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COST-EFFECTIVENESS OF WATER POLICY OPTIONS FOR SUSTAINABLE GROUNDWATER MANAGEMENT: A CASE STUDY IN SPAIN

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Abstract

Lately, a great increase has been produced in the use of the groundwater in arid and semi-arid countries and regions worldwide, such as the Mediterranean region. In Spain, the severe groundwater's pumping for irrigated lands has helped to the social and economical development in many rural regions. However, in many cases, the absence of an effective control has imposed stresses on groundwater systems, and it has produced far-reaching environmental and social problems. The Western La Mancha Aquifer in the Spanish southern central plateau is a remarkable example. The excessive, and sometimes illegal, water abstraction for irrigation agriculture has induced the Aquifer's overexploitation and has been responsible of the degradation of the associated wetlands of the national park "Tablas de Daimiel", an internationally reputed, Ramsar-nominated aquatic ecosystem of high ecological value. The objective of this paper is to propose and analyze alternative water conservation policies that will attain a reduction in water consumption, compatible with the natural recharge rate of the Western La Mancha aquifer. To undertake this analysis, a mathematical programming model has been developed to simulate farmers' behaviour and their responses to different water policy scenarios. Specifically, the policy simulations selected are: alternative water pricing schemes (uniform volumetric and block-rate water tariffs), water use quota systems and water rights market. Results show that controlling illegal water mining is a necessary condition but it is not sufficient to recover the aquifer. Consequently, other measures will be necessary for an effective water management in this area. Among these, the block-rate water pricing scheme seems the most cost-effective system to reach the goal of aquifer sustainability but will entail important income losses in several farms. Therefore, we cannot conclude that a unique water conservation policy instrument will be the best overall solution for all types of holdings and farmers that will respond to efficiency as well as to equity considerations. It seems reasonable to make a combination of the tools proposed, even including additional measures that promote an effective environmental protection and develop sustainable agricultural systems.

Key words: over-drafted aquifer, wetland degradation, mathematical programming model, water policies, cost-effective analysis, Spain.

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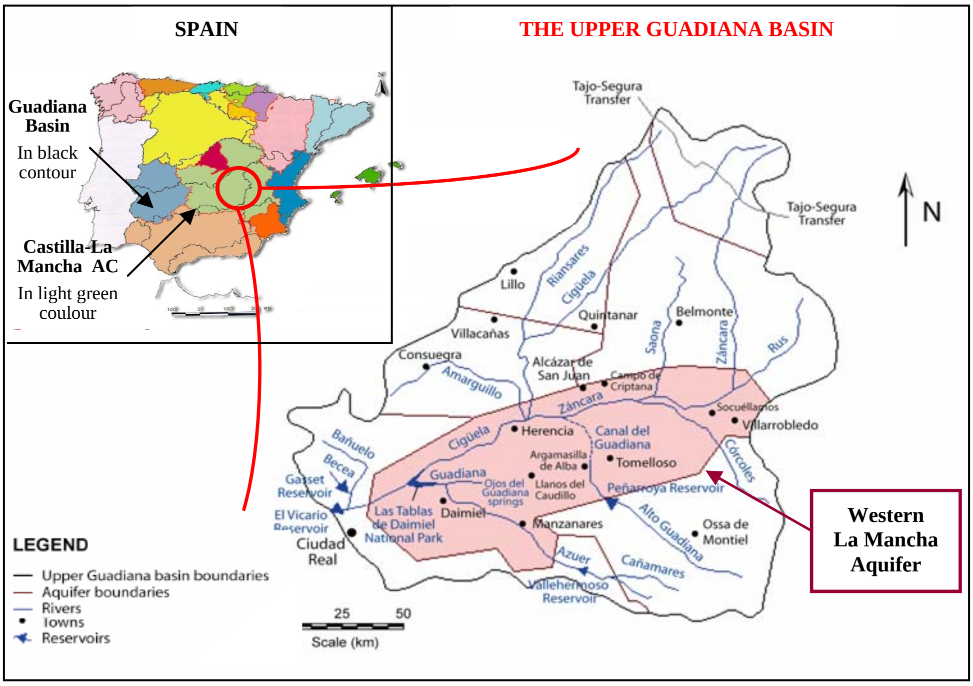
1. Introduction

Groundwater in Spain, as in other arid or semiarid countries worldwide, has been intensely used for the expansion of irrigated agriculture due to its easy access, low cost of irrigation infrastructure and high farming profitability (Llamas, 2005). Stating in the early 70's this phenomenon was induced due to technological development in well drilling and pump installations, improved knowledge of hydrology and the introduction of modern water-saving irrigation techniques and new cropping systems. Alongside, the effects of agricultural policies with production-based direct payments and other policy supports resulted in mounting water abstractions and expansion of irrigated surface (Varela-Ortega, 2007).

This booming development was carried out by many private farmers with no public subsidies and induced a remarkable socioeconomic development in many rural areas. In the absence of strict water abstractions regulations, this phenomenon has been popularized as the "silent revolution" (Llamas *et al.*, 2006), and the largely uncontrolled use of groundwater resources has resulted in the overexploitation of aquifers, environmental degradation and loss of associated valuable wetlands and aquatic ecosystems (Coleto *et al.* 2003, Llamas et al. 2005, Varela-Ortega 2007, Martinez-Santos 2007).

One remarkable example of overexploitation of groundwater resources can be found in the Spanish Western La Mancha Aquifer, situated in the inland central region of Castilla-La Mancha in the Upper Guadiana river basin (see figure 1).

Figure 1. Situation of the Western La Mancha Aquifer.



Source: Own elaboration from Martínez-Santos *et al.* (2007) and named in Sorisi (2006)

Groundwater in this aquifer can be defined as a common good with partial-free access. The difficulty and high cost in controlling water abstraction for irrigation agriculture (that uses up to 90% of all water resources available), has favoured the proliferation of numerous illegal drilling of wells and excessive abstraction. Official sources estimate that nowadays more than the 50% of the existing extractions in the

Western La Mancha Aquifer are not registered and that the total number of abstractions of the aquifer exceeds the natural recharge rate of the aquifer at length, , estimated to be 230 Hm^3 (CHG, 2005a; CHG, 2006). This type of free-riding behaviour is common to other areas in the world where subterranean water is the major source of water for irrigation farming (Provencher *et al.* 1994; Shah *et al.* 2000; Varela-Ortega *et al.* 2003; Varela-Ortega 2007; Schuyt, 2005; Llamas *et al.* 2006).

This phenomenon is often explained by the widely known "Tragedy of the Commons" (Hardin, 1968). This approach, in the case of groundwater, shows how the search of the own interest (to maximize the individual's consumption) leads each user to ignore the impact of his extractions on the future Aquifer storage. When private extractions exceed the optimum social rate, the aquifer will be overexploited causing the degradation of the common resources, an irrational behavior from the collectivity's perspective.

This type of behavior implies the production of negative externalities that affect other users and the whole society. (Milliman, 1956; Gisser *et al*. 1980, Provencher *et al.* 1993; Rubio *et al*. 2001; Iglesias, 2001 ; Brozovic *et al.* 2006). In the zone of study, overpumping by irrigators in the Western La Mancha Aquifer has resulted in economic and environmental negative externalities such us the following:

- Global diminution of the water table and intensification of control measures.
- Increased extraction costs.
- Loss of propriety rights due to drying-up of wells when water table falls.
- Increase in crop production, agricultural supply and drive decrease in crop prices.
- Pollution and degradation of the associated wetlands of the national park "Tablas de Daimiel", an internationally reputed, Ramsar-nominated aquatic ecosystem of high ecological value.

