Efficiency and acceptance of new water allocation rules - the case of an agricultural water users association

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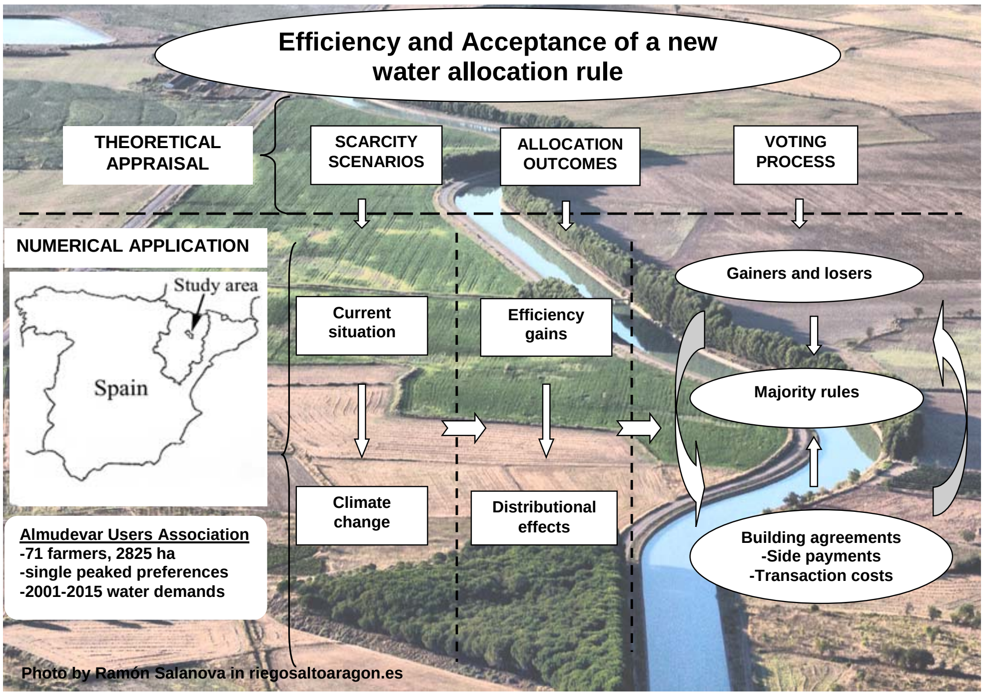
Abstract

Water scarcity is one of the major environmental problems in Southern Europe. High levels of water stress and increasing frequency of droughts, along with a greater environmental protection, make it necessary to design water management strategies that are allocative efficient and balance supply and demand. When functioning markets cannot be developed, the allocation rules proposed in the literature of social choice have been recognized as a suitable alternative. However, the application of new water allocation rules can be impaired by a lack of acceptance and implementation problems. This paper examines these obstacles for the case of an agricultural water users association (WUA), situated in the basin of the River Ebro, in relation to the governance structure and collective decision rule of the WUA. It analyzes the extent to which the gains and losses of the farmers affect their acceptance, and examines conditions for building agreements with side payments that provide incentives for the majority of the farmers to form part of a possible agreement. The results show that the uniform and sequential rules improve the allocative efficiency under normal conditions compared to the status quo and the sequential rule even in the case of droughts. In the presence of side payments this rule is likely to be accepted and has only an insignificant impact on distributional inequality.

Graphical Abstract



Keywords: social choice, voting, water allocation, agriculture, allocative efficiency

Highlights:

- Collective decision making (social choice) and the definition of water allocation rules in agriculture.
- Water allocation rules based on social choice theory improve economic allocative efficiency without introducing distributional inequality.
- The voting system of a water users association often does not support the adoption of new water allocation rules.
- Very small side payments are able to tip the balance towards the adoption of new water allocation rules in the voting process.

1. Introduction

Water scarcity and droughts in Europe, measured in terms of the water exploitation index (WEI)[1], are an increasing phenomenon that affects at least 11% of the population and 17% of the territory (European Commission, 2010). Water resources in Cyprus, Bulgaria, Belgium, Spain, Italy and Malta are exposed to constant water stress as these countries are currently using up 20% or more of their long-term supplies every year (WEI > 20%).

In Spain, for instance, the demand for water for irrigation purposes is about 15,000 Hm^3 per year and represents about 80% of the total national consumptive demand. Water scarcity is extreme in river basins such as the Segura, Júcar, Sur, and the upper Guadiana River (INE, 2016).

Water scarcity and droughts are expected to increase in the near future as a consequence of the concurrence of a variety of factors (European Commission, 2015). On one hand, the consumptive use of water is likely to increase as a result of the expansion of irrigated land, the intensification of tourism and higher transpiration ratios of crops due to climate change. On the other hand, the amount of available water is likely to decrease in the wake of a decrease in precipitations as well as a change of seasonal and geographical patterns.

The increasing level of water stress along with a more demanding regulation of the groundwater and surface water bodies at a European level (Water Framework Directive, 2000/60/EC), motivated and obliged the member states of the European Union to promote water management practices that allow a "good status" of all surface water, groundwater and coastal waters in terms of quality and quantity to be accomplished (Albiac et al., 2007).

Numerous studies have assessed the potential of water markets, or of administrative water pricing where private and social costs are considered. Both approaches aim at balancing the supply and demand of water and sustaining the efficient use of water, i.e., allocating water such that it provides the highest social welfare. Traditionally, the establishment of markets has been considered as a measure that allows the allocating of water among users in a decentralized manner and attenuates the effects of water scarcity. Similarly, administrative water pricing allows a reduction in the demand of

[1] The water exploitation index (WEI) indicates the amount of water abstracted each year as a proportion of total long-term freshwater resources. It is an indicator of the pressure or stress on freshwater resources. A WEI above 20% implies that a water resource is under stress, and values above 40% indicate severe water stress and clearly unsustainable use of the water resource.

water but there is no guarantee that the chosen price maximizes social welfare. Administrative water pricing is based on the costs and as such it takes only the supply side into account. In contrast, the demand side that is driven by the marginal utility of the consumers is not considered and therefore, the maximal social welfare cannot be realized. However, the existing economic literature shows that water markets offer the most efficient allocation of water and maximize social welfare (Howe et al., 1986; Easter and Hearne, 1995; Lee and Jouravlev, 1998).

The experience with water markets is, however, far from the theoretical ideal. In some cases, for example in the Murray-Darling basin in Australia (Bjornlund, 2003), the introduction of water markets even worsened the efficiency of water allocation. The reasons behind the failure of water markets are complex. It may be caused by the existence of political, institutional and/or physical barriers, which prevent vivid exchanges between sectors (Carey et al., 2002). Similarly, high transaction costs may be behind the difficulties in developing local water markets (Easter et al., 1998). Moreover, bureaucratic and legal problems, such as poorly defined water rights, may also prevent the functioning of water markets (Calatrava and Garrido, 2005). If functioning markets cannot be introduced or developed, allocation rules proposed in the literature of social choice may be a good alternative (Barberà, 2005). Goetz et al. (2005, 2008) analyzed the application of various allocation rules with Spanish data and concluded that their application could lead to significant water savings and improvements in the allocation efficiency.

A recent study by the Organization for Economic Cooperation and Development (OECD, 2015) states that, besides water availability, governance is a crucial issue for the management of water resources. According to the OECD (2015) poorly delineated multi-level governance structures and decision processes lead to an unclear allocation of roles and responsibilities. Consequently, improvements in water governance present a key challenge for better water management.

