Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar
doi: http://dx.doi.org/10.5424/sjar/20110904-498-10

Spanish Journal of Agricultural Research 2011 9(4), 957-970
ISSN: 1695-971-X
eISSN: 2171-9292

Pigouvian taxation to induce technological change and abate nonpoint pollution in the Ebro Basin, Spain

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Abstract

The implementation of policies to control nonpoint pollution is a complicated task because the lack of information about the biophysical processes and the asymmetric information between social planner and polluters. The objective of this paper is to evaluate the efficiency of using an input tax instrument (water tax) with a non-uniform tax rate to abate nonpoint pollution. This water tax instrument generates a reduction in the pollution level, and induces farmers to adopt abatement practices such as better irrigation technology systems. The model presents theoretically and empirically the salinity pollution problems in the Ebro Basin (Northeast of Spain). Farmers are heterogeneous in crop types, irrigation technologies, and biophysical field characteristics. Because of this heterogeneity each farmer generates a different level of emissions, so farmers should be taxed differently. In this analysis, the social planner implements two tax rates according with farmers' irrigation technology. Using a non-uniform tax rate, pollution emissions are reduced and farmers are induced to change their irrigation technology towards a more efficient one. The use of a more efficient irrigation technology increases social welfare and generates a cutback in the emission loads.

Additional key words: bioeconomic model; heterogeneous farmers; irrigation-based water tax; salinity; water pollution.

Resumen

Impuesto Piguviano para incentivar un cambio tecnológico y controlar la contaminación difusa en la Cuenca del Ebro, España

La contaminación difusa de origen agrario se caracteriza generalmente por la escasez de información sobre los procesos biofísicos que la generan y por un problema de información asimétrica entre regulador y agricultores. Estas características hacen que el diseño de las políticas de control sea especialmente difícil, ya que el regulador no dispone de suficiente información para utilizar los instrumentos más eficientes. El objetivo de este artículo es evaluar la eficiencia de un instrumento no uniforme sobre el input contaminante. Este instrumento basado en impuestos sobre el input genera una reducción en el nivel de contaminación, a la vez que incentiva al agricultor a adoptar tecnologías que reduzcan las emisiones, como son los sistemas de riego por aspersión. El modelo analiza teórica y empíricamente los problemas de contaminación por sales existentes en una región de la cuenca del Ebro. Los agricultores de la zona son heterogéneos en el uso de tecnologías de riego, tipo de cultivos y en las características biofísicas de sus parcelas. En consecuencia, cada agricultor genera un nivel distinto de emisiones y por tanto cada uno debería ser gravado con un impuesto diferente. En este análisis, el regulador introduce dos tipos de impuestos en función de la tecnología de riego utilizada. La ventaja de este instrumento es una reducción en las emisiones además de incentivar el cambio hacia una tecnología de riego más eficiente, que permita un menor uso de input contaminante. El cambio de esta tecnología incrementa el bienestar social y genera una reducción importante de la carga de emisiones de sales.

Palabras clave adicionales: agentes heterogéneos; contaminación de los recursos hídricos; impuesto sobre el agua; modelo bioeconómico; salinidad.

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Received: 15-12-10. Accepted: 06-10-11

Introduction

One of the main problems related with the control of agricultural pollution is the choice of the best policy to reduce the level of emissions. A common type of agricultural pollution is nonpoint pollution. It occurs when the point from which the pollution is emitted is unidentifiable, so typical characteristics of this class of pollution are the difficulty in identifying who is causing the emissions, the amount of pollution loads, and the location from which these emissions have been discharged. The lack of knowledge and randomness in biophysical processes, and also the existence of asymmetric information between regulators and polluters, impose important difficulties in regulating nonpoint pollution.

There are a large number of policy instruments available to control agricultural pollution, and the choice between them depends on the type and characteristics of the problem at hand. Pioneer studies about nonpoint pollution are the studies by Griffin and Bromley (1982), Shortle and Dunn (1986), and Segerson (1988). The first two studies focus on the use of input-based instruments to control nonpoint pollution. The input that originates the emissions is taxed, so the use of this input decrease and farmers compensate society. Segerson (1988) focuses on the use of ambient-based instruments. However, a difficulty of the Segerson's approach is that in most cases the regulator does not have enough information about the pollution that each agent is emitting of nonpoint pollution. As a consequence, the implementation of an ambient tax is quite difficult, so the alternative is the use of input tax policies. One characteristic of agricultural pollution is the presence of different dimensions that require the implementation of diverse instruments. Following Bennear and Stavins (2007), the use of multiple policy instruments can be justified in such a *second-best* world.

Saline emissions are a type of nonpoint pollution from agriculture. The use of saline water in irrigation areas, or the use of saline soils in agricultural production, generates a leaching and runoff of saline minerals into water bodies that degrade water quality. When salinity is present in irrigation water, salts accumulate in the root zone of the plants and affects negatively crop productivity. The problem of salinity is an important issue in irrigated agriculture worldwide; the irrigated acreage degraded by salinity problems reaches 80 million hectares, which is 30% of all irrigated land in the world. In Spain the acreage affected by salinity is around one million hectares, of which 312,000 ha are located in the Ebro Valley (Alberto *et al.,* 1986).

This study analyzes the efficiency of a water tax policy to abate salinity emissions loads from agriculture in the Ebro Valley. A group of heterogeneous agents produce several crops on different soils and using different irrigation technologies. The soils are categorized as saline, moderate saline, and non saline. Because farmers' irrigation, saline and moderate saline soils generate an important leaching of salts that goes into the rivers and other plots causing damages to ecosystems. In the case of the Ebro Basin, large quantities of dissolved salt enter annually into the Ebro River. The origin of these saline substances is surface leaching from the geologic formations of the basin. The augmented salinity of the river is affecting several ecosystems and can cause major damages to downstream users.

