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RESEARCH PAPER

Social choice and groundwater management: application of the uniform rule

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Abstract

Y. Martinez, and E. Esteban. 2014. Social choice and groundwater management: application of the uniform rule. Cien. Inv. Agr. 41(2): 153-162. In recent decades, the protection of groundwater resources has become a key element in environmental policies around the world as the control of groundwater extraction is necessary to avoid groundwater depletion. This paper proposes a system to improve the allocation of groundwater resources based on the theory of social choice. We propose the implementation of the uniform rule as a mechanism to achieve more efficient groundwater allocation. The uniform rule combines individual preferences to reach collective decisions and respects the anonymity between agents. Additionally, the rule is Pareto efficient and strategy-proof. The paper compares the results obtained under the uniform rule with results achieved under other allocation rules: the proportional rule and the market rule. A numerical application is developed for the Western La Mancha aquifer (Spain), where intensive irrigated agriculture in recent decades has created serious overexploitation problems. The results highlight how the uniform rule is able to substantially improve the efficiency of groundwater extraction.

Key words: Groundwater management, market rule, social choice rule, proportional rule, strategy-proofness, uniform rule, Western La Mancha aquifer

Introduction

As a common pool resource, groundwater provides an interesting case to study these resources from an economic perspective, particularly how to implement 'good' resource management. Aquifers are open access resources with no exclusion for consumption but with congestion from overuse. Currently, groundwater overexploitation in most countries is driving these resources toward total depletion unless limits on extraction are implemented. Government regulation to manage aquifers is a central issue because agents pump water from aquifers without taking water scarcity and the non-renewable character of aquifers into account in the medium term.

In Spain, one of the main problems is the degradation of groundwater resources. Controlling overexploitation of these water reserves is one of the objectives of Spain's water policy, but it is also an important issue for the European Union as a whole (Directive 2000/60/CE, October 23rd). In

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the case of Spain, greater efforts are needed to control and protect groundwater resources. The uncontrolled increase in demand for groundwater for irrigation is evidence of the necessity for improved regulation to balance water supply and demand.

Economic solutions to balance supply and demand have focused on different water pricing policies or the introduction of water markets. Theoretically, water markets provide the most efficient results by reallocating water and promoting more rational utilization of the resource (Lee and Jouravlev, 1998; Zilberman and Schoengold, 2005). However, water markets are not working as efficiently as predicted by theory due to institutional, political, and physical barriers (Qureshi *et al*., 2009). On the other hand, the implementation of water policies is not always easy and/or feasible because of the lack of information about extractions from aquifers. A major obstacle to the proper control of extraction is the existence of illegal groundwater pumping that undermines the effective implementation of water regulations. An example is the case of the Western La Mancha aquifer where there are approximately 50000 illegal wells that are beyond the control of authorities.

An interesting alternative could be the implementation of rules developed for cost and surplus sharing (Moulin and Hervé, 2002; Aadland and Kolpin, 2004). The problem with these rules is that the regulator needs to have complete information, which is not the case for groundwater resources. Usually, a regulator does not have enough information about groundwater users, and these agents have clear incentives to act strategically. To circumvent this information problem, a strand of research has developed allotment rules that are strategy-proof, which means that agents do not have incentives to lie or hide information from the other stakeholders (Barberà, 2005). The application of these rules produces allocations that are Pareto efficient and help to balance water supply and demand.

In the case of groundwater management, the regulator faces two important challenges: first, the control of the total amount of water extracted to avoid resource depletion and to maintain the sustainability of agricultural activities and, second, an efficient way of assigning resources to improve the economic benefit of the activities. Groundwater shortages will be more frequent as a result of the impacts of climate change, so under this scenario, the aim of this paper is to assess whether the regulator can achieve optimal use of the resource in times of shortage by designing an adequate sharing-rule. To the best of our knowledge, the existing literature on groundwater economics has not yet explored the potential benefits of applying allotment rules as a mechanism for groundwater management.