By the same token, the adoption of the above-mentioned allocation rules might not take place due to problems that are related to the process of collective decision making and water governance structures. Accordingly, this paper examines the conditions under which these allocation rules improve the allocation efficiency and are likely to be adopted by the members of an agricultural water users association. For this purpose, the study determines the number of gainers and losers and their associated gains and losses if these allocation rules were adopted. It also analyzes to what extent the gains and losses of the different farmers affect the outcome of the collective decision process to adopt or not a new water allocation rule. Based on the literature on the formation of coalitions (Serrano, 2004; Feldman and Serrano, 2006) we analyze if gainers can build agreements with side payments that provide incentives for the majority of the farmers to form part of an agreement to adopt a new water allocation rule. An empirical analysis based on the water allocation of the Almudevar irrigation district in the Ebro basin provides insights into driving factors for the acceptance or rejection of a new water allocation rule. Our study aims to contribute to the OECD's Principles on Water Governance which encourage evidence-based assessment of the distributional consequences of different water allocation rules (OECD, 2015).

The results show that water allocation rules exist which, in terms of water allocation efficiency, are always superior to the existing water allocation rule. However, if there is a moderate or severe drought only one of these rules is superior to the existing rule. The analysis of the decision process of the Almudevar irrigation district shows further that the established voting process would support the adoption of the most efficient water allocation rule provided that a small part of the overall gains is used to compensate the losers. Moreover, the adoption of the new water allocation rule does not lead to an increase in inequality between farmers.

2. Theory of voting and allocative efficiency

Collective decision making has been analyzed intensively in the economic literature. The results show that if side payments are permitted it is always possible to achieve allocative efficiency. It guarantees that the outcome provides the highest social welfare which in turn allows the gainers to compensate the losers (side payments) without using up all of their gains. Yet, it is an open question to what extent this general result still holds if the governance structure and the decision process itself are taken into account. The wide diversity of governance structures and rules of decision processes foreclose the possibility of obtaining a general answer to the question. Thus, one is left with the analysis of specific situations. For the case of water management and the acceptance of new allocation rules we concentrate on the most decisive characteristics of the collective decision process: the number of votes per person (governance structure) and the voting process (rules of the decision process).

An early finding in the field of cooperative governance and the efficiency of company takeovers was that the rule "one vote one share" will produce efficient outcomes if several bidders compete (Burkhart and Lee, 2008; Grossman and Hart; 1980, Grossman and Hart, 1988; Harris and Raviv, 1988). In a more recent article, Dekel and Wolinsky (2012) confirm this rule, and establish that vote buying may improve efficiency provided that votes and shares are traded simultaneously. The simultaneous trade of votes and shares guarantees that all voters have the same interests, i.e., they form a homogenous group.

In the context of water management, however, an analogy for shares does not exist. Yet, the notion of shares suggests that vote buying would improve efficiency if the party who tenders their vote receives additional future benefits from the adopted policy by the party who won the voting. In fact, this situation may arise when the available water is managed by a general assembly of the farmers. The general assembly may establish rules which control future access to the resource. Each specific rule that defines future water allocation presents future benefits that accrue to the individual members of the Water Users Association (WUA). In consequence the land values of the farmers are likely to increase or decrease depending on the allocated water rights. In this respect land values can be viewed as shares influenced by water allocation rules and the net benefits that accrue from the use of the water can be considered as profits that the shareholder is entitled to. Hence, decisions of the general assembly that distribute a given amount of water in one way or another (water allocation rule) can be viewed as an exchange of shares. Based on the analogy between shares and land values we analyze to what extent vote buying would improve efficiency in the context of water management, taking into account the voting rule and the number of votes per farmer.

With respect to the number of votes per person Dekel and Wolinsky (2012) assume that all shares have identical voting rights. While this assumption is mostly correct in the field of cooperative government, it is not in the field of water management. Our analysis considers the fact that the number of votes per person is frequently linked to the number of hectares owned by the farmer. This peculiarity of many WUAs is not only important for the voting process, but also for the determination of side payments. Moreover, and in contrast to the study by Dekel and Wolinksy (2012), we consider not only a decision rule based on the simple majority, but also on the qualified majority.

Vote buying may be considered as immoral or politically incorrect; yet, in reality, it is a widespread practice. Of course, it does not often occur in the form of monetary transfer but in form of negotiating the characteristics of the proposal to be voted. It is possible to include clauses, exceptions, and criteria etc. that favor or harm certain groups of agents so that it conditions the farmer’s vote.

3. Materials and Methods

The previous theoretical results will be tested empirically by using real data from a Spanish irrigation district, whose main characteristics are described in this section. The data collected will be incorporated into a farm economic model to evaluate the effects of different water allocation rules and to determine the farmers’ responses.

3.1. Area of study

The area of our numerical application is located in the mid-Ebro Valley; 18 km of Huesca in Aragón (Spain) (see Fig. 1). The climate of the zone is Mediterranean, with an annual average precipitation of 430 mm, and an average annual temperature of 13.8ºC.

Fig. 1. Map of the location of the study area

The Almudevar irrigation district is representative of one of the numerous traditional irrigation districts in the country. The Almudevar WUA is located in the province of Huesca, in the northeast of Spain. The total district area covers 3825 ha, with 3674 ha of irrigated land.

The WUA was developed for irrigation in the 1950s, and was designed to apply supplementary irrigation to winter cereal crops. Water demand in the area has increased since the 1970s due to changes in cropping patterns. In 2008, the modernization process of the district began by changing from surface to sprinkler irrigation. Traditionally, the most important crops have been winter cereals of wheat and barley (58.8%), corn (19.4%) and alfalfa (20.6%), followed by others such as sunflower, rice, fruit and orchards to a lesser extent (Torres, 1983). In the years before the modernization of the

WUA (2008-2009), the crop pattern had become more intensive, growing predominantly summer crops (Barros et al., 2011a). Since modernization (2011), corn has become the dominant crop (22% as a single crop and 29% as a second crop) followed by alfalfa (22%) and winter cereals (17%).

Over the last 30 years the Almudevar WUA has been studied intensively by researchers of the Department of Soils and Irrigation of the Agrifood Research and Technology Centre of Aragon (CITA). For example, a representative sample of farmers was surveyed in person during the years 2001 to 2015. Although the WUA has 615 members, only about 71 of them cultivate their own land and the rest of WUA members rent their land to these 71 farmers. Therefore, the cropping and managing decisions are in the hands of the farmers who cultivate their own land.

The CITA provided us access to data that they collected via farm surveys during the years 2001 to 2015. Specifically, the information about tillage techniques, the amount of water and inputs used by farmer and also the cultivated crop were obtained from these surveys. This agronomic data set was verified and validated on a number of occasions. The data set was employed for numerous publications, for instance by Barros et al. 2011a, 2011b; Faci et al. 2000; Lecina et al. 2010; Jiménez-Aguirre and Isidoro 2012, Jiménez-Aguirre et al. 2014.

The agronomic data set was used to define the characteristics of the 71 farmers considered and to calculate their benefit functions in order to evaluate the efficiency of the social rules and the possibility of adopting a new rule according to the outcome of the collective decision process (voting). For the purpose of our empirical application, we have selected the data of the main crops in the area: the winter cereals wheat and barley (irrigated and non-irrigated), corn, pea, alfalfa and sunflower. These selected crops covered 2348.5 ha in 2014 (62% of the total cultivated area). Table 1 shows the distribution of the main crops covered by the surveys.

