social welfare, which is reached at the intersection of the demand curve (average revenue or price) with the curve representing marginal cost. The quantity of water provided would rise to Q_{mc} but because the average costs are decreasing, and thus the marginal cost is below that of the average cost, the result would be a chronic deficit in the provision of this good (area $GFEP_{mc}$). Thus, although pricing according to marginal-cost, or efficient, pricing, is a principle occasionally resorted to in the provision of water, it is rarely applied in developed countries.

Figure 1. Pricing options for a natural monopoly



MR = marginal revenue; MC = marginal cost; AC = average cost

P_m = monopolist's profit-maximizing price Q_m = monopolist's profit-maximizing quantity

P_{ac} = fair-return price (social monopoly) Q_{ac} = quantity of social monopoly

P_{mc} = socially optimal price Q_{mc} = socially optimal quantity

Authors' own graphic design

If optimum tariffs are not enough to cover the cost of providing the required service in natural monopolies, the Administration (or regulator) has three options (Rodríguez-Ferrero, 2001):

1. – To replace the policy of marginal-cost pricing (P_{mc}) for one of average-cost pricing (P_{ac}).

In this way the monopolist may charge a higher price than that of the marginal cost, sufficient to gain a reasonable profit against its original investment. If this rate is higher than that which it could hope to get in a competitive market it will create an incentive to use more capital than that which will really minimize costs. This bias is known as the Averch-Johnson effect (1962).

2. – To adopt a policy of efficient price fixing, subsidizing the service in order to re-establish the economic balance (subsidy equal to the area *GFEPmc*). This option would be impossible nowadays in Spain as both the revised text of the parliamentary Water Act and the Directive enshrine the principle of self-sufficient pricing.

3. – To establish a policy of price discrimination.

Social welfare, defined as a producers' and consumers' surplus, is maximized for prices equal to marginal cost. But if the price charged by the natural monopoly cannot be equal to the marginal cost because this would generate losses (Figure 1), what then is the second-best price vector that will cover all the service-fulfillment costs whilst ensuring the least possible loss of social welfare? Ramsey came up with the reply to this question in 1927. His theoretical contribution is extremely interesting for the application of policies that are at one and the same time efficient and self-sufficient. We will take a look at the main arguments of his work in the following section.

2.2. Second-Best (Ramsey) Pricing: Formal Presentation and Solution

To demonstrate the Ramsey pricing rule and its distributional and welfare effects, we shall examine Boiteux's (1956) and Baumol and Bradford's (1970) formulas.

Let us consider the problem of a regulator seeking to set prices

$$(p_1, p_2, \dots, p_n)$$

for a multi-product monopolist with costs

$$C(x_1, x_2, \dots, x_n) = C(x),$$

where

$$(x_1, x_2, \dots, x_n)$$

are the outputs of the *n* products produced by the monopolist (prices of inputs are fixed).

If we suppose that the products are sold in separate markets, as is commonly the case, demands are independent and thus the cross-price elasticity of demand is zero. We also assume that the demand functions for the price vector $p = (p_1, p_2, \ldots, p_n)$ are given by the inverse demand functions $p_i(x_i)$ for good i *(=1,2,..n)*.

The profit function is

$$\pi = R(p, x) - C(x),$$

where R is total revenue

$$R(p,x) = \sum_{i=1}^{n} p_i \, x_i$$

Ramsey pricing is a policy rule determining what price a monopolist should set in order to maximize social welfare, W, subject to a constraint on profit. Profit should be equal to some fixed value, k. The welfare maximizing problem of the public agency or regulator is:

$$\textit{maximize} \quad W(p, x)$$

$$\textit{subject to} \quad R(p, x) - C(x) = k$$

This problem may be solved using the Lagrange multiplier technique to yield the optimum output values, and backing out the optimum prices. A solution to this constrained maximum problem is called "quasi-optimum" because it is a second-best solution forced upon us by the revenue requirement.