There are traditionally two management solutions to avoid the negative effects of the exploitation behavior and to internalize the externality cost in the total resource cost (Ostrom, 1990): centralized management (State's regulation) and decentralized management (market of tradable water rights). Currently, a quota system (centralized instrument), known as Water Abstraction Plan (WAP), is used by the Guadiana River Basin Authority to control water abstractions in the Western La Mancha aquifer. This regulation forbids the opening of new extractions and limits the water abstractions by means of a quota system with no compensation. The current WAP gives a global maximum extraction for the agricultural use of 213.4 Hm^3, and suggests a staggering of the maximum allowances for the herbaceus crops depending on farm size, so the largest farms have higher limits (CHG, 2005b). However, the strict quota system of the WAP in the Western La Mancha aquifer has neither produce the desired level of water use reduction, nor the recovery of the associated wetlands.

The revision of the current water policies and the application of new policy instrument and complementary measures for the rural populations is one of the major tasks than have to be address by water managers and policy makers in the area.

2. Objective of the research

In this context, the objective of this paper is to propose and analyze alternative water conservation policies that will attain a reduction in water consumption, compatible with the natural recharge rate of the Western La Mancha aquifer that will, ultimately, promote a sustainable groundwater management in the Upper Guadiana basin.

The impacts produced by these water demand management tools have been analyzed at sub-basin level, that is the aquifer perimeter, and at desegregated level focusing on the two sides of the conflict (the “legal water abstractions” and the “illegal water abstractions”), through a set of indicators aimed at representing the economic, social and environmental performances of irrigated systems.

3. Methodology

The methodology developed to undertake this analysis is summarized in figure 2. It comprises the following parts:

(1) Elaboration of a database supported by an ample field work carried out during 2005 and 2006 within NEWATER Project[2] that consists in surveys and interviews to the main stakeholders in the area (technical experts, irrigation communities, river basin managers, regional government officials, and environmental ONG’s, farmers unions, individual farmers and private law firms).

(2) Selection of the representative farms from an elaborated farm typology and irrigation associations’ typology that represent the agricultural sector in the area.

(3) Elaboration of an aggregated non-linear Mathematical Programming Model of constrained optimization developed to simulate farmers’ behaviour under different water policy scenarios and risk situations as a result of climate as well as market prices variability. The MPM maximizes the regional expected utility, while keeping the specificity of the individual constraints (technical, economic, social and policy). This dual characteristic of the model permits the analysis at aggregated level (basin) as well as at disaggregated level (farm) and it complements previous modeling work carried out in the area of study.

(4) Development of simulated scenarios that are stakeholder-driven as well as policy-driven. Stakeholders have been strongly encouraged during the different field-work interviews and along the NeWater project meetings to formulate scenarios that will contribute to the search of an acceptable and a sustainable water management model in the Western La Mancha aquifer. The policy simulations selected are namely the implementation of the on-going national water use quota system (water allotment rights), the application of alternative water pricing schemes (uniform volumetric and block-rate water tariffs), and the establishment of a water rights market. In all the simulated scenarios, it has been previously considered that all illegal wells have been legalized beforehand by paying an entry right fee.

(5) Analysis at different levels of aggregation: The effects of these alternative water conservation policy instruments have been analyzed at sub-basin level, that is the aquifer perimeter, and at disaggregated level focusing on the two sides of the conflict: the “legal water abstractions” and the “illegal water abstractions”. A set of indicators has been used to represent the economic, social and environmental performances of irrigated systems. The calculation of these parameters and the comparative cost-effectiveness analysis of the different policy programs proposed are at the core of this fifth stage of the methodology.

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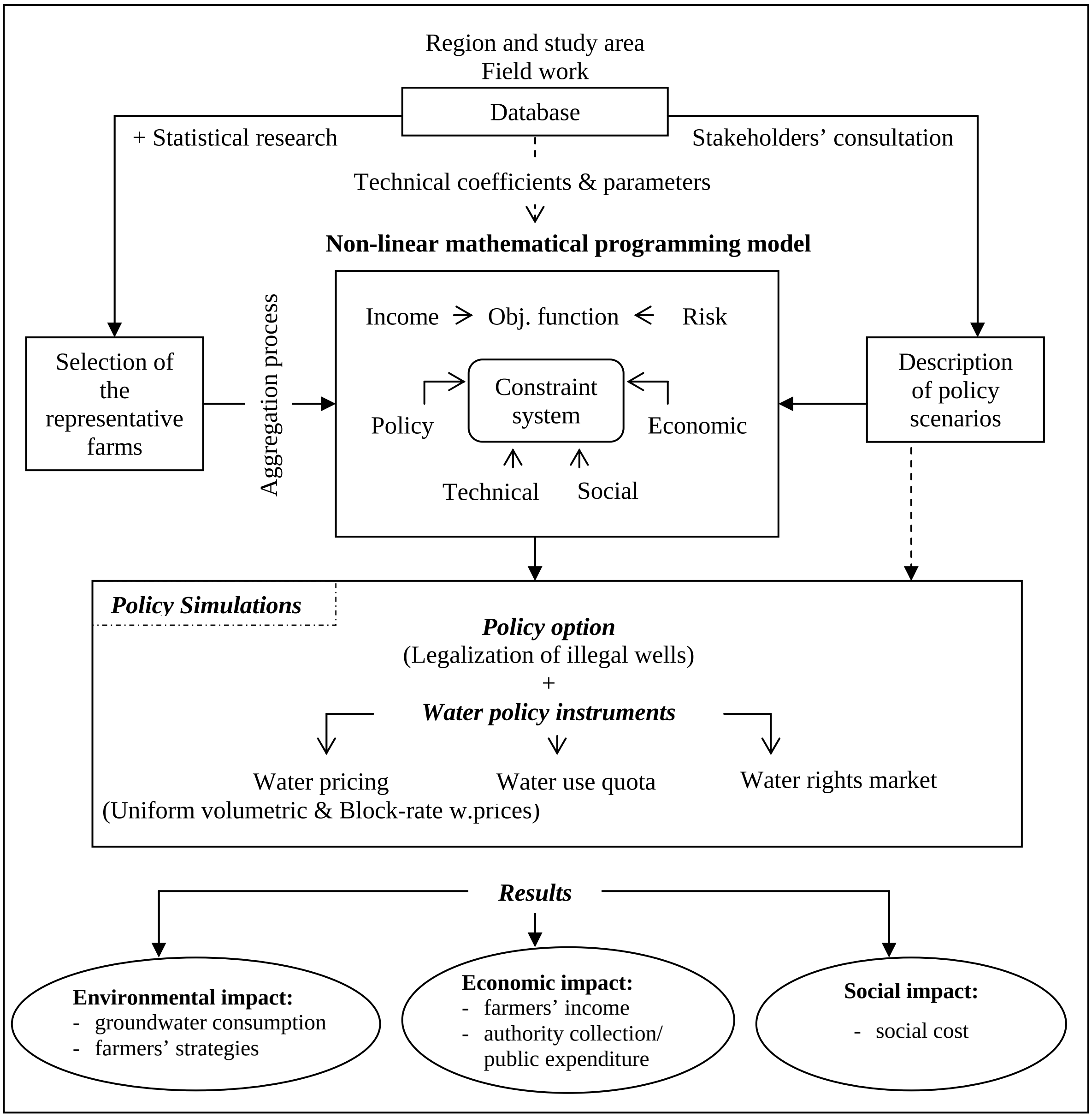
[2] “New Approaches to Adaptive Water Management under Uncertainty”, FP6-2003-GLOBAL-2-SUSTDEV-6.3.2-511179-2, DG Research. European Commission.