In this work, a water tax is suggested to reduce saline emissions from irrigation agriculture in the Flumen Basin (sub-basin of the Ebro Basin). Farmers in this area mainly use two irrigation technologies, flood and sprinkler. Sprinkler is more efficient that flood because it uses less water to produce the same output, so both water returns and salt emissions are smaller. Social planner can identify the irrigation technology of each farmer, and then different tax rates by irrigation technology can be implemented. Farmers using a more efficient irrigation technology should pay a smaller tax than farmers using a less efficient technology. The results of the model highlight how the implementation of an irrigation-based tax rate generates an increase in social welfare. With this tax instrument, the social planner limits the level of saline emissions to the Ebro River. Besides, it is also an incentive for farmers to change their irrigation technology to a more efficient one.

Methodology

Different policies can be applied to control nonpoint pollution. Ambient-based instruments are charges or

Abbreviations used: CIRCE (Centro de Investigación de Recursos y Consumos Energéticos); ECe (electric conductivity); EPIC (Environment Policy Integrated Climate); GAMS (General Algebraic Modeling System) subsidies based on the pollution of the water bodies. This kind of instrument is more efficient because the tax is on the emissions that arrive at the water media and cause the direct damages. In this line Segerson (1988) proposed a tax-subsidy instrument that fixes an environmental standard, and penalizes farmers when they emit over the standard or subsidizes farmers when they emit below the standard. This standard is measured in water bodies. The penalization or compensation depends on the total level of emissions in the water bodies for the whole group of farmers, since it is impossible to know the individual contribution of each one.

The problem with these policies is to obtain information about the transport and fate processes of salt loads between farmers' plots (source pollution) and water bodies (ambient pollution). The impact of a contaminant substance on ecosystems depends on several factors as the geology of the region, type of substance, climatic factors, etc. This information is rarely available in real world situations, so the implementation of ambient taxes is normally unfeasible.

An ambient-based instrument could be efficient in the salinity control problem, but would require the precise measurement of the quantity of saline materials that reach the river. It would also be necessary to identify the different impacts of each farmer's emissions, because their soil characteristics vary. Therefore, the social planner needs to know the soil characteristics of all farmers, which is unfeasible in practice at a reasonable cost.

Following the approach proposed by Griffin and Bromley (1982), if policy-makers want to implement a regulation to control nonpoint pollution, they need to take into account the biophysical information about the production alternatives and the emissions. These authors proposed the implementation of an input tax to control nonpoint pollution in a multiple farmer model. These authors establish that the regulator has information about the farmers' profit function and can estimate the emission function. Under the assumptions of no transaction costs and perfect information about the farmers' technology and runoff function, Griffin and Bromley show that an input tax is an efficient policy instrument to control nonpoint pollution[1].

The model begins with the private maximization problem. Farmers maximize the benefits obtained from crop production less the fix and variable costs. In the absence of regulation farmers choose the input vector x to maximize their private net benefit function. This model has a unique productive input, which is the irrigation water that farmers use. In this case, farmers are not taking into account the negative externality that their activity generates, and their choice problem is:

$$Max\ \Pi_{ci}(x) = p_c \cdot f_{ci}(x) - p_x \cdot x - F_c \qquad [1]$$

This formulation represents the maximization of the private benefit of the different farmers, where p_c is the output price, $f_{ci}(x)$ is the production function that is different by each farmer and depends on the choice of input x, the variable cost is $p_x \cdot x$, and F_c are the fixed costs of production that depend on the type of crop. The index c shows the type of crop (alfalfa, corn, or wheat), and the index i shows the type of irrigation system technology (flood or sprinkler).

The emission and production functions are different for each farmer due to different characteristics of soil, crop, and technology. The model assumes that farmers are risk-neutral and all the prices are exogenous variables determined by the market. This model also assumes that the regulator can observe the type of crop and the irrigation technology of each farmer, but cannot identify the soil type.

The first order condition of the private problem describes the farmer's choice of production activities. This expression represents the typical economic rule where marginal benefits equal marginal costs. In this case, farmers ignore the negative externality caused by their activity:

$$\Pi'_{ci} = p_c \cdot f'_{ci} - p_x = 0 \qquad [2]$$

Environmental damage costs are the alteration in the ecosystems caused by the leaching and runoff of harmful substances from lands into the water bodies. The damage function $D = D(r)$ is an increasing function of leaching ($D'(r) > 0$). The nonpoint pollution emission is a deterministic function of the polluting input, $r_{is}(x)$. The index s shows the type of soil of each farmer. Therefore, leaching function depends on the irrigation and soil type. The damage function is linear and can be expressed as $D[r_{is}(x)] = d \cdot r_{is}(x)$, where d is the economic value of the emissions. It is assumed that the damage function is additive, where the marginal damage

[1] Griffin and Bromley do not address two issues: the fact that nonpoint pollution is a stochastic process driven by stochastic variables affecting water runoff (such as weather); and the lack of information on nonpoint pollution emissions loads because of the scarce knowledge about the pollution transportation and fate processes.

for one farmer does not depend on the pollution emissions' function of the other farmers. The total damage is the sum of the individual damages of each farmer.

The social planner's problem includes the farmers' private benefits and costs, and also the pollution externalities. This problem depends on the crop type *c*, the irrigation system *i*, and the soil type *s*. The social planner's problem is thus to:

$$Max\ SP_{cis} = \sum_{c,i,s} (\Pi_{ci}(x) - d \cdot r_{is}(x)) \qquad [3]$$

The first order condition of the maximization problem is:

$$SP'_{cis} = \Pi'_{ci}(x) - d \cdot r'_{is}(x) = 0 \qquad [4]$$

This condition shows that the marginal private profits of using one additional unit of input must be equal to the marginal cost (variable costs and environmental damage) of using this input. In the absence of regulation, farmers will produce until their marginal net benefits are zero (Eq. [2]). In the social planner's problem, the internalization of damages means that marginal private net benefits must equal marginal damages (Eq. [4]).