Table 1. Distribution of main crops

Crop	**Acreage (ha)**
Irrigated winter cereal	206.7
Non-irrigated winter cereal	1672
Corn	124.5
Alfalfa	109.25
TH_Corn[1]	207
TH_Sunflower[2]	29
Total	2348.5

[1]TH_Corn corresponds to two harvests per year: cereal/others after corn
[2]TH_Sunflower corresponds to two harvests per year: cereal after sunflower

Market prices for the crops were collected from the Lonja Agropecuaria del Ebro for the period considered (2001-2015). The Lonja del Ebro is an association of buyers and sellers whose main purpose is to provide a market platform and to fix and record farmgate or market prices of agricultural products within the Ebro Valley. Moreover, for our study we employed the statistics for the prices of seeds and fertilizers that are published by the regional statistical service (Instituto Aragonés de Estadística, 2001-2015).

3.2. Description of the Almudevar Users' Association organization

The key decisions about water management are taken jointly by the two institutions operating within the watershed: the watershed regulatory authority (in our case Confederación Hidrográfica del Ebro, CHE) and the Almudevar Water Users Association. These institutions determine the water allocation for each user, set the administrative water price, assign the irrigation turns, and control investment in the physical infrastructure and individual water consumption, or its transfer to other users. The available water is assigned to each irrigation district in proportion to the size of the district. Likewise, the WUA assigns the water to each farmer in proportion to the amount of land cultivated by the farmer. Thus, the water is assigned according to the so-called proportional rule and each farmer is assigned the same amount of water per hectare.

In our case, the statutes of the Almudevar WUA establish the internal operating rules of the community. These rules refer to decisions on the distribution of irrigation water among shareholders (farmers), decisions on new collective irrigation investments, acquisition of additional water (from external users), claims and complaints with respect to the irrigation management, economic budgets, etc. In addition, the statutes of the WUA establish that any change in water use rights has to be supervised by the Ebro watershed regulator (CHE).

The internal decisions of the WUA are made through the General Assembly (*Junta General)*, where all the shareholders make decisions by voting. The *Junta General* adopts resolutions by absolute majority of the voters present. The shareholders may be represented in the *Junta General* by other shareholders with simple written permission, or by their administrators with legal permission verified by a public notary.

The distribution of the number of votes in the Almudevar WUA is presented in Table 2. Any farmer with an amount of land under 1 hectare can associate with others in order to accumulate enough land to obtain the corresponding votes. The information about the votes will be employed in our empirical illustration of the WUA's collective decision making on the acceptance of new water allocation rules.

Table 2. Distribution of votes in the WUA

Number of hectares	Number of votes
1	1
more than 1 to 5	3
more than 5 to 10	4
more than 10 to 15	5
more than 15 to 20	6
more than 20 to 40	7
more than 40 to 80	8
more than 80	9

Fig. 2 shows the distribution of votes among the 71 farmers considered in our empirical application. Information from surveys indicates that the farmers with less than 20 hectares accumulate the majority of the votes (211 of 413) with a total extension of 511 hectares (21.7% of the total area considered).

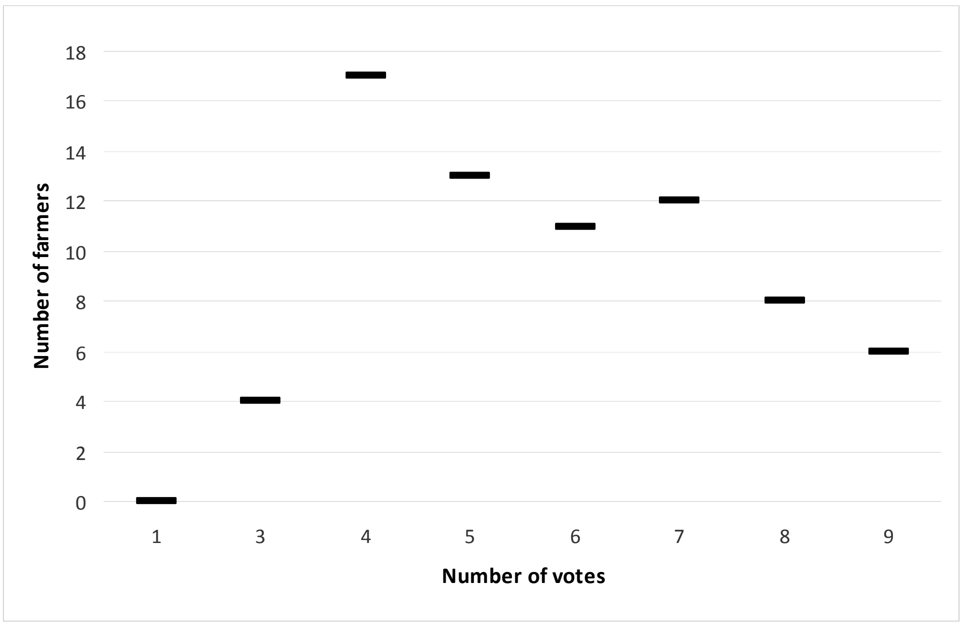


Fig. 2. Distribution of votes among the Almudevar Users' Community

3.3. Economic model

The evaluation of the different rules for assigning water among farmers requires the estimation of the net benefit functions of farmers. As a first step we estimated the crop production functions for each crop using biophysical data, which were previously generated with the biophysical simulator EPIC (Environmental Policy Integrated Climate, Mitchell et al., 1998). The EPIC model is able to reproduce the biophysical processes in the soil and the process of plant growth as a function of the inputs and the weather. The model was calibrated to accurately reflect local conditions with respect to climate, soil, and the usual tillage and operational activities and the results were validated with the real observed data. As an example of this validation process Table A1 of the appendix shows the average simulated yields for different crops by EPIC and the observed average yields.[2]

The crop production functions $\hat{y}_{i,}$ (t/ha) depend on water applied, following the polynomial specification:

$$\hat{y}_i = a_{i0} + a_{i1} \cdot w_i + a_{i2} \cdot w_i^2 \qquad (1)$$

where $w_{i,}$ (€/m^3) denotes the amount of water applied for crop *i*. In addition, we collected data on crop, fertilizer and seeds prices in order to calculate the net benefit functions for farmers. As a second step we employed the result of equation (1) for the determination of the farmer's net benefit function. The net benefits of farmer *j* (*j*=1,…,71), from production activities *i*=1,…,7 are given by the difference between farm returns and costs. The net benefit π_j (in € per hectare) for farmer *j* is calculated as follows:

$$\pi_j(E_j) = \max_{w_{i,j}, h_{i,j}} \sum_{i=1}^{7} \left(pc_i \cdot \hat{y}_{i,j}(w_{i,j}) - n_{i,j} - s_{i,j} - p_j \cdot w_{i,j} \right) \cdot h_{i,j}$$

$$\text{subject to:} \qquad \sum_{i=1}^{7} w_{i,j} \le E_j ; w_{i,j} \ge 0; \qquad (2)$$

where pc_i denotes the market price of crop *i* (€/tm), parameter n_i is the fertilizer cost of crop *i* (€/kg) and s_i denotes the seed cost for crop *i* (€/tm). The variable h_{ij} denotes the

[2] The EPIC model has been used successfully by many researchers throughout the world for local (Bontemps and Couture, 1999), regional (Barbier and Bergeron, 2001; Helfand and House, 1995; Mapp et al., 1994) and national studies (NOAA, 2000). From our own experience with EPIC (Goetz et al. 2008; Martínez and Albiac, 2004, 2006) we can confirm this positive valuation of the biophysical simulation model.

number of hectares cultivated with crop i. The function $\pi_j(E_j)$ determines the total net benefits of farmer j given the administrative water price p_j and the initial water endowment E_j (m^3/ha). The current value of parameter p_j in the study area is 0.0475 €/m^3.

