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Cooperation in Common Property Regimes under Extreme Drought Conditions: Empirical Evidence from the use of Pooled Transferable Quotas in Spanish Irrigation Systems.

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Abstract

The success of a common property regime can be partially judged on the basis of its ability to handle extreme events that stress its capacity for cooperation. This paper compares the performance of 38 irrigation associations in a large irrigation area in Spain during a severe drought as a test of hypotheses derived from property right theories. The case is particularly interesting because it contains a transferable quota institution that can potentially strengthen the effectiveness of common property regimes in scarcity conditions. According to the results the use of transferable quotas across associations can contribute to cooperation and drought performance. In this context, performance is higher when the associations enjoy (1) effective monitoring systems, (2) experience and legitimate leaders, and (3) facilitative biophysical conditions like soil water holding capacity. The analysis also suggests that biophysical properties like soil water holding capacity may compensate for weaker monitoring or leadership, and vice-versa.

Key words: common property regimes; common-pool resources; CPR theory; pooled transferable quotas; drought performance; irrigation; Spain.

1. Introduction

Theory on natural resource management has notably evolved in the last decades. Traditional economic theory long prescribed the need for public authorities to enforce public or private property rights in order to avoid the overexploitation of common pool resources (CPRs) like pastures, fisheries and irrigation systems (Gordon, 1954; Hardin, 1968). More recently, evidence has highlighted the existence of cases where direct users have achieved enough cooperation to self-regulate their use of those resources through common property regimes (Agrawal, 2001; Poteete et al., 2010). As a result, attention has turned to identifying the conditions under which different property right regimes, either alone or in combination, can contribute to successful management (Abbott and Wilen, 2011; Cole, 1999; Costello et al., 2008; Zhang et al., 2013). This line of inquiry has become particularly relevant in the context of climate change (Allan, 2011; Overpeck and Udall, 2010). Under which conditions can common property regimes be successfully combined with other regimes to cope with extreme events like droughts? Which cooperation factors contribute to the success of common property regimes in those conditions?

Voluntary and incentive-based approaches to policy making are receiving increasing attention as supplements to regulations in the field of environmental policy (Dietz and Stern, 2002). Natural resource management scholars have also pointed to the complementary strengths of common and private property institutions, suggesting that regimes that combine both types of institutions may work better than otherwise (Dietz et al., 2003; Ostrom, 2010; Rose, 2002). Empirical tests of this argument are, however, only nascent (Dietz and Stern, 2002).

The Spanish case is particularly appropriate to assess the performance of common property institutions under severe drought conditions as well as the potential contribution of complementary institutions. On the one hand, Spain has been internationally recognized for its dependence on water for economic growth (Cazcarro et al., 2013; Cazcarro and Sánchez Chóliz, 2009), and centenary tradition of its common property-based irrigation associations (Glick, 1970; Ostrom, 1990). On the other hand, an increasing number of Spanish irrigation associations have started to implement private property-based mechanisms to cope with droughts, including water markets and transferable quotas, (Arriaza et al., 2002; Pujol et al., 2006).

Methodologically, the study compares drought performance across 38 Spanish irrigation systems. Drought performance is measured as the ability of an irrigation association to adjust its crop water needs to the decrease in water availability. In the context of common property regimes, such ability requires cooperation. Farmers may not be willing to reduce their acreage or cultivating low instead of high water-demand crops during droughts in order to conserve water that they cannot own privately. Additionally, irrigation organizations in Spain and other countries have very limited authority over crop decisions by farmers, which makes the need to promote cooperation vis a vis those decisions particularly puzzling.

2. Background

2.1. Cooperation problems and theory in common pool resource contexts

An irrigation system is an example of a common pool resource (CPR), i.e., is difficult to partition for private consumption and can be depleted (Ostrom and Ostrom, 1977). In CPRs, sustainable management is usually tied to the resolution of cooperation problems. Cooperation problems in CPR contexts have been traditionally associated to the "tragedy of the commons" (Hardin, 1968). In the "tragedy of the commons", CPR users do not have the incentives to self-restrain resource extraction because they cannot exclude others from the benefits of such effort, so the resource is overexploited and may collapse. The persistence over time of many irrigation systems around the world shows that farmers can reach equilibrium between water demand and supply in the long term. However, that does not mean that farmers are able to sustain that balance when confronted with a drastic disruption in demand or supply. In the event of a drought, farmers need to adapt their cropping patterns to reduce collective water demand. In the context of a common property regime, that requires cooperation. Farmers may not be willing to decrease their irrigated acreage or switch from higher to lower water demand crops[1] if they cannot prevent other farmers from free riding on such effort.

Some of the most cited cooperation factors within Common pool resource theory (CPR theory) are monitoring, small group size and leadership (Ostrom, 1990). "Monitoring makes those who do not comply with rules visible to the community, which facilitates the effectiveness of rule enforcement mechanisms and informs strategic and contingent behavior of those who do comply with rules" (Cox et al., 2010). In many cases, monitoring emerges at a low cost through informal interactions among resource users. In some cases monitors like field guards are also hired. The effectiveness of monitoring depends on how widespread non-compliant behavior is, as well as on the cost-benefit balance for monitors to carry their duties effectively (Coleman and Steed, 2009).

Group size can increase monitoring costs and reduce the chances of cooperation (Ostrom et al., 1994). Additionally, coordination and decision making in large groups may

[1] Higher water demand crops like corn or alfalfa tend to yield higher economic returns than lower water demand crops like wheat or barley Lecina, S., Isidoro, D., Playán, E., Aragüés, R., 2010. Irrigation modernization and water conservation in Spain: The case of Riegos del Alto Aragón. Agricultural Water Management 97, 1663-1675.

entail high information and negotiation costs, thus discouraging users from collaborating (Lubell et al., 2002; Poteete and Ostrom, 2004).

Finally, leaders can help resource users to form agreements, rules or strategies to cope with the resource conditions, as well as perform more general functions such as trust building, conflict management, knowledge diffusion, and mobilization of users for change (Folke et al., 2005; Meinzen-Dick et al., 2002; Subramanian et al., 1997). A leader's authority can be based on education and experience (Meinzen-Dick et al., 2002), differences in wealth (Baland and Platteau, 1999; Velded, 2000) and/or formal organizational position (Pielstick, 2000). In all cases, however, it is important that leaders are accountable to users, as power misuse can weaken trust in the regime and its effectiveness (Theesfeld, 2009).

