Understanding robustness to disturbance through the theory of the commons: a Qualitative Comparative Analysis of responses to disturbances in five Spanish irrigation systems.

Sergio Villamayor-Tomas

Paper presented at the colloquium of the *Workshop in Political Theory and Policy Analysis* (*Ostrom's Workshop*)

10-24-2012

Abstract:

In this paper I use the theory of the commons to explain robustness to different types of disturbances in common pool resource (CPR) contexts. For that purpose, I build on two working hypotheses: (1) robustness is fundamentally mediated by collective action processes, and (2) robustness is contingent on disturbance characteristics. In the analysis, I identify and classify the responses that 5 Spanish irrigation systems have developed to cope with different disturbances in the last 20 years. Then I use Qualitative Quantitative Analysis (QCA) to assess whether the contribution of those responses to the robustness of the systems is mediated by different collective action factors and disturbance attributes. According to the results, one of the most consistent paths to robustness includes the combination of leadership, collective choice and cross-scale linkages, given the context of small or homogeneous systems, or both. That combination, however, is not the only path to robustness. Other combinations of the same factors are associated to robustness, most of which tend to be specific to different types of disturbances. Robustness to intense and frequent disturbances tends to rely on the role of leaders, while robustness to progressive and/or infrequent disturbances depends on a wider set of conditions. Also, not all collective action factors are equally relevant to explain robustness. Leadership and homogeneity show the most consistent effect while collective choice, cross-scale linkages and size are more sensitive to interactions with other factors. Overall, the findings show the explanatory power of the theory of the commons to understand sustainability in disturbance contexts, as well as the relevance of further exploring how disturbance characteristics mediate robustness.

1. Introduction

Contemporary societies are increasingly exposed to common threats such as pollution, climate change, or market crises that are the result of the socioeconomic development process itself and manifest at global, regional, and local scales. This situation has generated a new interest in understanding the manner in which associations organize in response to threats in different contexts (UNISDR 2004). Research in natural resource management has been particularly productive in that regard. According to ecology and complex systems scholars, to understand sustainability we have to study associations and natural phenomena as being part of complex social-ecological systems (SESs) whose equilibrium is always exposed to the occurrence of disturbances. In this regard, the ideal of sustainability is qualified by the concept of robustness (Carlson & Doyle 2002), and the understanding that SESs may be able to buffer the impact of some disturbances but not others (Berkes et al. 2003; Anderies et al. 2006). Also, political scientists studying the sustainability of natural resource management regimes have pointed to the collective-action problems that sustainable management entails, as well as to the role of institutions and social attributes in solving those problems (Lam 2006; Schoon 2008; Costeja 2009; Cox 2010).

This chapter aims to add to the understanding of how governance may enhance robustness by studying the recent history of 5 irrigation associations located along the Gállego and Cinca river watersheds, in northeastern Spain. The research questions that drive the research are:

1. Which types of disturbances have Spanish irrigation associations recently been confronted with?
2. Are there identifiable patterns in the way Spanish irrigation associations respond to different disturbances?
3. How do different governance social factors affect the ability of Spanish irrigation associations to cope with those disturbances?

Spain is well recognized for the long tradition and autonomy of its irrigation associations (Glick 1970; Ostrom 1990; Blomquist et al. 2005), many of which have successfully evolved to combat a variety of threats such as droughts, floods, wars, and plagues over centuries. Many of their attributes have disappeared, while some others have changed and consolidated. At the same time, new irrigation systems have emerged. Since the beginning of the 20th century, the Spanish government has actively engaged in the conversion of wasteland to irrigated land and the promotion of new irrigation associations (Bolea Foradada 1986). While some of the new systems have collapsed over the years, many others persist. In the last 20 years, however, a series of severe droughts and the growth of cities and industry in Spain have resulted in concern about the sustainability of the irrigation sector (Lopez-Galvez & Naredo 1997). This chapter aims to contribute to the understanding of the factors that explain the persistence of both traditional and state-promoted systems in the advent of old and newer disturbances.

As hinted at by the research questions, the study aims to understand robustness through the relationship between disturbance and response. That approach builds on the working hypothesis that robustness is contingent on the type of disturbance (Carpenter et al. 2001 Anderies et al. 2006, Schoon 2008, Cox 2010), i.e., that the robustness of Spanish irrigation associations depends on how each respond to specific disturbances. Thus, the study consists on a comparative study of responses to disturbances. The cases of the study are not the 5 selected irrigation associations but disturbance-response situations that those associations have experienced in their recent history. Each disturbance-response case is then characterized with regard to attributes of the disturbance and of the decision-making and implementation processes by which the association responded.

The analysis unfolds into an exploratory and a hypothesis-testing part. In the exploratory analysis, I identify and interpret patterns of disturbances and collective responses with regard to disturbance attributes (Salafski et al. 2008, Schoon and Cox 2011) and collective action costs (Ostrom et al. 1994). In the hypothesis testing part, I test the usefulness of the theory of the commons (Poteete et al. 2010) to explain robustness. Specifically I test whether responses that enjoy the presence of leadership, collective choice, external support, and are developed in small or homogeneous irrigation systems are associated to robustness. Additionally, I explore whether the impact of those attributes on robustness is mediated by characteristics of disturbances.

The hypothesis-testing part relies on the Qualitative Comparative Analysis technique (QCA). QCA is a tool specifically designed to explore causal relationships in small- to mid-sized samples (Ragin 2000). Cases are understood as types in terms of the combination of attributes that characterize them. Thus, QCA in this study compares disturbance-response cases representing different configurations of attributes that may contribute to robustness.

The chapter is organized in 8 sections. The introduction is followed by a theory section where I introduce theory on robustness to disturbance and the theory of the commons, and present the hypotheses of the study. Sections 3 and 4 introduce the area of study and explain the methods, respectively. Section 5 and 6 present the results of the exploratory and hypothesis-testing analyses, respectively. Section 7 discusses the findings through a review of some of the cases. Section 8 summarizes the main findings and suggests venues for further research.

2. Theory

2.1 Social Ecological Systems Theory

Robustness to disturbance

Irrigation systems can be seen as social-ecological systems, where some of the interdependent relationships among humans are mediated through complex interactions with nature (Berkes et al. 1998, Anderies et al. 2004). These interactions are complex because they can result in outcomes that that are not easily predictable from the observation of humans or natural events separately. Farmers' decisions of what to grow in a dry year may depend on other farmers' decisions, soil quality, the diversity of water sources available and the water storage capacity currently installed in the irrigation system, all of which may interact with each other, potentially resulting in overproduction of dry cereals, water conflicts, or other outcomes.

In SES studies, robustness has been defined as "the maintenance of system performance either when subjected to external, unpredictable perturbations or when there is uncertainty about the values of design parameters" (Anderies et al. 2004, 1). Thus, robustness has to be understood with regard to specific disturbances (Carpenter et al. 2001). The conditions that enable irrigation associations to handle severe droughts, for example, may not be the same as the conditions that help associations coping with urbanization, floods or even milder droughts (Anderies et al. 2006, Cox 2010).

Also, robustness can result from preventive and reactive strategies (Costeja 2009). Preventive strategies would encompass measures that contribute to cope with a disturbance before or its occurrence. Reactive strategies include those that are developed in response to the threat occasioned by a disturbance (Costeja 2009).

Disturbance Attributes

As indicated above, a premise of this study is that the robustness of irrigation associations depends on the characteristics of disturbances. To characterize disturbances the study follows Schoon and Cox (2011). Schoon and Cox (2011) build on Ostrom's (2007) SES framework to identify four main types of disturbances depending on the flow or static nature of the disturbing variable and on how connected is that variable to other variables within and outside the SES. Additionally, the authors identify a series of properties that can be used to characterize disturbances. Those properties include, among others: intensity, or the average deviation from a norm; and frequency, or the number of times per unit of time in which one such deviation occurs. This study follows that distinction of properties.

Intensity and frequency can be related to robustness. Robustness to a disturbance may require the commitment of collective resources and this can be challenging when the disturbance is not perceived as threatening in the short term or when the disturbance is infrequent. When a disturbance is the result of slow changes and/or only happens sporadically, feedback about the performance of coping strategies is also slow or infrequent, and that discourages investments in those strategies (Janssen and Anderies 2007). "Time erodes the vividness of experiences" (Janssen and Anderies 2007, 51) and it may not be very popular to invest in robustness to an infrequent or progressive disturbance that the collective memory does not recognize as such. Moreover, SESs can face different disturbances simultaneously but resources to cope with those disturbances may be scarce. That may aggravate the bias towards increasing robustness to intense and frequent disturbances vs. to more progressive and infrequent ones.

From a game theoretic perspective, frequency of experiences has also been related to learning, which is understood to be a factor of policy effectiveness (Lee 2000, Bennett and Howlett 1992). Disturbances that are recognized as such and also happen frequently open the opportunity for repeated interactions between affected individuals or groups, and recreate the ideal context of a repeated interactions game. In repeated games, chances of sustainable collective action are higher than in one shot games (Ostrom et al. 1994, Ostrom 2007). "When some individual initiate cooperation in a repeated situation others learn to trust them and are more willing to adopt reciprocity themselves, leading to higher levels of cooperation" (Ostrom 2010, 162).

2.2 Understanding robustness through collective action theory in common pool resource (CPR) contexts

A working hypothesis of this study is that the robustness of irrigation systems is mediated by the ability of farmers to act collectively. This hypothesis is based on the understanding that the situations created in the advent of a disturbance are not fundamentally different from the over-exploitation situations explained by collective action theory in common pool resource contexts.

Robustness or the capacity to solve collective action problems

Two fundamental activities defining the performance of irrigation systems are the allocation of water and the provision of the irrigation infrastructure. Water appropriation and infrastructure provision can be conceived as two distinct action situations. An action situation occurs whenever two or more individuals are faced with a set of potential actions that jointly produce outcomes (Ostrom et al. 1994). The appropriation and infrastructure provision situations in irrigation systems are permeated by collective action problems. Collective action problems can be defined as the lack of collective action when it is needed, and are in many cases the result of social dilemmas and/or transaction costs[1]. Social dilemmas are inherent to the management of common pool resources (CPR). That is the case because CPRs, like water and infrastructure in irrigation systems, are difficult to partition for private consumption and can be exhausted or degraded (V. Ostrom and E. Ostrom 1977). The fact that all farmers in an irrigation system can potentially benefit from water conservation efforts regardless of who makes those efforts discourages farmers to self-restrain consumption when it is needed. That creates a water appropriation problem. Similarly, the fact that all farmers in an irrigation system can potentially benefit from the irrigation infrastructure discourages farmers to contribute to its construction or maintenance. That creates an infrastructure provision problem. Solving those collective action problems may require coordination, communication or decision making processes that entail transaction costs. To the extent that those costs jeopardize the benefits of collective action, individuals may be discouraged to cooperate, even if reassured that others will also cooperate.

Much of the research on CPR management has observed provision and appropriation problems in the context of overexploitation situations like the one illustrated by the "tragedy of the commons" (Hardin 1968). The "tragedy of the commons" recreates a very specific action situation where CPR users have open access to the resource and do not have the incentives to self-restrain resource extraction because they do not have the means to exclude others from the benefits of such effort, so the resource system is overexploited and ultimately collapses (Ostrom 2007). In an irrigation system, the "drama of the commons" would translate as the inability of farmers to either create or maintain the irrigation infrastructure and/or to allocate water efficiently Ostrom 1994, Lam 1998).

Users can develop coordinated strategies to solve collective action problems. A coordinated strategy can be defined as a feasible strategy adopted by CPR users regarding how and under which conditions to use the resource and/or contribute to its infrastructure or production (Ostrom et al. 1994). Two types of coordinated strategies can occur in field settings (Ostrom et al. 1994). The first type consists on the adaptation of behavior without a change in the physical infrastructure or rules that shape the situation. The second type of coordinated strategy involves changing the rules-in-use or the physical infrastructure affecting the situation (Ostrom et al. 1994).