The regulator may introduce a water tax in the farmers' private problem (Eq. [1]) to force agents to internalize the external costs. With the tax, the farmers' problem consists in maximizing private benefits less the water tax, where t_{is} is the tax rate.

$$Max\ NB_{cis} = \Pi_{ci}(x) - t_{is} \cdot x \qquad [5]$$

The first order condition is equal to:

$$NB'_{cis} = \Pi'_{ci}(x) - t_{is} = 0 \qquad [6]$$

When the tax is equal to the marginal damage, the first order condition is equivalent to the one obtained in the social planner problem (Eq. [4]). The regulator could induce farmers to internalize the external costs by using a water tax equal to the marginal damage. The tax rate obtained is the Pigouvian rate. Equations [4] and [6] show that in order to induce efficient decisions, the regulator should set the tax rate equal to the value of the marginal environmental damage, *i.e.:*

$$t_{is} = d \cdot r'_{is} \qquad [7]$$

This analysis shows the first-best policy that can be applied to abate nonpoint pollution. Since the type of soil determines the quantity of saline substances that the farmers emit, the optimal tax rate must be different for each farmer. In the context of this work, the problem of implementing a first-best policy is the difficulty in identifying the type of soil of each farmer, so the tax rate can only be differentiated by the irrigation technology.

Other difficulties are the existence of transaction and administrative costs. Additionally the scarcity of information makes difficult to implement an input tax with differentiated tax rates for each type of farmer. Usually, regulators use a uniform tax rate for all agents, while trying to minimize the inefficiency. This is a second-best policy because the most efficient alternative would be to implement different tax rates reflecting the heterogeneity in pollution between agents, but the transaction costs and political hindrances make this alternative unfeasible.

The approach of this work is to study the use of a second-best policy to reduce pollution in the Ebro Basin. In this model regulator can differentiate farmers by irrigation technology but not by soil type, so it is no possible to achieve the first-best. The objective of the study is to analyze a water tax over heterogeneous agents, comparing the efficiency of a uniform tax versus irrigation-based tax (non-uniform). The water tax in this model depends on the irrigation technology; a more efficient technology a lower tax will be paid.

Study area

The Ebro River is the longest river with the biggest hydrographic basin in Spain. It covers 20% of the surface of Spain. The Ebro Basin is located in the northeast Spain and extends over an area of 85,362 km^2, with a longitude of 910 km.

The climate in this area is continental with extreme temperatures, very cold winters and very warm summers. The rainfall is around the national mean with 550 mm a year, distributed between the seasons of spring and autumn. It is important to highlight the frequent presence of a wind called "cierzo", with a high drying power, which gives rise to large evapotranspiration, accentuating the dryness of the area. It is thus necessary to use irrigation to provide supplementary water to the rainfall. A total of 780,000 ha in the Ebro Basin are dedicated to irrigated agriculture. This is 28% of the total cultivated area. The agriculture in this area is characterized by a large difference across farmers in terms of both crops and irrigation systems.

The salinity in the Ebro Basin is originated from geological processes related to the formation of this region. The problem has worsened with irrigation, which increases water circulation in soils and generates larger exports of salts that further deteriorate the water quality of the Ebro River. In this context salinity emissions to ecosystems are generated by the leaching of salts from the soil. The irrigation water that is used in the Ebro is a good quality one, so the problem is not because the use of saline water but rather the salinity into the soils. The salinity in the study area is identified from the study "Reconocimiento Territorial de Aragón" from the early 1980's. With the information of soils and their electric conductivity (ECe), a ranking of soils has been made (Table 1 shows the soil typology in the area).

The area of interest in this study is the Flumen Basin (sub-basin of the Ebro River Basin). The Flumen River flows into Ebro River, and is located in the northeast part of the Aragon region. The conversion to intensive agriculture in this area has generated the inefficient use of irrigation water that generates saline return flows to the ecosystems. It is also one of the rivers inside the Ebro Basin with the highest salinity levels. The returns from the irrigation districts in the Flumen Basin have high salinity loads, which come from the geological materials that form this area soils.

The Flumen Basin extends over 85,510 ha of the Ebro Basin where 54,469 ha are from agriculture. Irrigation agriculture extends approximately over 35,900 ha. The prevailing irrigation technology is surface or flood irrigation (26,500 ha), followed by sprinkler (11,300 ha) and drip (900 ha). The main crops planted in the Flumen Basin are corn (8,830 ha), alfalfa (9,600 ha) and barley (9,400 ha). Other important crops planted are wheat (2,200 ha), and rice (1,850 ha). In this paper we only consider three crops: corn (*Zea mays* L.), alfalfa (*Medicago sativa* L.) and wheat (*Triticum aestivum* L.). With respect to the salinity, a 34% of the soils are non-saline, around a 36% have a moderate salinity problem, and a 29% of them have high salinity problems.

Empirical model

This section describes the bio-economic model used in the analysis. There are different production and pollution functions for each type of farmer. Production functions depend on the type of crop produced (corn, wheat or alfalfa),[2] irrigation system (flood or sprinkler), and type of soil (saline, moderate saline or non saline). The pollution functions also depend on the type of soil and the irrigation technology. So, each farmer is different depending on his/her farm characteristics: type of crop, type of soil, and irrigation system.

Agricultural production generates a negative externality in the Flumen Basin through water percolation in the soil that brings salinity loads to river courses. This salinity affects the aquatic ecosystems and water users downstream. When farmers do not take into account the harmful effect that they are causing the farmers' private profit is:

$$\Pi_{ci} = p_{ci} \cdot y_{ci} - p_{xi} \cdot x - k_c + s_c \qquad [8]$$

where $y_{ci} = f_{ci}(x)$, in this model farmers produce a crop y_{ci}, with only one productive input that is the irrigation water use x, which also is the contaminant input. The crop and input market prices[3] are respectively p_c, p_x, and k_c and s_c are the fixed cost of production and subsidies that different crops receive[4], the fix costs and the subsidies are crop specific.

