

Devising irrigation water tariffs with overconsumption penalties

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Abstract

The paper analyses an irrigation water tariff model to control overconsumption by implementing effective penalties that can be seen as a supplementary tool to crop-specific quotas. This progressive pricing system is based on the financial loss that farmers would face when having to reduce their irrigation water consumption in order to comply with the commitment to achieving more restrictive quotas. Results show that a single fixed price system (with a flat rate) is costlier to farmers than the differentiated tariff system, which distinguishes the amount of water that exceeds the established allocation from the quantity below. This system of irrigation water pricing and overconsumption penalties, aimed specifically at each crop, facilitates efficient utilisation and the ability to adjust this consumption to resource availability and current economic and market situations, especially in response to crop subsidies. The practical barriers to implementing differentiated tariffs per crop with overconsumption penalties are the availability of irrigation water marginal productivity and net profit functions, and having to install technological equipment to control the water being used by individual farmers.

Additional key words: irrigation allocation; optimum water use; water management; water productivity; water value.

Resumen

Diseño de tarifas del agua de riego con sanciones al consumo excesivo

Este trabajo analiza un modelo de tarifas de agua de riego útil para disuadir consumos excesivos, a través de un sistema de sanciones eficientes, como instrumento de control complementario al de cuotas específicas de cultivo. Este sistema de precios progresivos se basa en la disminución de ganancias que habrían de afrontar los regantes cuando ajustan sus riegos a unas cuotas más restrictivas. Los resultados muestran que un sistema de tarifa única es más costoso para el agricultor que un sistema de tarifas diferenciadas, por el que se distingue entre el consumo por encima y por debajo de la cuota permitida. Este sistema de precios del agua y sanciones a los consumos en exceso, específico para cada cultivo, contribuye a lograr un uso eficiente de este recurso, ajustándolo a su disponibilidad, a la coyuntura de los mercados y a los subsidios a los cultivos. Para su correcta aplicación, es preciso conocer las funciones de productividad y beneficio marginal del agua de riego para cada cultivo y zona, y también la instalación de un adecuado equipamiento que permita el control individualizado de los volúmenes utilizados por los usuarios.

Palabras clave adicionales: asignación y uso óptimo del agua de riego; gestión del agua; productividad del agua; valor del agua.

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Abbreviations used: EMC (environmental marginal cost); NIS (New Israel Shekel); NPB (net private benefit); NPMB (net private marginal benefit); PC (private costs); PC_r (private costs related to the water fee); PC_{nr} (private costs of water not related to the water fee); PC_{NW} (private costs not related to water); PC_w (private costs related to water); PI (private income); PMC_r (private marginal costs related to the water fee); RMC (resource marginal cost); SMC (social marginal cost); WFD (Water Framework Directive).

Introduction

Water stressed regions, such as the Mediterranean and other arid regions in the world, are often faced with a situation in which available water resources are not sufficient to meet all the demands for water-related goods and services as different demands compete for water. Generally, the ownership or use of scarce resources generates major competitive advantages, thus creating a surplus. The sustainable management of the resources requires the administration to play an active role in order to satisfy all demands including environmental uses and to maintain competitive processes, constantly adjusting all companies' economic activities to market demands and to the resources available (Charhbaghi and Lynch, 1999).

In shortage situations, in which excessive water consumption might lead to negative effects on the environment, the conceptual idea of the cost of resources becomes more important. As Ferrer and La Roca (2006) point out, in arid or semi-arid regions it would make sense to manage these episodes by splitting the losses between users and ecosystems.

The Water Framework Directive 2000/60/CE (OJ, 2000) (WFD) requires member countries to conduct economic analyses of water uses in order to implement the program of measures. The WFD also requires the principle of *water related services costs recovery* to be applied, including the environmental and the resource-related costs, the latter being associated with the opportunity costs that are equivalent to the economic value of the opportunities waived when allocating the resource to a given user (Berbel *et al.*, 2007).

Molle (2009) concludes after a wide review of cases, that rational management is achieved mainly by implementing clear, flexible quotas, which can also be adapted to fluctuations in water availability by carrying out multiannual preventive drought management. The economic losses due to reduced supply would make it unnecessary to recover environmental costs.