2.2. Irrigation management and drought in the *Riegos del Alto Aragon* irrigation systems (Spain)

The irrigation systems under study are located in northeastern Spain, and expand throughout the inter-basin of the Gállego and Cinca rivers, mostly within the province of Huesca (region of Aragon). The Pyrenees mountain range, which is located at the north of the irrigable area, supplies most of the available water through snowmelt, as precipitation in the area is limited to roughly 350mm. About 66 % of the available water in the province of Huesca is used directly in the agricultural sector (Cazcarro et al., 2010), which makes the allocation the Pyrenees' water a crucial task to guarantee agricultural production. (Cazcarro et al., 2010). The irrigation systems under study rely on a series of reservoirs located in the Gallego and Cinca basins for that purpose. Water from the reservoirs is delivered to the systems via a network of main and minor canals. Ground water is almost inexistent in the irrigable area.

In the last 40 years, the area under study has suffered from a negative precipitation trend (López-Moreno et al., 2010) and an increased climatic uncertainty caused by rapid changes between wet and dry periods (Vicente-Serrano and Cuadrat-Prats, 2007). The most recent evidence of these trends was the drought of 2005 and 2006 (see Figure 1).

[INSERT FIGURE 1 ABOUT HERE]

Figure 1. Series of water availability (hm^3) in the area of study (1970-2010)

Source: Ebro Basin Agency
Note: Series calculated according to water entries in the main reservoirs of the area of study during each irrigation cycle (from October to September of each year). Total water use rights are calculated as in 2000 and equal to 1,523hm^3 (CHE, 2000). As per the information provided by the GCRAA and CHE officials, those water use rights were stable under the period of study. The severe drought threshold is calculated as one standard deviation below the average availability and equal to 1640hm^3 (Hisdal et al., 2001; Hisdal and Tallaksen, 2000).

As shown in Figure 1 and Table I, water availability in 2005 was 60% lower than the average availability in the 1970-2003 series ($p<0.001$), and 55% below the sum of water use rights in the area. In 2006, water availability was 30% lower than the series average ($p<0.001$) and more than 20% below the sum of water use rights. By 2007 water entries were not significantly different than the series average.

[INSERT TABLE I ABOUT HERE]

1.2.1 Soil characteristics

Two geomorphologic units with different soil characteristics can be distinguished in the area of study: platforms and alluvial terraces. Most common soil types in the platforms are Xerosol Gypsic and Xerosol Calcic, which tend to have low available water holding capacity (AWHC) and high infiltration. These soils can be highly productive, but only if enough water is available (Playan et al. 2000). Alluvial terraces are located at lower altitudes and are dominated by Fluvisol Eutric soils, which have poor drainage but high AWHC. These hydric soils can perform better than the soils in the platforms during periods of water scarcity (Playan et al. 2000). The higher productivity of hydric soils under drought conditions is expected to mitigate the impact of water scarcity crises and in turn decrease the collective action efforts required to readjust water demand to the decreased supply in the systems.

1.2.2 Water management institutions

Irrigation water in Spain is managed for the most part through common property regimes (Varela-Ortega and Hernández-Mora, 2010). Farmers who share a water outlet like a river weir or a well have to self-organize into an irrigation association to manage their common right to use the water from that outlet. The infrastructure that is used to deliver the water delimits the boundaries of the corresponding irrigation system. The amount of water that an association can manage depends on the extension of land to be irrigated within the system. In turn, associations sharing a water source like a dam, or an entire river or aquifer can form a higher level organization to coordinate the use of that source and manage the water across the corresponding irrigation systems. The first system-level associations of the area under study were constituted in the 1950s along with a higher level association called the *General Irrigation Association of Riegos del Alto Aragon* (GCRAA).

System-level associations have to include a general assembly and also an executive committee, a president, a secretary and a conflict solving committee (Varela-Ortega and Hernández-Mora, 2010). Both the members of the executive committee and the president are elected by the farmers every four years. In the area of study, the presidents represent their associations in the GCRAA. The associations can also employ a field guard to monitor the water allocation process.

Water is allocated across and within the irrigation systems according to a water request system. Farmers make daily water orders to the associations and then the associations send unified water requests to the GCRAA, which is in charge of managing the reservoirs. The water is then delivered among the systems by guards of the GCRAA, and within the systems by the associations' guards or by the farmers if the association does not have a guard. By default, there is no limit in the amount of water that farmers and associations can request during normal water availability conditions. In the few occasions that demand by some associations has been disproportionately high the GCRAA has implemented ad hoc restrictions to those associations. During droughts those restrictions are institutionalized by means of a *transferable common pool quotas* institution.

1.2.3 Transferable common pool quotas

To allocate water among irrigation systems during droughts, the CGRAA uses a "pooled transferable quotas" (PTQs) institution according to which each system is assigned a particular amount of water for the entire irrigation campaign (April to October). The decision of whether to apply the PTQs institution is made at the GCRAA level before the start of the sowing campaign (February) so farmers can adjust their cropping plan accordingly. The quotas are calculated according to two criteria. At the beginning of the irrigation campaign, the available water in the reservoirs is partitioned on a per hectare basis across the systems. Subsequently, new reservoir inflows are apportioned based on each system's average consumption during previous campaigns of normal water availability conditions.

Systems cannot go over their quotas, nor have access to the quotas of other systems, even if those quotas are underused. That said, quota shares can be transferred from one system to another if requested by a farmer who owns land in both systems. The transfer has to be requested by the farmer to the GCRAA at the beginning of the irrigation campaign, and it is measured by the amount of hectares to be irrigated in the receiving system. Once the request is approved, it holds for the entire irrigation campaign.

Probably the most persuasive argument for the use of private property-based institutions like transferable quotas is that right holders, whether individual or collective, have an incentive to make efficient investments in resource conservation because they can be assured that only they will receive the benefits of such efforts (Acheson, 2006; Copes and Anthony, 2004; Velez et al., 2012). Common pool quotas, like those shared by farmers within the systems under study, have been praised in other resource sectors as an effective way to balance resource use efficiency and risk under uncertainty conditions (Holland, 2010). When there is uncertainty about resource availability, pooled quotas allow users to share the risk of financial losses if the resource is more scarce than expected. In the irrigation sector, the mechanism would theoretically allow using the water conserved by farmers with lower dependence on irrigated agriculture to serve the needs of those that are more dependent on irrigation and incur in riskier cropping plans during droughts.