Figure 2. Schema of the research methodology



5.1. Identification of the representative farms

The zone of study has been identified by two representative farm types (F1, F2). These representative farms are a dichotomised simplification of the reality. Farm type F1 corresponds with a farm with legal wells (in rule to the law) and respectful to the Water Abstraction Plan determined by the Guadiana River Basin Authority in 2005. Farm type F2 represents the node of illegal water demand, that is, a farm with illegal wells (no registered) or with legal wells (registered or catalogued) of which more water than the allowed in the Water Abstraction Plan is being extracted.

Besides, these two types of farms feature different structural parameters, crop distribution and risk perception. The "legal farm" F1 has a lager size (140 has) than the illegal farm (15 has) and a higher proportion of rainfed crops (mainly barley). The "illegal farm" F2 grows mainly high-yield cash crop such us vegetables and irrigated vineyard (very difficult to be detected through satellite techniques and with a lower control risk by the River Basin Authority).

The two selected representative farms have been aggregated at sub-basin level following the hypothesis of linearity. Therefore, farms F1 and F2 represent respectively 69% and 31% of the total cultivated surface in the aquifer (192,538 hectares).

The main characteristics of each farm type (legal and illegal) are summarized in table 1.

Table 1. Aggregated representative farm types

	Aggregated "legal" farm type F1	**Aggregated "illegal" farm type F2**
Size of the representative farms (ha)	140	15
Total surface (ha)	132,538	60,000
Irrigated surface (%)	60	80
Number of wells	16,719	22,917
Soil type (%)		
Bad sol	60	20
Good sol	40	80
Crop distribution (%)		
Barley	40.00	10.00
Wheat	15.19	10.00
Maize	1.00	-
Vegetables	13.15	38.50
Vineyard	25.00	40.00
Set-aside	5.66	1.50
Total area (%)	100	100
Grouping parameter (%)	69	31

***Source*:** Own elaboration from INE (Statistic National Institute, 1999), IES (Statistic Institute of Castilla-La Mancha, 2006), CHG (Guadiana River Basin Authority, 2006) and farmers' surveys (2005&2006).

5.2. The model

For analysing the impact of different policy options we have developed a non-linear single-year static mathematical programming model (MPM) of constraint optimisation defined at regional scale (sub-basin aggregation)[3].

The model optimizes the regional expected utility, as an aggregation of the expected utilities of the two farm types, while keeping the specificity of the individual constraints (techniques, economic, social and policy) (Buckwell *et al.* 1972, Deybe 1994, Abbas *et*

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[3] A recursive model for two periods has also been developed to analyse the current conflict situation on the water use between "legal" and "illegal" farms. The following equations show how the availability of water for the "aggregated legal farm" in the year 0 ($watera^0_{f1}$) is reduced in the year 1 ($watera^1_{f1}$) because of the excess of water consumed as a result of illegal pumping (*exc*). This excess has been estimated as the difference between the total quantity of water used ($\sum_f wc^0_f$), less the highest water consumption allowed by the Guadiana river basin authority, usually stipulated in the Water Abstraction Plan (*wap*).

$watera^1_{f1} = watera^0_{f1} - exc$; $exc = \sum_f wc^0_f - wap$

al. 2005). Consequently, this model allows integrating the characteristics of the two aggregated representative farms and their potential water exchanges.

Following the mean-standard deviation analysis (Hazell *et al.* 1986), the objective function of the model is:

$$MaxU = \sum_{f} \left(Z_f - \phi \cdot \sigma_f \right) \tag{1}$$

where U is the expected regional utility, Z is the average net income, ϕ is the coefficient for the risk aversion parameter, and σ_f is the standard deviation of the income distribution.

Z, is calculated through the equation:

$$\begin{aligned} Z_f = & \sum_{c}\sum_{k}\sum_{r} gm_{c,k,r} \cdot X_{c,k,r,f} + md \cdot cp \cdot \sum_{c}\sum_{k}\sum_{r} sb_{c,r} \cdot X_{c,k,r,f} + md \cdot sfp_f \cdot numf_f \\ & - oc \cdot \sum_{p} fla_{p,f} - hlp \cdot \sum_{p} hl_{p,f} - tpc_f - sirrg_f \cdot wtarif - well_f \cdot wellt \end{aligned} \tag{2}$$

where $X_{c,k,r,f}$ are the decision-making variables that represent the growing area (in hectares) by crop type (*c*) soil characterisation (*k*), irrigation technique (*r*) and farm type (*f*); $gm_{c,k,r}$ is the gross margin (€/ha); *md* modulation rate; *cp* coupling rate; $sb_{c,r}$ is the CAP aid (€/ha); sf_{pf} is the single farm payment (€); $numf_f$ number of farms; *oc* family labor opportunity cost (€/h); $fla_{p,f}$ family labor availability (h); *hlp* wage for hired labor (€/h); $hl_{p,f}$ is hired labor (h); tpc_f is total abstraction costs (€); $sirrg_f$ irrigated surface (ha); *wtarif* is the water use tariff (€/irrigated ha); $well_f$ is the number of registered wells; *wellt* is the tax paid by well (€).

σ_f , the standard deviation is generated by a set of states of nature defined by climate variability (crop yields) and market variability (crop prices) as follows:

$$\sigma_f = \sqrt{\frac{\left(\sum_{sn}\sum_{sm} Z_{sn,sm,f} - Z_f \right)^2}{N}} \qquad 3)$$

where $Z_{sn,sm,f}$ and Z_f are the random and the average net income respectively; and *N* represents the combination of the different states of nature (*N=100*).

Land constraints:

$$\sum_{c}\sum_{r} X_{c,k,r,f} \leq surf_{k,f} \qquad (4) \qquad \sum_{c}\sum_{k}\sum_{ri} X_{c,k,ri,f} \leq sirrg_f \qquad (5)$$

where $surf_{k,f}$ is surface availability; $X_{c,k,ri,f}$ irrigated surface; $sirrg_f$ number of hectares declared for irrigation.

Labor constraints:

$$\sum_{c}\sum_{k}\sum_{r} lr_{c,r,p} \cdot X_{c,k,r,f} \leq fla_{p,f} + hl_{p,f} \tag{6}$$

where $lr_{c,r,p}$ is crop labor requirements; $fla_{p,f}$ family labor availability; $hl_{p,f}$ hired labor.

Water availability constraints:

$$\sum_{c}\sum_{k}\sum_{r} wr_{c,k,r} \cdot X_{c,k,r,f} \leq watera_{f} \tag{7}$$

where $wr_{ck,r}$ is crop water needs; $watera_f$ water availability.

$$tpc_f = \alpha_f \cdot \left(wc_f\right)^2 + \beta_f \cdot wc_f + \delta_f \tag{8}$$

where tpc_f is total water abstraction costs; wc_f water consumption; σ_f, β_f, δ_f, coefficients of the polynomial function, which has been obtained with an econometric analysis from the experimental data collected in the field work.