Furthermore, WFD encourages the use of pricing as an effective tool for regulating use, managing sustainable consumption and conserving the resource (Cornish and Perry, 2003; Hellegers and Perry, 2004). Navarro *et al.* (2007) state that installing water meters and establishing tariffs for crop-specific allocations that help to adjust doses and burden the actual use, would permit water saving and reward efficient farmers while sanctioning the inefficient ones. Pricing is especially useful when optimum allocations are surpassed, since it can

help to reduce water consumption sharply. This is very important in water shortage situations.

This paper examines the use of optimal pricing for irrigation water demand, as well as the use of optimal penalties to sanction water consumption that exceeds crop-specific quotas. As is explained in greater detail, these penalties can be fixed by estimating the loss of profit that may result from reducing water consumption to accurately defined quotas. This calculation can only be made when functions of marginal value or net marginal profit of water are available for each crop in every area.

Optimum social allocations of irrigation water

Irrigation water is considered an economic asset and consequently the cost associated with its supply, use or management and the perceived benefits should be considered when drawing up water pricing policies (Altmann, 2007). The WFD encouraged the analysis of water service cost recovery in compliance with Articles 5 and 9, and Appendix III. The cost associated with water use can be classified into three types: *financial cost*, related to water services, include provision and management cost, operational and maintenance cost, or capital cost; *environmental cost* means the cost of the negative impact that the unsustainable use of water resources has on the environment; *resource cost* means the opportunity cost associated with the losses that users face when resources cannot be used, due to overexploitation or depletion.

These different cost types determine the rational use of such resources as irrigation water, in the optimum social situation, which theoretically occurs when the net private marginal benefit (*NPMB*) and the social marginal cost (*SMC*) are the same ($NPMB = SMC$). Pearce and Turner (1995) show a similar model developed to deduce the socially optimum use of a natural resource or the optimum pollution level. However, the price of the end product is considered instead of the price of one of the inputs, as it is in this case with water.

According to these authors, social marginal cost is defined as the combination of environmental marginal cost (*EMC*) and the user marginal cost, the latter being equivalent to the resource marginal cost (*RMC*). Eq. [1] summarizes this definition:

$$NPMB = SMC = EMC + RMC \quad [1]$$

This can be seen in Figure 1, where q^* represents the amount of irrigation water that must be used in socially optimum conditions. Therefore, along with Eq. [1] the water consumed by irrigation in a socially optimum situation means that the private marginal profit is equivalent to the social marginal cost.

The analytical complexity involved in estimating the environmental and resource costs is mainly due to the difficulty in measuring external factors. The quota system is extensively used by way of a practical solution, because it is the system that is conducive to the suitable use of water while minimising external factors, theoretically because the quota setting is based on resource availability and the environmental flows required for good ecological and chemical status.

However, on the basis of the marginal value of water, integrating the area under the *NPMB* curve between two levels of irrigation water, provides a good estimation of the economic benefits associated with water use (measured as profit from water use).

Although demand curves have been developed using different methodologies in Spain (e.g. Berbel and Gomez-Limón, 2000; Berbel *et al.*, 2009), there have been very few studies relating net marginal profit of irrigation water on the basis of water supply at crop level, as most of the research estimates demand at farm level based upon a mixture of crops (e.g. Gomez-Limón *et al.*, 2001; Navarro *et al.*, 2007).

As an example of this type of study, Figure 2 shows a *NPMB* curve for irrigation water in Navarra (autonomous community located in northeastern Spain). We estimate this curve by ordinary least squares regression

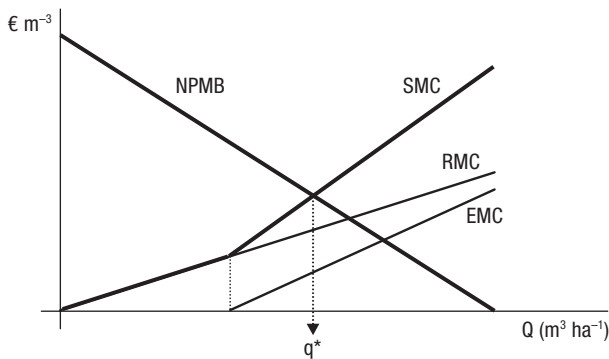


Figure 1. Socially optimum irrigation water allocation (q^*) Q ($\text{m}^3 \text{ha}^{-1}$) = irrigation water; *NPBM* (€ m^{-3}) = net private marginal benefit; *SMC* (€ m^{-3}) = social marginal cost; *RMC* (€ m^{-3}) = resource marginal cost; *EMC* (€ m^{-3}) = environmental marginal cost. Source: Own preparation.