Additionally, transferability can facilitate risk reduction by enabling the concentration of rights into uses that are more efficient or necessary (Copes, 1986). This can be particularly beneficial in the irrigation sector during droughts, as water use rights can be transferred from areas where the costs of reducing acreage or switching crops are higher to areas where the costs are lower (Chong and Sunding, 2006; Garrido, 2007). As reported by representatives from the GCRAA, the quota transfer mechanism is used by farmers to concentrate water use in those systems where resource and labor productivities are higher. The extra water brought to those systems would be expected to make the collective adaptation of demand to drought conditions more rewarding than otherwise.

Pooled transferable quotas integrate both common property and private property regime elements. The quotas are exclusive of each irrigation system and can be transferred under certain conditions (i.e. if requested by farmers who own land in two systems). At the same time, the quotas are shared among the farmers within each system, where common property institutions apply. Ultimately, the success of mixed regimes like the PTQs shall depend on factors that facilitate both property right security and transferability across groups, as well as compliance with common property rules within the groups. The existence of leaders who share information and coordinate decisions across and within groups, and the use of monitoring systems are potentially some of those factors (Dietz et al., 2003; Randall, 2002).

3. Methods and Materials

In the context of this study, cooperation is understood as the ability of farmers in an irrigation system to adjust their collective water demand to a decrease in water availability. This is an indicative of drought performance, as systems where water demand is equal to or lower than the supply are expected to yield higher crop productions than otherwise, everything else being equal.

Based in the background section, the hypotheses that drive the analysis are:

- H1. Drought performance of irrigation systems increases with the percentage of land that enjoys hydric soils in the systems.
- H2. Drought performance of irrigation systems increases as the number of users in the systems decreases.

- H3. Drought performance of irrigation systems increases with the experience and legitimacy of the leaders of the corresponding associations.
- H4. Irrigation systems with strong monitoring systems are more likely to perform better than otherwise during droughts.
- H5. Drought performance of irrigation systems increases with the amount of water use rights transferred to the systems.

The analysis includes also three control variables: out-transfers, whether the systems have access to other water sources, and the extent to which collective water use rights in the systems are complete. Irrigation systems may be both recipients of water transfers as well as the origin of those transfers. If transferability is to contribute to cooperation and drought performance across the board, water transfers should not result in any negative effect in the systems of origin.

Also, some irrigation systems in the area of study benefit from the reuse of drained water (Lecina et al., 2009). The conjoint use of underground and surface water can mitigate the impact of changes in water availability and contribute to sustained collective action (Cox and Ross, 2011; Fernald et al., 2007). In the area of study, however, drained water is considerably less abundant and reliable during droughts than under normal water availability conditions. Thus, it is not clear in this case whether having access to such alternative water source makes a difference in terms of drought performance.

Finally, landholders within irrigation systems can enjoy *full* or *partial water rights*. Full rights give landholders the right to water use regardless of water availability conditions, while partial rights are restricted to conditions of water abundance. During droughts, partial rights are left out from the initial quota computations; however, the rights are not discounted from the quota recalculations during the irrigation campaign. As mentioned before, those quota recalculations are based on each system's average consumption during previous campaigns of normal water availability conditions. Thus, the recalculations include both full and partial use rights[2]. This reveals an issue of incomplete property rights across systems as well as within systems during droughts (Brennan and Scoccimarro, 1999; Larson and Bromley, 1990), whereby systems with more partial water rights (and full water right holders within those systems) receive more water than they should. Whether that difference affects the ability of farmers within the systems to cooperate during droughts is an open question for the analysis.

3.1. Research design

Thus, to test the hypotheses, the study focuses on the 2005 year. The drought of 2005 was the most severe in the last 40 years. The PTQ institution was also implemented. Specifically, the analysis compares changes in the performance of irrigation systems from 2004 to 2005. Variation in those changes across the systems is explained through regression analysis.

3.2. Data Collection

To characterize the drought, monthly water storage records from the two main reservoirs in the area were obtained from the *Ebro Basin Water Agency* (CHE). The performance variable is derived from the integration of meteorological, crop and water supply data at the irrigation system level. Monthly meteorological data were obtained from a series of weather stations that are distributed across the area of study and managed by the *Spanish Meteorological Agency* (AEMET). Yearly crop data at the farm level were

[2] Thus, the extra water that systems get as a result of containing partial water rights benefits the farmers who hold full rights in the systems.

obtained from the *Regional Government of Aragon* (DGA). Data on water supplied to the irrigation systems were obtained from the GCRAA. Another important source of data to calculate the performance variable was a 2004-2007 series of digital maps including the limits of the irrigation systems and the farms within each system. The maps were obtained from the DGA and the GCRAA and constituted the basis to integrate the meteorological, crop and water availability data. A geographic information systems software (ArcGIS 10.0) was used for that purpose. The data for some the independent variables (group size variable) were obtained from the above sources. Data for the other independent variables were obtained from a survey to the presidents and secretaries of the 38 associations (leadership, hydric soils and formal monitoring variables)[3] and from the GCRAA records (water transfers, incomplete rights and drainage water variables)[4]. A series of 8 semi-structured interviews were also conducted with officials from the GCRAA and the water agency to fill knowledge gaps before the data collection and after the analysis.

3.3. Construction of Variables

3.3.1. Dependent variable

The dependent variable is based on a seasonal index of irrigation performance (Salvador et al., 2011). The index is a ratio between the water that is supplied to a system and the water that the system needs according to the crops that are planted[5].

$$\text{Irrigation performance} = \frac{\text{Supplied Water}}{\text{Crop Water Needs}}$$

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[3] Figure B1 in Appendix B includes the questions from the survey instrument used for that purpose.
[4] The compiled database is available upon request.
[5] This measure indirectly controls for both changes in crops and the extension devoted to those crops as well as to uncultivated land. For a detailed explanation of the factors included in this calculation see Appendix B.