Finally, to estimate the net benefit functions for each farmer we varied the parameter w_i, between 0 and 11000 m^3/ha. From the values obtained for $\pi_i(E_i)$, we estimated a new function, denoted by $\hat{\pi}_j(E_j)$ that relates the j farmer's net benefit obtained from the initial amount of water assigned.

$$\hat{\pi}_j = b_{j0} + a_{j1} \cdot E_j + a_{j2} \cdot E_j^2 \qquad (3)$$

As shown in equation (3), the estimated farm benefit functions $\hat{\pi}_j(E_j)$ have a quadratic form. Their parameters were specified using the SHAZAM package (White, 2002).

These estimated benefit functions were used to evaluate the allocation rules and to calculate the economic viability of economic compensations among users for impeding or facilitating changes of the allocation rules. Calculations were made using Mathematica (Wolfram Research, Inc., 2015).

For our empirical analysis, we first calculate the efficiency gains obtained by introducing two different allocation rules based on social choice theory in comparison with the proportional rule, the uniform allocation rule and the sequential allocation rule. The uniform rule was proposed initially by Sprumont (1991) and has the properties of anonymity, Pareto efficiency and strategy-proofness. The last property implies that agents cannot increase their allocations by misreporting their preferences, so they have no incentives to lie. Barberà et al. (1997) proposed the sequential allocation rule when there are asymmetries among the agents that need to be respected. Thus, the sequential rule maintains the last two properties but respects asymmetry.

The preceding social rules were defined and applied for the case of water allocation by Goetz et al. (2005, 2008) in the Flumen-Monegros irrigation district. In particular, the uniform rule starts with the allocation outcome from applying the proportional rule. However, it departs from the proportional allocation if there is a farmer or a group of farmers who claim less water than entitled to. In this case, the amount requested is allocated and the remaining water is available to be distributed equally among the rest of the farmers. This determines a new amount to be distributed proportionally. The former procedure is repeated until there are no farmers whose ideal amount of water, i.e., the amount of water that maximizes their net benefits is less than or equal to their newly assigned amount. In contrast to the proportional and uniform rules, the initial assignments of the sequential rule are not identical but take into account the heterogeneity of farmers. In our case, water is distributed according to the farmers' net benefit when there is no scarcity. The appendix provides an example to illustrate the operation of the two allocation rules (Tables A.2 and A.3). A more complete exposition of the functioning of social rules is found in Goetz et al. (2008).

After these intuitive explanations, we will state the specific procedure to evaluate each rule. The efficiency gains of any allocation rule are calculated by comparing the sum of the farmers' net benefits resulting from the application of the current proportional allocation rule and the newly designed uniform and sequential rules with the farmers' net benefits resulting from the introduction of a water market within the same water users association. Thus, we take the outcome of the water market as a benchmark for a comparison with respect to the outcomes of the proportional rule, the uniform rule and the sequential rule.[3]

Once we had calculated each farmer's gains or losses from changing the current proportional rule to a new allocation rule, we examined other aspects that influence its acceptance and implementation. Specifically, the identification of gainers and losers allows the number of votes and the side payments that are required to have sufficient support in the voting process to be calculated. Another relevant aspect is the role of transaction costs as an impediment to changing the status quo. Finally, we examine the robustness of our results with respect to changes in the climatic conditions. For this purpose, we consider the effects of climate change on the allocative efficiency and acceptance of the social rules.

4. Results and Discussion

In this section, we analyze the functioning and characteristics of the allocation rules established in the previous section. We focus on four key aspects that could affect the acceptance and implementation of a new rule in the context of the Almudevar WUA: i)

[3] A water market is different from typical good markets because the farmers do not trade the property right of the good but rather a temporary user right that was allocated to them. In this respect water markets are similar to markets for emission permits. The results of the water market were obtained by maximizing the sum of net benefits of all farmers subject to the constraint that farmers cannot sell more user rights that they dispose of and the sum of sold water user rights has to be equal to the sum of bought rights (market clearance) For more details about the mathematical formulation of this optimization problem we refer the reader to Goetz et al. (2008).

allocative efficiency, ii) the distribution of gains and losses among users and its influence on the voting process, iii) the effects of the existence of transaction costs and iv) the impact of climate change.

4.1. Efficiency of the rules

In a first stage, the allocation rules have been implemented by simulating increasing water scarcity situations (from 0% to 50% with respect to the sum of ideal shares of all members) in order to evaluate their allocative efficiency. The efficiency losses of rules are measured as a percentage of the benefits with respect to the most efficient outcome resulting from the introduction of a water market. Fig. 3 reveals that the implementation of the sequential rule leads to lower net benefit losses than the proportional and uniform rules. The uniform rule is superior to the proportional as long as water reduction is inferior to 30%. Thereafter, the net benefit losses are identical to the ones of the proportional rule. Hence, the analysis shows that applying the sequential rule in the case of droughts provides the opportunity to reduce efficiency losses associated with the proportional and uniform rules.

So far the proposed approach has received little attention in the economic literature and it is not really possible to compare our results with findings presented by other authors. However, the results are in line with previous finding by Goetz et al. (2008) for other irrigation areas (Flumen-Monegros district), where benefit losses reach 12% for the proportional rule and 1.5% for the sequential rule in a water scarcity scenario of 25%. Similarly, Gómez-Limón and Martínez (2006) situate the losses of the proportional rule between 12 and 20% for different water scarcity scenarios with respect to the water markets simulated for seven WUAs in the Duero Valley.

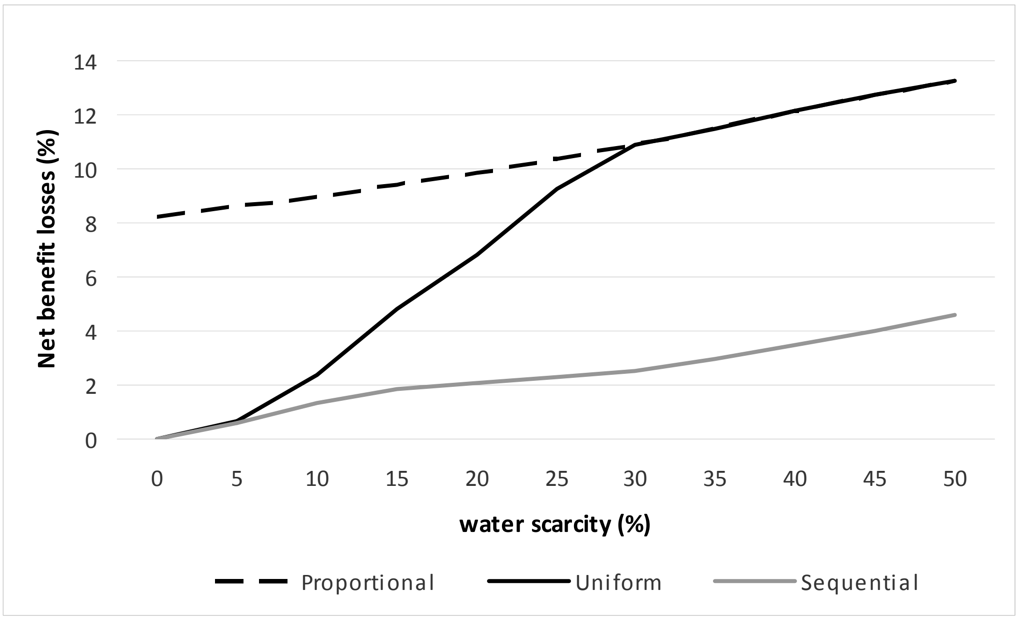


Fig. 3. Net benefit losses of the rules with respect to outcome of a water market (%)

In a second stage, the rules are implemented and the real water endowments for the years 2001 to 2015 were considered. This ex-post analysis allows their effect on efficiency to be evaluated under real conditions. The data show that only two of the last 15 years were especially dry (2009 and 2010), while there was no water scarcity in the other years. In the year 2009 severe restrictions were in place, cutting the total amount of allocated water by 63% of the water demanded. The subsequent year, 2010, was a year of moderate drought, where the available water was equal to 68% of the total amount requested.