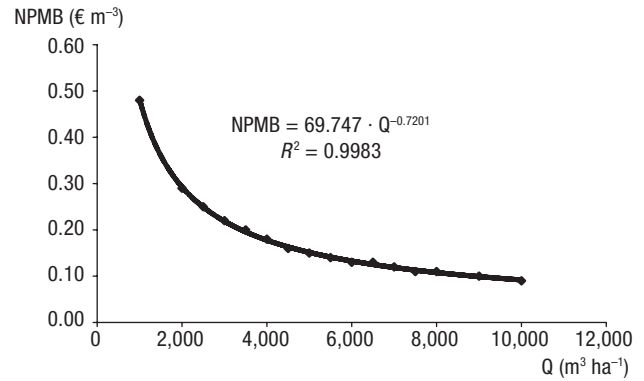


Figure 2. Estimated marginal value of irrigation water (*NPMB*) based on the allocation (Q) for Navarra. Source: Own preparation from Riegos de Navarra (2009).

using data on per hectare water allocation and gross margin per cubic meter taken from Riegos de Navarra (2009). Gross margin is defined as the difference between the total income and direct cost. Gross margin per cubic meter is calculated as the ratio between per hectare gross margin and per hectare water allocation. The *NPMB* curve in Figure 2 is not exactly the marginal value of water but it may be considered as a first approximation of the marginal value of water function in Navarra, as an average for all irrigated crops and areas there.

Pricing systems for irrigation water

In order to develop an operational methodology for optimal pricing, the farmers' net private benefit (*NPB*) may be broken down into the following Eq. [2]:

$$\begin{aligned} NPB &= PI - PC = PI - (PC_{NW} + PC_W) = \\ &= PI - [PC_{NW} + (PC_{nf} + PC_f)] \end{aligned} \quad [2]$$

where PI = private income; PC = private costs; PC_{NW} = private costs not related to water; PC_W = private costs related to water; PC_{nf} = private costs of water not related to the water fee; and PC_f = private cost related to the water fee.

Water price should be greater than the financial cost of water services, since the aim is not only to apply the cost recovery principle, but also to include the environmental and social cost as Eq. [1] proposes. The value of PC_f is defined by $PC_f = F_w q$, as long as F_w represents the rate or water use fee that should be collected per cubic metre; then $PMC_f = F_w$. That volumetric fee, F_w , considered by some authors as an "admin-

istrative price” of water, can take several forms. Consequently we may define the following tariff systems:

i) A single ‘flat rate - per area’ fee is used, regardless of the water consumption; this would be the case for an irrigation surface based fixed fees system.

ii) A single fee is used for every unit of water which is used, regardless of the total water consumption: $F_w = k$.

iii) Different fees are calculated individually per quotas or by consumption groups, a block-rate system with block tariffs as a type of step-wise volumetric charges:

$$\begin{aligned} F_w &= k_1 \leftrightarrow q < Q_1 \\ &k_2 \leftrightarrow Q_1 < q < Q_2 \\ &k_3 \leftrightarrow Q_2 < q < Q_3 \\ &\dots \end{aligned}$$

iv) A completely progressive fee system is preferred: $F_w = m(q) \cdot q$, or any other non-linear function that increases as q increases, so that ‘ $m(q)$ ’ is the volumetric fee (€ m⁻³, depending on ‘ q ’).

Penalties by charging higher fees for water use would be introduced when a certain optimum allocation is exceeded. By definition, this is the case in iii) and iv), since the unit price or volumetric fee increases directly as use increases, either in a discrete (step-wise) or a continuous fee system.