The second-best pricing rule is applicable in situations where a regulator wants to maximize social welfare whilst at the same time ensuring that the regulated monopolist's costs are adequately covered (the requirement that k = 0). Total surplus is given by the gross consumers' surplus minus the total costs of production:

$$W(p,x) = \left(\int_0^{x_1} p_1(x_1)\,dx_1 + \cdots + \int_0^{x_n} p_n(x_n)\,dx_n \right) - C(x_1, \ldots, x_n)$$

$$W(p,x) = \sum_i \left(\int_0^{x_i} p_i(x_i)\,dx_i \right) - C(x_1, \ldots, x_n)$$

Forming the Lagrange function, we have

$$\mathscr{L} = \sum_i \left(\int_0^{x_i} p_i(x_i) dx_i \right) - C(x_1, \ldots, x_n) + \lambda \left(\sum_{i=1}^{n} p_i \, x_i - C(x_1, \ldots, x_n) \right)$$

where λ is the Lagrange multiplier.

The first-order conditions on x are

$$\frac{\partial \mathscr{L}}{\partial x_i} = p_i - \frac{\partial C}{\partial x_i} + \lambda \left[\left(p_i + x_i \frac{d p_i}{d x_i} \right) - \frac{\partial C}{\partial x_i} \right] = 0$$

$$\left(p_i - \frac{\partial C}{\partial x_i} \right) + \lambda \left(p_i - \frac{\partial C}{\partial x_i} \right) + \lambda \left(x_i \frac{d p_i}{d x_i} \right) = 0$$

$$\left(p_i - \frac{\partial C}{\partial x_i} \right) (1 + \lambda) = -\lambda \left(x_i \frac{d p_i}{d x_i} \right)$$

$$\left(p_i - \frac{\partial C}{\partial x_i} \right) = \frac{\lambda}{(1 + \lambda)} \left(- x_i \frac{d p_i}{d x_i} \right)$$

Dividing by p_i and rearranging yields

$$\frac{p_i - \frac{\partial C}{\partial x_i}}{p_i} = \frac{\lambda}{(1 + \lambda)} \left(- \frac{x_i}{p_i} \frac{d p_i}{d x_i} \right)$$

$$\frac{p_i - \frac{\partial C}{\partial x_i}}{p_i} = \left(\frac{\lambda}{1 + \lambda} \right) \frac{1}{\varepsilon_i} \qquad i = 1, \ldots n$$

where ε is the (absolute value) elasticity of demand.

This is the standard Ramsey pricing result, which indicates that the percentage markup of price over marginal cost should be inversely proportional to the elasticity of demand. In general, the Ramsey solution is a mixture of marginal-cost pricing and monopoly pricing. Monopoly is in a second-best equilibrium, between ordinary monopoly and perfect competition; that is, the Ramsey solution goes part but not all of the way towards monopoly pricing.

2.3. Is price discrimination desirable from a social point of view?

As we have just seen, Ramsey prices are based upon price discrimination. The question that arises is then whether price discrimination is desirable from a social point of view.

The effect upon social welfare of third-degree price discrimination was first investigated by Joan Robinson (1933), who demonstrated geometrically that if a single-price monopoly that sells to two markets and whose costs are constant is allowed to discriminate in price between each, its total output would not alter if the demand curves of both markets were linear. Subsequently, Schmalensee (1981) and Varian (1985) were of the opinion that a necessary condition in order that price discrimination should increase social welfare (defined as a producers' and consumers' surplus) is that output should increase. Without this prerequisite third-degree price discrimination could result in a net loss in efficiency. Within this context, Yamey (1974) stated that economic welfare is less affected, or resources are distributed less inefficiently, when profit-maximizing quantity with price discrimination is higher than without it. The profitability of price discrimination in practice depends upon costs and efficiency in separating sub-markets and controlling resale between them.

Water supply is a typical case of a natural monopoly, due to the fact that in both its regulation and distribution there are scale economies, with submarkets being distinguished according to their use (domestic, agricultural, industrial or energy-producing) and each involving different elasticities as far as demand is concerned, for which reason a third-degree price-discrimination model such as that suggested by Ramsey is applicable. If we also bear in mind the cost-recovery principle demanded by the Directive, with no price discrimination the irrigation sector would be subject to a considerable increase in the regulatory price, which would, in Sumpsi Viñas' opinion (1998), imply a significant reduction in the area of land irrigated, which would then have to be turned over to unirrigated crops with a fall in agricultural production and a concomitant decline in social welfare.