Fig. 4 depicts the effect of scarcity on water allocations among users for the allocation rules examined. We illustrate the implementation of the rules considering three water scarcity scenarios: non-scarcity (regular), moderate scarcity (2010) and severe scarcity (2009). In addition, one representative farm has been selected arbitrarily from each of the group of low, medium and higher water demand farms. Based on the choice of these three farms we analyze how the social rules affect the assigned water shares in the case of water scarcity when farmers have different ideal demands. The selected farms are numbers 1, 7 and 12, whose ideal demands are 2385, 7914 and 4682m^3/ha respectively. Under the current proportional rule, all farms receive the same portion of water. In a regular year, only the farmer's demand that is below the proportional allocation (3252m^3/ha) is satisfied. It results in an inefficient allocation, since the excess water of some farmers is not used.

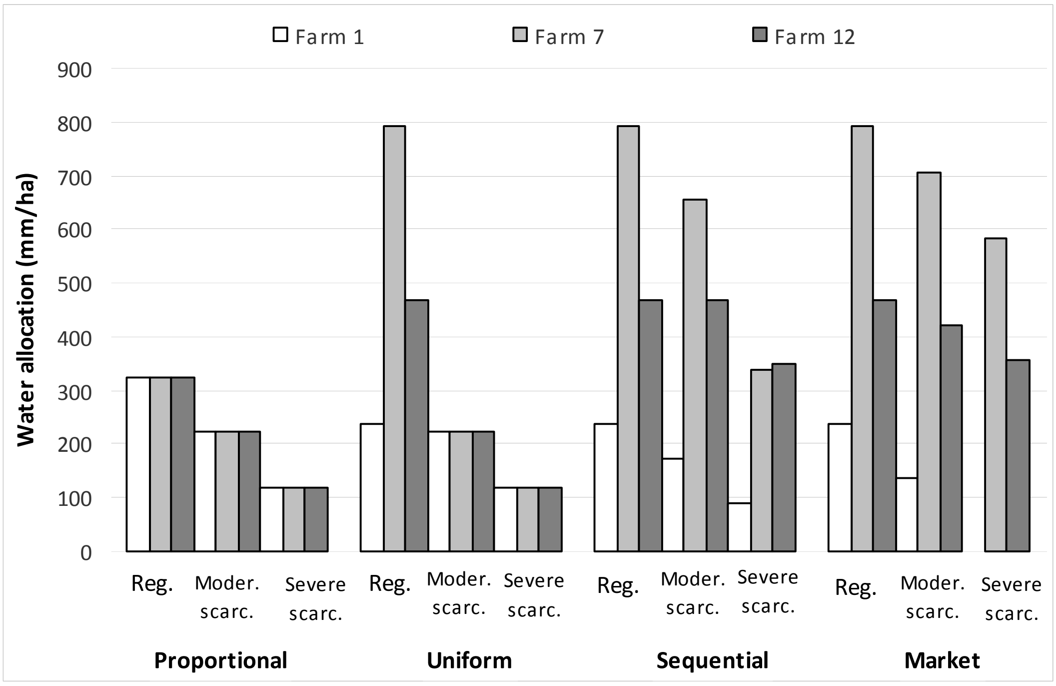


Fig. 4. Water allocation according to four different mechanisms for three different farms based on real water endowments

When no scarcity exists (regular years), the proportional rule is less efficient (8%) than the market outcome, while the social rules (uniform and sequential) are as efficient as water markets since all farmers obtain their ideal shares. In these periods, total net benefits from agriculture sum 1.75 million € when the proportional rule is applied, [4] while the net benefits would increase to 1.91 million € if either the uniform or sequential rule were implemented. The efficiency losses of social rules would be insignificant while the application of the proportional rule implied losses of around 8% of the benefit. Hence, with no water scarcity, social rules lead to better outcomes than the currently applied proportional rule.

In the case of moderate and severe water scarcities, Fig. 4 illustrates for farms 1, 7 and 12 that the uniform and proportional rules lead to the same allocations, while the sequential rule leads to an allocation that is close to the market outcome. Under moderate scarcity, only farm 12 receives its ideal share if the sequential rule is applied. However, in the case of severe scarcity all farms are assigned an amount of water that is below their ideal share. The efficiency losses of the proportional and uniform rules reach 11% and 14% in years of moderate and severe scarcity respectively while the losses of the sequential rule are 2.6% and 5.4%.

[4] Monetary values are not presented in graphical form to keep the presentation short.

Table 3 presents the total discounted net benefits of the Almudevar WUA over the last 15 years for the four different allocation mechanisms calculated for the years 2001-2015. It demonstrates that the efficiency losses of the uniform rule are much smaller than the ones of the proportional rule. It also demonstrates that the efficiency of the sequential rule is similar to that of the water market.

Table 3. Discounted net benefits over 15 years (2001-2015), calculated with a discount rate of 3%

Allocation rule	Discounted net benefits (thousand €)	Efficiency losses (%)
Proportional rule	20772	8.76
Uniform rule	22431	1.47
Sequential rule	22659	0.47
Market	22766	-

Thus, the sequential rule becomes the most interesting rule for analyzing the outcome of the voting processes, the effect of side payments and its distributional effects among farmers. Thus, the remaining part of the analysis from sections 4.2. to 4.5. will focus on comparing the sequential rule with the uniform rule, where the latter will be considered the status quo situation.

4.2. Distributional effects

Apart from efficiency, distributional justice is an important factor for acceptance or non-acceptance of rules. The distributional effects of the rules are analyzed with the Gini Index (or Gini coefficient), a measure of statistical dispersion initially intended to measure inequality between a country’s residents. The Gini Index is the most commonly used approach to measure inequality among values of a frequency distribution, where a value of 0 indicates equality and a value of 1 perfect inequality. Fig. 5 compares the distributional effects of the two rules, for a rising level of water scarcity. Fig. 5a) shows the values of the Gini Index with respect to net benefit per hectare while Fig. 5b) shows the Gini Index with respect to the total net benefit of the farm. As expected, the sequential rule implies an increase in the differences in the net benefit per ha between farms since water is assigned to favor the more efficient users (see Fig. 5a). However, when the Gini index is calculated with respect to the total net benefits Fig. 5b) shows a somewhat counterintuitive result. The application of the sequential rule leads to a lower Gini index compared to the uniform rule when scarcity reaches more than 30%. The explanation is that, under water scarcity, the sequential rule favors small farms whereas larger farms benefit less since they produce mainly on lands of poor quality.