Theoretically, it is not possible to evaluate the loss of efficiency that arises from allotment rules compared with the most efficient outcome achieved by the market rule. Therefore, this study proposes a) to design an allotment rule that is coherent with the theoretical concept developed by the social choice theory and b) to perform an empirical comparison of the efficiency of the allotments resulting from i) water markets, ii) the uniform rule, and iii) the proportional rule.

The allocation rules are empirically tested for one of the most important aquifers in Spain, the Western La Mancha aquifer. The results of this paper highlight how the implementation of the uniform rule in groundwater management can be used to achieve more efficient water allocation.

Materials and methods

The situation in which a group of agents must share a rationed good has been theoretically analyzed in the social choice literature (Benassy, 1982; Barberà and Jackson, 1995). This literature assumes that individuals have single-peaked preferences over their desired share of the rationed good, which means that each agent has an optimal share that maximizes his/her utility. In other words, the greater the agent's share, the greater the deviation from the optimal share and the lower the utility.

Thus, an allocation rule can be defined as a map that associates a division of the amount to be shared with each single-peaked preference vector. In the literature, this amount is normalized to 1, but in our case, we do not consider the utility of the farmer but rather the net farm benefits. The net farm benefit functions are strictly concave and thus single-peaked.

Sprumont (1991) defined the uniform allotment rule in a seminal paper. This rule requires that the outcome complies with the Pareto criteria, is strategy-proof, is anonymous, is consistent, and satisfies the conditions of one-sided replacement-domination and resource monotonicity (Barberà *et al.*, 1997; Thomson, 1995). An allotment rule is strategy-proof if an agent or groups of agents have no incentive to misreport their preferences independent from what the other agents report. Anonymity guarantees that all agents are identical from the decision maker's perspective (i.e., the regulator). Consistency requires that the allocation mechanism of the rule remain unchanged if it is re-applied to the remaining share after some agents have already received an allotment. Replacement-domination requires that the welfare of the agents be equally affected if some characteristics of the economy change. The monotonicity condition imposes similar requirements on the allotments.

All of these properties seem to make the uniform rule a very good candidate for the ''ideal'' allotment rule. The uniform allocation rule leads to an outcome where each agent gets what he/she wants within the limits of a lower bound and an upper bound common to all agents. In the context of water resources, Goetz *et al.* (2005) empirically showed that assigning irrigation water based on the uniform rule yields higher net farm benefits than the allotment mechanisms currently being applied (i.e., the proportional rule). In this paper, we apply the theoretical framework of Goetz *et al.* (2005) to groundwater resources. The main objective is to test whether the uniform rule can be an efficient instrument for the allocation of groundwater resources between the different users of a real aquifer.

The mathematical expression for the definition of a uniform rule was described by Barberà *et al.* (1997). Let N define a finite set of agents: N={1, 2, ... n}. The water allotments are n-tuples of a in the set .

$$A = \left\{ a \in [0,1]^n \mid \sum_{i \in N} a_i = 1 \right\}$$

It is assumed that preferences are continuous and represented by a continuous utility function u_i $(i \in N)$. The agents' benefits are measured by the net farm profits ϖ(to be presented later). It is also assumed that preferences are single-peaked with a unique ideal share. We define x^* as the peak of u_i $(i \in N)$, and we denote it as $x^*(u_i)$.

Let S denote the set of all continuous utility functions that represent single-peaked preferences in [0,1]. Preference profiles are given by n-tuples of u of the utility functions with u_{-i} representing the (n-1)-tuple obtained from u by deleting u_i, and (u_{i-1}, v_i) represents the n-tuple obtained from u by substituting v_i for u_i.

Let denote the n-tuple of the guaranteed share of agent i in the t^{th} iteration of adjusting q_i^{t-1}. An allotment rule associates a vector of shares with each preference profile, so a function $f{:}S^n \rightarrow [0,1]$ satisfies the feasibility $\sum_{i \in N} f_i(u) = 1 \;\; \forall \;\; u \in S^n$.