Pigou (1920) pointed out that the production of some goods that could not be produced profitably under purely competitive conditions may give rise to a net benefit to society in an economic setting of decreasing average costs (scale economies).

3. Regulatory tariff charged by the reservoirs at Quéntar and Canales

3. 1. The current calculation of the tariff

The regulatory tariff is intended to return hydraulic infrastructure costs and offset the expenses incurred in the operation, exploitation, maintenance and administration of these hydraulic works supported by the Administration, and is paid by those who benefit from the service at its upper reaches: water management companies, councils, irrigation groups, industries and so on. The tariff includes three main items:

1. The costs of operating, exploiting and maintaining the reservoirs.
2. The costs of administering the Basin Organization.
3. The annual depreciation charge on the investments entered into.

In this section we set out the regulatory tariff charged directly by the reservoirs at Quéntar and Canales in the province of Granada for supplying water for urban use[2] and for irrigation[3]. The tariff charged per cubic metre at the reservoirs for urban use and irrigation in 2009[4] is detailed in Table 1. To calculate the regulatory tariff charged by the Quéntar and Canales reservoirs we used the data set out in the annual records for the year 2009, to which we were allowed access by the Technical Management Board of the Guadalquivir Water Confederation. The tariff is the price charged per cubic metre of water released by the reservoir calculated to recover the three items of expenditure mentioned above. The price of water, or the tariff charged, was about 6 cents per cubic metre supplied (0.059807 €/m^3). Irrigation was responsible for 27.6% of this figure (0.0165 €/m^3), whilst urban usage paid the remaining 72.4% (0.0433 €/m^3). We set out below the principle technical details used to calculate the tariff charged for the water services in question.

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[2] Provision of water to Emasagra, the firm responsible for managing the water supply to the city and to three other municipalities in the urban area of Granada: Dúdar, Cenes de la Vega and Pinos Genil.

[3] The supply provided by the reservoirs at Quéntar and Canales to the Central Users' Syndicate of the River Genil (4,024 ha) and the Irrigation Group of the Ochava and Marachatalar District (81 ha) in the plain (vega) of Granada.

[4] The tariff for irrigation is charged per hectare and so it is necessary to know the number of units delivered to the irrigators.

Table 1. Calculation of the Regulatory Tariff for 2009

Expenses	Total Euros	Share of the Tariff		
		Total	Urban supply	Irrigation
a) Operating and exploitation costs and reservoir maintenance:				
Quéntar and Canales reservoirs	883,874.15	0.028029 €/m^3 100%	0.018747 €/m^3 80.60%	0.009282 €/m^3 19.40%
b) Administration of the Basin Organization:	399,498.15	0.010596 €/m^3 100%	0.010434 €/m^3 98.81%	0.000162 €/m^3 1.19%
Quéntar and Canales reservoirs				
c) Annual depreciation charge of the investment:				
Canales reservoir	545,532.36			
Quéntar reservoir	112,113.07			
Total	657,645.43	0.021182 €/m^3 100%	0.014122 €/m^3 66.67%	0.007060 €/m^3 33.33%
TOTAL	1,941,017.73	0.059807 €/m^3 100%	0.043303 €/m^3 72.40%	0.016504 €/m^3 27.60%

N.B. Total water provided during 2009 = 56,472,500 m^3 (urban supply: 38,000,000 m^3; irrigation: 18,472,500 m^3).

Regulatory tariff for the Quéntar and Canales reservoirs in 2008 and 2009. Table drawn up by the authors from information supplied by the Technical Management Board of the Guadalquivir Water Confederation.

3.1.1. Operating, exploitation and maintenance costs

The operating, exploitation and maintenance costs of the Quéntar and Canales reservoirs were € 883,874.15, calculated on the basis of the interannual improvements achieved in supply and irrigation[5]. The share of the total cost charged by these two reservoirs, according to criteria laid down by the Guadalquivir Water Confederation, is 80.6% for urban supply and 19.4% for irrigation.