Assuming a 100% efficient application of water to crops, a performance value of 1.00 means that the crop is not being under- or over-irrigated. However, 100% application efficiency cannot be assumed under commercial field conditions. In an optimistic scenario, the best systems attain 90% efficiency (Lecina et al., 2010). Under this scenario an appropriate performance value is 1.1. [6] Scores below that number would point to crop stress. Scores below or above that threshold may be also acceptable, depending on soil qualities, farmer's preferences or other factors.

The irrigation performance index is used to construct the dependent variable of the analysis, heretofore *drought performance* variable. This is calculated as the difference between the performance in 2004 and 2005. The difference is expressed in percentage value using the 2004 year as the reference. A negative percentage in a particular year means a relative decrease in performance as compared to 2004; and positive scores means the opposite.

The drought performance variable captures the ability of farmers in a system to maintain their performance during a drought year as compared to a non-drought year. This allows the analysis to control for pre-existing performance levels of each system as well as unobserved idiosyncratic effects that determine such performance, such as the efficiency in the application of water at the plot level or aspects related to the physical conditions of the canals.[7]

[INSERT TABLE II ABOUT HERE]

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[6] This benchmark can notably vary depending on a number of water productivity factors. The score of 1.1 is optimistic (see Sanchez-Chóliz, J.S., Sarasa Fernández, C., 2013. Análisis de los recursos hídricos de Riegos del Alto Aragón (Huesca) en la primera década del siglo XXI. Economía agraria y recursos naturales 13, 97-124. but is also within the range of previously reported values (between in 0.57 and 2.05) in the area Salvador, R., Martínez-Cob, A., Cavero, J., Playán, E., 2011. Seasonal on-farm irrigation performance in the Ebro basin (Spain): Crops and irrigation systems. Agricultural Water Management 98, 577-587..

[7] An alternative to control for preexisting performance levels would be to use lagged values of performance; however, that would also introduce potential problems of autocorrelation (Rabe-Hesketh and Skrondal 2008).

3.3.2. Independent variables

Table II describes the operationalization of the independent variables and their expected effect on drought performance[8]. Table III provides the summary statistics for the dependent and independent variables. Incomplete rights and leadership vary over time (i.e. from 2004 to 2005)[9]. This could result in an issue of endogeneity if there were reasons to expect that these variables co-vary with the occurrence of droughts and the implementation of the PTQs. That is, however, not the case. The granting of partial water rights and the appointment of presidents in the irrigation associations follow administrative and democratic election procedures, respectively, both of which are completely independent from fluctuations in water availability and the implementation of the PTQs.

[INSERT TABLE III ABOUT HERE]

4. Results and Discussion

4.1. Water supply, water needs, performance and robustness

Figure 2 shows the dramatic decrease in the water available in the reservoirs from 2004 to 2005 and 2006 (around a 65% and 38% decrease, respectively). As a consequence, the water provided to the districts decreased on average by 45% and 23%, respectively;

[8] The measurements in Table II aimed at being as instrumental as possible to the theoretical predictions and as empirically meaningful as possible. For example, although leadership can be measured in an association by assessing the presence or absence of a president, that would miss capturing differences in leadership qualities, which are critical to assess the direction of the leadership effects. Moreover, in this specific study such measured would have resulted in no variation across the observations as all associations have a president. Similarly acreage could be used as a measure of group size; however that would risk missing differences across observations in terms of farm/household structure, which is in the end a better proxy for number of decision making units.

[9] See Table D1, in Appendix D.

however, the system's water needs also decreased, by more than 25% and 20%, respectively (see table IV). Thus, the average irrigation system performance for 2005 and 2006 decreased proportionally less than the decrease in water availability (less than 25% and 3%, respectively, see also Table IV). This shows the relative ability of the ensemble of systems under study to absorb the impact of the drought (see Figure 2).

[INSERT TABLE IV AROUND HERE]

[INSERT FIGURE 2 AROUND HERE]

Figure 2. Evolution of total water available, average water received, average water needs and average performance (2004-2007)

Source: Ebro basin agency
All measures but the "Reservoir inflows" are calculated by aggregating irrigation system data (n = 38). The base year is 2004.

The robustness of the irrigation systems to the drought can be explained by a decrease in crop water needs by the systems (denominator of irrigation performance measure) relative to the water supplied to/received by the systems (numerator). This is interesting considering the potential lack of incentives for farmers to reduce acreage or switch from high-water to low-water demand crops, as well as the lack of authority that both the irrigation associations and the GCRAA have over crop decisions by farmers. Further analysis of water received and needed and cropping patters (see Appendix D) reveals interesting dynamics. As expected, from 2004 to 2005-2006 there was a dramatic decrease of land devoted to summer crops and a corresponding increase in the land used to cultivate winter crops and left fallow (see Table D2)[10]. Also expectedly, robustness in 2005 and 2006 was negatively associated to higher percentages of acreage devoted to summer crops and positively related to higher percentages of summer crops and fallow land (see Tables D3 and D4). Also, bigger reductions in water needed from 2004 to 2005 and from 2004 to 2006 were also strongly associated to robustness. Interestingly enough, summer crop acreage in both 2005 and 2006 was positively associated to reductions in water needs (from 2004 to 2005 and from 2004 to 2006, respectively), suggesting that water conservation efforts (i.e. reductions in summer crop acreage) tended to concentrate in systems with more summer crop cultivations.

[INSERT TABLE V AROUND HERE]

Table V provides Pearson univariate correlations between the independent variables for 2005. As shown in the table, hydric soils is negatively correlated to group size, monitoring and leadership. This suggests that the experience and legitimacy of a leader and formal monitoring mechanisms like hiring a field guard, are less relevant for water management in areas where soil characteristics help mitigate the impact of water scarcity, and vice-versa.

4.2. Hypothesis testing

The multivariate regression analysis assumes a linear relationship between drought performance and the independent variables, according to the following function:

[10] Summer crops need considerably more water than winter crops. Summer crops in the area under study include corn and alfalfa, which are planted in Spring and harvested in Fall. Their water demand peak occurs during summer time, i.e., when rainfall is at its minimum and temperature at its maximum. Winter crops consist mostly on wheat, which is planted by mid Fall and harvested by mid-Spring.

$$\begin{matrix}Drought\\ Performance_i\end{matrix} = \beta_0 + \beta_1 HydricSoils_i + \beta_2 GroupSize_i + \beta_3 Leadership_i + \beta_4 Monitoring_i + \beta_5 InTransfers_i + \beta_6 IncompleteRights_i + \beta_6 DrainWater_i + \varepsilon_i \quad (1)$$

A Shapiro-Wilk test of normality (Shapiro and Wilk, 1965) for all dependent variables in the study resulted in the non-rejection of the null hypothesis of normality.