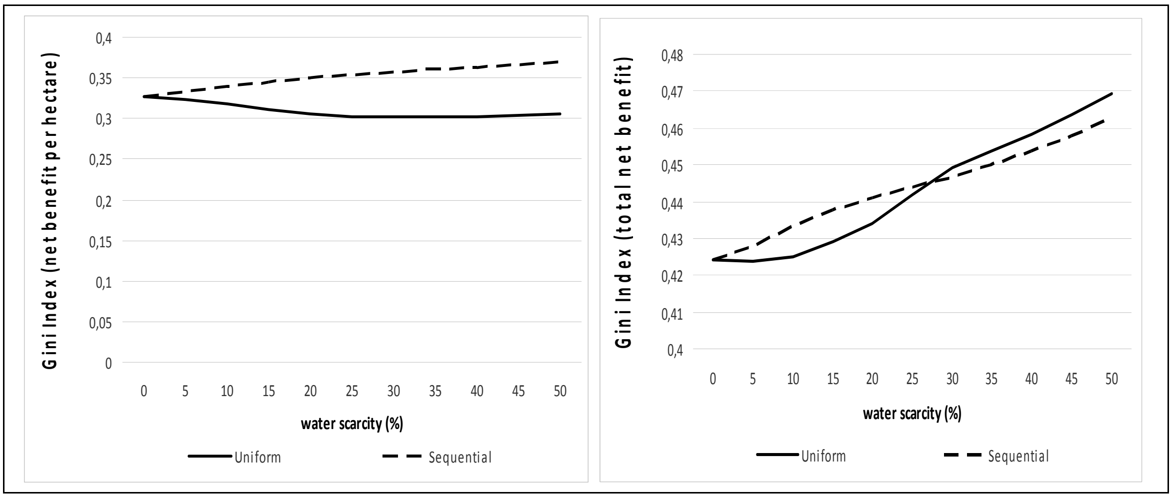


Fig. 5. Distributional effects of the water allocation rules. a) Gini Index with respect to the net benefit per hectare. b) Gini Index with respect to the total net benefits

4.3. Voting process and side payments

Three voting methods have been explored in order to evaluate how the sequential rule is accepted by users and how the new rule affects the distribution of benefits among users. The voting processes considered are: “one person-one vote”, “one hectare-one vote”, and finally the real voting method established by the statutes of WUA in Almudevar. In addition, two alternative majorities will be considered: the simple majority of the votes (50% of votes+1) and the qualified majority of two thirds of the votes (66.6% of votes). Farmers who obtain higher (or equal) profits under the sequential rule are expected to vote for change, otherwise they vote for the status quo (uniform rule). One expects that the likelihood of approval depends on the distribution of gains and losses among the users of the water association.

Simulations of water reductions from 0% to 50% as shown in Fig. 6 reflect that the sequential rule obtains a decreasing percentage of votes as water scarcity increases. This means that the higher the water scarcity, the more farmers lose with a change. Thus, they vote for the status quo. These results indicate that the voting method crucially affects the implementation possibilities of the sequential rule. In fact, when water scarcity is higher than 15% and a simple majority is required, the sequential rule would only be adopted if the “one person-one vote” method were in place. However, if a qualified majority were needed, any water scarcity higher than 10% would impede the approval of the new rule whatever the voting method applied. Hence, the "one person-one vote" system favors the change to the sequential rule in the presence of scarcity while "one hectare-one vote" and the current voting system tend to preserve the status quo.

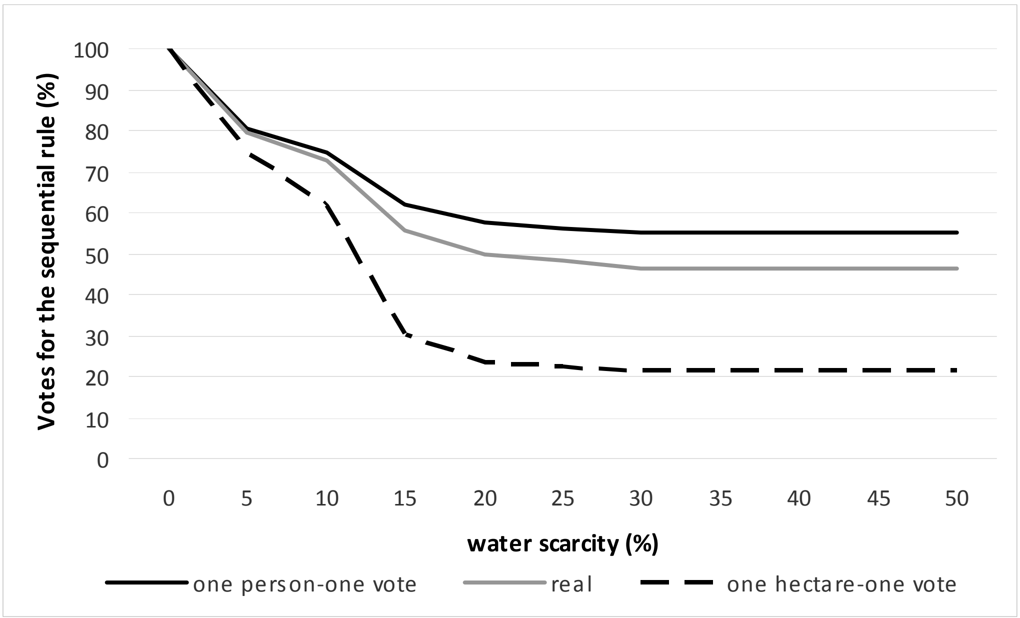


Fig. 6. Percentage of votes for the adoption of the sequential rule

Results with real water allocations over the last 15 years confirm the previous claim: the sequential rule is voted unanimously in regular years independently of the voting method. However, under water scarcity (years 2009 and 2010), the weighting of the votes has a strong effect on the probability of approving the sequential rule. In fact, only with "one person-one vote" will the sequential rule obtain the simple majority of votes in both years (54.9%), while with "one hectare-one vote" and the current voting system only 46.4% and 21.5% of users will vote for change (Table 4). The status quo will always be maintained in years of water scarcity with qualified majorities whatever the voting method. Thus, although the sequential rule improves the total net benefits, the degree of water scarcity and the type of majority rule may prevent its adoption due to the distribution of gains and losses among farmers.

Next, we analyzed the voting processes in more detail by examining their effects on the required number of votes and side payments for adopting the sequential rule. We considered the case where the change voters (gainers) have the possibility of purchasing additional votes from the opposite party. For the payment between users, it is assumed that users in favor of the new allocation rule can identify the users with the lowest net benefit losses among the farmers that prefer to maintain the current allocation rule. Moreover, we assume that the change voters are willing to pay the latter for tendering their votes. Table 4 shows the calculations of votes and payments for the specific cases of a moderate drought (2010) and a severe drought (2009). The side payments are always necessary under the qualified majority rule and payments are lower with “one person-one vote” as the number of votes to buy is also lower. After realizing side payments among users it is possible to determine that the total net benefits of the new rule remain positive. When side payments are permitted, the sequential rule would have an opportunity to be implemented for all analyzed voting methods. With a required qualified majority, payments would represent 0.005 to 5.98% of total gains in years with moderate scarcity and 1.34% to 13.1% in years with severe scarcity.