Thus, the uniform allotment rule can be defined as:

$$f_i^*(u) = \begin{cases} \min\left[x^*(u_i), \lambda(u)\right] \text{ if } \sum_{i \in N} x^*(u_i) \geq 1 \\ \max\left[x^*(u_i), \mu(u)\right] \text{ if } \sum_{i \in N} x^*(u_i) \leq 1 \end{cases} \qquad [1]$$

where λ(*u*) solves the restriction:

$\sum_{i \in N} \min\left[x^*(u_i), \lambda(u)\right] = 1$, and $\mu(u)$ solves the restriction $\sum_{i \in N} \max\left[x^*(u_i), \mu(u)\right] = 1$.

The uniform rule is similar to the proportional rule, but it is corrected to attain Pareto efficiency. Once the regulator knows the total amount of available water, he/she determines the initial guaranteed levels of water for the farmers. As the uniform rule is anonymous, the agent's guaranteed levels are identical, so each farmer receives the same proportional amount of the total water. The second stage of the rule requires the farmers to provide their ideal shares of water. If some agents' ideal shares are less than their guaranteed amounts, their guaranteed levels are adjusted to become their ideal shares. Any amount of water above the ideal shares is equally distributed among the rest of the agents, which determines their new guaranteed levels of water. Of course, these new guaranteed levels for the remaining agents cannot be adjusted downwards. Afterwards, if some agents' ideal shares are lower than their new guaranteed amounts, they receive their ideal. The adjustment is replicated until all of the agents' ideal shares are higher than or equal to their corresponding shares.

The strategy-proof aspect of the uniform rule is essential to the correct functioning of the allocation. Intuitively, the rule is strategy-proof because all of the agents claiming a lower share than their initial, equal portion will have their claims met. Once the water is assigned, lower amounts remain for the agents who ask for more than their equal share. Therefore, agents who overstate their water demands run the risk of being left with less water than if they had expressed their true demands. In contrast, agents who request less than their actual demands will never receive more than their claims. Thus, there are economic incentives to always report the true ideal share, and in practical terms, farmers are only required to report their ideal share. Following the steps above, a computer program works through the different stages of the algorithm to come up with the definitive allotments.

In contrast, the proportional rule assigns a fixed amount of water that is the same for all users. Under this rule, users' preferences are ignored, and the total water assignments just depend on the size of the farm (hectares). Thus, farmers can use all of the water assigned or not, but if they do not use their total allotment, they lose it without any compensation. We assume that users cannot keep their assigned water through the next allotment period.

The market rule is the well-known market system. Farmers have an initial water endowment, but they have the option to sell or buy water from other users. Theoretically, this system achieves the most efficient outcome as agents with higher water productivity will sell water to agents with lower productivity. The main problem with markets is the need for well-defined institutions to assign groundwater rights and control the market transactions (Calatrava and Garrido, 2005a).

In this paper, we compare the results achieved through the implementation of the three proposed rules (uniform, proportional, and market) for groundwater allocation. We consider the market rule as the benchmark as it is the one that achieves optimal water sharing. To evaluate the relative efficiency of the uniform rule compared with the proportional rule, we calculate the efficiency losses from both rules with respect to the results under the market rule.

Empirical application in the Western La Mancha aquifer

Study area. The Western La Mancha aquifer is one of the largest aquifers in the Iberian Peninsula, covering 5500 km^2 in the upper Guadiana Basin of central Spain. The aquifer supports a large area of irrigated agriculture in central Castilla-

La Mancha State. The total area of the aquifer is divided into three different regions: Ciudad Real, Albacete, and Cuenca. This aquifer supports approximately 200,000 ha of irrigated crops, of which approximately 23% correspond to cereals crops (mainly corn, barley, wheat, and alfalfa), around 15% correspond to vegetables (mainly watermelon, beetroot, and garlic), and finally around 62% correspond to fruit-trees (mainly vineyards) (MAPA, 2011).

Empirical model. To evaluate the effects of different water allotments and to determine farmers' responses, we employed a model that represents the decisions of the individual farmers that maximize their private net benefits. We assumed five different types of farmers, i (i = 1,..., 5), that are considered representative of the region. These farmers are heterogeneous in the type of crops they grow and thus in the amounts water they use, revenues they generate and costs they incur. The private net benefits of each farmer are represented as the difference between revenues and costs from growing crops j (j=1,…, 5). The model considers the following five crops: wheat, barley, corn, alfalfa and beetroot, which cover a total of 32,054 ha. We have chosen these crops due to the available information about their production functions.