Robustness in irrigation systems can be understood as resulting from the implementation of coordinated strategies by farmers. The idea of robustness implies the existence of an equilibrium situation that is then threatened by a change in one of its constituting elements, i.e., a disturbance. A likely status quo in a CPR like an irrigation system would involve an institutional regime that guarantees both infrastructure provision and water allocation to all famers in the

[1] A social dilemma exists when collective interests are at odds with private interests. The dilemma emerges because individuals can obtain joint benefits as a result of their joint actions but they are each tempted to refrain from contribute since they may receive the part or all the benefits of the contributions of others whether they contribute or not (Ostrom et al. 1994).

system (Ostrom 1990, Lam 1998, Cox et al. 2010). A less likely but still relevant status could be that of an open access situation where the resource is so abundant that there is no threat of overexploitation and where the provision and maintenance of the infrastructure is guaranteed by the government. A change disrupting any of those status quos, like a drought or a shortcut in the funds devoted to infrastructure maintenance, would require some form of response from farmers. Coordinating strategies would then be appropriate in order to rebalance the situation.

The diversity of changes that can threaten the performance of an irrigation system is wide, including from droughts and floods to changes in crop prices, land property fragmentation, immigration and emigration waves, urbanization and technological changes (Anderies et al. 2006, Tucker et al. 2010, Cox and Ross 2011). Ultimately, however, the potential impact of disturbing changes on the performance of irrigation systems comes down to the water allocation and infrastructure provision situations. An evident example is that of a drought: the reduction of water availability during a drought would represent a direct threat to a given water allocation status quo (Rutte et a. 1987, Oses-Eraso et al. 2008). A less evident but also relevant example is that of an immigration disturbance. Everything being equal, an increase in the number of water users and the use of the infrastructure would represent a challenge in terms of both water allocation and infrastructure maintenance (Gupta and Tiwari 2002, Anderies et al. 2004). All in all, the capacity of farmers to cope with a drought or the immigration disturbances would eventually be mediated by their ability to overcome the collective action problems that permeate the appropriation and infrastructure provision situations. In other words, responses that guaranteed water availability or infrastructure maintenance in the advent of the disturbances would benefit all farmers in the irrigation system regardless of who contributed to the solution, thus creating an incentive for farmers to not contribute. The ability of farmers to overcome such incentive and cooperate may then be crucial for them to collectively cope with those threats.

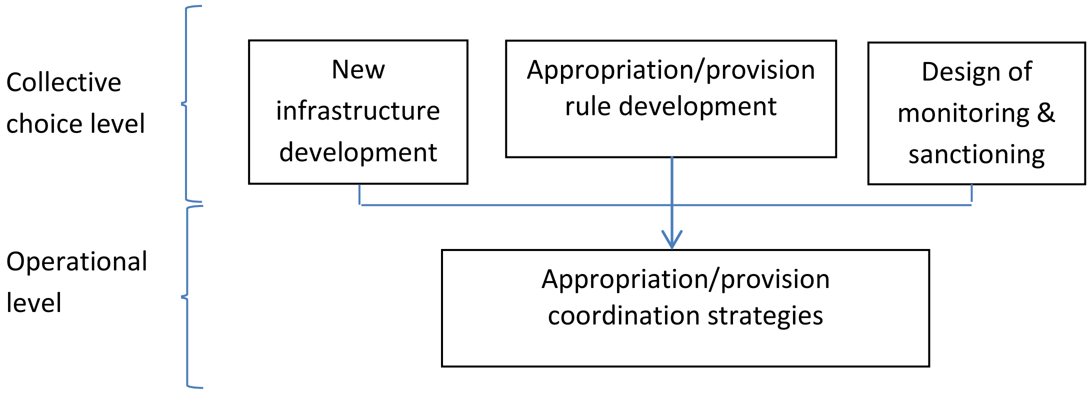
Responses and the costs of collective action

Not all the responses require the same collective action efforts. Some responses rely on negotiations, collective choice and investments while some others require just information sharing and common understanding. Ultimately, different collective action efforts translate in different transaction costs. In this study I focus on those transaction costs to classify responses to disturbances. For that purpose, I rely on the concept of adjacent actions situations (Ostrom 2005, McGinnis 2011).

As presented in the theory section, users in a CPR like an irrigation system can use two types of coordinated strategies to extricate themselves from collective action problems. They can either modify their behavior within a set of preexisting rules and physical infrastructure, or they can engage in changing such rules and/or infrastructure. If farmers engage in rule development, they may also need to develop monitoring and sanctioning mechanisms. There is always the temptation to break the rules and thus the risk that the agreed-upon rules crumble due to a generalized lack of compliance (Ostrom et al. 1994). Thus, the design of monitoring and sanctioning mechanisms is a task that almost necessarily adds to that of rule development.

The distinction between the two types of coordinated strategies can be understood in terms of actions situations (see Fig. 1).

Figure 1. Action situations at the operational and collective choice levels of decision making



Actions situations can be vertically linked across three decision making levels: the operational, the collective choice and the constitutional levels (Ostrom and Kiser 1982, Ostrom 2005). At the operational level, individuals interact with each other and with the world as constrained by operational rules and infrastructure. When individuals contemplate changing those rules or the infrastructure, they are acting at a higher, collective choice level. Ultimately, when individuals consider changing the rules that govern collective choice they are participating at an even higher, constitutional level. Irrigators who decide how much, when and with what technology to irrigate given biophysical conditions and water use rules are acting at the operational level. When the irrigators contemplate building a new water storage tank or creating a new rule to allocate water, they are engaging in a "level shifting strategy", from an operational to a collective choice level (Ostrom 2005). In doing that, they are also shifting to a different action situation, one that has its own rules and dynamics (see, for example, voting rules or social and political affinities). If farmers were to create or change those rules, they would be engaging in a new level shifting strategy, from a collective choice to a constitutional choice situation.

Ultimately, transaction costs are expected to increase as farmers shift from operational collective choice situations. Changing rules or the infrastructure is more demanding in terms of collective action than pure coordination strategies. Specifically, rule or infrastructure development entails solving a higher-order, provision problem (Ostrom 1994). All farmers in an irrigation system can benefit from the existence of the new rules or infrastructure, even those who did not contribute to their design. And that creates the dilemma for farmers as of whether contribute to the rule or the infrastructure provision or not. Additionally, monitoring and sanctioning rule violators are costly activities that may require the resolution of collective action problems. "Unless the rewards received by those who monitor and sanction are high enough and guaranteed, not monitoring and not sanctioning may be the individually preferred strategy even though everyone would be better off if that strategy were not chosen" (Ostrom 1994, 48). Ultimately, solving collective action problems entails transaction costs. Thus, we should expect that such costs increase as farmers engage in higher order collective strategies.

The above theoretical remarks offer grounding to rank coordinated strategies depending on the order of collective action problems that those strategies entail (see Table 1). At the bottom of the rank there would be coordination strategies that do not involve rule or infrastructure change. At the top of the rank there would be coordination strategies that entail infrastructure and institutional innovation as well as added monitoring and sanctioning efforts.

Table 1. Collective action strategies and costs in a CPR

	Transaction Costs
1st and higher order strategies: (Infrastructure and/or institutional development and monitoring & sanctioning)	High
Pure coordination strategies: (No infrastructure or institutional development)	Low

Source: elaborated from Ostrom et al. (1994)

To the extent that responses to disturbances in irrigation systems take the form of coordinated strategies among farmers, the above grid applies. The exploratory analysis section uses the grid to understand the responses to disturbances of the 5 irrigation associations of this study.

2.3 Applying the theory of the commons to disturbance contexts

The theory of the commons aims to explain the conditions under which common property regimes contribute to the resolution of collective action problems in CPR contexts. In common property regimes, provision and appropriation problems are solved via the use of rules and norms that guarantee cooperation among individuals (Ostrom 2003).

According to the theory of the commons a number of institutional and social factors can contribute to continual cooperation in common property regimes (Poteete et al. 2010). Two of the most cited arrangements in institutional studies of common property regimes are bottom-up collective choice and cross-scale linkages (Ostrom 1990, Cox et al. 2010). Bottom collective choice institutions allow direct users of the CPR to participate in the design and modification of the rules that govern their use of the resource. Direct users have first-hand and low-cost access to information about the resource use and thus enjoy a comparative advantage to design effective courses of action that are tailored to their contexts (Berkes 2001, Anderies et al. 2004, Costeja 2009). Additionally, enabling the participation of direct users in rule development can facilitate the legitimacy and implementation of the resulting decisions (Ostrom 1990, Ostrom 2005, Subramanian et al. 1997).

Cross-scale linkages or the organization of governance activities in multiple layers of nested enterprises (Ostrom 1990) may be also instrumental to cope with threats to sustainability. Federations of associations can provide staff assistance, information and material resources for the associations to cope better with disturbances. Also, "nesting a set of local institutions into a network of medium- to larger-scale institutions helps ensure that larger-scale problems are addressed as well as those that are smaller" (Anderies et al. 2004). Overall, external resources and rules can complement and reinforce those existing at local levels thus creating synergies and redundancies that enhance the functionality of local associations (Lam 2006). Finally, nested enterprises can help to address disturbances at the appropriate scale and protect local institutions, organizations and processes from large scale disturbances (Berkes and Folke 1998).

Three of the most well studied social factors contributing to sustained CPR regimes are group size, heterogeneity and leadership (Poteete et al. 2010). Although nuanced by empirical evidence (Poteete and Ostrom 2004, Varughese and Ostrom 2001) and resource dependency arguments (Agrawal 2000), theory posits that coordination, decision making and monitoring costs increase with group size, thus reducing the chances of effective cooperation (Olson 1965, Ostrom et al. 1994, Lubell et al. 2002, Poteete and Ostrom 2004). Similarly, heterogeneity has been associated to conflicts of interest and distrust among resource users, and in turn with lack of cooperation (Poteete and Ostrom 2004). That said, empirical evidence shows that the relationship between heterogeneity and collective CPR management is complex and depends on the criteria used to measure heterogeneity as well as on other mediating variables (Poteete and Ostrom 2004, Velded 2000, Varughese and Ostrom 2001, Lam 1998).

Leadership, on the other hand, has been consistently associated with enduring cooperation. Leaders can assist 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 (Meinzen-Dick et al. 2002, Subramanian et al. 2007, Folke et al. 2005). Leadership's authority can be based on education and experience (Meinzen-Dick 2002), differences in wealth (Velded 2000, Baland and Platteau 1999) and/or formal organizational positions. In all cases, however, it is important that leaders are accountable to users, as power misuse can weaken trust on the CPR regime and its effectiveness (Theesfeld 2009).

2.3 Hypotheses

The hypotheses of this study are:
H1. Robustness is enhanced when the disturbance is intense and frequent.
H2. Robustness is not enhanced when the response is elaborated in the context of a large irrigation system.
H3. Robustness is not enhanced when the response is elaborated in the context of a heterogeneous system.
H4. Robustness is enhanced when the response is elaborated through bottom-up collective choice.
H5. Robustness is enhanced when the response is supported by external entities.
H6. Robustness is enhanced when the response is assisted through leadership.