3.1.2. Administration costs of the Basin Organization

The administration costs of the Basin Organization (in this case the Guadalquivir Water Confederation) for both reservoirs were € 399,498.15, divided between urban supply and

[5] Improvement refers to the flow provided by the reservoir over that of the river itself at any one moment.

irrigation in different proportions from the expenses detailed above. This organization takes into account both the percentage of the improvement over the total water consumed and also the interannual improvements in urban supply and irrigation of the entire number of reservoirs under its management.

3.1.3. Annual depreciation charge

The revised text of the Water Act sets out a formula to calculate compensation to the state for its investments in water projects. This includes all the expenses incurred in drawing up the projects themselves, the main and subsidiary construction work, expropriations and compensation payments and all the investment expenses in general, whether or not of prime import. The Act fixes a technical depreciation period of 50 years in the case of dams and reservoirs. The annual depreciation charge consists of applying an annual discount rate of 4% to a taxable base obtained by subtracting the technical linear depreciation during the year from the total investment, which can be written as[6]:

$$Taxable\,base\;\;for\,the\;year\;n = \frac{50 - n + 1}{50} * Total\;investment$$

where *n* is the number of years, with a value of from 1 to 50. To fix the current value of the investments the Act establishes an updating factor on the annual depreciation charge calculated according to the excess above 6% of the legal interest on money in force during the corresponding financial year. The Technical Management Board of the Guadalquivir Water Confederation obtained a depreciation charge on their investment for the year 2009 of € 112,113.07 for the reservoir at Quéntar and € 545,532.36 for the reservoir of Canales, i.e. a total of € 657,645.43 (Table 1).

3.2. Alternative calculation of the annual depreciation charge

In the previous section we saw the current tariff charged for water supplied by the reservoirs of Quéntar and Canales. Nevertheless, the third item included in the calculation, that of the annual depreciation charge on the investment, is calculated in nominal rather than real terms

[6] According to the stipulation in art. 300 of the Regulation of the Public Hydraulic Domain (RD 849/1986) section c.

and takes no account of inflation. Although it is true that the Guadalquivir Water Confederation applies the formula included in the Water Act, this way of compensating the investment made by the state is arbitrary and makes little financial sense; it rather corresponds to the paternal idea of extending and protecting irrigated land, which was initially applied at the beginning of the 20th century (Rodríguez-Ferrero, 2001; Rodríguez-Ferrero *et al*., 2010).

The equation in the previous section hardly compensates the state in that after 50 years the quantity recovered, in euros at the value of each year, will be 1.02 of the original outlay, and thus it is quite clear that if the annual depreciation charges were calculated in real terms the amount invested would not be completely recovered. To illustrate this we shall simulate a water works at an initial cost of one million euros, to be repaid in 50 years under different scenarios (Table A1). An economic analysis of water use, such as that demanded by the Directive, would require that these organizations charged a tariff that took inflation into account, which will influence the calculation of the technical depreciation charges of the expenditure on the work.

In this section we propose an alternative financial equation to calculate the annual depreciation on the investment. If we bear in mind that the state may not charge interest on money invested in works for public welfare but may recover the total cost of its outlay in real terms in accordance with the principle established in the Directive, we believe that we must make a different type of calculation in which the annual depreciation charges are estimated taking inflation into account, and thus we have undertaken an alternative estimation of these annual depreciation charges on the basis of a price index[7].

In fact, it can be seen in the simulation shown in Table A1 that by discounting the annual depreciation quotas at different updated rates, such as 3.5% and 4.0% for example, the quantity recovered by the Water Confederation would be 81% and 76% of the investment respectively, whilst with our proposal the percentage would always be higher, 102% and 94% in either case. With our proposed rate (using an discount rate of 3.5%) the annual repayments for the year 2009 would be € 166,206.36 for the Quéntar reservoir and € 871,279.8 for that at Canales, i.e. a total of € 1,037,486.16 (Table 2). To these figures it is

[7] To bring the tariff base up to date we use the deflator of the PIB with an average price growth rate of 3.5%.

necessary to add the operating, exploitation and maintenance costs, together with the administration of the Basin Organisation, to arrive at a total expenditure of € 2,320,558.