The individual farmer's problem under the proportional rule is stated as follows:

$$\pi_i(E_i) \equiv \max_{w_{ij}, h_{ij}} \sum_{j=1}^{5} \left(p_j \cdot y_{ij}(w_{ij}) - c \cdot w_{ij} - k_{ij} + s_{ij}\right) \cdot h_{ij}$$
$$\textit{subject}\ \text{to}: \sum_{j=1}^{5} w_{ij} \le E_i\ ;\ w_{ij} \ge 0; \qquad [2]$$

where p_j denotes the market price by crop, j (€ per ton); the parameter c is the price of pumping water, w_{ij} (€ per m^3); k_{ij} is the fixed cost of crop j (€ per ha); s_{ij} is the direct payment from the European Common Agricultural Policy for crop j (€ per ha), and y_{ij} is the yield of crop j as a function of water per ha. The variable h_{ij} denotes the number of hectares cultivated under crop j.

The function $\varpi_i(E_i)$ determines the maximum value for problem [2], *i.e.*, the total net benefits for farmer i given the current water pumping cost, c, and his/her initial water endowment, E_i (m^3 per ha). In principle, the function $\varpi_i(E_i)$ also depends on the parameters p, c, k, and s, but as these do not vary at any stage of the empirical study, we chose to suppress them to simplify the notation.

The formulation of equation [2] represents the situation when farmers receive an initial endowment of water (a fixed amount) that they can either use completely or not; water exchanges are not permitted in this case. This equation can easily be modified to represent the water market, and the theoretical formulation of the market rule has been widely presented in the literature (see, for example, Martínez and Goetz, 2007).

The yield production functions, $y_{ij}(\times)$, were collected from Goetz *et al.* (2008), and Calatrava and Garrido (2005b) adapted them for our study area. They are denoted by $\hat{y}_{ij}$. The functions for wheat, barley, corn and alfalfa were previously generated with the EPIC biophysical simulator package (Texas Agricultural Experiment Station, Temple, USA), which is able to reproduce the biophysical processes in the soil and plant growth as a function of the agricultural inputs and the weather (see Martínez and Albiac (2004) for a complete description of the calibration and validation of the EPIC simulation model). We have also contrasted the crop yield results with real data from the area (MAPA, 2011). The economic parameters of the farm model were obtained using data from the Spanish Ministry of Agriculture, Fisheries and Food (MAPA, 2011). Information about the crops, subsidies, fixed costs, and market prices as well as the estimated coefficients for $\hat{y}_{ij}$ are shown in Table 1. The production function depends on the water used and follows a polynomial function:

$$\hat{y}_{ij} = a_{ij,0} + a_{ij,1} w_i + a_{ij,2} w_i^2 \qquad [3]$$

The maximization problem (Eq. [2]) was solved with the GAMS package (General Algebraic Mod-

Table 1. Crop information and production function coefficients by crop.

	Wheat	Barley	Corn	Alfalfa	Beetroot
Coefficient $a_{i,0}$	1.9	1.29	-2.78	4.42	12
Coefficient $a_{i,1}$	0.599x10^{-3}	0.95x10^{-3}	0.349x10^{-3}	2.67x10^{-3}	0.015
Coefficient $a_{i,2}$	-0.69x10^{-7}	-1.02x10^{-7}	-0.269x10^{-6}	-1.66x10^{-7}	-0.10x10^{-5}
Total area (ha)	4,302	20,305	3,852	756	2,839
Market price (€ kg^{-1})	0.15	0.13	0.15	0.12	0.05
Subsidy (€ ha^{-1})	270.5	270.5	346.3	-	-
Fixed Costs (€ ha^{-1})	211.2	221.5	716.6	621.1	1,524.4

eling System, GAMS Development Corporation, Washington, USA) using the CONOPT2 algorithm and used to obtain the net farm benefit function, $\varpi_i(E_i)$, for each farmer, *i*. To estimate the function $\varpi_i(E_i)$, we varied the *E*i parameters between 0 and 8,000 m^3 per ha. As shown in equation [4], the estimated net farm benefit functions, $\varpi_i(E_i)$, have a quadratic shape. The equation's parameters are calculated using the SHAZAM econometrics package (SHAZAM Analytics Ltd., London, UK).