Farmers only consider their private benefit, but not the social damage, $D(r_{is})$, from pollution leaching $r_{is}(x)$. To correct the external damage the regulator imple-

Table 1. Soil typology by saline level

Soil type	Electrical conductivity, ECe (dS m^{-1})	Soil depth ps (cm)
Saline soil	>8	120-80
Moderate saline soil	2-6	80-60
Non-saline soil	<2	60-40

[2] The crops chosen are alfalfa, corn and wheat; these are some of the most important crops in the study area, and additionally, there were available estimations of the production functions (Uku, 2003).

[3] Farmers are price-takers.

[4] This private profit (π_{ci}) is the quasi-rent, which is the difference between the production activity revenues and subsidies less the production costs as input costs, salaries, etc.

ments a water tax. With the tax the restricted private benefit (π^t_{cis}) of farmers becomes:

$$\Pi^t_{cis} = p_c \cdot y_{ci} + s_c - p_x \cdot x - k_c - t_{is} \cdot x \qquad [9]$$

where t_{is} is the tax rate that depends on the irrigation technology (i) and the soil type (s).

The introduction of the tax rate to internalize the social damage causes that the restricted private benefit depends on the type of soil too. The regulator chooses the optimal tax rate, the set of values of tax rates that are equal to the marginal damage that each farmer is generating. As the marginal damage is different by each farmer the tax rates too. Social welfare $SW_{cis}(x)$ is given by the expression:

$$SW_{cis}(x) = \sum_{c,i,s} (\Pi^t_{ci} + t_{is} \cdot x) \qquad [10]$$

Social welfare is the restricted private benefit function plus the tax that society receives. This tax goes directly to the society as compensation for the emissions that agents generate.

The production functions take a quadratic polynomial specification. This specification is common in the literature due to its properties of substitution between inputs, maximum level of production, and no convergence problems in estimation.

$$f_{ci}(x) = \alpha_{ci} + \beta_{ci} \cdot x + \delta_{ci} \cdot x^2 \qquad [11]$$

where α_{ci}, β_{ci}, and δ_{ci} are the production function parameters that depend on the type of crop and the irrigation system of each farmer.

The parameters of production functions have been calculated from the estimations of Uku (2003). In his work, Uku calculate the data to estimate different production functions, among them for wheat, corn, and alfalfa, with the EPIC (Environment Policy Integrated Climate) crop growth simulation package. EPIC simulates the relationship between the crop growth and variables as soil, weather, water use, and crop management. The EPIC model has been calibrated to represent the crop production functions in the study area. The results of the model have been tested with two systems surveys distributed to farmers in the Ebro basin and checking the result with field experiments. Table 2 shows the parameters of the production functions for corn, alfalfa and wheat under different irrigation systems (flood and sprinkler).

The pollution functions $r_{is}(x)$ relate saline emission loads with input irrigation water. The specification is linear, and is given by the expression:

$$r_{is}(x) = \gamma_{is} + \eta_{is} \cdot x \qquad [12]$$

where the parameters of this equation γ_{ci} and η_{ci} depend on the irrigation system and in the type of soil of each farmer. So, salinity loads depend on the soil salt contents and the water leaching from crop cultivation. Accordingly, different pollution functions have been defined for each combination of soil type (saline, moderate, and no saline) and irrigation system (flood and sprinkler). A total of six different functions have been calculated. Table 3 shows the values of the coefficients for the emissions functions.

The data to estimate the salinity pollution functions are obtained using the Hoffman (1986) formula, modified by Quílez (1998). The equation from Quílez relates the initial salinity in the soil with the final salinity when there is a leaching process from percolation:

$$\frac{CE}{CE_0} = \frac{cl}{\left[\dfrac{pr}{ps} + cl\right]} \qquad [13]$$

Table 2. Production functions by crop and irrigation technology

Coefficient	Corn	Alfalfa	Wheat
Flood			
α_{ci}	–5.64	–2.36	–1.42
β_{ci}	$3.06 \cdot 10^{-3}$	$2.90 \cdot 10^{-3}$	$3.02 \cdot 10^{-3}$
δ_{ci}	$-1.42 \cdot 10^{-7}$	$-1.29 \cdot 10^{-7}$	$-3.20 \cdot 10^{-7}$
Adjusted R^2	0.92	0.93	0.89
Sprinkler			
α_c	–8.00	–0.52	1.90
β_{ci}	$5.14 \cdot 10^{-3}$	$4.09 \cdot 10^{-3}$	$2.73 \cdot 10^{-3}$
δ_{ci}	$-3.03 \cdot 10^{-7}$	$-2.56 \cdot 10^{-7}$	$-3.57 \cdot 10^{-7}$
Adjusted R^2	0.97	0.97	0.81

Table 3. Pollution functions parameters by soil type and irrigation technology

Coefficients	Saline		Moderate saline		Non saline	
	Flood	Sprinkler	Flood	Sprinkler	Flood	Sprinkler
γ_{is}	–2,260.1	–1,551.4	–1,231.7	–780.9	–471.1	–281.8
η_{is}	1.797	1.017	0.827	0.449	0.286	0.150
Adjusted R^2	0.997	0.998	0.995	0.997	0.999	0.995

where CE is the soil final salt concentration, CE_0 is the initial soil salt concentration, cl is the leaching fraction, pr is the percolation, and finally ps is soil depth.

$$CE_0 - CE = CE - \left[CE \cdot \frac{cl}{\frac{pr}{ps} + cl} \right] \quad [14]$$

This equation leads to the expression:

$$s = \left\{ CE \left[CE \cdot \frac{cl}{\frac{(1-ef)\cdot x}{ps} + cl} \right] \right\} \cdot 640 \cdot 10^{-6} \cdot [(1-ef)\cdot x] \quad [15]$$

where salinity emissions s depend on the irrigation water used (x), this function also includes the effect of the irrigation system in the coefficient ef that is the irrigation system technology efficiency. The irrigation technology generates different levels of percolation, since the irrigation efficiency is 0.55 for flood and 0.75 for sprinkle. Eq. [14] was adapted by Mema (2006), from the Quílez one, to obtain values for salinity leaching in tons per cubic meter of water. This equation has been used to generate the data of salinity emissions s for quantity of irrigation water x.