It is customary in most irrigation schemes to distribute the available water following an egalitarian criterion, so that farmers choose crops and cropland on the basis of this availability. This means that some crops may receive more than the average doses while others are irrigated in deficit or even in a rain-supplied situation. One alternative is to assign crop-specific quotas, on the basis of the crops’ theoretical needs and, should allocations be reduced, redefine these quotas on the basis of the consequent loss of profit.

An example of block-rate system, seen in MARM (2008), was proposed in Navarra where consumption exceeding more than 10% and up to 20% leads to a water fee increase of 300%, and consumption over 20% of allocation leads to a 500% increase in price. A crop-specific pricing system for irrigation water is also presented in MARM (2008), together with a simple calculation methodology: differences in water needs between certain crops and the ones consuming least water (grain cereals) are established. Then, taking the water fee for the latter as the benchmark, correlative

fees can be proposed on the basis of the differences in water needs. Such a methodology for designing quotas and fees may be based upon Water Planning Technical Guidelines (Ministerial Order ARM2656/2008 published in BOE, 2008), where acceptable net water necessities are indicated for several crops groups and for each hydrographic district.

This system of crop-specific quotas, together with progressive pricing, has been successfully used in the Jordan Valley, where it has not only helped to obtain some saving in water use, but has also encouraged farmers to upgrade their irrigation systems (Molle *et al.*, 2008). In Israel, a distinction is made between types of agricultural water on the basis of its quality, average prices being charged for high quality water, partially salty water and treated waste water. A differentiated pricing system based on an original 1989 reference quota is now established for at least the first type: up to 50% of that allocation is charged at NIS¹ 0.691 m⁻³; from 50 to 80% of it, at NIS 0.833 m⁻³, representing a tariff increase of 20.5%; and for consumptions over 80%, NIS 1.118 m⁻³, equivalent to a raise of 61.8% from the original price (Fernández Buckley, 2001).

Methodology

Calculating fees and efficient overconsumption penalties

The following methodology is based on establishing penalties for water consumption over the optimum allocations, as a way of achieving efficiency in irrigation. It is essential to define the quota itself, which should be crop-specific and correlated to water reserves. To simplify matters, it will be assumed that there are no crop changes in the area used as an example.

Penalties are established using the obtainable net private marginal profit curve for a crop, (*NPMB*), as a function of the water used q . Therefore, when establishing suitable tariffs to control overconsumption it is required that: i) the *NPMB* curve must enable the user to estimate, specifically for every point, the marginal profit yielded by the level of used water; ii) integration of the *NPMB* curve up to a level of water use provides the economic profit that can be attributed to that water use. Therefore, the model will only be reliable if these *NPMB* curves are accurately defined.

¹ NIS (New Israel Shekel) would be changed in 2010: 1 NIS = 0.35 €.

Figure 3 illustrates the point when an allocation q_0 is set so high that it involves external factors and opportunity costs, hence it should be reduced to q_1 , which could be called “critical”. Even so, as long as the water fee is low enough, farmers would rather keep the original water use q_0 , over q_1 , as it would enable them to carry on making extra profit, shown in the shaded area below the *NPMB* curve between q_1 and q_0 and with a value given by:

$$NPB_1^0 = \int_{q_1}^{q_0} NPMB(q) dq - \int_{q_1}^{q_0} f_0 dq \quad [3]$$

where f_0 is the water fee farmers pay.

This extra profit for a given individual farmer can be seen by the rest of the farmers as an unwanted cost, in the sense that they would be deprived of using that extra amount $q_0 - q_1$; therefore this cost valuing NPB_1^0 is the cost of a $q_0 - q_1$ water resource.

On this basis, if the objective is to achieve an efficient consumption in the interest of saving water resources, a pricing system that suitably taxes the use of water over and above new given quotas could be introduced, in order to deter farmers from consuming too much water. Therefore, it is necessary for the penalty or fee increase that would be imposed to be greater than unfair profit: $S_1^0 > NPB_1^0$. Charging this penalty would make it feasible to recover the cost of the resources arising from the $q_0 - q_1$ overconsumption.