Table 2. Items of expense included in the calculation of the regulatory tariff (€)

	2009	
	Normal practice C.H.Guadalquivir	Our Proposal with Recovery Costs
	Costs of operating, exploiting and maintaining the reservoirs	
Canales and Quéntar reservoirs	883,874.15	883,874.15
	Cost of administering the Basin Organization	
Canales and Quéntar reservoirs	399,498.15	399,498.15
	Annual depreciation charge on the investments made	
Canales reservoir	545,532.36	871,279.80
Quéntar reservoir	112,113.07	166,206.36
Total	657,645.43	1,037,486.16
Total Costs	1,941,017.73	2,320,858.46

Table drawn up by the authors from information provided by the Technical Management Board of the Guadalquivir Water Confederation. Regulatory tariff charged by the reservoirs at Quéntar and Canales, 2008 and 2009.

4. Calculating the regulatory tariff using Ramsey's equation and the recovery of costs in constant euros

4.1. Water Services: Rule for Quasi-Optimum Pricing

The Water Framework Directive requires member states to take account of the principle of recovery of the costs of water services. The different water uses (residential *vs* non-residential) shall deliver an adequate contribution to the recovery of the costs of water services. As long as demands between these two groups are sufficiently independent, Ramsey pricing is a useful policy guide. The second-best pricing rule, specifically designed for utility firms where marginal costs of many or most outputs are below average costs, requires that the percentage deviation of price from marginal cost for each water service be inversely proportional to its price elasticity of demand:

$$R = \frac{\frac{(P_R - MC_R)}{P_R}}{\frac{(P_N - MC_N)}{P_N}} = \frac{E_N}{E_R} \qquad [1]$$

where E_R and E_N are the demand elasticity coefficients for residential water services (urban water services) and non-residential (irrigation) respectively; P_R and P_N are the real (quasi-optimum) prices charged and *MC* is the marginal cost (In our case, as the water for both uses derives from the same source the marginal cost is analogous). Thus, in Equation [1] $MC_R = MC_N$.

According to this result, social welfare will be served most effectively not by setting prices equal or even proportional to marginal costs, but by causing unequal deviations in which water services with elastic demands are priced at levels close to their marginal costs. The prices of water services showing inelastic demands diverge from their marginal costs by relatively wider margins. In short, the price of urban water services must exceed marginal cost to a greater degree than that of agricultural services for the Ramsey ratio (*R*) to be optimum[8].

At the same time, the optimization of tariffs under equilibrium service conditions (second best) demands that the total revenue should equal total costs, in other words, the following budgetary restriction must apply:

$$Y_R P_R + Y_N P_N = TC\ (Y_R Y_N) \qquad [2]$$

where Y represents the quantities of water supplied for the different uses.

4.2. Estimating the regulatory tariff

As stated above, Ramsey prices require that both the marginal cost and elasticity be known. In our case we can define the marginal cost as the increase in the total cost divided by the increase in the water supplied during 2008 and 2009. To calculate these we have taken into account the three important items included in the regulatory tariff (annual depreciation charges in real terms, operating costs and reservoir maintenance, and the general administration costs of the Basin Organization) for the two years in question (in 2008 the total costs were € 2,109,418.12 and in 2009 € 2,320,858.46). The difference in cubic metres provided can be put down to the fact that in 2008 38 hm^3 was supplied for urban use whilst, due to the severe drought that year, only 550 m^3/ha was supplied to the 4,105 ha of irrigated

[8] Generally speaking, λ/(1+λ) is defined as the “Ramsey number” given by *R* , which should be the same for both urban and agricultural consumers.

land. In 2009 the same quantity of water was provided for urban use but this was added to by an increased quantity of 4,500 m^3/ha for irrigation. Once the marginal cost has been estimated the following step is to calculate the price elasticity of demand. To this end we must know the function of the water demand. Studies into this problem use econometric techniques to relate water consumption as far as possible to its price and other explicative variables. One commonly used procedure is to estimate a doubly logarithmic equation which results directly in elasticity estimations. The price elasticity values for water demand are estimated mainly for urban (Arbués *et al*., 2003; Dalhuisen *et al.*, 2003) and industrial water demand (Reynaud, 2003). The authors find in general that this demand is quite inelastic, although the estimated values vary widely according to the study in question. As far as Spain is concerned, from an analysis of a temporal series of data concerning water demand for urban use in Sevilla (Andalucia) Martínez- Espiñeira (2007) found that price elasticity of demand turned out to be –0.1 in the short term[9].