$$\hat{\pi}_i(E_i) = b_{i,0} + b_{i,1}E_i + b_{i,2}E_i^2 \qquad [4]$$

The net farm benefit functions, $\hat{\pi}_i(E_i)$, are strictly concave and therefore comply with the uniform rule requirement that the utility of the benefit functions must be single-peaked with a unique ideal share.

Results

Using the estimates of the benefit functions from equation [4], we numerically solve the market equilibrium (the results under the market rule) using GAMS. For the numerical analysis, we consider scenarios of different initial water endowments (from 500 to 8000 m^3 per ha). We report the results for the farmers' private benefits and water use for the three rules considered: market, proportional and uniform.

Table 2 shows the main results under the water market allocation system for percentage of water exchanged, water price, and total benefits based on the initial endowments. As expected, the less productive farms (F1 and F2 in our case) are water sellers, and the more productive farms (F3, F4 and F5) are water buyers. The percentage of water exchanged ranged between 19 and 74.5% of the total water, which shows that farmers will respond by selling their allotments to more productive farmers in cases of severe water scarcity. The results show that markets are especially active up to initial endowments of 5500 m^3 per ha when buyers lose the economic incentive to obtain more water from the market. As initial endowments rise, the economic incentive for exchange decreases to 0 when allotments are higher than 5,500 m^3 per ha. Water market prices ranged between 0.015 and 0.48 € per m^3. When water is scarce, the marginal utility of water for farmers (the benefit) increases, and thus, water prices are high. In the following analysis, we will consider the market case as the benchmark or the most efficient case. Thus, we will calculate the benefit losses from the proportional and uniform social rules with respect to the market rule.

Table 3 shows the allotments of water and the farmers' benefits under the proportional rule. With this rule, farmers receive a fixed water endowment calculated as an equal share of the total water per hectare assigned by a regulator; it is assumed that the regulator knows the total water available in the aquifer and the recharge rate. When the initial endowment is higher than the optimal (ideal) amount for any farmer, he/she only pumps his/her ideal. For example, F1 attains his/her ideal at 2891.3 m^3, and he/she uses only this amount and liberates the remaining 3000 to the aquifer (see Table 3). Endowments in excess of the ideals are unproductive because the rule does not permit reallocation of water among farmers. This rule has the property of anonymity (*i.e.*, the identity of the farmer is not relevant), so the resulting allotments are symmetrical, and farmers do not envy each other's allotments. However, as the farmers' preferences are not identical, the proportional allotments are not Pareto-efficient.

The main advantage of the uniform rule is that it allows for large increases in efficiency compared with the proportional rule. As we can see in Table 4, the uniform rule permits the reassignment of water among firms when one farm is attaining

Table 2. Water market results.

Water endowment (m^3 per ha)	Water exchanged (%)	Water market price (€ per m^3)	Total benefits (in 10^3 €)
500	74.5	0.484	9002.6
1000	60.0	0.372	14683.8
1500	55.2	0.276	20896.3
2000	43.2	0.224	22208.5
2500	40.0	0.171	22094.0
3000	39.5	0.118	21188.3
3500	36.6	0.078	20628.6
4000	30.5	0.053	20286.3
4500	24.4	0.034	19718.5
5000	19.5	0.015	19129.1
5500	0	0	19129.1
6000	0	0	19129.1
6500	0	0	19129.1
7000	0	0	19129.1
7500	0	0	19129.1
8000	0	0	19129.1

Source: MAPA (2011).

Table 3. Results under the proportional rule.