Models 1.a and 2.a explain drought performance in 2005. Model 2.a includes only the variables that were significant in Model 1.a. The exploration of a model including a minimum set of variables was considered appropriate given the relatively small sample size[11].

[INSERT TABLE VI AROUND HERE]

As indicated in the last rows of Table VI, the Breusch-Pagan/Cook-Weisberg test of homoskedasticity and the Ramsey RESET of linear specification fail to reject their respective null hypotheses. The mean Variance Inflation Factor (VIF) and Condition Index (CI) do not indicate the existence of multicolinearity issues either.

A source of potential bias is spatial correlation. The ability of farmers in an irrigation system to maintain cooperation during droughts may be influenced by what farmers in neighboring systems do. If this is the case, the performance of irrigation systems would tend to be correlated with that of neighboring systems, and OLS estimators could be biased. Figure A2 (Appendix A) displays the distribution of drought performance scores across

[11] Statistical power, or the chances of detecting a true effect, increase with sample size and decrease with the number of variables studied Kennedy, P., 2003. A guide to econometrics. MIT press..

irrigation systems, and visually there appears to be clustering of similar values among neighbors. Spatial dependence can be modeled as Spatial Autoregressive model (SAR),

$$y = \rho W y + X\beta + e \qquad (2)$$

or Spatial Error Model (SEM):

$$y = X\beta + v \qquad (3)$$

$$v = \lambda W v + e$$

In both models, the error term *e* is the normal Gaussian error with constant variance, W is a normalized *n* x *n* weight matrix that identifies the spatial relationships, and X is the *n* x *k* data matrix of explanatory variables. Determining between Eqs. (2) and (3) is in practice an empirical question. In the spatial error model spatial dependence is modeled through the error term as if originated by a multiplicity of unknown causes, while the SAR model assumes that spatial dependence originates in the dependent variable. To distinguish between the SEM and SAR models, the Lagrange Multiplier (LM) tests on the residuals of an OLS regression is employed (Won Kim et al., 2003). As shown in table VI only the LM-Lag diagnostic is rejected, at the 95 percent confidence level, suggesting that the appropriate model is the SAR model. Models 1.c and 1.d present the SAR estimates for irrigation performance in 2005. The minor differences across the OLS and SAR models reveal that the spatial autocorrelation had some but not a dramatic effect on the standard errors.

All the hypotheses but the group size hypothesis are confirmed by the models. The impact of group size variable is almost inexistent. This result was not expected and suggests the mediating effect of other factors such as group heterogeneity (Poteete and Ostrom 2004, Varughese and Ostrom 2001). Indeed, as informed by representatives from the GCRAA, not all farmers depend equally on irrigated agriculture and this has some effect on how they react to droughts. Some farmers combine irrigated agriculture with jobs in the industry, services or public sectors, and are more eager to reduce cropping acreage or switch crops during droughts than otherwise. To the extent that larger associations are more heterogeneous than smaller associations vis a vis irrigation dependence, the potentially negative effect of group size might be cancelled out by the positive effect of heterogeneity. The impact of the in-water transfer variable goes in the expected direction and illustrates the suitability of PTQs during droughts. The effect holds controlling for the *out-water transfer* variable, which is not significant. The effects of monitoring, hydric soils and leadership variables also go in the expected direction. The impact of these variables is particularly strong. Counting on an effective field guard can increase drought performance around 8.7%; counting on an experienced and legitimate leadership can increase drought performance by around 10%; and one extra percentage point of hydric soils can improve drought performance around 0.2%.

Also, the coefficient of the incomplete rights variable is positive and significative. According to this, the extra water received by systems with more partial rights would be facilitating cooperation among their members. This is congruent with qualitative evidence showing the effective limitation of water access to farmers with full water rights during droughts in those systems. The results also indicate the existence of an externality that benefits systems with more partial water rights, as well as farmers with full water rights within those systems[12].

[12] As indicated in the methods section, the externality stems from the formula used to recalculate the quotas during the irrigation campaign..

The sign and significance of the explanatory variables does not change dramatically from Model 1.a to Model 1.b, and Model 1.c to Model 1.d, indicating the robustness of the results to the elimination of the irrelevant variables.

The use of water efficient technologies (i.e., sprinkler irrigation in the area under study) can contribute water conservation in some contexts (Burt and Styles, 1999; Lecina et al., 2010; Pereira et al., 2002). In this study the technology variable was not included in the analysis for theoretical reasons. First, the technological variable does not fulfill a central role in CPR theory. Although recognized as an important contextual variable, its effects are considered to be mediated by other socio-institutional variables such as group size, monitoring or leadership (Poteete et al., 2010). Additional, it was not straight forward from a theoretical point of view that efficient technologies such as sprinkler irrigation would make a difference (i.e. in promoting cooperation) from non-drought to drought periods. The percentage of land irrigated through sprinkler irrigation vs. flood irrigation did not change from 2004 to 2005 or 2006. Also there was no sufficient reason to expect non-linear effects of that variable from normal to drought conditions. That was not the case of the hydric soils variable, which was expected to have an effect only during drought conditions (Cox and Ross, 2011; Lecina et al., 2010); and it was not either the case of any of the control variables, which apply only during drought conditions. That said, additional regressions based on Models 1.a and 1.b were run including a “current percentage of sprinkler irrigation”. In none of the models the variable was significant.

4.3. Exploratory analysis of PTQ and drought severity effects

Table VII contains two additional models. Model 2 explains performance in 2006 as compared to performance in 2004, and Model 3 explain performance in 2007 as compared to performance in 2004.