This penalty could be applied either to the whole consumption, with one single extra fee to be added to the original, or only to the surplus, to which an additional fee is applied exclusively (differentiated fees per consumption groups), which seems to be the more

reasonable option. As can also be seen in Figure 3, when considering the effective penalty, the area $f_0AB(f_a+f_0)$ should be larger than the shaded area for the first case, and the rectangular area *ACDE* should be larger than that shaded area for the second option.

Once the efficient q_1 quota is approved, the efficient fee to be charged for the irrigation water actually used, q , can be calculated for both systems. In the two cases, if the allocation is observed ($\forall q < q_1$), there would be no penalty ($S_1^q = 0$), so, the initial fee f_0 would remain unchanged.

a) *Single fee system*

$\forall q \leq q_1$, the original fee, f_0 , remains unchanged.

$\forall q > q_1$, a new flat and single rate, f_a , for the entire amount used is added to f_0 (the penalty is applied to the whole water quantity without distinction).

f_a can be obtained with the following formula:

$$S_1^q > NPB_1^q \rightarrow q \cdot \int_{f_0}^{f_a} df > \int_{q_1}^q NPMB(q) dq - \int_{q_1}^q f_0 dq \quad [4]$$

Integrating and isolating f_a :

$$f_a > \frac{NPB(q) - NPB(q_1)}{q} + f_0 \frac{q_1}{q} \quad [5]$$

When the *NPMB* function is linear, the previous expression could be restructured as:

$$f_a > \frac{m \cdot (q^2 - q_1^2)}{2 \cdot q} + k \frac{(q - q_1)}{q} + f_0 \frac{q_1}{q} \quad \forall NPMB(q) = m \cdot q + k \quad [6]$$

where $m(q)$ is the slope of that straight line

$$(m = \frac{\partial NPMB(q)}{\partial q}) \text{ and } k \text{ is its independent term.}$$

The penalty concerned will be determined by the difference between the amount to be paid with this new tariff and the amount originally paid:

$$S_1 > f_a \cdot q$$

b) *Differentiated fees system*

$\forall q \leq q_1$, the original f_0 fee is applied.

$\forall q > q_1$, a new f_b tariff is added to f_0 , which is applied exclusively to overconsumption $q - q_1$ (for the part that remains under q_1 , f_0 is applied). On the basis

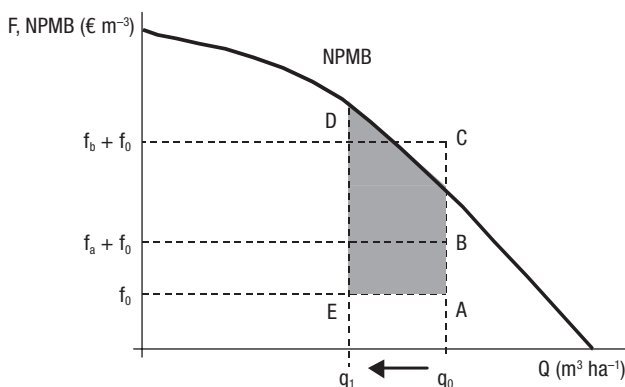


Figure 3. Fees and overconsumption penalties (*F*) established on the basis of the obtainable net private marginal benefit (*NPMB*) from water allocation (*Q*). Source: Own preparation.

of the above, f_b can be calculated from the following formula:

$$S_i^q > NPB_i^q \rightarrow (q - q_1) \cdot \int_{f_0}^{f_b} df > \int_{q_1}^q NPMB(q) dq - \int_{q_1}^q f_0 dq \quad [7]$$

Then, considering that:

$$(q - q_1) \cdot \int_{f_0}^{f_b} df = (f_b - f_0) \int_{q_1}^q dq \quad [8]$$

the following is obtained:

$$(f_b - f_0) \int_{q_1}^q dq + f_0 \int_{q_1}^q dq > \int_{q_1}^q NPMB(q) dq \quad [9]$$

Integrating and isolating f_b :

$$f_b > \frac{NPB(q) - NPB(q_1)}{q - q_1} \quad [10]$$

When the $NPMB$ function is linear, the above expression can be rewritten as:

$$f_b > \frac{m \cdot (q^2 - q_1^2)}{2 \cdot (q - q_1)} + k \quad \forall NPMB(q) = m \cdot q + k \quad [11]$$

where m is the slope of the straight line

($m = \frac{\partial NPMB(q)}{\partial q}$) and k is its independent term.