	Water use (m^3 per ha)					Net benefit (€ per ha)					
Water endowment (m^3 per ha)	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5	Total benefits (in 10^3 €)
500	500	500	500	500	500	372.04	261.75	-549.84	50.52	-576.90	3197.7
1000	1000	1000	1000	1000	1000	394.20	298.55	-332.75	180.90	-254.40	5890.6
1500	1500	1500	1500	1500	1500	411.19	328.73	-135.84	301.27	43.10	8271.6
2000	2000	2000	2000	2000	2000	423.00	352.27	40.90	411.64	315.60	10337.3
2500	2500	2500	2500	2500	2500	429.64	369.18	197.46	512.02	563.10	12090.8
3000	2891.3	3000	3000	3000	3000	431.22	379.47	333.85	602.38	785.60	13531.9
3500	2891.3	3500	3500	3500	3500	431.22	383.12	450.06	682.75	983.10	14675.1
4000	2891.3	3525.6	4000	4000	4000	431.22	383.13	546.10	753.12	1155.60	15588.2
4500	2891.3	3525.6	4500	4500	4500	431.22	383.13	621.96	813.48	1303.10	16344.8
5000	2891.3	3525.6	5000	5000	5000	431.22	383.13	677.65	863.84	1425.60	16945.2
5500	2891.3	3525.6	5500	5500	5500	431.22	383.13	713.16	904.20	1523.10	17389.3
6000	2891.3	3525.6	6000	6000	6000	431.22	383.13	728.50	934.56	1595.60	17677.1
6500	2891.3	3525.6	6130.1	6500	6500	431.22	383.13	729.18	954.91	1643.10	17830.0
7000	2891.3	3525.6	6130.1	7000	7000	431.22	383.13	729.18	965.26	1665.60	17901.7
7500	2891.3	3525.6	6130.1	7267.5	7200	431.22	383.13	729.18	966.69	1667.60	17907.9
8000	2891.3	3525.6	6130.1	7267.5	7200	431.22	383.13	729.18	966.69	1667.60	17907.9

its ideal share. For example, when F1 attains its ideal at 2891.3 m^3, the rest of the water remaining in the endowment (3,000 or more) can be used in a productive manner by the rest of the farmers. The flexibility of the rule results in the full and more efficient use of initial water endowments. More efficient water distribution is measured in terms of benefit gains, and Table 4 shows the benefits per hectare under the uniform rule, which obtains higher benefits than the proportional rule for all relevant ranges of water allotments (from 3,000 to 8,000 m^3 per ha). In terms of benefits per hectare, the losses under the uniform rule are 9 to 15% lower than under the proportional rule with respect to the market rule. In contrast, when the initial endowments are low (500 to 2,500 m^3), both the proportional and uniform rules lead to the same benefits. The reason is that under severe water scarcity scenarios, the structure of the farms, *i.e.*, their soil characteristics and climate conditions, limits the farmers' crop selection and even prevents their farming activities. In fact, within the allotment range of 500 to 1,500 m^3, our results show that farmers F3 and F5 will abandon their activities.

A comparison of the efficiency losses for the total region from using the uniform and the proportional rules is shown in Figure 1. The results indicate that the efficiency gains from the uniform rule equate to a minimum of 1.1 million euros and a maximum of 2.9 million euros, 7.5 and 17%, respectively, for a range of 3,500 to 5,000 m^3 per ha.

Although we do not show these numerical results here, we have calculated the impacts from duplicating pumping costs. An increase in pumping costs leads to better results for the uniform rule compared with the proportional rule (between 4 and 8% in the interval from 3,500 to 5,000 m^3).

The results above indicate that the uniform rule has the potential to improve the economic efficiency of water allocation. This advantage can be explained by the fact that the uniform rule considers the users' preferences for water allotments without requiring institutional changes as needed under the proportional rule. The applicability of the uniform rule seems more straightforward than the market rule because the uniform rule can be applied in the current

Table 4. Results under the uniform rule.