Policy constraints:

$$setmn \cdot \sum_{cop}\sum_{k}\sum_{r} X_{cop,k,r,f} \leq \sum_{k}\sum_{r} X_{set,k,r,f} \leq setmx \cdot \sum_{cop}\sum_{k}\sum_{r} X_{cop,k,r,f} \tag{9}$$

where *setmn* and *setmx* are compulsory minimum and maximum land set aside rates; $X_{set,k,r,f}$ set aside surface; $X_{cop,k,,r,f}$ COP growing area (cereals, oilseed and protein crops).

$$\sum_{vi}\sum_{k}\sum_{r} X_{vi,k,r,f} = surfvi_{f} \tag{10}$$

where $X_{vi,k,r,f}$ vineyard surface; $surfvi_f$ is the vineyard surface actually cropped in the farm defined by the CAP plantation rate and fix in this single period model.

Calibration and validation of the model

The risk aversion parameter is used as a calibration coefficient that prevents the introduction of additional constraints that would imply unjustified inflexibilities in the model[4]. To complement the calibration analysis we have used the Percent Absolute Deviation (PAD) to verify that the model reproduces the initial crop distribution, as the main decision-making variable in the model. This parameter measures the weighed absolute difference between predicted and measured values, expressed as a percentage deviation[5]. When this deviation is lower than 15%, the calibration is accepted. In this case, the PAD obtained was 5.11% and 5.68% in the aggregated farms F1 and F2 respectively, values ranked in the excellent upper limit of Hazell and Norton classification (Hazell and Norton, 1986).

5.3. The policy scenarios

The considered baseline is the real situation (over-drafted aquifer) with strict water abstraction quotas to the legal farms from their licensed wells and a free-riding behavior out of control in the form of illegal drilling of wells and excessive mining. The agricultural policy scenario is the same in all the simulations. It is represented by the new CAP reform (2003), adopted by Spanish law. That is the partial decoupling formula, consisting in a 25% of payments coupled to production and a 75% decoupled

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[4] The risk aversion parameter selected was 1.65. It indicates that the probability to have an income higher or equal to Z is 95% with an error of the hypotheses test lower to 5%.

[5] $PAD(\%) = \left[\sum_{i=1}^{n} \left|\overline{X}_i - X_i\right|\right] \cdot 100 \Big/ \sum_{i=1}^{n} \overline{X}_i$; $\overline{X}_i$ measured level; X_i estimated level

(single farm payment). The CAP's second pillar reform has also been taken into account, simulating a subsidies modulation of 4%, whose funds are available since 2006 and will finance rural development projects (UE Regulations 1782/03 and 796/04).

The first policy measure analysed is the legalization of the illegal wells. We have simulated this hypothetical administrative policy option to control water abstractions and to put an end to the historical conflict between "legal" and "illegal" wells[6]. All the illegal wells have been legalized by paying an entry right fee of 6000 €/ha irrigated (CHG 2004), (400 €/ha irrigated/year on a horizon of amortisation of 15 years). This value reflects two essential costs. On the one hand, the administrative cost paid by the legal farms since its creation (year 1985) and on the other hand, the opportunity cost of illegal water that was extracted during the last 15 years. This policy option has been subsequently combined with other water demand management instruments. In all the cases, the Water Abstraction Plan is not henceforth considered.

The second policy scenario analysed is a uniform volumetric water pricing system, that is, a charge per volume applied measured as t €/m^3. We have considered a gradual increase of 0.009 €/m^3 in water price for fifteen price levels (P_1, P_2, P_3...P_{15}), starting from a value of 0 €/m^3 and ending in 0.126 €/ m^3.

The third policy scenario studied is a block-rate charge defined by a set of prices (t-t'' €/m^3) and quantities delivered (% of water allotment right) such as follows: (i) t, 0-33%; (ii) t', 33-66% ($t'>t$); (iii) t'', 66-100% ($t''>t'$). Table 2 shows the simulated block-rate water pricing structure.

Table 2. Block-rate water pricing structure.

Blocks of water consumption in the Western La Mancha Aquifer	*Set of prices*	*Price levels*				
		P_1	P_2	P_3	...	P_{15}
0-80 Hm^3	t	0	0.003	0.006	...	0.042
80-160 Hm^3	t'	0	0.006	0.012	...	0.084
160-240 Hm^3	t''	0	0.009	0.018	...	0.126

The forth policy scenario analysed is a quota-volume system, which limits the total water abstractions close to the aquifer natural recharge rate (estimated in 230 Hm^3 per year, CHG 2006). This global water quota has been individually allocated to the farms through a public system of non exchangeable concessions (water allotment rights), following the "grandfathering" criteria[7]. It has been supposed that the threat of being controlled from the government is sufficiently dissuasive to make everybody respect their imposed quotes.

The fifth policy scenario simulated is a water rights market. In this case, the aggregated farms (F1 and F2) are allowed to exchange the water allotment rights defined by the water use quotas in the previous simulation. The price of exchange (0.10

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[6] We have ruled out the policy option of close the illegal wells, to consider that it's not a feasible option (it could bring about important social unrest and farmers' litigations), and the policy option of a free legalization, to consider that it could constitute an example to follow in other parts of Spain and it could incite to a more water rebelliousness. In this policy scenario, the legal farm F1 is required to respect the Water Abstraction Plan 2005.

[7] That is, according to the farm size. The water allotment right attributable to the F1 farm is 161,300 thousands of m^3 (equal to the global water quota by F1grouping parameter) and the quota for the F2 farm is 72,500 thousands of m^3 (equal to he global water quota rate by F2 grouping parameter).

€/m^3) has been chosen between the dual values of water obtained from the prior model[8]. We have supposed 5% of transaction costs[9].

6. Results and discussions

6.1. The open access problem: policy option for legalizing the illegal wells

Simulations show that current water abstractions in the Western La Mancha aquifer (407.2 Hm^3) are greatly exceeding the natural recharge rate from the aquifer (230 Hm^3), in spite of the limit imposed on the "legals" (213.4 Hm^3) according to the current Water Abstraction Plan (CHG, 2005b) (see table 4). Almost half of the total abstractions (193.8 Hm^3), which is equivalent to 84% of the Natural Recharge Rate of the aquifer, are consumed in an irregular way.

This situation, as pointed out in the first part of this article, produces important ecological and hydrologic problems as well as important social conflicts between farmers. Results indicate that the "aggregated illegal farm" F2 (where water consumption is limited only by its extraction costs) uses almost double amount of water per surface (3,230.61 m^3/ha) than the "aggregated legal farm" F1 that comply with the quota system imposed by the River Basin Authority (1,610.10 m^3/ha). Furthermore, the "aggregated illegal farm" F2 obtains twice as many income per hectare (1,268.51 €/ha) than the "aggregated legal farm" F1 (607.72 €/ha).

Table 4 summarizes the current situation in the Western La Mancha aquifer and shows the main results obtained from the simulated "legalization policy".

Table 4. Effects of the legalization of illegal wells *versus* current situation.