Water availability in 2006 was higher than in 2005 but still lower than in 2004. Thus farmers within each system still faced the dilemma of conserving water (as compared to their pre-2005 use patters). Also, in 2006 the PTQs were not implemented, meaning that irrigation associations were not constrained in the water they could demand; however, just like at the farmer level, it was not guaranteed that there would be enough water if all systems needed as much water as in a non-drought year. Indeed, both average water received and needs were noticeably lower in 2006 than in 2004. Only one system was supplied more water in 2006 than in 2004, and none system needed more water in 2006 than in 2004. Moreover, although the average water received by the systems increased noticeably from 2005 to 2006, water needs did it only slightly (see Table IV and Figure 2), showing a generalized concern across the systems about the need to avoid a water deficit situation despite the improvement in the conditions.

[INSERT TABLE VII AROUND HERE]

The explanatory capacity of the Model 2 is around 20%. The effects of the hydric soils and monitoring variables are significant in the expected direction and particularly high; however, those of leadership and incomplete rights are low and not significant. These results can be interpreted with regard to qualitative evidence about the implementation of PTQs in the systems. When the PTQs are implemented water can be transferred from plots with high water retention capacity to soils with lower water retention capacity thus partially cancelling out the potential effects of soil qualities on performance (see negative relationship between the hydric soils and out-transfers variables in Table V). Thus, in the absence of PTQs but still drought conditions (like in 2006) those soil qualities may come particularly salient as compared to years when PTQs are implemented (even if under more severe drought conditions like in 2005). Also, the implementation of the PTQs involves a series of accountability measures that make field monitoring by guards (i.e. formal monitoring) less relevant than otherwise. The GCRAA officials keep records of the quotas used by irrigation systems. This motivates that the secretaries of irrigation associations keep also records of water requests and use by farmers. By these means the secretaries aim to guarantee that their systems do not exhaust their quota too early as well as a fair distribution of the quota among the farmers. Thus, again it is also reasonable to expect that, in the absence of PTQs but still drought conditions (like in 2006), those monitoring duties may come particularly salient as compared to years when PTQs are implemented.

This same reasoning can be used to interpret the low impact of the leadership and incomplete rights variables. The role of the presidents (i.e., leaders) of the associations notably intensifies when the PTQs are implemented. One of the most important tasks of the presidents in that regard is transmitting information from the GCRAA to the farmers about water availability and the evolution of the quotas. The presidents are also responsible for shaping farmers' cropping decisions at the beginning of the irrigation campaign to adapt them to the quotas and minimize issues of crop stress during the campaign. The tenure of presidents provides them not only the necessary expertise but also authority to fulfill that shaping role. When the PTQs are not implemented, even if under drought conditions (like in 2006), the role of the presidents is notably reduced. Similarly, when the PTQs are implemented systems with more partial water rights and full water right holders within those systems receive more water than they should. They take advantage of the dual criterion to calculate the quotas, which includes water consumed (both by full and partial water right holders) during non-drought years. In the absence of PTQs that advantage would fade off.

The above insights can only be presented as conjectures for further analysis. Findings from Model 2 (2006) cannot be directly compared to Model 1.a (2005) to formally test the effect of the PTQs. The drought was less severe in 2006 than in 2005 and thus it is not possible to assert whether differences across the models are due to the PTQs or the change in drought severity[13]. This is partially unveiled when looking at correlations between water needs, water received and robustness in 2005 and 2006 (see Tables D3 and D4). Although both in 2005 and 2006 there was a negative relationship between summer crop acreage and robustness, the association was stronger in 2005. More importantly, in 2005 there was a strong positive association between the reduction in water received (i.e., expectedly resulting from the implementation of the PTQs) and the reduction of water needs (i.e., water conservation efforts). Such relationship was absent in 2006 (i.e., expectedly due to the absence of PTQs); however, that did not prevent water conservation efforts in that same year to be strongly associated to robustness.

Model 3 explains performance in 2007 as compared to performance in 2004. The drought and the PTQs were absent in 2007. As expected, the explanatory capacity of the model is almost inexistent, indicating that the explanatory variables are not particularly relevant in the absence of disturbances like droughts. As suggested by scholars studying

[13] Changes in crop prices from 2005 to 2006 might also be a source of noise. In this particular case, however, there were no dramatic changes. Average prices of wheat and barley in the area were around 14.8 and 14 Euros/100kgs in 2005, and 14.5 and 13.5 Euros/100kgs in 2006, respectively DGA, 2012. Gobierno de Aragon, Zaragoza..

robustness in irrigation systems, cooperation problems that emerge during droughts may not hinder performance beyond the drought period if water availability conditions are restored relatively quickly (Cox and Ross, 2011).

5. Conclusions

This paper contributes to the understanding of community-based natural resource management under extreme event conditions. Specifically, the paper assesses (1) the performance of common property institutions in combination with a transferable quota institution in a water scarcity context; and (2) tests the effects of biophysical, social and institutional variables on performance in that scenario. Methodologically, the study tests a series of hypotheses derived from common pool resource (CPR) and private property right theory. The tests are carried through a series of OLS and spatial regression models explaining the irrigation performance of 38 irrigation associations during a severe drought. Empirically, the study relies on a unique dataset filled with field survey and spatial quantitative data, as well as on qualitative insights from semi-structured interviews.

According to the analysis, transfers of pooled quotas (PTQ) across irrigation systems can contribute to irrigation performance during droughts. The added flexibility gained through the transfers allows farmers to reallocate water to systems that enjoy higher productivities, and this in turn enhances cooperation in those systems. In this context, performance is higher when irrigation associations enjoy (1) the monitoring role fulfilled by field guards; (2) the information-sharing and coordination leadership fulfilled by experience and legitimate presidents; and (3) facilitative biophysical conditions like soil water holding capacity. As a caveat, complete property rights may be necessary if negative externalities are to be avoided. In the area under study, the externality exists both across irrigation systems and across holders of different types of water use rights. Internalizing the externality would require consolidating the different types of property rights into one type or a reform in the way the quotas are calculated. Also, attention shall be paid to the specific institutions that articulate the use of quotas. Although not empirically assessed in this study, quota calculation criteria that are based on historical use patterns may well discourage long term investments in water conservation. Similarly, transferability, even if regulated, may well open up for corruption and/or the concentration of self-reinforcing dynamics of drought vulnerability and crop losses in some areas.

Exploratory analysis also suggests that biophysical properties like soil water holding capacity may compensate for weaker monitoring or leadership, and vice-versa. Also, preliminary analysis indicates that some cooperation factors like leadership may be particularly relevant for the successful implementation of PTQs.