Different heterogeneous farms are defined by combining the type of crop, irrigation technology, and soil characteristics. For each crop the production function is concave and the salinity pollution function is linear, and both functions only depend on the irrigation water input in a deterministic manner. The negative externality generated by the production activities of farmers affects the environment but it has no direct impacts on the other farmers. The private farmer's problem is expressed as:

$$Max\ \Pi_{cis}(x) = p_{ci}\left(\alpha_{ci} + \beta_{ci} \cdot x + \delta_{ci} \cdot x^2\right) - \\ - p_{xi} \cdot x - k_c + s_c \quad [16]$$

The fix costs and the subsidies differ for each crop type like the crops' market prices. Farmers are rational and there is not cooperation between them. Table 4 shows the values of prices, subsidies, and fixes costs. In the case of the fix costs, farmers with sprinkler have an additional cost that is the capital amortization. To change the irrigation technology farmers need to invest an important quantity of capital. The change in the technology supposes a cost about € 6,000 to 7,000 ha^{-1} by farmer (Uku, 2003). This investment is amortized in a period of 15 years that is the approximated time of duration of the irrigation technology (life of the technology). The amortization of the technology supposes an annually increase in the fix costs by farmers with sprinkler in[5] ~ € 500 ha^{-1}. This price internalizes the amortization costs of the technology, and the increase in costs like the energy or the maintenance of the technology.

The difference between the social planner's problem and the private maximization problem is the negative externality. In the social planner's problem the regulator implements a water tax and the problem becomes:

$$Max\ \Pi^{t}_{cis}(x) = p_{ci}\left(\alpha_{ci} + \beta_{ci} \cdot x + \delta_{ci} \cdot x^2\right) - \\ - p_{xi} \cdot x - k_c + s_c - t_{is} \cdot x \quad [17]$$

The difference between equations [16] and [17] is the last term $t_{is} \cdot x$, which is the water tax. The tax rate is different for each farmer since it is taxing the damage that each farmer generates.

The regulator can calculate the different tax rates by using the optimal quantity of emissions. The value of the environmental damage from salinity pollution is not known, but this value has been approximated by calculating the costs of extracting the salts from the

[5] This value is obtained dividing the approximate cost of the technological change (~ € 6,000 ha^{-1}) by the life expectancy or the service life of the technology that is ~ 15 years.

Table 4. Values of economic parameters

Parameters	Corn	Alfalfa	Wheat
p_x (€ m^{-3})	0.03	0.03	0.03
p_y (€ t^{-1})	193	115	223
k (€ ha^{-1})	1,259	733	930
s (€ ha^{-1})	100	10	60

Source: MARM (2008).

water. CIRCE (Centro de Investigación de Recursos y Consumos Energéticos, Zaragoza, Spain) estimates that the value of clean water that can be used for human consumption is[6] ~ € 0.036 kg^{-1}. This value is the price of the emission, or the economic value of the damage, that farmers cause to the ecosystems. In this model, it is the value of d.

Using information about the profit functions and the cost of cleaning salinity from water bodies, the social planner can calculate the optimal quantity of emissions and output. The social planner uses this quantity of emissions to calculate the optimal tax rate for each farmer.

Table 5 collects the values of the different taxes. These taxes are the rates that must be applied to farmers in order to obtain a socially optimal level of emissions. There are a total of six different tax rates.

The implementation of an instrument with six different tax rates is infeasible because the information problem in identifying each farmer with its soil type[7]. However, it is relatively easy for a government to know the irrigation technology that each farmer is using. So, a tax rate differentiated by irrigation technology can be implemented. The regulator identifies each farmer with its irrigation technologies and s/he applies different tax rates. The tax rates chosen are the optimal ones by moderately saline soils (with flood and sprinkler). The water tax rates are t_s = € 0.016 m^{-3} and t_s = € 0.030 m^{-3}, where t_s = taxes farmers using sprinkler and t_f = taxes farmers using flood (see Table 5).

Results and discussion

Three different scenarios were analyzed: i) baseline scenario (or non regulation), where farmers do not take into account the environmental costs of their activity; ii) first best, where six different tax rates are implemented so farmers pay the total damage of their activity; iii) irrigation-based water tax, where two tax rates by irrigation technology are implemented.[8]

The results of the model have been calculated using the program GAMS (General Algebraic Modeling System, GAMS Dev. Co.) designed for modeling optimization problems. For each scenario there are results of social welfare, farmer's profits, water use, emissions and tax payment. As simplification, we assumed that farmers are cultivating one hectare of land, therefore, all the results are per hectare.