Index	Current situation (baseline scenario)			Simulated (legalization of illegal wells)		
	F1	**F2**	**Total**	**F1**	**F2**	**Total**
Farm income (thousand of €)	80,545.66	76,110.87	156,656.53	80,545.66	43,904.72	124,450.38
Unit farm income (€/ha)	607.72	1,268.51	812.56	607.72	731.75	646.17
Public revenue (thousand of €)	598.24	0.00	598.24	598.24	14,928.44	15,526.68
Unit public revenue (€/ha)	4.50	-	4.50	4.50	248.80	80.24
Public expenditure (thous. of €)	13,609.76	1,637.24	15,246.99	13,609.76	3,225.37	16,835.13
Unit public expenditure (€/ha)	102.68	27.29	79.31	102.68	53.76	87.52
Water consumption (thousand of m^3)	213,400.00	193,836.64	407,236.6	213,400.00	120,718.1	334,118.10
Unit water consumption (m^3/ha)	1,610.10	3,230.61	2,112.46	1,610.10	2,011.97	1,734.68
Pumping cost (€/m^3)	0.069	0.085	0.079	0.069	0.081	0.076
Cropping pattern (%)	100.00	100.00	100.00	100.00	100.00	100.00
- Rain-fed crops	40.70	18.18	33.71	40.70	36.09	39.27
- Irrigated cereals	13.85	0.00	9.56	13.85	0.00	9.56
- Vegetables	15.00	40.00	22.75	15.00	20.33	16.65
- Irrigated vineyard	25.00	40.00	29.65	25.00	40.00	29.65
- Set-aside	5.45	1.82	4.33	5.45	3.58	4.87

Note: In all the cases, the water demand in the aggregated farm F1 have to respect the Water Abstraction Plan of the Guadiana River Basin Authority (2005b).

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[8] Any price situated between the value of 0,04 €/m^3 (water dual value of the "aggregated legal farm" F1) and the value of 0,15 €/m^3 (water dual value of the "aggregated illegal farm" F2) constitute a potential price of exchange.

[9] Consequently, the price obtain by the seller will be only 0.095 €/m^3.

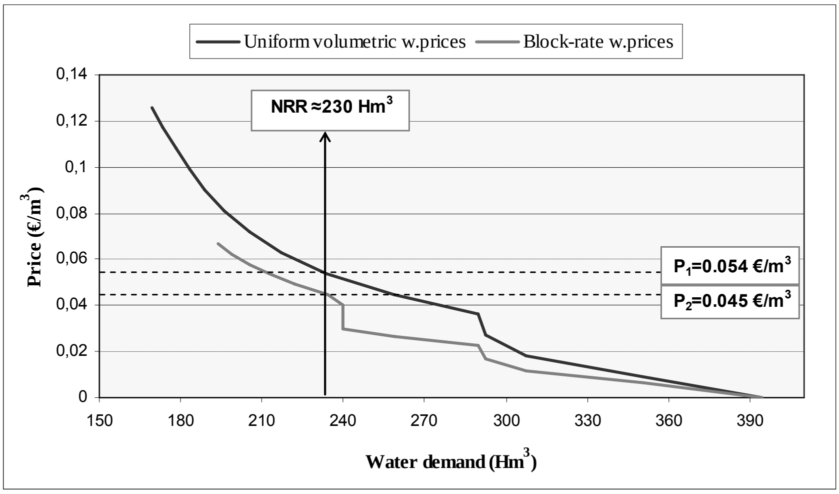
When this policy option is applied, the situation for the “aggregated legal farm” F1 doesn’t change. For the “aggregated illegal farm” F2, the payment of this entry right bring about 42.31% of income loss (from 1,268.5 €/ha to 731.7 €/ha), and have a decisive influence in the strategies that farmers will adopt, inducing farmers to reduce irrigated surface and to save 37.7% of the water used (from 3,230.6 m^3/ha to 1,610 m^3/ha). The implementation of this policy option will tend, therefore, to make equal the farms performance, more similar unit water consumption and unit income than the baseline situation between the two farms selected, contributing in a very significant way to minimize the farmer’s litigations and to balance the public budget. Nevertheless, on the point of view of an ecological approach, the upshots show that the formula adopted will not be enough to recover the aquifer and the wetlands associated. Aggregated results at sub-basin level indicate that the legalization of the illegal wells under these conditions reduce global water consumption to 334.12 Hm^3 (saving of 18%), what is in spite 45% higher than the natural recharge rate of the Western La Mancha aquifer.

Henceforward, different complementary tools of water management will be added to incite a correct rationalisation in the use of groundwater in order that extractions do not surpass the desired target of 230 Hm^3 necessary to recover the aquifer. This means reducing the current water consumption by 43.5% (from 407.2 Hm^3 to 230 Hm^3).

6.2. Water pricing systems

The establishment of water pricing systems is one of the most widely economic instruments used for water regulation (Ward *et al.* 2002; Johansson *et al.* 2002; Agudelo 2001, Sumpsi *et al.* 1998; Varela-Ortega *et al.* 1998; Rosegrant *et al.* 2002; Chohin-Kuper *et al.* 2003, Molle *et al.* 2005). Figure 3 shows the results of the application of uniform volumetric and block-rate water prices on water demand at sub-basin level. Figure 4 shows the water demand curves of the aggregated farms when water pricing systems are applied[10].

Figure 3. Water demand with a uniform volumetric and block-rate water pricing system in the Western La Mancha Aquifer.



NRR: Natural Recharge Rate of the Western La Mancha Aquifer. *P_1&P_2:* Uniform volumetric and block-rate water prices when water demand is equal to the NRR of the aquifer.

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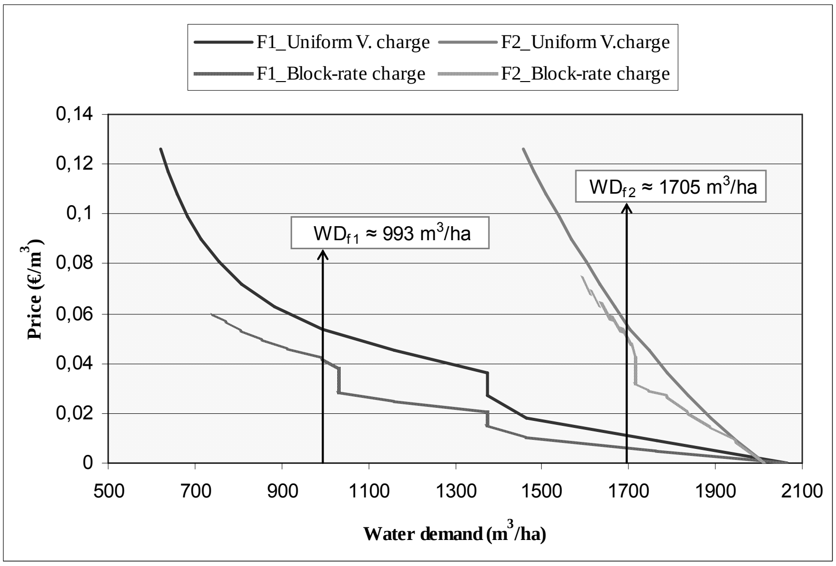
[10] Demand curves corresponding to the block-rate pricing system, have been represented based on the equivalent medium tariffs instead block-rate prices.

Figure 4. Water response curves with a uniform volumetric and block-rate water pricing system in the two aggregated farms of the Western La Mancha aquifer.



WD_{f1}&WD_{f2}: Water demand (m^3/ha) in the aggregated farm F1 and F2, when the global water consumption is equal to the Natural Recharge Rate (230 Hm^3).