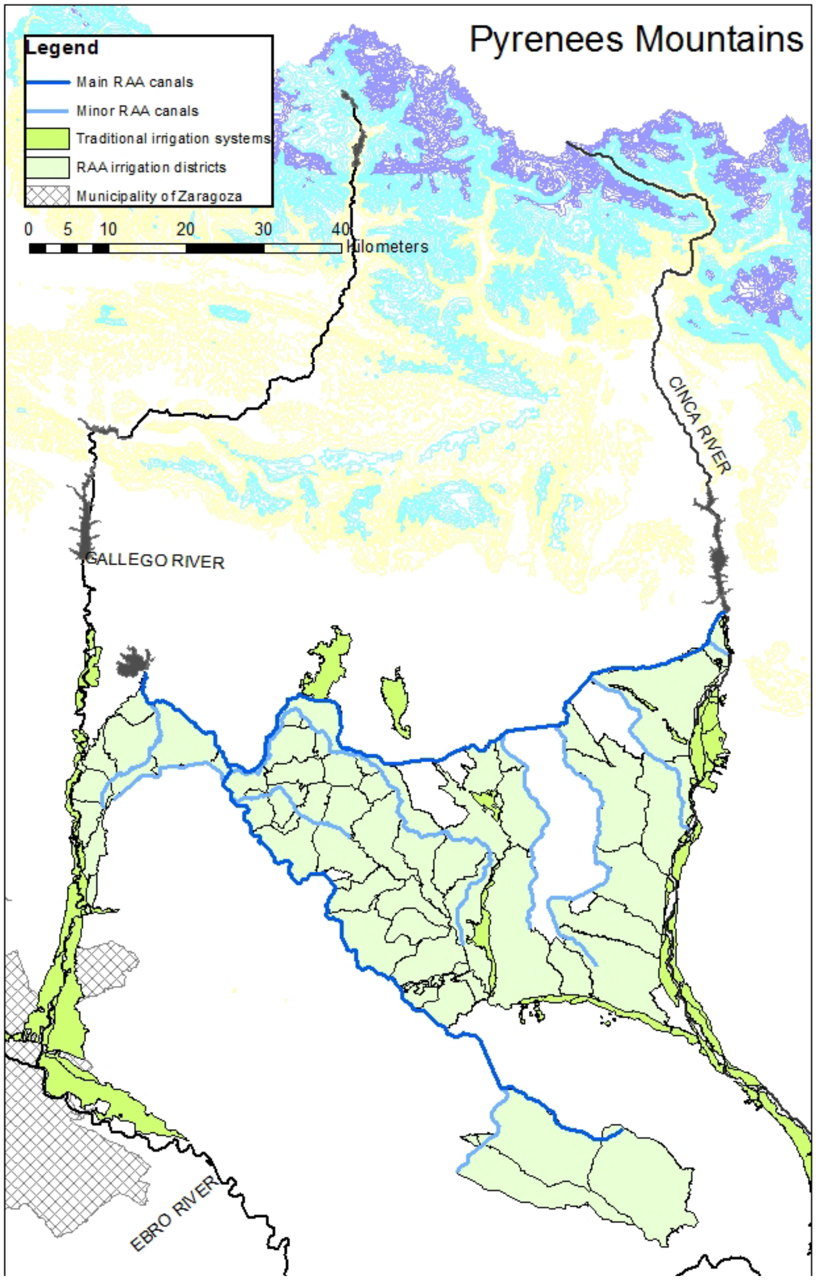
All hypotheses are drawn from the theory reviewed in this section. Hypothesis 1 is drawn from robustness theory (Janssen and Anderies 2007) and captures the expected positive relationship between the "vividness" of intense and frequent disturbances and robustness. Hypotheses 2 to 6 are drawn from the theory of the commons (Agrawal 2001, Poteete et al. 2010). Group size and heterogeneity (H2 and H3) are expected to decrease the efficiency of collective responses, while bottom-up collective choice (H4), cross-scale linkages (H5) and leadership (H6) are expected to increase it.

3. Site background

The site selected for the study is the inter basin of the Gállego and Cinca rivers. The Gállego and Cinca rivers are born in the Pyrenees Mountains and flow into the Ebro River by the city of Zaragoza, within the Spanish region of Aragon (see Fig. 2).

The site is an appropriate area of study for two main reasons. First, irrigation systems located along the area of study are representative of a good share of the Spanish irrigation sector. An important cleavage within the Spanish irrigation sector is that existing between traditional irrigation systems and state-promoted systems. Traditional irrigation systems emerged during the Roman and Arabic empires. Governance in those systems is the result of a centenarian, bottom-up process of conflicts and agreements among farmers. Alternatively, state-promoted irrigation systems are the result of government's intervention. Since the beginning of the 20th century and for more than 90 years, the Spanish government actively engaged in the conversion of dry land to irrigated land and the promotion of new irrigation systems as a means for economic development (Bolea Foradada 1986). Governance in the resulting systems was top-down designed through state law according to a standardized image of traditional irrigation systems. The area selected for this study encompasses approximately 90 irrigation systems. Around 36 of them are traditional systems, encompass around 20,000has and are mostly located in the lower part of the the Gallego and Cinca riversides. The other 50 irrigation systems are the result of a government's irrigation project that diverts water from the Gallego and Cinca Rivers to a more than 100,000 hectares' area that is located in the inter-basin of the two rivers (see Fig. 2).

Figure 2. Map of the area of study



Source: Data obtained from GCRAA and Regional Government of Aragon

Second, the persistence of both traditional and state-promoted systems in the area of study constitutes evidence of their robustness to historical disturbances such as water scarcity, floods and plagues. In the last decades, however, the systems have been confronted with new disturbances, including new water demands from the industrial and urban sectors, and a diminished agricultural labor force, among others (Sancho Martí 1984; CESA 2009). The new situation offers an opportunity to double-check the robustness of those systems to different disturbances.

Finally, irrigation systems in the area are relatively diverse in terms of physical, social and institutional variables that can be relevant to understand why some irrigation associations are more robust to some disturbances than others. Two of the most evident physical and social attributes are the size of the systems and their heterogeneity (see table 2).

Table 2. Size and heterogeneity statistic of irrigation systems in area of study

	State-promoted				Traditional				Both			
	Mean	St.dv.	Min.	Max.	Mean	St.dv..	Min.	Max.	Mean	St.dv..	Max.	Min.
Size (has.)	2,440	1,800	142	9,800	550***	704	13.5	3,820	1,643	1,718	9,800	13.5
Farm size heterogeneity[1] (has)	0.42	0.11	0	0.5	0.17***	0.18	0	0.5	0.32	0.19	0.5	0

n_{state}=50; $n_{traditional}$=36

Note: Heterogeneity is calculated through a Gini-Simpson index (Gibbs and Martin 1962). A perfectly homogeneous population would have a diversity index score of 0. A perfectly heterogeneous population would have a diversity index score of 1 (assuming infinite categories with equal representation in each category). As the number of categories increases, the maximum value of the diversity index score also increases (e.g., 4 categories at 25% = .75, 5 categories with 20% = .8, etc.

[1]: Calculated with regard to two categories: less than 30 hectares vs. more than 30 hectares[2].

As table 2 shows, size and heterogeneity differences across systems are partially captured by the distinction between state-promoted and traditional systems. That said, variation within each of those groups is also notable.

The basics of the organization of irrigation in the country are prescribed by law. At the district level, water is managed by water user associations (WUAs). For that purpose, WUAs are to be organized into a chapter of users, an executive board and a president. The chapter meets at least once per year to assess the management of the executive committee and the president and make decisions that require the direct approval of users. The executive board and the president are elected by the chapter every four years and are in charge of the day-to-day affairs of water allocation, infrastructure maintenance and any other issues that may affect the performance of the system. Despite the standardization of the internal organization of WUAs, it is expected that there is significant variation across systems in terms of rules-in-use, attendance to chapter meetings, experience of leaders and other attributes.

At the basin level, water is managed by the Ebro River Water Agency (CHE). In that role, the agency is responsible for allocating water use rights among individuals and WUAs, flood control, water quality control and the promotion of new infrastructures. Additionally the water agency hosts a water court to solve conflicts among individual users, WUAs and other organizations. Some WUAs have also created second order organizations. That is mainly the case of the 50 state-promoted irrigation systems, which created in the 1950s the General WUA Association of *Riegos del Alto Aragon* irrigation project (GCRAA). The GCRAA is responsible for coordinating the water service across the 50 state-promoted irrigation systems, as well as to assisting the WUAs in solving issues related to water allocation and infrastructure.

[2] According to Cavero and Hernandez (1987), the minimum farm size for an economically viable irrigation cultivation is 30 hectares.

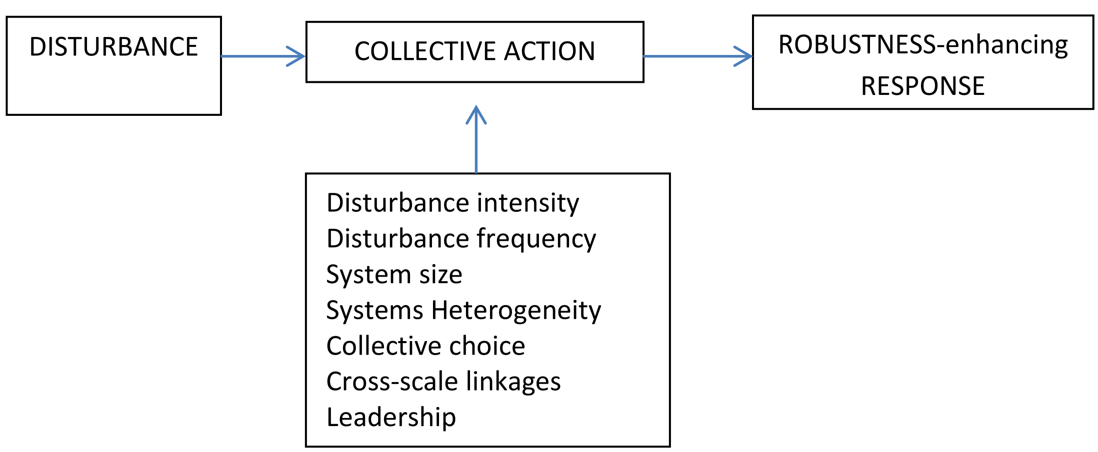
Also, there are the local governments associated to the municipalities where the systems are located. It is not infrequent that WUAs bargain with local governments for support to cope with issues like floods, urbanization processes, the arrival of new users or problems with the water infrastructure.

Finally, there are the regional government of Aragon (DGA) and the central government of Spain. As responsible for agricultural development both governments have developed different initiatives, mostly in the form of subsidies for infrastructure development and modernization (Lecina et al. 2010). In some occasions the WUAs have also requested the government's support to cope with other issues like floods or urbanization processes.

4. Methods

As mentioned in the introduction section, this study aims to understand robustness through the relationship between disturbance and response. For that purpose, the study adopts a disturbance response framework (Costeja 2009, Anderies et al. 2006, Fleischman et al. 2010) where the unit of analysis are dyads of disturbances and responses (see Fig. 3).

Figure 3. Analytical model



The focus on reactive strategies, i.e. responses, rather than preventive actions, or both, responded to a data collection limitation. Collecting field data on preventive strategies in systems where the disturbances were not perceived as such (due to the supposed robustness of the systems) was particularly challenging and would have put a considerable burden on the research right from the beginning..

The analysis is divided in two parts, an exploratory part and a hypothesis testing part. In the exploratory analysis I aim at answering research questions 1 and 2: Which types of disturbances have Spanish irrigation associations recently been confronted with? Are there identifiable patterns in the way Spanish irrigation associations respond to different disturbances? To answer those questions, I classify disturbances and responses into types according to the theory on disturbance attributes and transaction costs of collective action. Then I use descriptive statistics to identify patterns in how different types of disturbances and responses are related to each other.

The hypotheses testing aims to answer research question 3: How do different governance social factors affect the ability of Spanish irrigation associations to cope with those disturbances? To answer that question the theory of the commons is tested via a Qualitative Comparative Analysis (QCA).

4.1 Qualitative Comparative Analysis

Qualitative Comparative Analysis (QCA) is a novel analytical tool that offers the possibility to compare small to medium size samples of cases and to assess the necessity and sufficiency of conditions (i.e. variables) in relation to an outcome. Cases are understood as types in terms of the configurations of attributes that characterize them (Ragin, 2000). Thus, the method does not permit comparing independent and dependent variables like statistical techniques, but cases representing different combinations of conditions that lead to a given outcome. QCA is based on set theory meaning that, cases are characterized according to their membership in different sets of conditions and the outcome. The fuzzy-set version of QCA (fsQCA) draws on fuzzy logic (Zadeh, 1965), and permits assessing the membership of cases along a continuous scale rather than just in terms of absence or presence. In this project, the configurational approach and the fuzzy-set version of QCA seem particularly well suited to identify the interactions between disturbance and response attributes that contribute to robustness.