The penalty concerned will only sanction overconsumption, with this new fee, the following expression

being used (for the consumption under the q_1 quota the original tariff is applied):

$$S_2 > f_b (q - q_1)$$

Case study: irrigated olive groves in the Guadalbullon River Sub-basin

This section applies the model described to a case study involving irrigated olive groves in the Guadalbullon River Sub-basin, in the Upper Guadalquivir Basin (Southern Spain). The aforementioned sub-basin is affected by specific water scarcity problems, because it is not regulated yet still supplies major irrigation areas, especially olive groves. The marginal profit function for irrigation water in Figure 4 has been obtained by applying a regression analysis to the original data on water production function in Mesa-Jurado *et al.* (2010), where these authors adapt the water production function used by Moriana *et al.* (2003) to the Guadalbullon area and production system.

In some Guadalquivir olive grove areas such as Guadalbullon, a water allocation of $1,500 \text{ m}^3 \text{ ha}^{-1}$ is available, but in the Guadalbullon Sub-basin, this crop rarely has such amounts at its disposal. The average quota for the last four years was around $1,000 \text{ m}^3 \text{ ha}^{-1}$, according to the information obtained from some irrigation communities. Figure 4 shows the marginal value or $NPMB$ function of water, once the variable production costs (including the cost of irrigation and harvesting) have been deducted from the marginal

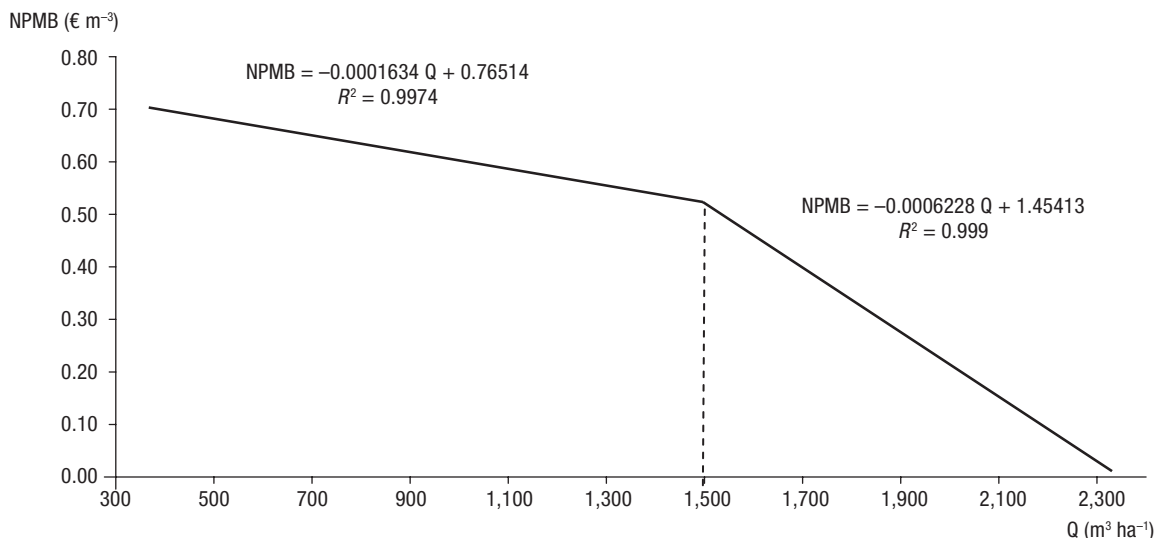


Figure 4. Water marginal value or net marginal profit vs. water allocation for Guadalbullon River Sub-basin olive grove. Source: Own preparation from Mesa-Jurado *et al.* (2010).

income. Since the economic value of water in agriculture can be measured by the profit farmers obtain from a given amount of this resource, for irrigated olives groves in the Guadalbullon River Sub-basin the marginal value amounts to € 0.60 m³ ha⁻¹ for an annual allocation of 1,000 m³ ha⁻¹, and € 0.53 m³ ha⁻¹ for 1,500 m³ ha⁻¹ (average 2005-2008 data series analysed). This calculation reveals how the *NPMB* function changes its gradient as a consequence of the law of diminishing marginal returns.