	Water use (m^3 per ha)					Net benefits (€ per ha)					
Water endowment (m^3 per ha)	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5	Total benefits (in 10^3 €)
500	500	500	500	500	500	372.04	261.75	-549.84	50.52	-576.90	3197.7
1000	1000	1000	1000	1000	1000	394.20	298.55	-332.75	180.90	-254.40	5890.6
1500	1500	1500	1500	1500	1500	411.19	328.73	-135.84	301.27	43.10	8271.6
2000	2000	2000	2000	2000	2000	423.0	352.27	40.90	411.64	315.60	10337.3
2500	2500	2500	2500	2500	2500	429.64	369.18	197.46	512.02	563.10	12090.8
3000	2891.3	3027.2	3027.2	3027.2	3027.2	431.22	379.83	340.69	607.01	796.98	13601.4
3500	2891.3	3525.6	3694.3	3694.3	3694.3	431.22	383.13	489.77	711.28	1053.1	15048.1
4000	2891.3	3525.6	4527.7	4527.7	4527.7	431.22	383.13	625.57	816.53	1310.54	16381.6
4500	2891.3	3525.6	5361	5361	5361	431.22	383.13	705.31	893.98	1498.5	17280.9
5000	2891.3	3525.6	6130.1	6226.5	6226.5	431.22	383.13	729.18	945.01	1620.21	17757.1
5500	2891.3	3525.6	6130.1	7267.5	7200	431.22	383.13	729.18	966.69	1667.6	17907.9
6000	2891.3	3525.6	6130.1	7267.5	7200	431.22	383.13	729.18	966.69	1667.6	17907.9
6500	2891.3	3525.6	6130.1	7267.5	7200	431.22	383.13	729.18	966.69	1667.6	17907.9
7000	2891.3	3525.6	6130.1	7267.5	7200	431.22	383.13	729.18	966.69	1667.6	17907.9
7500	2891.3	3525.6	6130.1	7267.5	7200	431.22	383.13	729.18	966.69	1667.6	17907.9
8000	2891.3	3525.6	6130.1	7267.5	7200	431.22	383.13	729.18	966.69	1667.6	17907.9

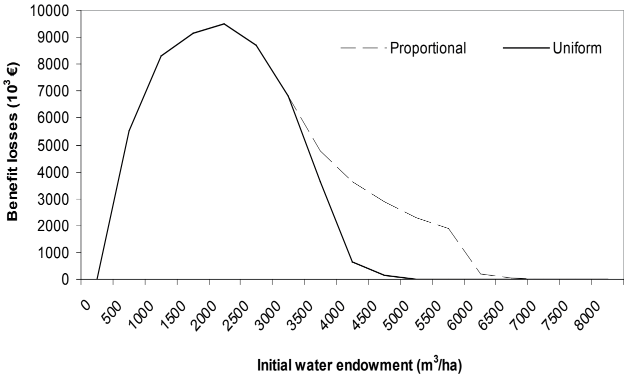

Figure 1. Total benefit losses from social rules with respect to the market.

institutional environment, so transitional transaction costs are not expected to occur. Furthermore, with the uniform rule in place, the agents do not interact within the market, so there are no searching or bargaining costs for individual farmers.

The current study evaluates the efficiency of the different allotment schemes without considering transaction costs, i.e., ex-ante costs of drafting, negotiating and safeguarding an agreement, and ex-post costs associated with contractual breakdowns and rent-seeking behavior. We think that the inclusion of transaction costs in the model is an interesting issue for future research and will substantially improve the comparison of the different allotment schemes.

Despite the limits inherent to our numerical approach, our findings may be useful for providing practical recommendations for the implementation of rationing rules, especially in the case of groundwater where water shortages and aquifer exhaustion could become more frequent due to climate change. Under a scenario of moderate limitations on extraction, the implementation of sharing rules that lower tensions between water users and improve efficiency with respect to the current sharing rule can be important in the long-term.