Measurement and calibration of fuzzy-sets

Disturbance-response cases are assessed with regard to attributes of the disturbance, response and irrigation system at hand. System attributes include size and heterogeneity. The disturbance attributes are frequency and intensity. The response attributes include leadership, cross-scale linkages and collective choice. Robustness, the outcome, is also assessed as an attribute of the responses. In this study, complex constructs like leadership, collective choice, cross-scale linkages and heterogeneity are assessed through different qualitative and quantitative measures that are aggregated following theoretical and logical criteria (see table 3 for a synthesis of the measures, and table A1 in the Appendix for a more detailed explanation and account of the data sources). Robustness is also evaluated through different measures, all of which build on the understanding of robustness as capacity to respond to disturbances. The measures include the ability to mitigate the impact of a disturbance, farmer satisfaction with the response, timeliness of the response and unattended consequences of the response.

Table 3. Synthesis of measures for the outcome and causal conditions

Outcome and conditions	Sub-measures	Description
Robustness (ROBUST)	Satisfaction	Lack of complaints or concerns at any general assembly meeting about how the organization coped with the disturbance.
	Mitigation	Contribution of the response to mitigate the impact of the disturbance
	No externalities	Whether there were unattended and unaddressed negative effects of the response or the disturbance
	Timeliness	Promptness of the response
Disturbance frequency and intensity (LFD)	Frequency*	Number of times that the disturbance hit the system in the last 20 years
	Intensity	Magnitude of the disturbance within the time frame of one irrigation campaign
Cross-scale linkages (CROSS)	Institutional embeddedness	Embeddedness (Lam 2006) of the WUA's response into regional/national or municipal regulations created to cope with the disturbance.
	Institutional complementarity	Complementarity (Lam 2006) between the WUA's response and regional/national/municipal regulations created to cope with the disturbance.
	Mediation	Mediation role played by the water agency or regional/local government as part of the WUA's response to the disturbance
	Co-decision	Co-decision making between national/regional/local actors and the WUA as part of the WUA's response to the disturbance
	Financial support	Financial support provided by the national/regional or the local government as part of the WUA's response to the disturbance
Collective choice (CHOICE)	Unanimity	Existence of consensus at the WUA's general assembly level about the course of action followed in response to the disturbance
	Bottom-up	Lowest collective choice level at which the WUA's response to the disturbance was articulated
	Deliberation	Discussion of the disturbance and/or the response in general assembly meetings previous to the decision.
	Attendance*	Average percentage attendance of farmers to the WUA's general assembles in the last 20 years
Leadership (LEAD)	Monitoring and sanctioning	Monitoring and sanctioning role of the president or a person under his authority in the elaboration/implementation of the response
	Representation	Representation role of the president or a person under his authority in the elaboration/implementation of the response
	Coordination	Coordination role of the president or a person under his authority in the elaboration/implementation of the response.
	Mobilization	Mobilization role of the president or a person under his authority in the elaboration/implementation of the response
	Expertise*	Average tenure in number of years of the WUA presidents since 1980
	Education	Average education level of the WUA presidents since 1980
Size (SIZE)	System's size*	Average area of the irrigation systems in hectares since 2000. (*size*)
Heterogeneity (HETE)	Endowment heterogeneity*	Gini-Simpson index (Gibbs and Martin 1962) of number of hectares that belong to to small (<30 has.) vs. large farms. (2000-2010)

*: quantitative measures that were calibrated following the direct method (Ragin 2008). The remaining measures (qualitative measures) were calibrated according to the technique developed by Basurto and Speer (2012)

The use of QCA requires the calibration, or transformation, of quantitative and qualitative data into membership scores. Data calibration is a central step in the analytical process that has a strong influence on the results of the QCA (Speer 2011). Only a few studies, however, have paid enough attention to that step when dealing with qualitative data. To calibrate such data, I follow a recent technique developed by Basurto and Speer (2012). The technique consists on the application of content analysis to the data according to a series of specific criteria that rely on both theory and knowledge of the cases.

Fuzzy sets are sets in which cases are assigned a value between zero (full exclusion from the set) and one (full membership in the set) according to a membership function (Zadeh, 1965). For some qualitative measures four verbal labels were defined that correspond to the four values of a fuzzy set "fully out" (0), "more out than in" (0.33), "more in than out" (0.67), and "fully in" (1). Three verbal labels ("fully out" = 0, "neither in nor out" = 0.5 and "fully in" = 1) were also used for some other qualitative measures. Then, each case was assigned one of those three or four labels based on the content analysis of archival and interview data (for more details of the qualitative calibration, see Basurto and Speer 2012).

The quantitative measures were directly calibrated following the technique described in Ragin (2008). The fuzzy-set anchor points of "fully out" (0), "neither in nor out" (0.5), and "fully in" (1) were determined based on statistical data and case knowledge. Then, the calibration algorithm in the software fsQCA 2.0 was applied to calibrate the quantitative data (Ragin et al. 2006). All verbal label and anchor point definitions can be looked up in table A2 in the Appendix. The fuzzy-set values of the conditions and the outcome are listed in table A3, also in the Appendix.

Two-step FsQCA and case-level analysis

The hypothesis testing is conducted in two steps. The two-step approach was introduced by Schneider and Wagemann (2006) as a remedy to the too-many-variables/too-few-cases problem in medium N studies, and is employed to avoid overloading the fsQCA with too many variables. In the first step, the fsQCA truth table algorithm is applied to an underspecified model that contains only remote conditions. Remote conditions create the environment in which proximate conditions unfold their effect on the outcome (Schneider and Wagemann 2006). In this study, system attributes like size and heterogeneity are analyzed as remote conditions.

In the second step, the analysis is run with the proximate conditions and the remote conditions that are found to be sufficient[3] for the outcome in the first step. In this study, intensity and frequency of disturbances, leadership, cross-scale linkages and collective choice are analyze as proximate conditions. Whether those conditions are sufficient for the outcome is used in the second step as the criterion to reject or accept the hypotheses of the study.

Finally, the results are interpreted by drawing on theory and case-level evidence. The internal validity of the results is assessed by identifying the causal mechanisms that link the conditions to the outcome in a series of examples. The external validity of the findings is also assessed by reviewing cases that do not support the results or support counterintuitive ones.

4.2 Selection of irrigation systems

The selection of irrigation systems was purposive and was designed to maximize the diversity of disturbances studied. It is expected that a fair amount of the disturbances and responses that irrigation systems have been confronted with are different in terms of immeasurable characteristic that . In this scenario, following the ideal *method of agreement* (Mill 1858, cited in Sekhon 2004) can be appropriate. According to the method of agreement, if two sets of cases with different sets of outcomes do not share any attribute but one, this common attribute is inferred to be the cause of the different outcomes. A way to approach Mill's ideal scenario of most different disturbances and responses is to increase the diversity of disturbances studied. According to some preliminary fieldwork, one factor that seems to be driving distinctive changes in the irrigation sector at the local level is urbanization. Urbanization entails not only urban sprawl but also new water demands, industrialization and the construction of transportation ways. Capturing those disturbances required stratifying the sample according to distance to urban centers (see Fig. 4). The urban center chosen for that purpose was Zaragoza, an approximately 700.000 inhabitant city and capital of the region of Aragon.

At the same time, there was an interest in controlling for the state vs. traditional origins of the irrigation systems. Both types of systems may be face different types of disturbances due to their different origins. Additionally, it is expected that the different origins also translate in different attributes and types of responses, as hinted at in the background section. Thus, the origin of the systems was used as a second stratifying variable for sampling.

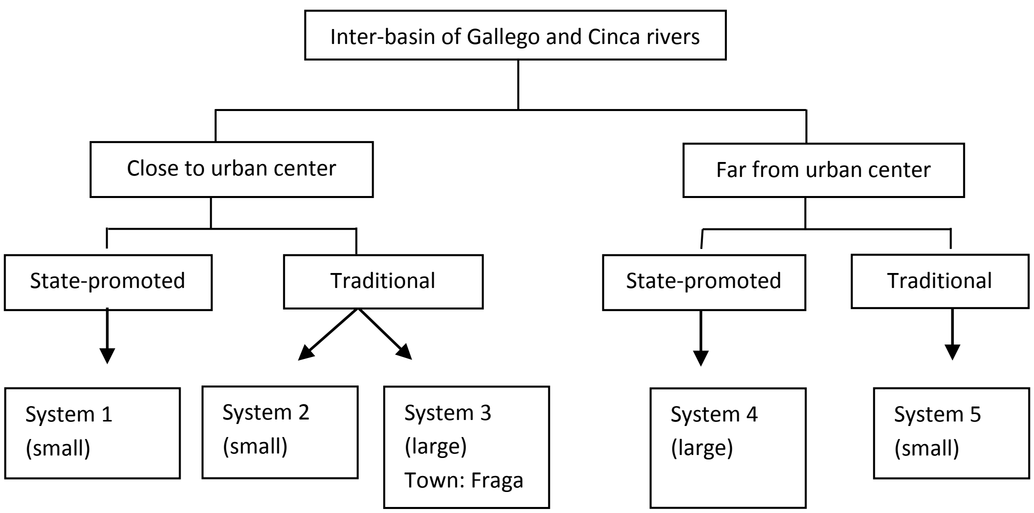
Finding state and traditional systems that shared the proximity to an urban center was not easy task. The city of Zaragoza was selected because it is the biggest city in the area by far and has gone through notable growth in recent decades. However, there are no systems that are

[3] If a causal condition is sufficient, all cases that display the causal condition also display the outcome (Rihoux & Ragin, 2009). A complementary criterion is that of necessity. If a causal condition is necessary, all cases that display an outcome display the causal condition. Necessity in this study was tested as part of the robustness checks.

traditional and also large[4] in the area surrounding Zaragoza. To cope with the issue, I selected two small irrigation systems that are close to Zaragoza (one traditional and one promoted by the state), and then I added a traditional and large system that is located in the surroundings of a different town. The only other traditional irrigation system within the area of study that is large enough[5] is located in the surroundings of Fraga, which is a urban center that has gone through significant urban growth in recent decades.

To effectively select the systems, the population of irrigation systems in the area of study was reconstructed from public records. A 1994 catalogue of Spanish irrigation associations issued by the Department Public Works and Transportation (MOPT 1994) was combined with the Ebro River Water Agency's records (CHE 2010) to obtain a reliable database of systems and the attributes of interest (see Fig. 1 in section 3).

Figure 4. Sampling Strategy



4.3 Selection of disturbances

Disturbances in each of the 5 irrigation systems were sampled according to their magnitude, i.e., only disturbances that represented a significant change from the norm were ultimately selected. As it will be further discussed in the data collection section, the selection was carried by crossing-checking information from meeting minutes and interviews.

All the selected disturbances were associated to at least one response, and in most cases to more than one. No disturbance was found without response. Disturbances that were addressed by more

[4] Systems size is one of the conditions tested in the study and it was important to have variation in that regard within the group of systems that are close to an urban center (see Fig. 4).
[5] In this study, large systems are those that are larger than the average size in the area of study.

than one response were counted as separate cases in the analysis. Correspondingly, the contribution of each response to robustness was assessed separately. That was accomplished by combining different performance measurements and formulating the interview questions in a particular way. As further illustrated in the data collection section, the focus of the inquiry was not whether a WUA coped with a disturbance but whether a particular response contributed to it. By these means, it was not strictly necessary to identify all the responses that a WUA had developed to cope with a disturbance to have a good sense of how performing the WUA was.

The fact that several disturbance-response situations within an irrigation system are considered as separate cases requires a working hypothesis, to wit, that the robustness of WUAs does not depend as much on the WUAs attributes as on how those attributes are used to cope with different disturbances. Or, in other words, that robustness is contingent on the type of disturbance (Carpenter et al. 2001 Anderies et al. 2006, Schoon 2009, Cox 2010).