Table 4. Voting methods and side payments for change

Voting Method	**Majority rule**	**Total # of votes**	**% Votes for change**	**Voting results without side payment**	**Votes to buy for change**	**Payments for change (€) (% over total efficiency gains)**	
						Moderate scarcity	**Severe scarcity**
one pers-one vote	**SM[1]**	71	54.92	Seq.	-	0	0
	QM	71	54.92	*St-quo*	9	827.22 (0.0054)	1860.72 (1.34)
real	**SM**	413	46.48	*St-quo*	15	33.58 $(2.19\cdot10^{-4})$	127.86 $(9.15\cdot10^{-4})$
	QM	413	46.48	*St-quo*	84	2421.54 (1.61)	4783.67 (3.54)
one ha -one vote	**SM**	2340	21.58	*St-quo*	666	4113.27 (2.75)	8789.91 (6.70)
	QM	2340	21.58	*St-quo*	1055	8652.08 (5.98)	16183.29 (13.09)

[1]SM: simple majority; QM: qualified majority;

We also analyzed the effect of different voting methods on the distributional justice for the application of the sequential rule. The results are presented in Fig. 7 in the form of the Gini Index with respect to total net benefit. When a simple majority is required (Fig. 7a), voting processes have no effect on the total benefit distribution among users. On the contrary, the requirement of a qualified majority affects distributional justice if the scarcity is larger than 10%. In these situations, the real voting method leads to a slightly more equalitarian distribution of the net benefits.

From the analysis of the Gini Index we can affirm that side payments have a limited effect on the distributional effects of voting methods, whatever the majority requirement imposed.

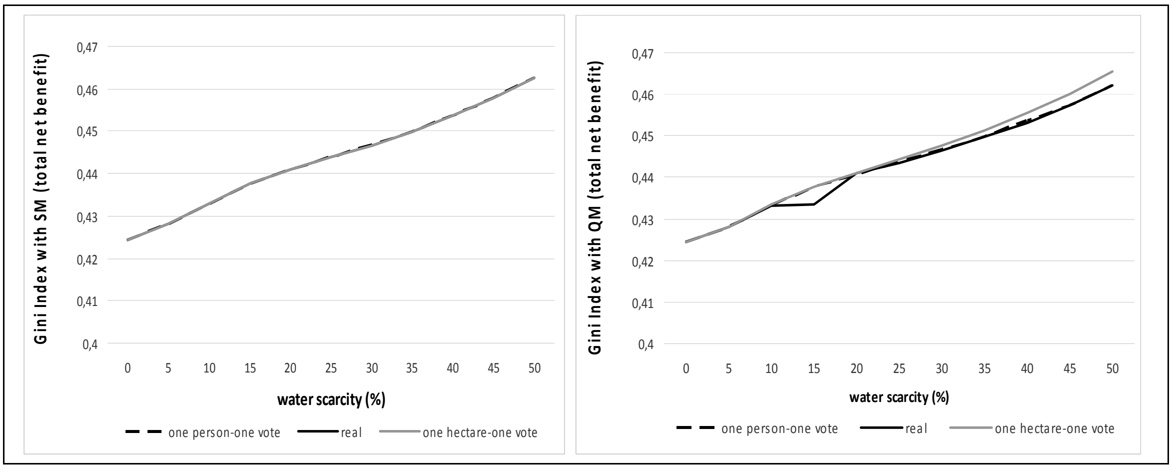


Fig. 7. Distributional effects of different voting methods: a) Simple majority, b) Qualified majority

4.4. Transaction costs

A determining factor for the implementation of a new water allocation rule may be the level of transaction costs. If they are sufficiently high, they may annihilate all gains, which renders the application of social rules useless. In the context of the water users association under study, transaction costs include ex ante costs of drafting and negotiating agreements, and the ex post costs associated with verification and enforcement of contracts. In this section the effect of transaction costs on private gains are assessed by simulating rising levels of these costs from 0 to 2000 € per farmer receiving a side payment. Fig. 8 illustrates the benefit gains of change when transaction costs are considered in year 2009 (severe scarcity case). The benefits are expressed as a percentage with respect to benefit gains when there are no transaction costs.

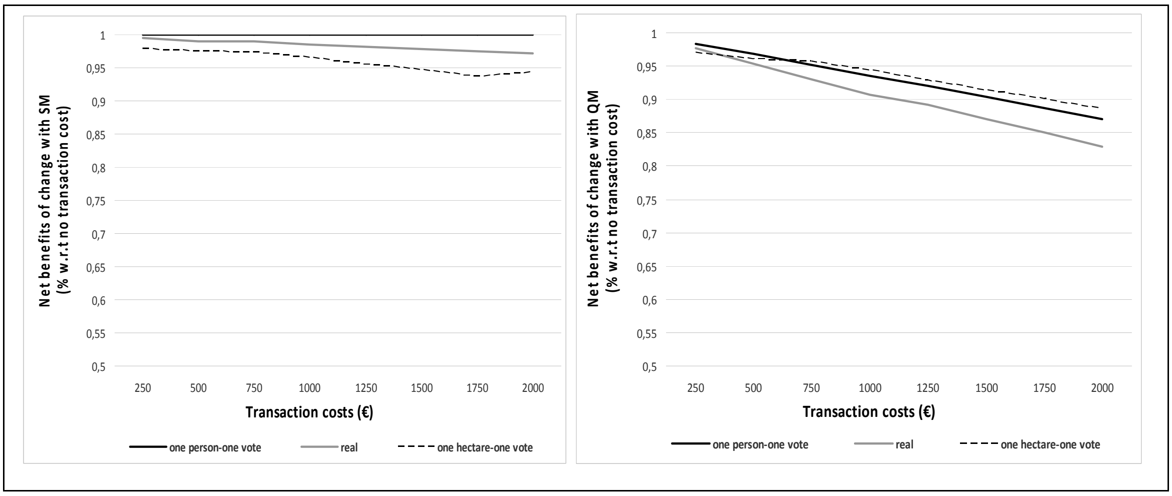


Fig. 8. Gains (%) of the adoption of the sequential rule under different transaction cost scenarios. a) Simple majority, b) Qualified majority

Fig. 8 a) shows the influence of different voting methods under the simple majority rule on the total net benefits as a function of transaction costs. With "one person-one vote" the total net benefits are not affected by transaction costs since the optimal farmers' decision with simple majority is always the sequential rule. Results reveal that the net benefits decrease with "real" and "one hectare-one vote" voting methods. With respect to the cases of no transaction costs, the gains decrease to 97.1% for the "real" voting method and to 94.3% for "one hectare-one vote" method.

Fig. 8 b) is like Fig. 8 a); however it shows the case of a qualified majority. In this situation, the transaction costs reduce total gains for all voting methods. The gains in this case decrease to 87.1% with the "one person-one vote" method, to 82.8% with the "real" method and to 88.6% with "one hectare-one vote". The results show, in general, that the introduction of increasing transaction costs, even in the case of severe scarcity, does not eliminate the private gains of change.