The combination of different property right institutions for effective natural resource governance has been recognized by scholars in different environmental sectors (Cole, 1999; Costello et al., 2008; Dietz et al., 2003; Dietz and Stern, 2002; Ostrom, 2010); however, studies testing the conditions under which such institutions can be successful are relatively rare (Calatrava and Garrido, 2005; Gómez-Limón and Riesgo, 2004; Holland, 2010; Molle, 2009). This study addresses that gap by focusing on the combination of common property institutions with pooled transferable quotas in water scarcity scenarios. Quotas, however, are not the only solution to drought management. Other institutional solutions have been put forward, including water markets (Arriaza et al., 2002; Ostrom, 1990; Pujol et al., 2006), crop planning (Hook, 1994; Raman et al., 1992), *ad hoc* agreements (Cox and Ross, 2011) and turn-based water allocation protocols (Trawick, 2001b). Further research might assess the performance of combinations of those and other institutions, as well as test the results of this study in other environmental sectors. Finally, the analysis covered only four years of data and included only one drought event. The data fulfilled the purpose of the study, but came short to assess the impact of the variables under different drought severity and length conditions. Further research shall be developed in that direction.

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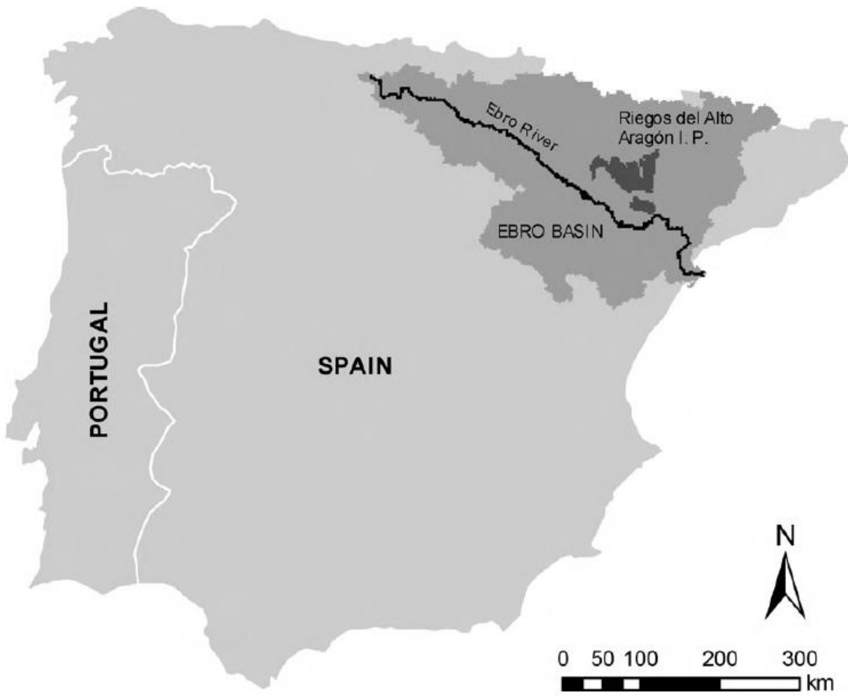
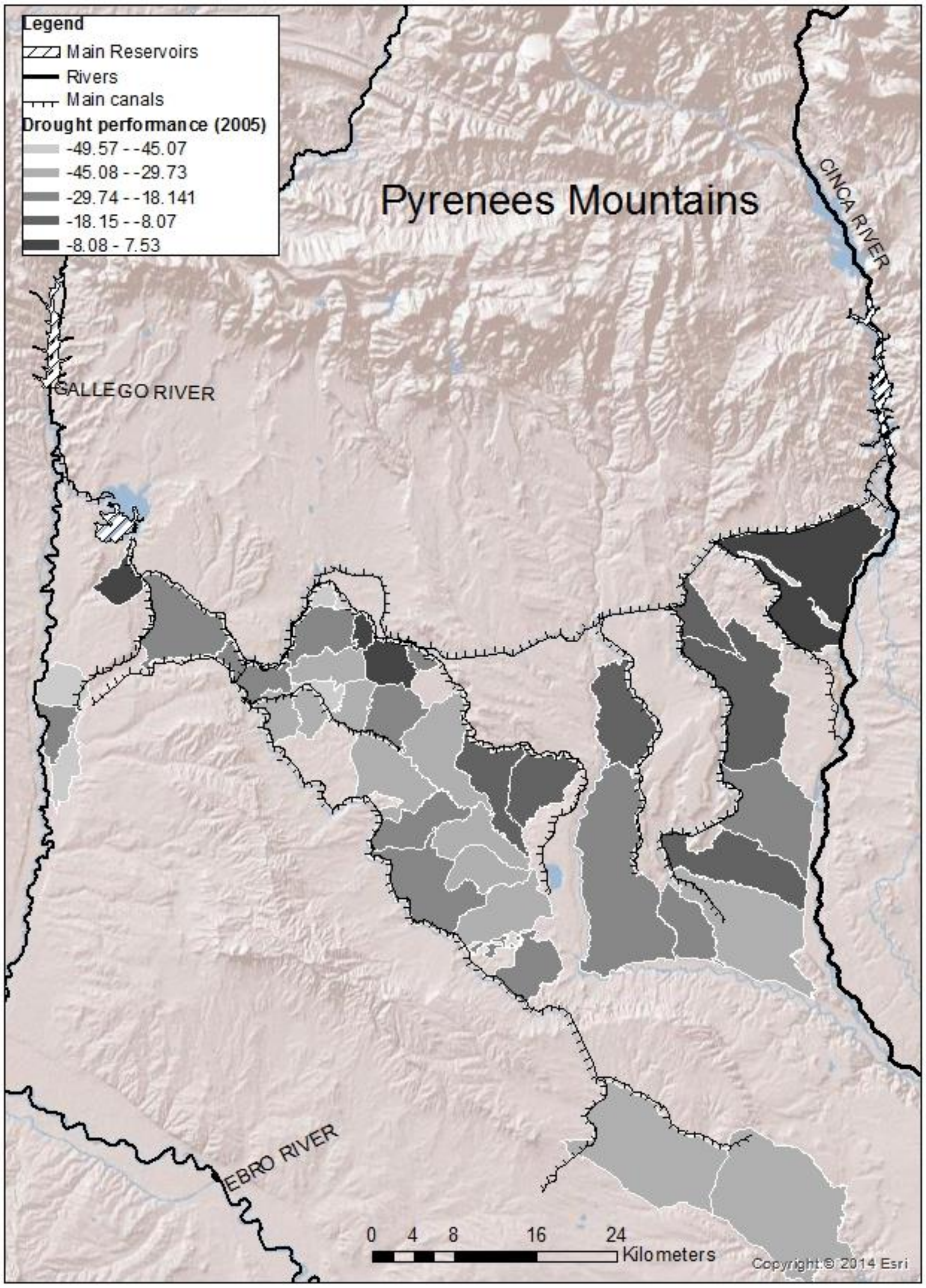
Appendix A: Maps

Figure A1. Location of the *Riegos del Alto Aragón* (RAA) irrigation systems in the Iberian Peninsula.