Figures 3 and 4, shows that the lower water demand curve corresponds in all cases to the block-rate water pricing system. That is, to save a determined level of water, higher prices are needed in the uniform volumetric system than in the block-rate system. Figure 3 shows that to reduce the total water extractions of the Western La Mancha aquifer up to a medium level compatible with its natural recharge rate (NRR), it will be necessary to apply a block-rate charge equivalent to 0.045 €/m^3, whereas with the uniform volumetric pricing system, water price must increase up to 0.054 €/m^3. These pricing levels are included in the different values that have been considered in several studies carried out in other Spanish irrigation areas, which indicates that with prices between 0.04-0.06 €/m^3 all cost will be recovered, and in some cases even the environmental ones linked to the resource (Sumpsi *et al.* 1998, Gómez-Limón *et al.* 2004, Berbel *et al.* 2004, Iglesias *et al.* 1998, Mejías *et al.* 2004, Varela-Ortega *et al.* 2006).

At these pricing levels, total water consumption is close to the natural recharge rate of the aquifer, 234.1 Hm^3 if we are talking of block-rate pricing system, 233.8 Hm^3 in the case of uniform volumetric pricing system, of which and considering approximately a medium value, 131.6 Hm^3 (about 993 m^3/ha) are used for the "aggregated farm" F1 and the rest 102.3 Hm^3 are consumed by the "aggregated farm" F2 (about 1,705 m^3/ha) (see figure 4). In an uniform volumetric pricing system, both farms must pay 0.054 €/m^3 for the aforementioned water consumed. With block-rate pricing system, the amount of water consumed is priced at different levels according to the different block-rates of the pricing system, so the "aggregated farm" F1 will pay 0.027 €/m^3 for the first 56.2 Hm^3 consumed and 0.054 €/m^3 for the next 75.4 Hm^3. The equivalent price that corresponds to this water consumption level for the "aggregated farm" F1 is 0.042 €/m^3. The "aggregated farm" F2 will pay 0.027 €/m^3 for the first 23.7 Hm^3, and 0.054 €/m^3 for the next 78.6 Hm^3, with a total equivalent price of 0.048 €/m^3. It is important to remark that none of the farms reaches a water consumption level of 0.081 €/m^3, that corresponds to the last block-rate of the block-rate pricing system.

In both cases, the water demand responses are very different according to the farm analysed. As we can see in the figure 4, the aggregated farm F2 shows a much more stressed inelastic trend than the aggregated farm F1. This situation can be explained if we focus the attention on the structural farm characteristics as well as the different strategies followed by the farmers. The introduction of progressive water prices induces farmers to change the production techniques and the irrigation systems, as well as to switch strategies to less water-intensive crops, leading to an extension of the growing study area. In the "aggregated farm" F2, these adaptative techniques are strongly limited due to their small size, very intensive and very crop diversified[11]. We can emphasize that when water prices are increased, intensively-irrigated but highly profitable crops (such as potatoes, peppers or melons) tend slightly to diminish slightly. This inelastic demand response results, when water tariffs reach the rate that allow reduce water consumption to the natural recharge rate (0.054 €/m^3 with an uniform volumetric water pricing system, or 0.048 €/m^3 with a block-rate water pricing system), in water use reductions of 15% (from 2,011.97 m^3/ha to 1,705 m^3/ha) that face higher income losses (about 20.2% and 18.7%, from 731.75 €/ha to 583.77 and 594.45 €/ha, in the case of uniform volumetric and block-rate water pricing, respectively), a result widely found in the literature. (See figure 4 and table 5).

On the contrary, the bigger and more extensive aggregated farm F1 presents a more flexible adaptation to change. In this case, the establishment of progressive water prices induces farm F1:

- First (at water tariffs between 0-0.027 €/m^3 with a uniform volumetric scheme, or 0-0.015 €/m^3 with a block-rate scheme), to diminish the crops that are not very intensive in water (such as wheat grown with sprinkler irrigation).
- Second (at water tariffs between 0.027-0.036 €/m^3 with a uniform volumetric scheme, or 0.017-0.020 €/m^3 with a block-rate scheme) to change water-intensive horticulture (such as potatoes) to other specialized vegetables, such as peppers and melons, the latter a low-water-demanding and lucrative adapted crop in the area that is grown with drip irrigation.
- Finally (at water tariffs between 0.036-0.054 €/m^3 with a uniform volumetric scheme, or 0.020-0.042 €/m^3 with a block-rate scheme), to reduce the intensively-irrigated growing area (vegetables) and to increase non-irrigated barley surface.

The adoption of these strategies, permit farm F1 to reduce used water volume and to absorb increased water use costs without drastically reducing its farm income. This explains why, when prices rise to the desired target of 0.054 €/m^3 (uniform volumetric scheme) or 0.042 €/m^3 (block-rate scheme), water use is reduced by 52% (from 2,065.87 m^3/ha to 993 m^3/ha), whereas farm income is only reduced by 24.2 % and 22.3 % (from 607.88 €/ha to 460.46 and 471.92 €/ha) with uniform volumetric and block-rate water prices, respectively. (See figure 4 and table 5).

The results obtained indicate that there is an inverse relationship between water demand elasticity and income loss. Furthermore, we can see that income loss follows a direct relationship with the revenue collected by the government, specially the inelastic segments of the water demand curves, since the revenue is equivalent to the water cost increase that the farmer bears as consequence of the pricing policy. Thus, high water saving levels at low price rates account for low income loss and low revenues collected by the water management agency in the flexible farm F1 with high demand elasticity.

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[11] It is remarkable that the 40% of the surface is occupied by irrigated vineyards, an evergreen crop not easily replaceable from one year to the next. de un año para otro.

On the contrary, in the more rigid farm F2 we can see that low water saving levels at low-medium price rates concur with high income loss and large public revenue. The trend in the public expenditure, strongly conditioned by the strategies followed by the farmers, differs also between farms The other founding of water prices increases the rain-fed-growing area in F2 that was dedicated to horticulture crops before (with no right to agricultural financial assistance from the CAP), thus produces an increase of the public associated expenditure (from 50.75 to 60.29 €/ha). On the contrary, the public expenditure relative to the farm F1 is reduced when the water prices increase (from 143.11 to 90.22 €/ha), because the increase of the public expenditure, produced by an extension of the rain-fed-growing area is proportionally smaller than the saving of the public expenditure that entails the reduction of the land dedicated to cereals in irrigated land (with higher agricultural financial assistance) (see table 5). In any case, applying pricing policies, net public expenditure, associated to the farm F1 decreases and net public revenue associated to farm F2 increases.

These relations between water demand elasticity, income loss and public revenue are however more evident with a volumetric pricing system than with a block-rate pricing system. The uniform volumetric system is against farmers interests, since a volume rate is charged no matter how much is consumed by the farmer; nevertheless it is the best system to collect public funds.

It is necessary to clarify that the results obtained indicate that for the desired level of water saving, that which reduces the total number of water extractions to levels compatible with the natural recharging of the aquifer, there is not much difference in income loss between the two pricing systems. The same results have been obtained in other studies that have been made of different irrigated areas of Spain, which indicate that for higher saving levels, uniform volumetric and block-rate systems are quite similar in respect of income loss.(Sumpsi *et al.* 1998, Varela-Ortega *et al.* 1998).

In table 5 we can observe that with the same level of water consumption, that the uniform volumetric pricing system produces a slightly higher income loss than the block-rate pricing system, (1.5% and 2% in farms F1 y F2) but it also provides greater collections for the water agencies (11.46 y 10.68 €/ha in farms F1 y F2). For a certain water saving level, the public expenditure does not change (same crop distribution), which is the reason that the net public expenditure is also less (greater net public revenue) with the volumetric system than with the block-rate pricing system (the net public expenditure for farm F1 will be a 11.46 €/ha smaller, and the net public revenue for farm F2 will be a 10.68 €/ha greater).