Table 6 presents the results of the baseline scenario, when no regulation is implemented and farmers maximize their private profits without considering the pollution costs. The results of this scenario show that the crop with the highest productivity was alfalfa, followed by corn and wheat. The highest private profits were

Table 5. Water tax rates by soil type and irrigation technology

	Flood irrigation system	Sprinkler irrigation system
Saline soil	0.065	0.037
Moderately saline soil	0.030	0.016
Nonsaline soil	0.010	0.005

[6] This value is estimated by CIRCE. The cost of desalinization is € 0.030 m^{-3} and the runoff of salt is 1.2 kg m^{-3} then the extraction costs of salts are € 0.036 kg^{-1}.
[7] Furthermore, farmers can have more than one soil type.
[8] The tax rates are the optimal in the case of moderate saline soils for both irrigation technologies.

with corn followed by alfalfa and wheat. These results stay independent of the type of irrigation technology. Sprinkler technology was more efficient in the production of all crops than flood. The decrease in the emissions between flood to sprinkler was around 60% for all crops. The most contaminant crop was corn followed by alfalfa and wheat. The difference in the emission levels between irrigation technologies generated a greater reduction in the social welfare between saline, moderate, and non-saline soils[9].

Table 7 shows the simulations under the first-best scenario. Farmers internalize the total damages of their activity.[10] Comparing this scenario with the previous one it is possible to observe an increase in the social

Table 6. Farmers results by irrigation technology, soil and crop type under the baseline scenario where no regulation exists

	Saline	Moderate	Non saline
Corn Flood			
Welfare (€ ha^{-1})	403.0	723.0	894.7
Private profits (€ ha^{-1})	983.1	983.1	983.1
Water use (m^3)	10,227	10,227	10,227
Crop yield (t)	10.80	10.80	10.80
Emissions (t)	16.11	7.22	2.46
Corn Sprinkler			
Welfare (€ ha^{-1})	661.6	797.3	865.3
Private profits (€ ha^{-1})	898.3	898.3	898.3
Water use (m^3)	7,994	7,994	7,994
Crop yield (t)	12.61	12.61	12.61
Emissions (t)	6.58	2.81	0.80
Alfalfa Flood			
Welfare (€ ha^{-1})	201.8	521.2	692.5
Private profits (€ ha^{-1})	780.7	780.7	780.7
Water use (m^3)	10,208	10,208	10,208
Crop yield (t)	13.8	13.8	13.8
Emissions (t)	16.08	7.21	2.45
Alfalfa Sprinkler			
Welfare (€ ha^{-1})	865.5	597.5	660.0
Private profits (€ ha^{-1})	690.4	690.4	690.4
Water use (m^3)	7,488	7,488	7,488
Crop yield (t)	15.7	15.7	15.7
Emissions (t)	6.06	2.58	0.84
Wheat Flood			
Welfare (€ ha^{-1})	261.2	381.8	442.2
Private profits (€ ha^{-1})	471.8	471.8	471.8
Water use (m^3)	4,513	4,513	4,513
Crop yield (t)	5.71	5.71	5.71
Emissions (t)	5.85	2.50	0.82
Wheat Sprinkler			
Welfare (€ ha^{-1})	331.1	377.7	398.8
Private profits (€ ha^{-1})	408.4	408.4	408.4
Water use (m^3)	3,617	3,617	3,617
Crop yield (t)	7.12	7.12	7.12
Emissions (t)	2.15	0.84	0.26

[9] In the case of farmers with non saline soil the social welfare is higher with flood than with sprinkler, this is because the large investment to change technology (decrease in private profits) and the low emission level under this soil type.

[10] Social planner implements the six different tax rates, so the emissions of all farmers are the optimal ones.

welfare by all crops and irrigation technologies. The increase in social welfare was higher by farmers with flood than farmers with sprinkler. With flood the social welfare increased a 50% in saline soils, a 20% in moderate saline soils, and a 10% in non-saline soil. With sprinkler the increase in welfare in saline soils was a 20%, 10% in moderate saline soils, and 5% in non-saline soils[11]. Crop yields decrease by all farmers due to the internalization of the social costs and the decrease in the production. Like in the previous scenario, the most productive crop was alfalfa and the lowest, wheat. Private profits were lower by all farmers in the first-best scenario because farmers took into account the social cost of their emissions. Unlike the scenario without regulation in the first best the private profits of farmers with sprinkler were higher than the private profits with flood. This effect is consequence to the difference in the emissions costs, farmers with flood

Table 7. Results by irrigation technology and soil type under the first-best scenario

	Saline soil	Moderate saline soil	Non-saline soil
Corn Flood			
Welfare (€ ha^{-1})	944.7	974.8	982.2
Private profits (€ ha^{-1})	356.7	684.3	881.7
Water use (m^3)	9,047	9,684	10,039
Crop yield (t)	10.42	10.68	10.77
Emissions (t)	13.99	6.77	2.40
Corn Sprinkler			
Welfare (€ ha^{-1})	838.9	897.2	898.2
Private profits (€ ha^{-1})	608.5	771.5	858,4
Water use (m^3)	7,681	7,856	7,948
Crop yield (t)	12.53	12.58	12.60
Emissions (t)	6.26	2.74	0.91
Alfalfa Flood			
Welfare (€ ha^{-1})	710.5	765.8	778.9
Private profits (€ ha^{-1})	188.0	489.5	680.3
Water use (m^3)	8,038	9,210	9,863
Crop yield (t)	12.62	13.41	13.69
Emissions (t)	12.18	6.38	2.35
Alfalfa Sprinkler			
Welfare (€ ha^{-1})	978.7	988.2	990.1
Private profits (€ ha^{-1})	724.9	872.7	953.2
Water use (m^3)	6,859	7,216	7,403
Crop yield (t)	15.52	15.69	15.76
Emissions (t)	5.42	2.46	0.83
Wheat Flood			
Welfare (€ ha^{-1})	456.9	468.7	471.4
Private profits (€ ha^{-1})	193.3	339.7	427.0
Water use (m^3)	4,054	4,302	4,440
Crop yield (t)	5.59	5.67	5.70
Emissions (t)	5.02	2.33	0.80
Wheat Sprinkler			
Welfare (€ ha^{-1})	304.1	307.5	308.3
Private profits (€ ha^{-1})	178.0	251.1	290.2
Water use (m^3)	3,407	3,537	3,605
Crop yield (t)	7.07	7.11	7.12
Emissions (t)	1.91	0.81	0.26

[11] These percentages are similar to all crops studied in the work.

generate higher emissions and need to pay higher taxes. The reduction in private profits was greater for farmers with flood than with sprinkler. The higher reduction in private profits was for farmers with saline soils.