4.5. Effects of climate change on efficiency and implementation possibilities

To evaluate the robustness of our results with respect to changes in the context we analyze the allocative efficiency of the social rules in the presence of climate change. According to existing climate change scenarios for Spain, temperatures will increase, particularly in Southern Spain, and water resources will be severely affected; exacerbating droughts. The set of projections by Estrela *et al*. (2012) considers two different scenarios. For the Ebro River basin, where the study area is located, the projections for a moderate climate change scenario (B2)[5] indicate that available water will decrease by 11% and 14% over the time horizons 2041–2070 (medium term) and 2071–2100 (long term) respectively. Forecasts in the more pessimistic scenario, A2, estimate a reduction of water resources by 14% and 28% in the medium term and long term respectively. We use these two scenarios in order to analyze the effects of climate change on the efficiency and the probability of acceptance. It is assumed that the rest of the parameters and variables different from the available water remain constant, i.e., prices, costs, number of hectares, number of farmers and the employed technology do not change over time.[6]

The similarity of the results of the long-term B2 and the medium-term A2 scenario, and the little differentiability between results of medium-term B2 and long-term B2 suggests concentrating on the medium- and long-term results of A2 (14% and 28%). Table 5 illustrates that the frequency of droughts will increase by 50% (from 2 to 3 every 15-year period) in the medium term and by 200% (from 2 to 6) by the end of the XXI century. As a consequence, climate change increases the number of periods where the sequential rule should be adopted. The discounted net benefits of the WUA for all water allocation rules will decrease and the sequential rule continues to be superior to the other rules.

Table 5. Discounted aggregate net benefits over 15 years when climate change is considered

Projections with climate change	Frequency of droughts	Allocation rule	Discounted net benefits (thousand €)	Efficiency losses (%)
Medium term (14%)	Every 5 years	Proportional rule	20694	8.72
		Uniform rule	22350	1.41
		Sequential rule	22573	0.43
		Market	22670	-
Long term	Every 2.5 years	Proportional rule	20553	7.07

[5] The emission scenarios (B2 and A2) are part of the set of scenarios of emission of greenhouse gases used in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007).

[6] In the case that some of these parameters change, we conjecture that our conclusions remain valid as long as the net benefits of the farmers as a function of the available water remain the same. Likewise, the conclusions remain valid if the net benefits change but the changes affect all farmers in the same way, i.e., the ranking of the farms with respect to net benefits is not altered. In the case that the ranking is affected, our results are likely to be enforced if the spread of the ranking is amplified. For the contrary case where the spread of the ranking diminishes, the comparative advantage of the new allocation rules is also likely to decrease.

(28%)	Uniform rule	22118	1.24
	Sequential rule	22397	0.65
	Market	22543	-

Despite the superiority of the sequential rule, one can observe in Table 6 that the status quo often prevails if side payments are not implemented, especially if a qualified majority is required for its approval. Therefore, side payments are necessary to obtain a sufficient number of votes. The maximal payments can rise in the medium and long term by up to 11.82% and 10.53% of the total gains respectively. These magnitudes confirm the previously obtained result that even in the case of severe droughts a small part of the gains is already sufficient to compensate the losers.

Table 6. Results of the voting process when climate change is considered

Projections with climate change	**Voting method**	**# of years the sequential rule will be implemented (without side payments)**		**Maximum payment for change (€) (% over total efficiency gains)**	
		SM[1]	**QM**	**SM[1]**	**QM**
Medium term	one person-one vote	3	1	0	1771,74 (1.36)
	real	1	1	120,91 (0.09)	4557,39 (3.5)
	one hectare-one vote	1	1	8401,5 (6.45)	15402,64 (10.53)
Long term	one person-one vote	6	3	0	1820,3 (1.21)
	real	4	3	116,21 (0.08)	4671,92 (3.10)
	one hectare-one vote	3	2	8480,1 (5.62)	15895,22 (10.53)

5. Conclusions

Water scarcity and droughts are one of the major environmental problems in Southern Europe and are likely to affect many river basins. Moreover, the situation is expected to aggravate in the near future due to climate change. Thus, policy makers are confronted with the challenge of designing policies that balance water demand with supply. Water markets are often seen as an efficient instrument to this end. However, functioning markets can frequently not be established due to legal, physical or social barriers. As an alternative to markets, the economic literature proposed water allocation rules. The application of these rules, however, may be impaired by lack of acceptance and implementation problems.

For the case of an agricultural water users association, this paper compared the allocative efficiency of the new allocation rules with the current water allocation rule and the market outcome. The results show that the sequential rule is superior to the uniform rule and both are superior to the current allocation rule. Their efficiency losses are relatively small compared to the market outcome. This result holds even more in the case of more frequent and severe droughts (climate change). However great the superiority of the new rules, the water users association might not adopt them since the number of losers might be greater than the number of gainers. The chance of the new allocation rules being approved in the water users association general assembly depends on the assignment of votes per person and the type of majority required (simple or qualified). Our empirical study of the Almudevar water users association located in the Ebro river basin shows that the distribution of gains and losses among the farmers often impedes the approval of a new rule, mostly independently of the assignment of votes per person and the type of majority rule. However, side payments may tip the balance in favor of new allocation rules. The calculations show that only a very small part of the gains is needed to compensate the losses of the farmers whose votes are necessary for the approval of a new allocation rule. Taking transaction costs into account hardly affects the acceptance of a new allocation rule. Even high transaction costs are of minor magnitude compared to the overall gains of new allocation rules. Overall, the study shows that the implementation of new allocation rules would help to balance supply and demand in an efficient manner in particular with climate change taking place in the future.

To our best knowledge, this is a first empirical application of the new allocation rule and more empirical studies are necessary to confirm our results. Another interesting option for future research would be the realization of a pilot study where a water users association (or at least some of the farmers from a water users association) examines the effect of new allocation rules in practice. To provide incentives for farmers to participate we suggest that the allocation rules are introduced gradually. For instance, the farmers that are willing to take part in the pilot study could enroll only 10% or 20% of their irrigated land. In this way they can learn about the organizational issues of the rules and its impact on their net benefits. The partial adoption of the new rule facilitates the initial participation since in the case of problems the monetary consequences are limited.

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Appendix

Table A.1. Observed and simulated yields for different crops

Crops	Observed average yield (kg/ha)	Simulated average yield (kg/ha)	Water use (m^3/ha)
Pea	2880	2869	3000
Alfalfa	16072	16088	7500
Barley	4571	4572	3200
*Corn**	13974	13960	8000
*Sunflower**	2700	2638	2500
Wheat	5775	5828	5500
Vetch	3700	3684	2500

*Corn and Sunflower can be cultivated after Pea, Vetch or Barley giving rise to two harvests (TH) per year that are denoted by TH_Corn and TH_Sunflower in Table 1.

Table A.2. Water allocation following the uniform rule
(It is assumed that all farmers have 1 ha and quantities are given in m^3/ha.)

Allocation	Farmers 1	Farmers 2	Farmers 3	Farmers 4	Remaining water
Ideal share	2385	7914	4682	3313	13008
Initial guaranteed portion	3252	3252	3252	3252	
Water assigned 1st round	2385				10623
Guaranteed portion		3541	3541	3541	
Water assigned 2nd round				3313	7310
Guaranteed portion		3655	3655		
Water assigned 3rd round		3655	3655		

Final allocations	2385	3655	3655	3313	0

Table A.3. Water allocation following the sequential rule
(It is assumed that all farmers have 1 ha and quantities are given in m^3/ha)

	Farmers				**Remaining**
Allocation	**1**	**2**	**3**	**4**	**water**
Ideal share	2385	7914	4682	3313	13008
Initial guaranteed portion	3902[1]	3252	4553	1301	
Water assigned 1st round	2385				10623
Guaranteed portion		3794	5311	1518	
Water assigned 2nd round			4682		5941
Guaranteed portion		4243		1698	
Water assigned 3rd round		4243		1698	
Final allocations	2385	4243	4682	1698	13008

[1]Water is initially assigned proportional to each farmer's maximum benefits per hectare

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