Also, progressive disturbances (for example, rural depopulation) were counted as a single event (even if extended over years), and all responses developed by a WUA during the event were linked to that event in the analysis. Disturbance frequency in those cases was understood as absent. Alternatively, only the most recent event of punctuated and frequent disturbances (for example, droughts) was included in the study. And all the responses developed by a WUA to cope with that event as well as with previous events of the same disturbance were linked to the event.

4.4 Data Collection

Data for the study was obtained from group and individual interviews with farmers as well as meeting minutes and internal documents from the 5 WUAs. The data was collected in three stages. First, data was obtained from chapter meeting minutes of the last 20 years in each WUA. The data obtained was used to elaborate a chronological list of disturbances and responses as well as to identify some of their characteristics.

Second, the list was used as a template in a series of group interviews conducted with executive committee members of the WUAs. The purpose of those interviews was to select a number of disturbances and responses from the list according to their relevance for the association, as well as to collect more information about the characteristics of those disturbances and the associated responses. Focus groups and group interviews in general are recommendable when the topic of interest is habit or not thought in detail by participants (Morgan 1997). According to previous fieldwork experience in the area of study, farmers do not easily recall incidences that are older than 5 years other than big crisis, nor remember details of the way they and their associations responded to those incidences. In that regard, group discussions were expected to be more effective than individual interviews. Along the group discussions, emphasis was made on tracing the process through which the responses to different disturbances were developed. Process tracing is largely a within-case methodology that lays out, usually in a linear fashion, the course of events that connect a hypothesized cause and effect (George and Bennet 2005). The emphasis on the process helped to disentangle relevant responses to disturbances from other actions of unclear purpose.

Third, the information collected in the first and second stages was used to elaborate semi-structured questionnaires that were then applied to samples of farmers from each of the five associations. The questionnaires were used mostly for triangulation purposes. Information obtained from group interviews may be biased due to uncontrolled interactions among the group participants as well as the influence of social norms on participants' contributions (Morgan 1997). Everything else being equal, individual interviews can guarantee a much more controlled environment (Morgan 1997). Thus, individual interviews with members of the irrigation associations were used to confirm information that was most vulnerable to group bias, such as the evaluations of responses to disturbances, characterizations of the role of leaders, or observations about the frequency and duration of disturbances.

Farmers in each association were sampled through the snowball technique. The interviewees from the group interviews were used as a first source of references in that process. The use of the snowball technique responded to two reasons, both grounded in previous fieldwork experience in the area of study. First, farmers in the area are not easily accessible and are much more willing to collaborate if contacted via people they trust on, like other members of their WUAs. Second, the questions in the interviews covered a long time frame and wide scope of events, and responding effectively to the questions required notable knowledge of the system and its history. The snowball sampling was used as a method to filter and have access to farmers with that level of knowledge. The ultimate sample size was determined according to the saturation criterion. New farmers were sampled until no significant new information was obtained with the last interviewee (Glaser & Strauss 1999).

5. Exploratory Results

Data collection resulted in the identification of 30 disturbances cases across the 5 systems ($n_{disturbance} = 30$). Four disturbances occurred across more than one system. The irrigation associations developed an average of two responses per disturbance, resulting in a pool of 61 disturbance-response cases ($n_{disturbance\text{-}response} = 61$). No disturbance without response was identified (see tables A3 and A4 in Appendix containing raw membership scores of the 61 disturbance-response cases and summary statistics of those scores, respectively).

5.1 Disturbances

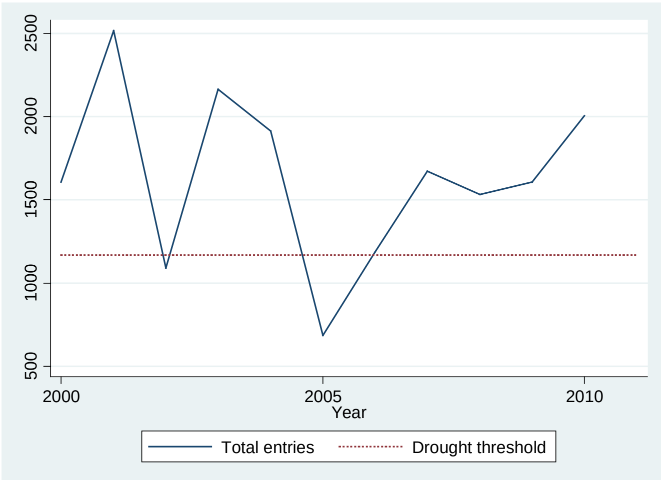
Almost all the disturbances identified in this study represented a direct threat to the water allocation situation. Some of the most paradigmatic are droughts, crop intensification waves or canal breakages. Only 7 disturbances represented a direct threat to the infrastructure provision situation. One of the disturbances is a progressive decrease of workforce due to depopulation in rural areas. Many WUAs in the area of study, including the 5 associations under study, rely on labor contributions from farmers to maintain part of the infrastructure, while the maintenance of other parts is performed by day laborers and funded via a maintenance fee system. The progressive rural depopulation has threatened the effectiveness of that division of labor in all 5 systems. On the one hand, young farmers who remain in rural areas aim to develop scale economies by concentrating land and mechanizing labor. In that path to professionalization those farmers tend to see infrastructure maintenance as a secondary duty. On the other hand, other farmers who remain in rural areas are for the most part over their 60s and face increasing difficulties in performing the heavy manual labor involved in maintenance duties. The other disturbance is a debt crisis that originated after an ambitious infrastructure modernization project in one of the irrigation systems under study (the “SXI” system). A rise in the number of unpaid fees by farmers put in jeopardy the solvency of the irrigation organization both to repay the investment loans and to cover the costs of carrying maintenance duties.

Finally, two disturbances represented a direct threat to both water allocation and infrastructure provision situations. One of them was the transformation of irrigated land into residential or industrial land experienced in one of the irrigation systems (the “JC” system) over the last decades. The process involved an increase in the number of residential and industrial users in the WUA. The wavering interest of the new users in maintaining the irrigation infrastructure created uncertainty among farmers about the efficacy of the maintenance system. At the same time, the fact that urban and industrial users usually need much less water but on a more continuous basis than irrigators threatened the water allocation status quo in the system. The other disturbance is the conflict between the leaders and an important number of farmers that occurred more than a decade ago in one of the systems (the “FVT” system). By the end of the 1990s, the executive committee of the WUA had launched an initiative to introduce dripping irrigation in the system. The project required remodeling the conveyance infrastructure of the entire system. The project was approved in a chapter meeting but was not accepted by a significant number of landowners who did not considered the process legitimate. After some violent incidents, the executive committee and the president resigned from their positions, which remained vacant. The lack of leadership translated in a situation of great uncertainty about compliance with the water allocation and the infrastructure maintenance systems.

The disturbances identified in this study can be classified into three mutually exclusive categories according to different combinations of frequency and intensity attributes: intense and frequent disturbances (LFD) like droughts, landslides or algae proliferation; intense but infrequent disturbances (LID) like the construction of highways across the irrigation systems, the occurrence of floods or a rise in energy prices; and progressive and infrequent disturbances (STRESS) like crop intensification or the abovementioned decrease of workforce in rural areas.

A paradigmatic example of LFD in the area of study is droughts. Four of the five irrigation systems under study have experienced severe droughts in the last 20 years, most of which lasted between one and two years (see Fig. 5).

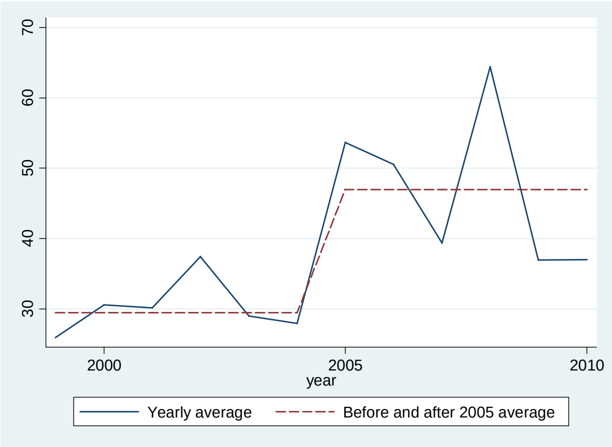
Figure 5. Water entries in reservoirs (hm^3) of the area of study[1] for 2000-2010



[1]: All systems in the area of study depend directly or indirectly from the water that is stored in a series of water reservoirs located in the Gallego and Cinca rivers.
Note: Series calculated from October to September of each year.
Note: "drought threshold" = 1 standard deviation below the mean (~1,200hm^3) from the series 19, which is close to the approximate average consumption of water by the irrigation systems in the area (CHE 2000).
Source: Data obtained from Ebro water agency

A paradigmatic example of LID is the liberalization of the energy market (see Fig. 6). In 1999, the Congress approved the deregulation of the energy sector. That entailed the suppression of preferential tariffs that irrigation associations using sprinkler irrigation had enjoyed until then and a subsequent increase in the price of energy for those associations. After a series of moratoriums, the government started in 2005 a program of price penalties to promote the transition of irrigation systems from the tariff to the market system. The program ended in 2008 with the total cancellation of the preferential tariff. The change jeopardized the performance of many irrigation systems that need to pump water to irrigate, including one of the systems included in this study (the "SXI" system).

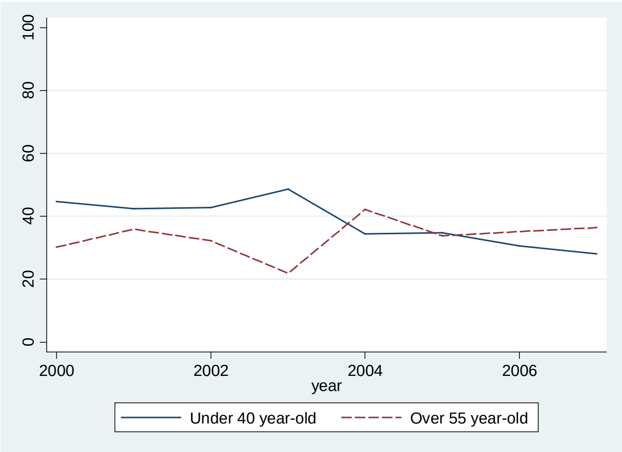
Figure 6. Market energy prices (Euros/MW/h) before and after 2005[1]



[1]: In 2005 the WUA of the "SXI" system put in operation a new sprinkler irrigation system that required pumping water and thus the consumption of energy. The project that the chapter of the WUA had approved in 2002 to install the sprinkler irrigation system had not foreseen the dramatic increase in energy prices that would occur in 2005-2008. In the graph, the dashed line before and after 2005 represents the expected price of energy when the sprinkler irrigation project was designed and the actual price when the new system was put into operation, respectively.
Source: data obtained from OMEL (2012).

Finally, a paradigmatic example of STRESS disturbance is the phenomenon of progressive rural depopulation experienced in the entire area of study (see Fig. 7). The phenomenon can be traced back to the 1960s and is expected to continue at least in the next decade (Pinilla Navarro and Saez Perez 2009).

Figure 7. Percentage of self-employed farmers across selected age groups (2000-2007)



Note: the groups were selected to show contrast between younger and older farmers.
Source: elaborated with data from Regional Government of Aragon.

Table 3 displays the number of instances per type of disturbance. According to the table disturbances seem to be similarly distributed across the LFD, LID and STRESS categories.

Table 3. Frequency table of types of disturbances

	Number of disturbances ($n_{disturbance}$=30)
Intense & Frequent Disturbance (LFD)	12
Intense & Infrequent Disturbance (LID)	8
Progressive Infrequent Disturbance (STRESS)	10

5.2 Responses

The exploration of the pool of 61 responses resulted in the identification of 5 categories, including internal mitigation strategies, bargaining with external entities, delegation on external entities, institutional change, infrastructure change, and infrastructure & institutional change (see table 5).