The irrigation system allows farmers to produce more efficiently the same quantity of output with less quantity of input. With the sprinkler technology the leaching of saline materials to the ecosystem decreased by a significant proportion. Another important reason to use sprinkler technology is water scarcity problems; farmers can be more efficient in the use of water when they use a more efficient technology, in this case sprinkler.[12]

Table 8 shows the results under the irrigation-based water tax scenario. Two different tax rates were implemented by irrigation technology. The values of the tax rates chosen were the optimal values for both irrigation systems when farmers had a moderate saline soil. The decision to choose these rates was because it is the intermediate value between a high value, the one for saline soil, and a low value, the one for non-saline soil. Farmers with flood were taxed with a rate of 0.030, and farmers with sprinkler were taxed with a rate of 0.016.

The results show that the implementation of an irrigation-based water tax improved the social welfare in all soil types comparing with the baseline scenario. Farmers with moderate saline soil achieved the optimal social welfare because the tax rate used was the optimal by this type of soil. The social welfare by farmers with saline and non-saline soils was lower than in the first best due to the tax was not the optimal. Tax rates chosen were higher for non-saline soils and lower for saline soils.Private profits decreased with respect the baseline scenario because the tax pushed farmers to consider the pollution costs. With respect to the first-best scenario, the profits of the farmers who had saline soils were higher; this is because these farmers are not internalizing all the damage that their activity is causing. In the case of farmers with moderate saline soil the profits were equal to the optimal; the tax rate was the optimal for them. In the case of farmers with non-saline soils the profits were lower because they paid a higher tax than the optimal.

Comparing the results of the irrigation-base water tax instrument with the results of the first-best (Table 7) it is possible to observe how the social welfare decreased by all farmers (by farmers with moderate saline soil the social welfare was the same). Social planner implements a second-best policy due to there is no enough information to identify the soil type of each farmer. Social planner cannot implement the six optimal tax rates, but at least can introduce some extra information like the irrigation technology.

One of the most important results of this work is the comparison between the use of a uniform water tax rate and a non-uniform one. When there are heterogeneous agents, social welfare improves when the social planner could differentiate the tax instead of using a unique tax rate. Shortle *et al.* (1998) showed in their work that using non-uniform tax rates can be more cost-efficient in pollution control because it is possible to deal different polluters with different characteristics and different level of emissions. When farmers are heterogeneous using a uniform tax rate generates inefficiencies because each farmer pollutes differently. With a uniform tax all farmers reduce the same amount of emissions. In a heterogeneous world, when taxes are non-uniform, farmers do not reduce the same amount of emissions but rather reduce them proportionally.

The problem of implementing non-uniform tax rates is an information one. It is complicated for the social planner to have enough information to identify the types of agents and their particular levels of emissions, especially with nonpoint pollution. Nevertheless, there are situations in which the social planner can easily obtain information about farmer types. S/he can identify the farmers' irrigation technologies and implement a water tax based on this difference.[13] As Table 8 shows the implementation of an optimal tax requires the use of six different rates. To implement six different tax rates is practically unfeasible, however the use of two, determined by each irrigation technology, is not.

Table 9 shows the comparison between a water tax with uniform tax rate, and an irrigation-based water tax. This table compares the social welfare, quantity of emissions, and private profits between these two alternatives. The tax rate chosen to simulate the scenario in which the social planner uses a uniform tax rate was

[12] It is assumed that farmers do not increase the number of hectares or change to a more productive and water intensive crop. Under this assumption a technological change from flood to sprinkler reduces the water use.

[13] In the Spanish case, there are river basin authorities that have information on the type of irrigation system of each farmer. So, the social planner can obtain the necessary information to implement a non-uniform tax rate based on that difference.

Table 8. Irrigation-based water tax instrument (two tax rates)

	Saline soil	Moderate saline soil	Non-saline soil
Corn Flood			
Welfare (€ ha^{-1})	933.8	974.9	971.2
Private profits (€ ha^{-1})	684.5	684.5	684.5
Water use (m^3)	9,680	9,680	9,680
Crop yield (t)	10.68	10.68	10.68
Emissions (t)	15.13	6.77	2.30
Tax payment (€ ha^{-1})	290.4	290.4	290.4
Corn Sprinkler			
Welfare (€ ha^{-1})	890.9	897.2	896.8
Private profits (€ ha^{-1})	771.5	771.5	771.5
Water use (m^3)	7,857	7,857	7,857
Crop yield (t)	12.58	12.58	12.58
Emissions (t)	6.44	2.74	0.90
Tax payment (€ ha^{-1})	125.7	125.7	125.7
Alfalfa Flood			
Welfare (€ ha^{-1})	690.3	765.6	758.9
Private profits (€ ha^{-1})	489.6	489.6	489.6
Water use (m^3)	9,202	9,202	9,202
Crop yield (t)	13.41	13.41	13.41
Emissions (t)	14.27	6.380	2.16
Tax payment (€ ha^{-1})	276.1	276.1	276.1
Alfalfa Sprinkler			
Welfare (€ ha^{-1})	960.7	988.2	987.2
Private profits (€ ha^{-1})	872.7	872.7	872.7
Water use (m^3)	7,216	7,216	7,216
Crop yield (t)	15.69	15.69	15.69
Emissions (t)	5.785	2.46	0.80
Tax payment (€ ha^{-1})	115.4	115.4	115.4
Wheat Flood			
Welfare (€ ha^{-1})	452.5	468.6	467.1
Private profits (€ ha^{-1})	339.5	339.5	339.5
Water use (m^3)	4,300	4,300	4,300
Crop yield (t)	5.67	5.67	5.67
Emissions (t)	5.47	2.33	0.76
Tax payment (€ ha^{-1})	129.0	129.0	129.0
Wheat Sprinkler			
Welfare (€ ha^{-1})	302.7	307.5	307.2
Private profits (€ ha^{-1})	250.9	250.9	250.9
Water use (m^3)	3,537	3,537	3,537
Crop yield (t)	7.11	7.11	7.11
Emissions (t)	2.04	0.81	0.25
Tax payment (€ ha^{-1})	56.6	56.6	56.6

the optimal value for sprinkler in a moderate saline soil (0.016).[14]