The discontinuity in the curve around 1,500 m³ ha⁻¹ is due to the saturation of the system with the present density of 100 trees ha⁻¹. Obviously, this is an estimation of the performance of an average farm but it is considered to reasonably reflect the performance of irrigated olive groves in the Upper Guadalquivir Basin.

Results

In accordance with the theoretical fundamentals explained above, the pricing system to be introduced in order to limit overuse in a given allocation, can be calculated once the *NPMB* function is estimated by a regression for irrigated olives groves in the Guadalbullon River Sub-basin. The penalty imposed is calculated as shown in previous sections of this paper, bearing in mind that in this case, m is different depending on whether q is over or under the critical allocation (1,500 m³ ha⁻¹), which defines the *NPMB* inflection point. Both pricing systems results are explained at the end of the paper. However, the way that the differentiated fees for the consumption groups are calculated is explained in detail below.

Calculating differentiated fees for the case study

i) Assuming that the aim is to reduce the original allocation $q_0 = 1,500$ m³ ha⁻¹ to $q_1 = 1,000$ m³ ha⁻¹; for calculation purposes, this is equivalent to stating that when breaking this limitation by using $q = 1,500$ m³ ha⁻¹, an overuse of 500 m³ ha⁻¹ is being made. Since $q_1 < 1,500$ m³ ha⁻¹, $NPMB(q) = -0.0001634 q + 0.76514$ is presented (see Figure 4). So it holds that:

$$m = \frac{\partial NPMB(q)}{\partial q} = 0.0001634$$

In this case, when imposing tariffs for consumptions over the new allocation ($q > q_1$), fees should be applied exclusively to the excess ($q - q_1$). Therefore:

$$f_b > \frac{m \cdot (q^2 - q_1^2)}{2 \cdot (q - q_1)} + k = € 0.5609 \text{ m}^{-3}$$

As a result, the 500 m³ of overused resources would be sanctioned with the following penalty:

$$S_2 > f_b (q - q_1) = € 280.43 \text{ ha}^{-1}$$

ii) Let's assume that the original allocation is $q_0 = 2,000$ m³ ha⁻¹, and the aim is to cut it down to $q_1 = 1,500$ m³ ha⁻¹; for calculation purposes, if the quota is exceeded by $q = 2,000$ m³ ha⁻¹, there is again an overconsumption of 500 m³ ha⁻¹. Now, $q_1 > 1,500$ m³ ha⁻¹ and $NPMB(q) = -0.0006228 q + 1.45413$ (see Figure 4), so it holds that:

$$m = \frac{\partial NPMB(q)}{\partial q} = 0.0006228$$

Therefore, the extra charge to be applied to the quota exceeding the proportion ($q - q_1$) would be:

$$f_b > \frac{m \cdot (q^2 - q_1^2)}{2 \cdot (q - q_1)} + k = € 0.3643 \text{ m}^{-3}$$

The 500 m³ ha⁻¹ of overused resources would be sanctioned in the following way:

$$S_2 > f_b \cdot (q - q_1) = € 182.16 \text{ ha}^{-1}$$

These results and those for the equivalent single fee system are shown in Table 1. It can be seen that penalties are applied only when the quotas are surpassed. Considering an original fee of $f_0 = € 0.35$ m⁻³, the consequences of complying with the established q_1 allocation are considered.

The last column in this table shows the cost of water a farmer would have to pay for irrigating one olive grove hectare, with both pricing systems, when the respective penalties are applied. It can be seen in this column that the differentiated fees system involves a lower cost.