Table 5. Frequency and transaction cost categorization of response types (n=61)

Response type	***freq.***	**Collective action costs**
Infrastructure and institutional change	10	High (first and higher order strategies)
Institutional change	10	
Infrastructure change	4	
Internal mitigation strategy	14	Low (pure coordination strategies)
Bargaining with external entities	7	
Delegation on external entity	16	

Internal mitigation strategies rely mostly on the initiative of the WUA leaders, whose actions are then ratified by the farmers either explicitly in a chapter meeting or implicitly through the absence of complaints. A paradigmatic example is how the WUAs of the “SA” and “JC” systems respond to the blockage and breakage of the infrastructure due to landslides. In both systems the landslides occur with relative frequency at particular points of the infrastructure. In one of the systems, the landslides seem to result from urban developments in an adjacent area. In the other system, the landslides are the result of water filtrations from a neighboring irrigation system. When a landslide breaks or blocks the infrastructure, whoever first notices it informs the guard, who then coordinates farmers or day laborers and sometimes also heavy machinery to clean the canal as soon as possible. The event and the measures taken by the guard are then reported to farmers in an ordinary chapter meeting. Another example is one of the responses used in 4 of the systems (“SA”, “JC”, “SXI” and FVT”) to cope with maintenance problems due to the decreased workforce. In all systems, the guard has the authority to carry the maintenance duties of farmers if they fail to perform said duties. Then the costs of the works and a penalty are charged to the farmers. The institution pre-existed the phenomenon of rural depopulation. Thus, just like in the example of the landslides, the response does not involve any rule or infrastructure change.

The bargaining and the delegation response types are similar in that both involve dealing with external actors. The role of leaders and collective action is, however, more accentuated in the former than in the later. Common examples of the delegation type are the use of letters of complaint and the request of investments to the water agency, the government, or second order organizations (like the GCRAA). Associations have addressed letters of complaint to public authorities in the case of the landslides and also in response to canal breakages when the maintenance of those canals was the responsibility of the water agency. Requests of investments have also been addressed to public authorities in response to canal breakages, river floods, and issues derived from urbanization processes. An interesting example of the delegation type is the response of farmers in the "FVT" system to the abovementioned conflict that left the association without leadership. The request of farmers triggered the intervention of the water agency. The goal of the intervention was to restore the management of the organization and the governability of the system.

A good example of the bargaining type is the response developed by two and three WUAs to cope with highway and railway constructions, respectively. The constructions intersected the main and secondary canals of the systems, representing a threat to the normal flow of water. In all systems the chapters of farmers explicitly authorized the presidents of the WUAs to deal with the construction companies and the department of public works, and guarantee that the affected infrastructure was reconstructed properly. Whenever the president had to consult with farmers he met with groups of them depending on the section of the infrastructure at stake. A similar example is how the WUA of the "SA system responded to the flooding of part of the irrigable area due to the progressive leveling up of water in a neighboring lake. The lake had been receiving waters from a neighboring irrigation system since the 1960s. Water percolation in the lake was minimal so all new water inflows automatically translated into higher water levels. By the mid-1980s, the lake had flooded close to 300 hectares of the "SA" irrigation system. Initially, the WUA limited its actions to sending letters of complaint to the regional government and the water agency. That measure and the threat that the lake flooded a neighboring municipality triggered the reaction of the regional government and the water agency. The solution considered by the public authorities was drying up the lake; however, environmental groups opposed to the measure. A mediation process was then initiated among public authorities, the environmental groups, the WUA and the municipality. Thus, although the WUA had initially turned to the public authorities to resolve the problem, the WUA ended playing an important bargaining role.

Institutional and infrastructure change are the two types of response that entail the highest collective action costs (see table 4). Both types of responses require the development of binding decisions and the use of monitoring and sanctioning systems. In some occasions, responses involved both new infrastructure investments and the development of rules to manage the new infrastructure. A good example of rule development is the response of two WUAs to droughts and to crop intensification. To cope with those disturbances the WUAs created a quota system. Under the quota system every farm is allotted a rate of water per hectare. The quotas cannot be sold and may be reallocated if not fully used by farmers. Thus the quotas enable water use control while permitting some flexibility in the water allocation. Another example of rule development is one of the responses developed by the WUA from the "SXI" system to cope with the rise of energy prices. In addition to the elimination of the preferential tariff, the energy sector reform created a system of price floors that varied across periods during the day and over the week. The WUA, in an attempt to reduce the energy costs self-imposed mandatory irrigation schedules that permitted irrigating during valley periods and restricted water use during peak periods.

The lack of labor workforce to perform the maintenance duties has been an important trigger of infrastructure change responses, a fair number of which have been accompanied by institutional changes. In an attempt to reduce and mechanize the infrastructure maintenance tasks, among other things, the WUAs of the "SXI" and the "FVT" systems opted for investing in dripping and sprinkler irrigation technologies. The new technology triggered changes in water allocation rules, as and sprinkler and dripping irrigation require water to be applied on a much more continuous basis than furrow irrigation[6]. Also in response to the lack of labor factor those WUAs and other WUAs have permitted, and in some cases promoted, that farmers pave or pipe sections of the conveyance infrastructure by their own initiative, as lined ditches and tubes require considerably less maintenance than unlined ditches. To guarantee that the water flow is not affected by inconsistencies in how farmers carry out the improvement works, the WUAs have also elaborated rules about the types of materials and dimensions of the new infrastructure.

Table 6. Number of disturbances that are addressed through combinations of high- and low-cost responses

	Low cost	High cost
High cost	13	4
Low cost	6	--

Note: The table includes only disturbances that were addressed by more than one response. Disturbances addressed by more than one high-cost and/or low-cost response were counted only once.

As mentioned in the introduction to this section, a fair number of disturbances was addressed through more than one response. According to table 6, low collective action cost responses tended to cluster with high collective action cost responses. One possible interpretation of that pattern could be related to a strategy of cost diversification. According to that strategy,

[6] Furrow irrigation is the traditional irrigation technique, which consists on flooding the land with water.

associations would be aiming at diversifying the number of responses to disturbances to increase their chances of success while keeping the transaction costs low.

Table 7. Average number of responses per type of disturbance

	LFD	LID	STRESS
Number of responses (n=61)	21	13	27
Number of disturbances (n=30)	12	8	10
AVERAGE responses per disturbance	1.7	1.6	2.7

Also, according to table 7, the average number of responses varies significantly across disturbance type. The highest average corresponds to STRESS disturbances, with 2.7 responses per disturbance. This score is relevant if compared to the scores of LFDs and LIDs, which are 1.7 and 1.6 respectively. The difference between the average number of responses of the STRESS type (2.7) and the average of the LFDs and LIDs types together (1.7) was significant at the 10% level (t-test = 1.5; df = 10; p-value = 0.08). According to one possible interpretation, WUAs would have more chances or be more eager to diversify their coping strategies when facing disturbances that emerge progressively than when confronted with more intense disturbances, even if the later were also frequent. A similar interpretation would suggest that disturbances that develop progressively are more difficult to assess in terms of magnitude and duration and thus require more trial and error than intense disturbances.

Table 8. Proportion of high-cost responses per type of disturbance

	LFD	LID	STRESS
High cost strategies	7	4	13
Low cost strategies	14	9	14
TOTAL	21	13	27
Proportion of high cost strategies	0.33	0.31	0.48

Finally, table 8 explores whether the number low- vs. high-cost responses varies across types of disturbances. According to the table, the number of low-cost responses is as much as twice the number of high cost responses when coping with LFDs and LIDs; however, that is not the case for STRESS disturbances, where high- and low-cost responses are almost equal in number. Correspondingly the proportion of high-cost strategies is considerably higher in STRESS disturbances than in in LFD’s and LID’s. The difference is close to be significant at the 10% (t-test = 1.67; df = 59; p-value = 0.108). The results can be related to the progressive nature of STRESS disturbances. Everything being equal, slow moving disturbances would give WUAs more time to engage in complex collective action enterprises than otherwise.

6. FsQCA Results

6.1 First Step: Analysis of Remote Causal Conditions

In the first step of the analysis the QCA truth table algorithm is applied to test whether system size (SIZE) and heterogeneity (HETE) enhance robustness to disturbance (ROBUST) (see table A3 in the Appendix for the truth table for the 61disturbance-response cases). The conditions correspond with hypotheses H2 and H3, respectively. I follow Schneider and Wagemann (2006) in applying a low consistency threshold (0.7)[7] and in using a parsimonious solution. For deriving the parsimonious solution the computer program uses any counterfactual (unobserved configuration of conditions) that makes the solution formula simpler[8]. Table 9 displays the result of the first step of the analysis.

Table 9. Remote conditions associated to *presence* of robustness

Model: **ROBUST** = *f* (*size*, *hete*)			
Parsimonious Solution	Raw Coverage[1]	Unique Coverage[2]	Consistency[3]
hete	0.79	0.36	0.84
SIZE	0.51	0.08	0.91
Solution coverage: 0.93 Solution consistency: 0.79			

[1]: Raw coverage refers to the proportion of cases with a positive outcome that are covered by a condition or combination of them.
[2]: Unique coverage refers to the proportion of cases with a positive outcome that are covered only by the same condition of combination of them.
[3]: Consistency refers to the degree to which the cases that share a combination of conditions agree in displaying the outcome (Ragin 2006).
Note: upper-case letters indicate presence of the outcome or condition, lower case letters indicate absence.
The consistency value would be conceptually similar to the significance value of inferential statistics, and some of the coverage values might share some characteristics with measures which we know from regression analysis, such as the r^2 and partial correlation coefficients. However, statistics and QCA measures respond to completely different logics and such analogies have to be taken with extreme caution (Wageman and Schneider 2007).

According to table 9, responses that are elaborated either in the context of large or homogeneous irrigation systems contribute to robustness. Thus causality turns out to be equifinal, i.e., there are more than one path that lead to the outcome. The solution coverage is 0.93, which indicates that the solution accounts for 93% of the responses with a positive outcome. The solution consistency

[7] A consistency threshold is the minimum proportion of cases that represent a configuration of conditions and agree in displaying the outcome, and it is used by the analyst as a benchmark to associate the solution to the outcome. Schneider and Wagemann (2006) use a threshold of 0.7 both for the first and second steps of the QCA. Schneider and Wagemann (2010) also recommend a 0.7 threshold. .

[8] The parsimonious solution accounts for much of the empirical evidence, but it is less precise than the complex solution (which only uses the configurations of conditions that are represented by the empirical data). It is used for the first step of the analysis because this step aims at identifying all relevant remote conditions that foster robustness without yet providing an exact solution. (Schneider and Wagemann 2006).

is 0.79, i.e., 79% of the responses that share the combination “hete + SIZE” (“absence of heterogeneity” or “presence of large system”) also contribute to robustness.

The first part of the solution formula (“hete”) is in line with the theoretical prediction that low heterogeneity contributes to robustness by facilitating consensus over the courses of action to follow and thus the timeliness and effectiveness of the responses (H 3) The second part (“SIZE”) implies that large size, which is measured as the number of hectares of an irrigation system, is associated to robustness. That result does not correspond with the prediction emerging from the theory of the commons and with hypothesis 2. Alternatively, the results would confirm the argument that large irrigation systems enjoy scale economies and thus are able to develop better responses (Agrawal 2000).

6.2 Second Step: Analysis of Proximate Causal Conditions

The second step of the fsQCA tests what proximate causal conditions are sufficient for the outcome. The analysis is structured across three models. In the first model, only the proximate conditions are tested. In the second and third models the conditions of heterogeneity and size are added alternatively. The outcome in all models is again ROBUST and the proximate conditions are intense & frequent disturbances (LFD), collective choice (CHOICE), cross-scale linkages (CROSS) and leadership (LEAD). The conditions represent H1, H4, H5 and H6 respectively. The consistency threshold is still 0.7 (Scheider and Wagemann 2006), and I use the complex solution, which does not allow the computer program to make any assumptions about unobserved combinations of conditions. Tables 10, 11 and 12 display the results of the second step of the analysis.