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Resumen

Y. Martinez y E. Esteban. 2014. Social choice and groundwater management: application of the uniform rule. Cien. Inv. Agr. 41(2): 153-162. En las últimas décadas, la protección de los acuíferos se ha convertido en un aspecto clave en las políticas ambientales en todo el mundo. El control de las extracciones de agua subterránea es necesario para evitar el agotamiento de estos recursos. Este artículo propone un sistema para mejorar la asignación de los recursos subterráneos utilizando la teoría de la elección social. Se propone la introducción de la regla uniforme, que tiene en cuenta las preferencias de los usuarios para alcanzar decisiones colectivas, respecta el anonimato de los agentes y mantiene las propiedades de eficiencia de Pareto y no manipulación. El artículo compara los resultados obtenidos con esta regla uniforme con los de otras reglas de reparto del agua (regla proporcional y regla de mercado). La aplicación numérica se lleva a cabo en el acuífero de La Mancha Occidental (España) donde la agricultura intensiva en las últimas décadas ha provocado serios problemas de sobreexplotación. Los resultados muestran que la regla uniforme es capaz de mejorar sustancialmente la eficiencia en el uso de los recursos subterráneos.

Palabras clave: Acuífero de La Mancha Occidental, gestión de aguas subterráneas, no manipulación, regla de elección social, regla de mercado, regla proporcional, regla uniforme.

References

Aadland, D. and V. Kolpin. 2004. Erratum to "environmental determinants of cost sharing". Journal of Economic Behavior & Organization 55:105-121.

Barberà, S. 2005. Strategy Proofness. In: Arrow, K.J., A.K. Sen, and K. Suzumara (eds.). Handbook of Social Choice and Welfare. Volume II, Elsevier Science, Amsterdam.

Barberà, S. and M. Jackson. 1995. Strategy-proof exchange. Econometrica 63:51-88.

Barberà, S., M. Jackson, and A. Neme. 1997. Strategy-proof allotment rules. Games and Economic Behavior 18:1-21.

Benassy, J. 1982. The Economics of Market Disequilibrium. Academic Press, NewYork.

Calatrava, J. and A. Garrido. 2005a. Spot water markets and risk in water supply. Agricultural Economics 33:131–143.

Calatrava, J. and A. Garrido. 2005b. A modelling water markets under uncertain water supply. European review of agricultural economics 32:119-142.

Carey, J., D. Sunding, and D. Zilberman. 2002. Transaction costs and trading behavior in an immature water market. Environmental and Development Economics 7:733-750.

Goetz, R., Y. Martínez, and J. Rodrigo. 2005. Eficiencia de las reglas de asignación de agua en el regadío: asignación a través de mercados, de la regla proporcional y de la regla uniforme. Economía Agraria y Recursos Naturales 9(5):115-138.

Goetz, R., Y. Martínez, and J. Rodrigo. 2008. Water allocation by social choice rules: The case of sequential rules. Ecological Economics 65:304-314.

Lee, T. and A. Jouravlev. 1998. Los precios, la propiedad y los mercados en la asignación del agua. CEPAL (Naciones Unidas). Santiago, Chile.

Martínez, Y., and J. Albiac. 2004. Agricultural pollution control under Spanish and European environmental policies. Water Resources Research 40(10): W10501.

Martínez, Y., and R. Goetz. 2007. Ganancia de eficiencia versus costes de transacción de los mercados de agua. Revista de Economía Aplicada XV (43):49-70.

MAPA, Ministry of Agriculture, Fishery and Food. 2011. Análisis de la Economía de los Sistemas de Producción. Resultados Técnico-económicos de Explotaciones Agrícolas de Aragón en 2000. Dirección General de Planificación Económica y Coordinación Institucional. MAPA, Madrid, España.

Moulin, H., and H. Hervé. 2002. Axiomatic Cost and Surplus Sharing. Chapter 6. In: Arrow, K.J., A.K. Sen, and K. Suzumara (eds.). Handbook of Social Choice and Welfare, Volume I, Elsevier Science, Amsterdam.

Qureshi, M.E., S. Tian, E. Sumaira, and W.P. Qureshi. 2009. Removing barriers to facilitate efficient water markets in the Murray-Darling Basin of Australia. Agricultural Water Management 96:1641–1651.

Sprumont, Y. 1991. The division problem with single peaked preferences: a characterization of the uniform allocation rules. Econometrica 59:509-519.

Thomson, W. 1995. Population-monotonic solutions to the problem of fair division when preferences are single-peaked. Economic Theory 5:229–246.

Zilberman, D., and K. Schoengold. 2005. The use of pricing and markets for water allocation. Canadian Water Resources Journal 30:47–54.