Investigations into price elasticity for irrigation water are, however, harder to find in economic publications, although one work on the subject has been published recently by Scheierling *et al.* (2006). Here the authors look into the reasons for the variations in the empirical estimations of price elasticity in irrigation-water demand and on the basis of information collected in the USA since 1963, which includes the results of mathematical programming, field experiments and econometric studies, estimate an average price elasticity of -0.48 for the demand for irrigation water.

This absence of publications relating to Spain means that we been obliged to estimate the value for price elasticity of the demand for water in the irrigated areas that depend upon the reservoirs at Quéntar and Canales. Our source of information is a report, *Elasticidad de la*

[9] The study of price elasticity for residential water demand in the province of Granada would require a whole research project in itself, based upon surveys among the residents of Granada and its metropolitan urban surrounds, which is clearly beyond the scope of our study here. Nevertheless, we consider the work of Martínez-Espiñeira (2007) to be relevant to our own study because Granada lies in the same region of southern Spain, has the same climate and shares similar levels of income and life-styles. In fact, in 2002 this same author had estimated the price elasticity for urban water demand in the north of Spain and arrived at values very similar to those he found for Sevilla (Andalucia)

demanda de agua de riego y efecto de los precios de los servicios de agua, (Elasticity of demand for irrigation water and the effect of water supply prices), contained in a work by the Economic Analysis Group of the Rural and Marine Environment (2008). From the data obtained from this work and using a doubly logarithmic equation to determine the function of irrigation-water demand in this area we calculated that the elasticity value is one of –0.29. The technical details of the calculation are set out in Annex 2.

Once we have the basic data for the calculation, the Ramsey prices can be arrived at by solving the following system of equations:

$$\left.\begin{array}{r} \dfrac{\dfrac{(P_R - 0.01304)}{P_R}}{\dfrac{(P_N - 0.01304)}{P_N}} = \dfrac{-0.29}{-0.10} \\[2em] 38{,}000{,}000\,P_R + 18{,}472{,}500\,P_N = 2{,}320{,}858.46 \end{array}\right\}$$

Resolving the system

$$P_R = 0.0525182 \text{ €/m}^3$$

$$P_N = 0.0176028 \text{ €/m}^3$$

$$\mathrm{P_T} = P_R + P_N = 0.07121 \text{ €/m}^3$$

On resolving the system we get that the regulatory tariff that the Water Confederation ought really to charge in 2009 is one of € 0.07 per cubic metre of water supplied, i.e. a little over € 0.01 per cubic metre more than the tariff actually charged at the moment. This cost would be divided between the 25.1% paid by the irrigation groups at 0.0176 €/m^3) and the 74.9% charged to urban supply at 0.0525 €/m^3.

If this is compared with the regulatory tariff paid in fact in 2009, it would increase by 21.28% for urban use, whilst irrigators would only have to pay 6.65% more (Table 3). This goes to confirm the theoretical results predicted by Ramsey's formula for calculating prices in as far as it discriminates between users of a good according to price elasticity, with the higher tariff falling to those whose demand is more inelastic, in our case, residential compared to agriculture.

Table 3 Details of the regulatory tariff as calculated according to the different options

	Total regulatory tariff		Urban supply	Irrigation
The Technical Management Board of the Guadalquivir Water Confederation (CHG)	0.0598 €/m3	Share % Distribution	0.0433 €/m3 72.4%	0.0165 €/m3 27.6%
Recalculation by Ramsey pricing and recovery of outlay	0.070 €/m3	Share % Distribution % ∆ s/Tariff CHG	0.0525 €/m^3 74.9% 21.28%	0.0176 €/m^3 25.1% 6.65%

Table compiled by the authors.