Table 5, shows for all simulated policy scenarios (included the current situation), farmer´s income, income collected by the water agencies, public expenditure related to the PAC aids and net public expenditure.

Table 5. Effects on the private and public sector of the application of different policy options in the two representative farms of the western La Mancha aquifer.

Policies	**Farmers' income (€/ha)**		**Public revenue (€/ha)**		**Public expenditure (€/ha)**		**Net public expenditure (€/ha)**	
	F1	F2	F1	F2	F1	F2	F1	F2
Baseline [(*)]	607.72	1,268.51	4.50	-	102.68	27.29	98.18	27.29
Legalization [(**)] (*WAP is not considered, only area tariff*)	607.88	731.75	4.50	248.80	143.11	53.75	138.61	- 195.05
Uniform V.w.p ($P=0.054$ €/m^3)	460.46	583.77	58.17	321.66	90.22	60.29	32.05	- 261.37
Block-Rate w.p ($P_1= 0.042$ €/m^3, $P_2=0.048$ €/m^3)	471.92	594.45	46.71	310.98	90.22	60.29	43.51	-250.68
Water use quotas	568.75	541.38	4.50	197.92	85.27	70.98	80.77	-126.94
Water rights market	536.78	624.64	4.50	228.30	90.03	60.70	85.53	-167.60

(*) This baseline scenario corresponds to the current situation mentioned before. The parameters indicated are a summary of the ones shown in table

(**)These results correspond with those shown in table 5. The results shown here correspond only with those shown in table 5 (in the "simulated legalization of the illegal wells") for farm F2. In this case, farm F1 is not under obligation to comply with the Water Abstraction Plan, thus results for this farm and for the aggregated are different. This situation corresponds with the price level L1 (P=0 €/m^3) in the uniform volumetric and block-rate water pricing system. Their results are shown in this table in order to make the comparison between the two pricing systems easier, however the comparative analysis with the other water policy scenarios (water use quotas and water rights market) will be always made respect the baseline situation.

P, is the uniform volumetric price which a water consumption equal to the natural recharge rate of the aquifer is reached. P1& P2, are the volumetric price equivalents for the F1 and F2 farms, with which a water consumption levels similar to the natural recharge rate of the aquifer are also reached.

6.3. Water use quotas

The quota system simulated in this research limits the global water consumption in the Western La Mancha Aquifer to 233.8 Hm^3/year (close to the recharge rate of the aquifer stipulated in 230 Hm^3) [12]. Following "grandfathering" criteria and in accord with the grouping parameter this global quota has been individually distributed between F1 and F2 farms. Results show that each farm consumes the total of its quota, 161.3 Hm^3 (1,217.61 m^3/ha) are used by the "aggregated farm" F1 and 72.5 Hm^3 (1,208.4 m^3/ha) are used by the "aggregated farm" F2.

In previous sections (water pricing scenarios) it can be verified that with environmental sustainability prices, farm F2 has a higher water consumption per surface than farm F1 (1,705 and 993 €/m^3 respectively). This can be explained because F2 farm presents a higher willingness to pay, which allows it to accede voluntarily to a higher volume of resources. When individually quotas are assigned, water consumption per surface is equalized. Comparing these results with the reference situation, it can be observed that the quota-volume system strongly penalizes the farm F2, which must

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[12] The global water consumption (233.8 Hm^3) has been matched with the volume of water used when applying a volumetric price of 0.054 €/m^3 (see section 6.2), in order to make the compared analysis between the different management instruments easier.

reduce a 62.6% its water consumption (from 3,230.61 m^3/ha to 1,208.4 m^3/ha) opposite to the 24.38% of reduction that undergo farm F1 (from 1,610.10 m^3/ha to 1,217.61 m^3/ha) to fulfil as well with the environmental restrictions. With the pricing systems, the reductions are of 47.2% (from 3,230.61 to 1,705 m^3/ha) in farm F2 and of 38.33 % (from 1,610.10 to 993 €/ha) in farm F1 (see table 5)

Strategies adopted by farmers to reduce the volume of water used, follow the general trend consisting in replacing those horticultural crops that are most water intensive with cereals not requiring irrigation, especially barley. However, it is important to emphasize that in the intensive farm F2 some horticultural crops, such as potatoes, have been abandoned.

As shown in table 5, the quota-volume system is the water management instrument that produces, with regards to reference scenario and farm F2, the highest income loss (57%, of 727.13 €/ha), the lowest amount collected by public water agencies (197.92 €/ha)[13], the highest public expenditure in agricultural subsidies (70.98 €/ha) and the lowest net public revenue (126.94 €/ha). It is worth mentioning that with the use of pricing policies income loss is lower, 54% (from 1,268.51 to 583.77 €/ha) when a uniform volumetric pricing system is applied and a 53 % (from 1,268.51 to 594.45 €/ha) when a block-rate pricing system is used. The same analysis carried out for the more flexible large farm F1 indicates that to comply with the assigned quota, this farm would have only to sacrifice a 6.4% of its income (38.97 €/ha). Unlike farm F2, the establishment of water prices would produce higher loss income, from 24.2% and 22.3% with the uniform volumetric system and block-rate system respectively. Therefore, the quota system is presented as the instrument that least penalizes the farmers income and public expenditure (85.27 €/ha) for F1 farm. However, the net public expenditure doesn’t decrease very much since the income collected by the water agency doesn’t increase with respect to the situation we are referring to.

6.4. Water rights market

Water rights markets are more flexible instruments for water management than the control systems analyzed before. Usually, they promote economic growth and reduce social stress, since the resource is being used for more valuable purposes due to concessions agreed on by all parties. (Kemper 2002, Kemper *et al.* 2006, Garrido *et al.*, 2007).

The water rights market simulated in this research makes reference to a system where two agents (in this case, farms F1 and F2) are authorized to exchange their extractions rights, voluntarily negotiating the exchange conditions. It corresponds to an intra-sectorial market (agrarian sector), which has been geographically limited to the area of the Western La Mancha aquifer and physically, as the total groundwater use of 233.8 Hm^3. The quotas assigned for farms F1 and F2 in the previous section (161.38 and 72.5 Hm^3 respectively), constitute the initial distribution of property rights before water market system comes into operation. For this reason, although the free exchange of water is allowed, the global natural recharge rate of the aquifer is respected.

The dual water values obtained when a quota system is applied, delimit the potential price range of exchange. As shown in table 6, any price between 0.04 y 0.15 €/m^3 will

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[13] The public income received from farm F2 corresponds with what will be collected with the legalization, that is the entry right by hectare irrigated, plus what is collected with the present pricing system. The public revenue referring to farm F1 concerns exclusively what is obtained with the present pricing system.

incite a theoretical exchange since the global utility increases. The aggregated farm F1 will have interest to sell it's rights, because the water price of exchange is higher to the opportunity cost of the resource (what it is willing to pay to get an additional unit of water), whereas farm F2 will have interest to buy rights, because the price of water is lower than what it is willing to pay. However, only the market prices between 0.06 and 0.011 €/m^3 will produce real exchanges when providing mutual profits to both farms.

Table 6. Water rights market whit potential exchange prices.