Discussion

The use of water tariffs and quotas has been widely studied in literature and suitable results have been achieved for the purpose of reducing consumption when farmers find that the value of water is unequal

Table 1. Example of tariffs (f), overconsumption penalties (S) and water cost (W) under single fee and differentiated fees systems. Source: Own preparation

Scenario	q_0	q_1	NPMB(q)	f (€·m ⁻³)	S (€·ha ⁻¹)	W (€·ha ⁻¹)
Single fee system						
$\forall q \leq q_1$	1,000			$f_0 = 0.35$	$S_i^0 = 0$	$W_i^0 = f_0 \cdot q_0 = 350$
$\forall q > q_1$	1,500	1,000	$-0.0001634 q + 0.76514$	$f > f_0 + f_a = 0.7703$	$S_i^0 > f_a \cdot q_0 = 630.43$	$W_i^0 > f_0 \cdot q_0 + S_i^0 = 1,155.43$
$\forall q \leq q_1$	1,500			$f_0 = 0.35$	$S_i^0 = 0$	$W_i^0 = f_0 \cdot q_0 = 525$
$\forall q > q_1$	2,000	1,500	$-0.0006228 q + 1.4541$	$f > f_0 + f_a = 0.7036$	$S_i^0 > f_a \cdot q_0 = 707.16$	$W_i^0 > f_0 \cdot q_0 + S_i^0 = 1,407.16$
Differentiated fee system						
$\forall q \leq q_1$	1,000			$f_0 = 0.35$	$S_i^0 = 0$	$W_i^0 = f_0 \cdot q_0 = 350$
$\forall q > q_1$	1,500	1,000	$-0.0001634 q + 0.76514$	only to $q_0 - q_1$: $f > f_0 + f_b = 0.9109$	$S_i^0 > f_b (q_0 - q_1) = 280.43$	$W_i^0 > f_0 \cdot q_0 + S_i^0 = 805.43$
$\forall q \leq q_1$	1,500			$f_0 = 0.35$	$S_i^0 = 0$	$W_i^0 = f_0 \cdot q_0 = 525$
$\forall q > q_1$	2,000	1,500	$-0.0006228 q + 1.45413$	only to $q_0 - q_1$: $f > f_0 + f_b = 0.7143$	$S_i^0 > f_b (q_0 - q_1) = 182.16$	$W_i^0 > f_0 \cdot q_0 + S_i^0 = 882.16$

Note: calculations for $f_0 = € 0.35 \text{ m}^{-3}$.

(see *e.g.* Chohin-Kuper *et al.*, 2002; Rieu, 2005; Rodríguez-Ferrero *et al.*, 2008).

This paper explains a water tariff system that implements effective penalties aimed at controlling overconsumption. It can be regarded as a tool that is supplementary to crop-specific quotas since this progressive pricing system is based on the loss of income that farmers would face when adjusting their irrigation amounts to more restrictive quotas. The fundamentals of this economic system are conducive to fulfilling the commitment of recovering the cost of the water service, although its achievements and effects should be carefully tested in practice.

The sustainable management of natural resources should be achieved through allocating them in a socially optimum way, as has been explained in this paper. This means minimising the private and social cost associated with such resources. Consequently, i) quotas ought to be assigned on the basis of the water requirements for each crop, depending on where it is grown and the irrigation system used; ii) penalties for overuse should be higher than the potential profit that those irrigated areas could yield, so that they will either dissuade users from consuming excessively, or to make it possible to recover the cost of the extra resources that have been consumed.

The study focused on the Guadalbullon River Sub-basin has shown that a single fixed price system (with a flat rate) is costlier for the farmer than the differentiated fees system, which makes a distinction between the amount that exceeds the established allocation and the quantity below that allocation. This irrigation water pricing and overconsumption penalties system, both of which are crop-specific, makes it easier to achieve efficient consumption and to adjust this consumption to the resource availability and current economic and market situations, especially in response to crop subsidies.

There are two practical barriers to implementing differentiated tariffs per crop with overconsumption penalties: both crop-specific functions of the marginal value of irrigation water and measurement of the water used by individual farmers are essential. With respect to this, it should be pointed out that the water legislation currently in force in Spain encourages farmers to install metering devices (Order ARM/1312/2009, published in BOE, 2009). Research in this field should be encouraged, with a view to obtaining a better understanding of the economic value of water in agriculture and so that socially effective economic tools can be devised to control water consumption. Further research should also be conducted into estimating water re-

sources availability, so that the regulating quotas can be constantly updated in response to this availability.

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