5. Conclusion

The growing difficulties involved in extracting ever greater quantities of water from the environment, for diverse reasons, including among others the high cost of building hydraulic infrastructures and factors conditioning the environment, demand that we use this resource efficiently, an obligation addressed in the European Water Framework Directive, which states in its Article 9 that the costs of water provision must be recovered in their entirety. Nevertheless, in Spain this aim to recover the costs of supplying water has still to be achieved, in the same way that pricing should provide suitable incentives for a rationalization of the use of water, as laid out in the Directive. In fact, the degree of cost recovery for providing all the services involved in supplying water in Spain vary between 65% and 95%, depending upon the service, the users and the basin in question (Ministry of the Environment, 2007).

The results of our study demonstrate that the Guadalquivir Water Confederation does not at the moment recover all the costs of its investment in infrastructure because the depreciation charge is calculated in nominal rather than real terms. We have calculated a new annual depreciation charge using Ramsey's equations, which, if applied, would lead to the Confederation's recovering the costs involved in its provision of water in 2009. In fact, the total cost per cubic meter that should be charged is one of 0.0701 €/m^3, somewhat more than a cent above the rate currently charged of 0.0598 €/m^3. Of this tariff, 74.9% would be charged for urban use and 25.1% for irrigation. i.e. 21.28% and 6.65% respectively above the present tariff. This result confirms the theoretical predictions of Ramsey pricing, which is that users whose demand is less elastic should pay a higher price, in this case, urban users as opposed to irrigators.

Whatever the case, we have been unable to include in our analysis environmental and opportunity costs, which are also required by the Directive. In fact, it is far from easy to calculate these costs because we are dealing with reservoirs built in the 1970s, and so we are probably underestimating the costs of water services. We find ourselves without doubt in a field still open to considerable discussion and research if we are to achieve the objectives proposed by the Directive. At present all new reservoir projects are incorporating environmental costs into their budgets but not opportunity costs, although a recent law allows transactions between concessionaries and non-concessionaries, which makes this calculation more complicated. Finally, a good way of passing on a reduction in prices to the users for the supply of water at its origin is by controlling operating costs, and above all those of administration, and thus efficient management is the key to reducing costs and eventually the tariff charged.

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Annex 1. Simulation of the annual depreciation charge on the initial investment

Let us suppose an investment of one million euros. The depreciation period is one of 50 years, beginning the year following that in which the reservoir comes into service. The annual depreciation charge will be 4% of the investment and thus will finally amount to 200% of the initial outlay, and thus, according to the current regulation included in the Water Act, taking into account the technical depreciation in the value of the reservoir, the quantity of the investment is reduced every year linearly from the real value of the work (first year) to one fiftieth part in the final year. Thus, the amount recovered on the investment will be one million and twenty thousand euros (the sum of column 3), or, 102%. Nevertheless, this example is not entirely representative due to the considerable time-lag between the initial investment and its recovery via the tariff. Both depreciation because of inflation and the lower value of the deferred payments should be taken into account. The Guadalquivir Water Confederation, however, does not take inflation into account, merely correcting the annual depreciation charges by applying to them the legal interest rate in excess of 6%, for which reason, if the current value of the investment is brought up to date, this will not be recovered.

The proposal we make here, on the other hand, takes into account inflation for each financial year in its correction of the annual depreciation charge. To this end we have presumed a constant rate of inflation of 3.5%. To compare the Confederation´s present recovery of its costs with those resulting from our proposal, we have discounted for the time being the annual depreciation charge. In fact, it can be seen in Table A1 that if we discount, or bring up to date, the annual depreciation charge by either 3.5% or 4%, the amounts recovered by the Confederation will be 81% and 76% of the investment respectively (*cf.* columns 5 and 6), whilst on the basis of our proposal these percentages will always be higher, at 102% and 94% respectively (*cf*. the two right-hand columns).