Source: Lecina et al. (2010)

Figure A2. Spatial distribution of drought performance values (2005)



Source: Ebro basin agency, Government of Aragon, Esri©

Appendix B

Figure B1. Survey questions

All questions were originally formulated in Spanish

Hydric soils variable:

Could you indicate which types of soils dominate in the irrigable area of your irrigation system by the percentage?

Soil characteristics	Percentage of the irrigable area
"Sasos" (gravel dominated soils)	__________%
"Suelos Fuertes" (*clay loam and silty clay loam soils*)	__________%
"Suelos Salinos" (*salt dominated soils*)	__________%
"Suelos Arenosos" (*sand dominated soils*)	__________%

Leadership variable:

Please indicate the following information about the presidents of your irrigation association in the last decade (back to 2000)

Starting and ending year in presidency	Full time/part time farmer?	Highest education degree?

Monitoring variable:

Did your association have a field guard before and during the 2005-2006 drought?

☐ Yes ☐ No

In case your association had a field guard, did he/she have to increase its monitoring efforts during the drought?

☐ Yes ☐ No

Appendix C: Calculation of irrigation performance index

The performance index was selected as an indicator of irrigation performance for three reasons: It is the result of an standardization effort led by FAO's International Program for Technology and Research in Irrigation and Drainage (IPTRID); it does not require field data collection beyond the use of publicly available meteorological and crop data; and it has been previously used to characterize irrigation performance in Mediterranean environments (Salvador et al. 2011).

$$\text{ARIS} = \frac{\text{Irrigated Water}}{\text{Crop Water Needs}} = \frac{\text{Irrigated Water}}{\sum_{i}^{k}(NHn * ha)_i}$$

Where:

i = specific crop

k = number of different crops in the irrigation system

NHn = Net Crop Water Needs (in m^3)

ha = hectares

The most important factors that condition NHn are the crop evapotranspiration (ETc) and the amount of rainfall that can be effectively used by the crop (PE) (Tejero 2003). Following Allen et al. (1998), ETc was obtained from multiplying a crop water coefficient (Kc) and a potential evapotranspiration coefficient (ET_0):

$ETc = ET_0 * Kc$

Kc is a theoretical index of the water that a crop needs depending mostly on the species and life cycle stage (Allen et al. 1998). ET_0 measures the amount of surface water that is removed to the atmosphere due to plant transpiration or direct surface evaporation in a hypothetical reference surface of grass with an assumed crop height of 0.12 m, and a moderately dry soil and radiance reflectance (Allen et al. 1998).

Although the FAO provides *Kc* values of reference on major crops across climatic regions, it has been recommended using site specific *Kc* values whenever available (Allen et al. 1998). Monthly *Kc* values of the dominant crops in the area of study in 1995 were obtained from Martínez-Cob et al. (1998) and used as reference for the period under study[14]. The ET_0 was calculated following the Hargreaves method, as adapted to the study area by Tejero (2003). Finally, monthly total rainfall data was transformed into PE measures following the method recommended by the *Soil Conservation Service (SCS)* (Dastane 1978, cited in Tejero 2003).

[14]Martinez Cobb et al. (1998) is not the most recent reference of crop coefficients. There is also data provided in more recent publications (Martínez-Cob and García-Vera, 2004; Moratiel and Martínez-Cob, 2013); these data, however, do not include all crops under analysis in this study and those included are not notably different from those in Martinez Cobb et al. (1998). Given this, a decision was made to give priority to consistency in the source over using most updated data.

Appendix D: Descriptive statistics

Table D1. Descriptive statistics of time-variant variables

	2004	2005	2006	2007
Drought performance (%)	100	-23.88	-1.03	+10.55
Base year= 2004				
Leadership	0.39	0.31*	0.36	0.39
Incomplete rights	4.03	3.85	3.84	4.53

n=38

Note: Hydric soils, group size, formal monitoring and drainage water do not vary over 2004-2007. Water transfers only apply to 2005 year.

Table D2. Average percentage of land use by the systems

Year	Summer crops	Winter crops	Fallow
2004	75.1	16.3	7.3
2005	56***	18.9	24.3***
2006	57.6	27.6***	14***
2007	57.3	30.6*	11.4**

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

n=38

Note: One-tailed mean test comparing current and previous year's percentage distributions.

Table D3. Correlations between drought performance and related variables (2005)

	Drought perform	**% Summer crops**	**% Winter crops & fallow**	**Change needs**	**Change water use**
Drought perform	1				
% Summer crops	-0.55*	1			
% Winter crops & fallow land	0.576*	-0.987*	1		
Change water needs	-0.238	0.328*	-0.334*	1	
Change water use	0.688*	-0.233	0.244	0.529*	1

n=38

Note: the variables "change summer crops" "change water needs" and change water use" all contained negative scores (i.e., decreases from 2004 to 2005), and the variable "change winter crops & fallow" contained all positive scores).

Table D4. Correlations between drought performance and related variables (2006)

	Drought perform	% Summer crops	% Winter crops & fallow	Change needs	Change water use
Drought perform	1				
% Summer crops	-0.302	1			
% Winter crops & fallow land	0.287	-0.988*	1		
Change water needs	-0.707*	0.448*	-0.454*	1	
Change water use	0.706*	0.067	-0.096	-0.015	1

n=38

Note: the variables “change summer crops” “change water needs” and change water use” all contained negative scores (i.e., decreases from 2004 to 2006), and the variable “change winter crops & fallow” contained all positive scores).