The results of this comparison highlight the increase in the efficiency between a uniform water tax instrument and an irrigation-based water tax. But this increase in the efficiency in the case of this study was relatively small. So assuming positive transaction costs it will be justified the use of a uniform tax rate instead

[14] Results are similar for any uniform rate.

Table 9. Comparison between uniform water tax and irrigation-based water tax

	Uniform water tax instrument			Irrigation-based water tax instrument		
	Saline	Moderate	Non-saline	Saline	Moderate	Non-saline
Corn Flood						
Welfare (€ ha^{-1})	923.2	973.1	979.7	933.8	974.9	971.2
Private profits (€ ha^{-1})	821.8	821.8	821.8	684.5	684.5	684.5
Emissions (t)	15.60	6.98	2.37	15.13	6.77	2.30
Corn Sprinkler						
Welfare (€ ha^{-1})	890.9	897.2	896.8	890.9	897.2	896.8
Private profits (€ ha^{-1})	771.5	771.5	771.5	771.5	771.5	771.5
Emissions (t)	6.44	2.74	0.89	6.44	2.74	0.90
Alfalfa Flood						
Welfare (€ ha^{-1})	670.7	762.6	774.5	690.3	765.6	758.9
Private profits (€ ha^{-1})	621.7	621.7	621.7	489.6	489.6	489.6
Emissions (t)	15.12	6.76	2.30	14.27	6.38	2.16
Alfalfa Sprinkler						
Welfare (€ ha^{-1})	960.7	988.2	987.2	960.7	988.2	987.2
Private profits (€ ha^{-1})	872.7	872.7	872.7	872.7	872.7	872.7
Emissions (t)	5.78	2.46	0.80	5.78	2.46	0.80
Wheat Flood						
Welfare (€ ha^{-1})	449.1	468.1	470.4	452.5	468.6	467.1
Private profits (€ ha^{-1})	400.4	400.4	400.4	339.5	339.5	339.5
Emissions (t)	5.64	2.40	0.79	5.47	2.33	0.76
Wheat Sprinkler						
Welfare (€ ha^{-1})	302.7	307.5	307.2	302.7	307.5	307.2
Private profits (€ ha^{-1})	250.9	250.9	250.9	250.9	250.9	250.9
Emissions (t)	2.04	0.81	0.25	2.04	0.81	0.25

of a two taxes instrument. The establishment of an irrigation-based instrument in the context of this work tries to obtain two results, the control of salinity leaching and the incentive for a technological change. An irrigation-based instrument is preferred to a uniform policy because it increases the social welfare and generates incentives for farmers changing their irrigation technology.[15]

Conclusions

This study follows the approach of Griffin and Bromley (1982) to control the pollution problem of salinity leaching in the Ebro Basin (Spain). The soils in the area have different salinity levels, and farmers use several irrigation technologies, so each farmer emits a different level of salinity to the basin. The purpose of the work is to ascertain the efficiency of using a water tax instrument to abate pollution. A water tax instrument is easier to apply by the social planner because it does require much less information than other policy instruments such as ambient-based instruments.

The work explores the efficiency of using a non-uniform, second-best water tax instrument instead of a uniform tax. The social planner has enough information about the type of irrigation technology that each farmer is using, and can implement larger penalizations

[15] This incentive appears in the case of farmers with corn and alfalfa, in the case of wheat there are not incentives by farmers switching their irrigation technology. In the case of corn and alfalfa the private profits are higher with sprinkler than with flood, so the tax creates an incentive to change the irrigation technology to a more efficient one.

to farmers using more polluting technologies. This analysis shows how a water tax with two differentiated tax rates by irrigation technology, is an efficient instrument to control salinity leaching. With this kind of instrument farmers will pay a lower tax whenever their technology would be more efficient. Moreover, a non-uniform tax that differences farmers according their irrigation technology is an incentive to change towards a cleaner technology (sprinkler irrigation).

An important benefit of this instrument under the study area climate conditions is that it helps the social planner to control water scarcity. In the Ebro Basin, one important problem is the scarcity of water resources. The effect of the water tax is a reduction in the quantity of water that farmers use as consequence of the increase in the price. Therefore, a tax on irrigation water achieves the objective of reducing the emission level but also allowing a more efficient use of water, therefore preserving the resource. A higher water price also internalizes the scarcity problem of resource, generating a more efficient use of water.

It is important to take into account that an irrigation-based water tax policy must be applied whenever the transaction costs are low enough. Problems of farmers' heterogeneity, number of farmers, and technological differences can make costly the implementation of a nonpoint pollution policy. The implementation of an irrigation-based tax rate is associated with higher transaction costs than a uniform tax rate. Therefore, if the transaction costs of implementing two tax rates are high it will be more cost-efficient to use a unique tax rate. In the context of this work, transaction costs are expected to be low due to the abundant information regarding farmers' irrigation technologies.

This study shows that an irrigation-based water tax can be an efficient instrument in the control of nonpoint pollution. This result is conditioned to the model presented in this work, where the emissions function is a lineal one with only one productive input.

Acknowledgments

This research was supported by the project RTA2010-00109-C04 of the Spanish Ministry of Science and Innovation.

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