Price of the exchange (€/m^3)	Global utility gain regarding the water quota system (thousand of €)	Utility gain per farm regarding water quota system (thousand of €)		Water rights market	
		F1	F2	Theoretical	Real
0.04-0.05					
0.05	+1,896	-4	+1,901	OUI	NON: F1 leaves the market
0.06-0.11					
0.06	+1,882	+273	+1,608	OUI	OUI
0.11	+1,810	+1,630	+179	OUI	OUI
0.12-0.15					
0.12	+1,795	+1,895	-100	OUI	NON: F2 leaves the market

In order to analyze the cost-effectiveness of the water market system and compare it with the other management instruments, the balance price finally chosen has been of 0.10 €/m^3. The results obtained indicate that at this price level, the aggregated farm F1 sells 28.7 Hm^3 to the aggregated farm F2. Water consumption, once the transaction is finished, is of 132.68 Hm^3 (1,002 m^3/ha) for the farm F1 and 101.12 Hm^3 (1,685.3 m^3/ha) for the farm F2, what means a reduction of the water volume extracted per farm with respect to the reference situation of the 37.77% (608.1m^3/ha) and of 47.83% (1,545.31 m^3/ha) respectively (see table 5).

This reduction of the amount of water used which is necessary to comply with the environmental requirements, shows values quite close to the ones obtained by the pricing policies simulated before, stimulating changes in the farm strategies that also follow very similar trends. If these results are compared with the ones obtained in previous sections, it can be observed that the quota market is the system (after pricing systems) that most penalizes water consumption and produce the most extensive use of land farm F1. On the contrary, the water market is the one that, after the water use quota system, least penalizes water consumption and the irrigated crops in farm F2. In both cases, the water market assumes an intermediate position between pricing systems and quota system.

With regard to the income received by the farmers, the water market is the one of the instruments that least erodes the farm rents. As shown in table 5, the income of farm F1 decreases a 11.67% (70.94 €/ha) with regards to the reference situation, more than 6.4 % produced by the water use quota system, but lower than the income coming from the pricing systems (24.2 and 22.3 %). It is worth remembering that although this farm receives income related to the saled rights, it also has to assume the transaction costs of the operation estimated to be 5% of the sale price, which is equivalent to a loss of 142.6 thousand of € of the sale value. However farm F2 will receive, the net amount corresponding to the exchange price. The income loss that this farm must assume to preserve the aquifer is about the 50.76% (from 1,268.51 to 624.64 €/ha), the lowest in comparison with other management simulated instruments. Public expenditure assigned to PAC aids, is similar to the expenditure invested with the pricing system, however the revenues collected are smaller. As shown in table 5, net public expenditure for farm F1 (85.53 €/ha) is the highest of all the management instruments analyzed

7. Cost-effectiveness analysis

Cost-effectiveness analysis has been used to identify the most cost-effective option for achieving a pre-set objective or criterion (Turner *et al.*, 2004). This approach is strongly recommended (as opposed to cost-benefit analysis) in this study because the environmental benefits produced by a global reduction of water abstractions are very difficult to asses. It consists in comparing the social net costs of the different simulated policy options that comply with the same physical aim of reducing the global water extractions of the aquifer to reach the natural recharge rate of the aquifer, estimated to be 230 Hm^3.

Social net costs have been calculated as the algebraic sum of the private costs and public costs related with each policy measurement (following Vatn *et al.* 1999; Schou *et al.* 2000; Seeman *et al.* 2006, Varela-Ortega 2007). Private costs represent the net income loss of the farmers. They cover the costs related to the changes in cropping-pattern and resources use, taxes and subsidies. Public costs represent the amount of money paid (subsidies) o received (taxes) by the government when the policy systems have been implemented.

Table 7 indicates the private and public costs of each management instrument simulated with respect to the reference situation (baseline), as well as net global social costs at sub-basin level (the Western La Mancha aquifer).

Table 7. Net social cost of the water policies simulated in the Western La Mancha aquifer.

Index	**Water policy option**			
	Uniform V.w.p (P=0.054 €/m^3)	**Block-Rate w.p (P'=0.045 €/m^3)**	**Water use quotas**	**Water rights market**
Private cost (€/ha)	315.25	303.82	253.66	249.71
Public cost (€/ha)	-135.54	-124.31	-60.08	-69.46
Net social cost (€/ha)	179.71	179.51	193.57	180.25
Range(*)	**2**	**1**	**4**	**3**

(*) The simulated management instruments have been ranked from 1 to 4, from the least to the greatest social costs.

P&P', volumetric prices (P, is the equivalent price) that reduce the volume of water extracted to the optimum desired level.

As shown in table 7, the most cost-effective instrument is the block-rate water pricing system (ranked 1) because it allows reaching the objective with the lowest social cost (179.51 €/ha). The uniform volumetric water pricing system (ranked 2) produces a social cost of 179.71 €/ha. Results show that a price of 0.054 €/m^3 produces the highest private costs (325.25 €/ha) but also the highest public benefits (135.54 €/ha). The water rights market policy is ranked in third position (social cost of 180.25). It produces the lowest private cost (249.71 €/ha). Finally, the water use quota system is ranked in forth position. This management instrument produces the highest net social cost (193.57 €/ha) and the lowest public benefits (60.08 €/ha).

8. Concluding remarks

- Based on the results we can conclude that controlling illegal water mining is a necessary condition but it is not sufficient to recover the aquifer. This policy option will contribute to reduce conflicts and social unrest among irrigators, establishing the basis for cooperation among economic agents, but this option will not decrease the volume of water extracted to the optimum desired level. Consequently, other measures will be necessary for an effective water management in this area.

- Water policies implanted must consider the agronomic and structural characteristics of the studied region (according to the article 9 of the FWD) since the aggregated results at sub-basin level can hide important divergences at farm level. The block-rate water pricing scheme (ranked 1) seems the most cost-effective system to reach the goal of aquifer sustainability but will entail important income losses in those farms with less flexible cropping patterns, (such as vineyards) and could therefore put at risk the viability of these farms. On the contrary, the quota system (ranked 4) has the highest social cost but induces lower income losses to the farmers. The water rights markets are situated in between (ranked 3), casting doubts about the superiority of these instruments for an efficient assignment of water among users under certain conditions. This can be explained because a perfect market requires that a certain number of important hypothesis be respected, which is not the case in our model (second rank solutions): (a) the initial property rights distribution is not neutral, since farm F2 have paid a legalisation price to enter the market; (b) buyers and sellers are not numerous, with only one buyer (farm F1) and only one seller (farm F2); (c) transaction costs could have been included in the model and their effect could be larger than expected.

- Therefore, we cannot conclude that a unique water conservation policy instrument will be the best overall solution for all types of holdings and farmers that will respond to efficiency as well as to equity considerations. It seems reasonable to make a combination of the proposed tools, such as water pricing plus the establishment of a quota system.

- Aggregated results at basin level show that social cost is not very different across policy options, ranking for a maximum of 194 €/ha in the quota system to 179 €/ha for the block-rate tariff. For high water saving levels, the two types of water tariffs (volumetric and block-rate) produce similar results especially in relation to income loss. The establishment of a quota system or a water market lead also to similar social cost. This reflects that the initial distribution of quotas (property rights), based on the “grandfathering” criteria, is close to the optimum.

- The choice of a political instrument will require the carrying out of additional studies where other criteria, not considered in this research, should be taken into consideration, such as long term recurrent costs, agreement of users, institutional capacity (administration, monitoring and enforcement) and the transaction costs related to the implementation of the selected policy measures. Along these lines, it seems advisable for the region of the Upper Guadiana Basin to promote the integration of agricultural policies and water policies to develop sustainable agricultural systems (cross compliance measures) and the protection of water bodies according to the principles of the WFD and the new CAP.

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