Table 10. Model 1: Configurations of proximate conditions associated to *presence* of robustness

Model: ROBUST = *f* (*lfd*, *choice*, *cross*, *lead*)			
Parsimonious Solution	Raw Coverage	Unique Coverage	Consistency
1. LEAD*CHOICE*CROSS	0.44	0.1	0.94
2. LDF *LEAD*choice	0.18	0.07	0.90
3. lfd*cross	0.43	0.21	0.80
Solution coverage: 0.742 Solution consistency: 0.84			

According to the solution in table 10, there are three combinations of conditions or ‘paths’ that are sufficient for robustness regardless of context conditions. The first sufficient path to robustness combines collective choice, cross-scale linkages and leadership (see configuration 1 in table 10). The second sufficient path (configuration 2 in table 10) is specific to intense and frequent disturbances (LFDs). According to that path, responses that count on leadership in the advent of LFDs can contribute to robustness, despite the lack of collective choice. The third sufficient combination (configuration 3 in table 10) is contingent on progressive or infrequent disturbances (LID's or STRESS disturbances). According to the path, the lack of external support in the advent of those types of disturbances would be associated to robustness. The entire solution accounts for 72% of the responses with a positive outcome (solution coverage = 0.72). According to the solution consistency, 84% of the disturbance-response cases that follow any of the paths also contribute to robustness. All individual paths are also highly consistent and explain decent percentages of the outcome (see raw coverage values). The last path is more unique in that it covers 30% of the responses contributing to robustness by itself (see unique coverage value); however, that path is also less precise than the other two. Finally, causality is again equifinal, and also conjunctural, i.e., there are more than one response path that contribute to robustness and each path consists of a combination of conditions. Contrary to the remote conditions, none of the proximate conditions is found to be individually sufficient for the outcome.

Table 11. Model 2: Configurations of proximate and remote conditions associated to *presence* of robustness

Model: ROBUST = *f* (*lfd*, *choice*, *cross*, *lead*, ***hete***)			
Complex Solution	Raw Coverage	Unique Coverage	Consistency
1.1 **LEAD*CHOICE***CROSS***hete	0.40	0.04	0.96
2.1 **LFD***LEAD***choice*hete	0.18	0.07	0.92
2.2 LFD***LEAD***CHOICE***CROSS**	0.16	0.12	0.93
3.1 **lfd***cross***hete	0.37	0.09	0.85
3.2 **lfd***cross***CHOICE *LEAD	0.31	0.03	0.93
Solution coverage: 0.67 Solution consistency: 0.88			

Note: in bold the paths found in in the model without context conditions (model 1).

According to the solution in table 11, there are five combinations of conditions or ‘paths’ that are sufficient for robustness when we consider the heterogeneity of the systems. In three of those paths, the lack of heterogeneity qualifies configurations identified in the first model (see configurations 1, 2 and 3 in table 10, and 1.1, 2.1 and 3.1 in table 11). Two other paths (configurations 2.2 and 3.2 in table 11) represent new alternatives for robustness when the systems are hit LFDs or by LID's/STRESS disturbances, respectively. According to the first of those configurations (2.2), responses to intense and frequent disturbances that enjoy collective choice, external support and leadership contribute to robustness. According to the second configuration (3.2), responses to progressive or infrequent disturbances that count on leadership and collective choice despite the lack of external support still contribute to robustness. The solution coverage and consistency are still relatively high (0.67 and 0.88 respectively). Also, each individual path explains individually in between 16 and 40% of the responses contributing to robustness. Finally, the findings point again to the equifinal and conjunctural nature of causality when explaining robustness.

Table 12. Model 3: Configurations of proximate and remote conditions associated to *presence* of robustness

Model: ROBUST = *f* (*lfd*, *choice*, *cross*, *lead*, ***size***)			
Complex Solution	Raw Coverage	Unique Coverage	Consistency
1.2 **LEAD***CHOICE***CROSS***size	0.40	0.04	0.95
1.3 choice*****cross*****LEAD	0.42	0.05	0.88
2.2 LDF***LEAD***CHOICE***CROSS**	0.16	0.01	0.93
2.3 **LDF*LEAD** *CHOICE *****size	0.16	0.01	0.93
3.3 **lfd***cross***LEAD	0.32	0.087	0.96
3.4 **lfd***cross***CHOICE *****size	0.20	0.008	0.93
3.5 **lfd***cross***choice*****SIZE	0.30	0.06	0.96
Solution coverage: 0.69 Solution consistency: 0.89			

Note: in bold the paths found in in the model without context conditions (model 1).

According to table 12, there are seven paths to robustness when we consider the size of the systems in the analysis. Robustness is associated to small size in three of the paths and to large size in one. One of those four paths (1.2 in the table) adds the condition of small size to the configuration where cross-scale linkages, leadership and collective choice are present. In another configuration (2.3) the small systems condition is associated to the presence of collective choice and leadership, given the occurrence of LFDs. The final two paths build on the lack of external support given the occurrence of progressive or infrequent disturbances. One of those paths (3.4) includes small systems and also collective choice. The other path (3.5) includes large irrigation systems in the absence of external support or collective choice. Coverage and consistency measures are similar to the previous models and the equifinal and conjunctural nature of causality is again confirmed.

6.3 Robustness checks

The robustness of the fsQCA results was assessed in three ways. All models were recalculated for the absence of the outcome. This is necessary because fsQCA does not rely on the assumption of causal symmetry, i.e., the conditions that lead to the presence of an outcome are no assumed to be the same than the conditions that lead to the absence of the outcome. According to the analysis, there is not a pattern of symmetric causation. Interestingly enough, a number of paths addressing LIDs/STRESS disturbances and associated in models 1 to 3 to robustness were also found to be associated to the absence of robustness. This finding indicates the need to further refine the conditions under which LIDs/STRESS disturbances can be successfully tackled. The results of the exercise are displayed in the Appendix, table A5.

Second, the analysis was repeated with alternative aggregated measures of the conditions and the outcome. As mentioned in the methods section, the outcome and most of the conditions were assessed through different measures that were then aggregated. To check for the robustness of the results I use aggregation strategies that are more conservative than those used in the initial analysis. The results and comments to this exercise can be looked up in tables A6 to A9 in the Appendix. Overall, the analyses with alternative measures confirm the main results that have been described in this section.

Finally, all conditions were individually tested for necessity. Among all remote and proximate conditions, only leadership passed the test of necessity (see table A10 in the Appendix). This result reinforces the findings about the role of leadership. The lack of necessity of the other conditions does not invalidate the findings so far, but just qualifies them.

7. Discussion: Case-level analysis

In this section I draw on case-level evidence to interpret and evaluate the solution formulas across the three models of the second stage of the analysis.

As hinted at in the previous section, there are three groups of configurations, depending on whether the solution applies to responses addressing intense and frequent disturbances (i.e. LFDs), responses addressing progressive or infrequent disturbances (i.e. STRESS disturbances and LIDs), or responses in general (see configurations 1, 2 and 3 in table 10 and their subsequent versions the tables 11 and 12, respectively). The configurations vary across the three groups. That confirms the thesis that robustness is contingent to disturbance (Carpenter et al. 2001, Janssen and Anderies 2007) and the relevance of assessing disturbances with regard to their intensity and frequency to understand the contribution of responses to robustness (Schoon and Cox 2012). That said, the existence of a group of configurations encompassing responses in general (see #1 configurations in tables 10, 11 and 12) also indicates that LFDs and STRESS and LIDs can share common paths to robustness. In other words, disturbance intensity and frequency cannot explain all variation across disturbances.

In addition to the variation across the type of disturbance addressed, there is also variation across contexts. The paths to robustness vary across models depending on whether none remote cause is considered (model 1) and whether the conditions of size or heterogeneity are considered (model 2 and 3, respectively). As it will be further explored below, variation across the three models indicates the existence of interactions between those context attributes and the proximate conditions.

Despite variation across models and disturbance types, some configurations and conditions seem to be pretty consistent across specifications. That is specially the case of the path

“LEAD*CHOICE*CROSS”,

which can also be combined with “LFD” (see “LFD*LEAD*CHOICE*CROSS”), “size” (“LEAD*CHOICE*CROSS*size”) or “hete” (see “LEAD*CHOICE*CROSS*hete”); the path of

“LDF* LEAD”,

which can also be combined with “choice” and “hete” (see “LDF* LEAD*choice*hete”) or with “CHOICE” and “SIZE” (see “LDF*LEAD*CHOICE*SIZE”); and the path of

“lfd*cross”,

which can be combined with a variety of conditions. The discussion in this section revolves around the above three configurations.

7.1 Collective choice, Cross-scale linkages and Leadership

The prevalence of the “LEAD*CHOICE*CROSS” and the “LEAD*CHOICE*CROSS*hete” configurations, which are illustrated by the same disturbance-response cases, constitutes evidence to support hypotheses 3, 4, 5 and 6. A paradigmatic example of both configurations is one of the responses that two WUAs (the “JC” and “SXI”) developed to cope with droughts. As briefly explained in a previous section, the response consisted on the design of quota system to allocate water. In both WUAs, the decision was discussed and chosen through a series of chapter meetings after being proposed by the president of the WUA. The presidents of both WUAs acted as intermediaries between a second order organization (seethe GCRAA in the background section) and the WUA members. Representatives of all the WUAs belonging to the GCRAA (including WUAs from the “JC” and “SXI” systems) had developed by that time a similar rule to allocate water across WUAs, and saw in extending the rule at the system level a necessary step to guarantee the performance of water allocation during droughts.

Another example is the case of how the WUA from the “SA” system coped with a lake flood. As reviewed in a previous section, the lake had progressively flooded part of the irrigation system. When finally the water agency reacted to the WUA’s complains, environmental groups opposed to the agency’s solution and a mediation process started between the public authorities and stakeholders, including the WUA. Even if not particularly quick, the role of the water agency and other public authorities in enabling the negotiation process was crucial to find a solution to the lake flooding. Also, both the representation role played by the executive committee of the WUA and the power of farmers to be consulted and ratify any potential solution that emerged from the mediation process contributed to the stability and legitimacy of the final agreement.

It is important to note that not all the conditions included in the hypotheses seem to be equally consistent in their association to robustness. CROSS (cross-scale linkages) is only present in versions of the configuration "LEAD*CHOICE*CROSS". Moreover, the condition is absent in all the configurations associated to LIDs and STRESS disturbances and in the configuration of "choice*cross*LEAD". A potential explanation of the varying effect of cross-scale linkages may be related to the variety of overlapping forms that such linkages can take. The coding of disturbance-response cases distinguished three main types of cross-scale linkages: collaboration in decision making or bargaining, financial aid, or institutional support. Among the 61 disturbance-response cases, 28 counted on collaborative decision making or bargaining, 21 included financial aid, and 13 were supported by external regulations. As reviewed below different forms of external support might be more or less demanding in terms of collective choice and action at the system level and that could be affecting farmers' strategies to cope with disturbances.

Collective choice is present in configurations across the three disturbance type groups. That said, the condition is also absent in a number of configurations, including "LFD*choice*LEAD", "LFD *LEAD*choice*hete"; and "lfd*cross*choice*SIZE". That does not invalidate the hypothesis of this study but just qualifies it. A plausible interpretation of the two first configurations (the third one will be reviewed further below) can be related to the nature of LFDs and the role of leadership in collective action processes. The frequency of some LFDs would make potential solutions more evident and certain than otherwise. That would make less necessary the deliberative and legitimizing function of collective choice given the appropriate leadership. An example supporting this argument is the abovementioned case of landslides in the "SA" and "CA" irrigation systems. In both systems, the landslides occur relatively frequently. Carrying any major collective decision process every time the landslides occur would be too burdensome over time. Moreover, the problem is relatively simple to solve in the short term. Basically someone has to take the lead and clean or repair the infrastructure as quick as possible. In the "SA" and "CA" systems, that leadership role is fulfilled mostly by the guard. Overall, the above aspects would make collective choice relatively unnecessary, given that there is implicit consensus over the course of action to follow and someone leads its implementation on behalf of the rest of farmers.