Table A1. Different depreciation schemes								
Investment	**Year**	**Depreciation Normal practice CHG**	**Discounted depreciation Normal practice CHG**			**Discounted depreciation Recovery cost**		
1,000,000	0	$\frac{50-n+1}{50}\times 4\%\times Investment$	Annual depreciation charge by legal interest less 6.0%	Discounted Investment Discount Rate 3.5%	Discounted Investment Discount Rate 4.0%	Annual depreciation charge GDP Deflator (Average Inflation 3.5%)	Discounted Investment Discount Rate 3.5%	Discounted Investment Discount Rate 4.0%
	1	40,000	41,800	40,583	40,192	41,400	40,000	39,808
	2	39,200	42,398	39,579	39,199	41,992	39,200	38,824
	3	38,400	42,778	38,584	38,030	42,575	38,400	37,849
	4	37,600	43,144	37,597	36,880	43,147	37,600	36,882
	5	36,800	43,493	36,620	35,748	43,707	36,800	35,924
	6	36,000	44,249	35,997	34,971	44,253	36,000	34,974
	7	35,200	44,996	35,367	34,194	44,784	35,200	34,032
	8	34,400	45,733	34,730	33,416	45,298	34,400	33,099
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	45	4,800	7,078	1,505	1212	22,571	4,800	3,864
	46	4,000	5,898	1,212	971	19,468	4,000	3,205
	47	3,200	4,718	937	747	16,119	3,200	2,551
	48	2,400	3,539	679	539	12,513	2,400	1,904
	49	1,600	2,359	437	345	8,634	1,600	1,263
	50	800	1,180	211	166	4,468	800	629
Total		**1,020,000**		**810,412**	**758,332**		**1,020,000**	**939,783**
Recovery costs (Percentage)				**81%**	**76%**		**102%**	**94%**
Table compiled by the authors from information provided by the Technical Management Board of the Confederación Hidrográfica del Guadalquivir								

Annex 2. Measuring the price elasticity of water demand for irrigation purposes

An exponential regression model $Y_i = \beta_1 X_i^{\beta_2} e^{u_i}$ can be expressed as $\ln Y_i = \ln \beta_1 + \beta_2 \ln X_i + u_i$, which is known as a doubly logarithmic equation and has an interesting characteristic in that it demonstrates that the estimated coefficient β_2 measures the elasticity of *Y versus X*, i.e. the percentile change in *Y* against a percentile change in *X* (Gujarati, 2003). As far as the demand for irrigation water is concerned, the data afforded by the Economic Analysis Group of the Ministry of the Environment for the irrigated land in the municipality of Granada are set out in the two left-hand columns of Table B2. The first column shows the price of irrigation water (P) in €/m^3 and the second column shows its consumption rate (q) in cubic hectometres, which is translated into cubic metres (Q) in column 3. In the two right-hand columns we calculate the natural logarithms both for the price (LNP) and the consumption (LNQ) of the water.

Table B1. Water prices and consumption

P	q	Q	LNP	LNQ
0.50	92.20	92200000	-0.69314718	18.3394707
0.48	92.20	92200000	-0.73396918	18.3394707
0.46	92.20	92200000	-0.77652879	18.3394707
0.44	92.90	92900000	-0.82098055	18.3470342
0.44	93.98	93980000	-0.82098055	18.3585926
0.44	92.87	92870000	-0.82098055	18.3467112
0.43	96.04	96040000	-0.84397007	18.3802753
0.42	99.40	99400000	-0.86750057	18.4146627
0.42	100.88	100880000	-0.86750057	18.4294422
0.41	104.72	104720000	-0.89159812	18.4668007
0.40	106.94	106940000	-0.91629073	18.4877785
0.39	111.10	111100000	-0.94160854	18.5259413
0.39	111.14	111140000	-0.94160854	18.5263012
0.38	115.60	115600000	-0.96758403	18.5656465
0.34	117.20	117200000	-1.07880966	18.5793924
0.27	117.20	117200000	-1.30933332	18.5793924
0.24	117.20	117200000	-1.42711636	18.5793924
0.23	123.51	123510000	-1.46967597	18.6318327
0.22	127.10	127100000	-1.51412773	18.6604847
0.13	127.50	127500000	-2.04022083	18.6636269

The results of the regression are set out in Table B2. The value for price elasticity is one of -0.29 (statistically significant coefficient).

Table B2. Price elasticity of demand for irrigation water

	Coefficient	*t-ratio*	*p-value*
Constant	18.1781	395.6528	0.0000
LNP	-0.2893	-6.8590	0.0000
R^2	0.72		
F	47.05		
Critical value F	0.0000		
Observations	20		