The case of the land transformation explained in a previous section is also illustrative. As reviewed, the transformation of irrigated land into residential or industrial land experienced in the “JC” system created uncertainty about the efficacy of the maintenance system as well as the performance of the water allocation system. One of the responses of the WUA consisted on the bargaining with public authorities to guarantee that the WUA would have the right to enforce the collection of maintenance fees from the new residential and industrial users. The president fulfilled a crucial representation role in that regard. The president of the WUA had faced the issue in a previous occasion and knew that it was important to retain the fee collection power to guarantee the economic viability of the association. Bottom-up collective choice in this occasion was not central to the process as the response was mostly the result of the free initiative of the president, who only updated the chapter about the negotiations on an ad hoc basis. In this case, the acquired knowledge of the president was an important factor for his venture to have a good ending. The other response of the WUA consisted on the organization of the irrigation schedule so the new users’ water requests, which are lower in volume but more frequent than the farmers’, would not disrupt the irrigation schedule. That role was (and is) performed on an ad hoc basis by the guard. Basically he uses his expertise to coordinate the irrigation schedule and the residential and industrial users’ demand on an ad hoc basis. This response did not emerge from a collective choice or planning process but resulted from the reactive capacity of the guard and the implicit consent of farmers. In both responses to the land transformation disturbance in the “JC” system, collective choice was more absent than not while leadership was particularly important. The course of action in both responses was relatively clear and the WUA had experienced the disturbance before.

Contrary to collective choice and external support, leadership (LEAD) shows a very consistent pattern. The condition is present in all the configurations representing general responses (group 1) and responses addressing LFDs (group 2). The condition is also present in some of the configurations related to LIDs and STRESS disturbances (group 3). Indeed, as indicated in the robustness checks, leadership was the only condition found to be necessary for responses to contribute to robustness.

It is important to note that the leadership scores were generally high across cases (above 0.5 in around 90% of the cases). Far from being a limitation of the analysis, however, the predominance of high leadership scores constitutes a finding in itself[9]. The ubiquity of leadership across responses can be illustrated with regard to the variety roles performed by leaders vis a vis the development of responses as well as the relatively high level of knowledge of the leaders across the WUAs under study. According to the data, the most common leadership functions are the representation role (41 cases) followed by the monitoring and sanctioning (33) the mobilization (30) and the coordination (14) roles. Also, the average tenure of presidents across

[9] As indicated in the robustness checks section, other measures resulting from more conservative aggregation strategies were also tested. The results were similar to those obtained with the original composite (see table A5 in Appendix).

the five WUAs and over the 20 years frame of the study was 6.4 years, and 24% and 38% of the WUA presidents had university and secondary degrees, respectively.

The functions played by the presidents in the lake flood and quota rule examples are illustrative of the representation and mobilization roles, respectively. Additionally, both the president and the guard in the quota rule case performed an important monitoring and sanctioning role, as they were responsible for controlling that farmers would not use more water than allocated through the quotas. Finally, the tasks fulfilled by the guard in the landslides example are illustrative of the coordination role, as he is responsible for coordinating the workforce and machinery to clean and repair the infrastructure.

The path of "LEAD*CROSS*CHOICE" is probably the most self-explaining among all the configurations that include the presence of leadership. That was illustrated in the quota rules and the lake flood examples. The second most revealing configuration including the presence of leadership is "LFD*LEAD*choice". As commented above, the synergy between the frequency of the disturbance and leadership justified the relative irrelevance of collective choice. A third configuration of interest is "LDF*LEAD*CHOICE*size". While this configuration shares with the "LFD *LEAD*choice" the type of disturbance it also contains the presence of collective choice. That makes it an interesting configuration to further qualify the nature of the fit between LDF and leadership. A good example in that regard is the response developed by the WUA of the "JC" system to cope with the construction of a railway. Similar to the example about the construction of a highway that was explained in a previous section, the chapter of the WUA explicitly authorized the president to deal with the construction company and the department of public works to guarantee that the affected infrastructure was reconstructed properly. Contrary to the negotiations carried by the president of that same WUA to cope with the new residential and urban users, the process in the railway case required continuous consultations with farmers. While in the new users situation the leader was knowledgeable enough to deal with the negotiation process by himself, in the railway situation he depended more on the knowledge and different preferences of the farmers about the best way to accommodate the infrastructure to the crossing of the railway. The fact that the system was relatively small also seem to have facilitated the role of the president in consulting groups of farmers on an ad hoc basis depending on the sections of the infrastructure at stake.

7.2 System size and heterogeneity contexts

As mentioned above, size and heterogeneity interact with the proximate conditions in meaningful ways. The lack of heterogeneity is, with the presence of leadership, the most robust of all conditions. Heterogeneity is absent in configurations across all the disturbance groups. This is consistent with the robustness check results for the first stage of the analysis, which showed that the presence of heterogeneity is related to lack of robustness (see table A5 in the Appendix)[10].

The example of the quota rule in the "JC" system is illustrative of the relevance of system's homogeneity, given the presence of all the proximate conditions (see "LEAD*CROSS*CHOICE*hete"**)**. No major issues were recorded in the meeting minutes of the WUA regarding the approval of the rule or its implementation. The fact that the irrigation system is relatively small and homogeneous seems to have played a positive role in that regard, as a related case in the "SXI" system puts in evidence. The "SXI" system also belongs to the GCRAA, i.e., the second organization that promoted the implementation of the quota rule to cope with droughts. However, the implementation of the quota rule in the "SXI" system was more problematic than in the "JC" system, as the former was more heterogeneous. While big landholders in the "SXI" were eager to use the quota system, small landholders saw in an alternative turn system a more efficient solution to water scarcity. The disagreement was related to the size of the farms, as the quota system is more efficient in larger farms and the turn system is more efficient in smaller farms[11]. After some initial disagreements, the farmers decided to use both systems simultaneously, with a considerable increase in the transaction costs of operating the water allocation system. 9 years after, the two systems were finally consolidated under the quota system. The comparison of the "JC" and the "SXI" examples illustrates the added difficulty of developing responses that satisfy all interests when these are heterogeneous and the solution requires a minimum consensus among stakeholders.

The small systems condition ("size")is also relatively robust across groups (see model 3). Only one out of the four of the configurations that speak to that condition involves the context of a large system (see model 3). Such configuration combines also the lack of both external support and collective choice ("lfd*cross*choice*SIZE"). The logic behind this configuration is difficult to explain through the lenses of the theory of the commons. An alternative explanation would point to the role of scale economies (Agrawal 2000). WUAs in larger systems would be able to pull more resources than in smaller systems and those resources would facilitate both reactive capacity and the development of costly responses. A good example of both this argument and the "lfd*cross*choice*SIZE" configuration is a debt crisis that originated in the "SXI" system after a modernization project in 2005. The rise in the number of unpaid fees by farmers and the uncertainty about the ability to repay the investment loans and carry the maintenance duties,

---

[10] Variation in the heterogeneity condition was considerably higher than in leadership. Heterogeneity was present in 16 cases (26%).

[11] The quota system is based on volumetric water requests. The minimum volume of water that can be requested for one farm is 1,000m^3. This is problematic for small landholders for they do not need as much water at each time.. Alternatively, in the turn system farmers irrigate one after the other and there is no minimum amount of water to be used at each turn. This enables small landholders to better adjust their water use to their needs. That said, the turn system is more time consuming in terms of coordination, which is something big farmers tend to dislike.

were responded by the WUA with a little increase in the fees. The resulting increase in the revenues is used as a reserve to guarantee the payment of the financial obligations of the association. That would not have been possible in a small system without a notable increase in the fees, which would have faced much more resistance from farmers.

That said, the other three configurations that speak to the size condition fit the perspective of the theory of the commons and illustrate the importance of a small system's context. The comparison of an example illustrating one of those configurations ("LEAD*CHOICE*CROSS*size") and a new example of the "lfd*cross*choice*SIZE" configuration is illustrates the point. Both examples are responses elaborated to cope with the decreased workforce to maintain the infrastructure in the "JC" and "CA" systems, and the "FVT" system, respectively.

In an attempt to reduce future maintenance efforts, a number of farmers in the "FVT", "JC" and "CA" systems have progressively paved or piped sections of the infrastructure by their own initiative. In the "FVT" system, the initiative has been far from general and there is still a majority unlined ditches in the system. The size of the system, with kilometers of ditches, made more difficult than in other systems that the executive committee take a mobilization role. The transaction costs of such enterprise made it not particularly appealing given the lack of serious maintenance problems in the short term[12]. As a result the full positive effects of the individual investments were not reached. Not only a number of sections of the infrastructure are still threatened by a progressive reduction in maintenance, but also the sections that have been remodeled cannot enjoy an improved water flow, as such benefit depends on the conditions of the infrastructure located upstream.

Alternatively, farmers in the "CV" and "JC" systems, which are notably smaller than the "FVT" system, counted on the mobilization role of the WUA executive committees. In both systems, the executive committee coordinated the collective choice, the works, the request of governmental aid and the fee collection among farmers at each major ditch. The enterprise was less demanding in the "CV" and "JC" systems than in the "FVT" system. The number of major ditches in the "CV" and "JC" systems is not higher than 10 while the number of major ditches in the "FVT" system is at least twice. As a result, the percentage of major ditches that have been paved in the smaller systems is higher than in the larger system.

7.3 Responses addressing LFD's vs. LID's and/or STRESS disturbances

There are meaningful differences between the configurations associated to LFDs and those associated to LIDs and STRESS disturbances.

[12] As mentioned in a previous section, the issue of rural depopulation and decreased workforce emerged progressively and its impact on the systems has been noticeable only in the long term.

A first difference in terms of the hypotheses of this study is related to the association of LID and STRESS configurations to the *lack* of robustness (see tables 6 to 9 in the Appendix). As pointed in the robustness checks section, almost all configurations contributing to the lack of robustness are associated to LIDs and STRESS disturbances, while only one is associated to LFDs. That finding supports theoretical predictions about the contribution of intensity and frequency to robustness (Janssen and Anderies 2007).

A second difference emerges with regard to the role of cross-scale linkages. The condition is absent in all LID/STRESS configurations across models 2 and 3, and is mostly present in "LFD" configurations. According to the results, the core combination of "lfd*cross" can interact with a diversity of conditions to contribute to robustness. Those interacting conditions include leadership, collective choice, large or small systems and lack of heterogeneity (see models 2 and 3). According to the theory of the commons, all the interacting conditions would be facilitating the development of collective responses that contribute to robustness.

The theory of the commons cannot explain alone why the cross-scale linkages condition is absent in the "lfd" configurations. Considering the theory on disturbances as well as the costs of collective action involved across different forms of external support can help in that regard. First, the most frequent forms of external support across the 61 disturbance-response cases were financial aid and collaborative decision making, both of which are particularly demanding in terms of collective action among farmers (at least as compared to institutional forms of external support). The request of governmental aid was in all disturbance-response cases associated to collective investments and thorough collective choice processes; and collaborative decision making was in most of the cases linked to bargaining and mediation processes that required the consultation with farmers. Second, the added collective action costs of enjoying those forms of external support would have made such support less appealing in the case of LIDs and STRESS disturbances than in the case of LFDs. The progressiveness of STRESS disturbances and the infrequency of LIDs would have made the impact of those disturbances and the need of effective responses less vivid over time. Thus, the benefits of ambitious collective action processes would have been less salient for farmers than in the presence of LFDs (Janssen and Anderies 2007). Thus, we might expect that WUAs are reluctant to rely on some forms of external support if that entails higher transaction costs than otherwise, particularly given the advent of disturbances (i.e., LIDs and STRESS disturbances) whose impact and evolution is not very salient to the ensemble of farmers. By the same token, governments and other external authorities would be less eager to develop large scale measures to cope with LIDs and STRESS disturbances than LFDs.

As a final difference, it is important to note the strong reliance of "LFD" configurations on the presence of leadership, as compared to "lfd" configurations. All 5 "LFD" configurations across models 1, 2 and 3 counted on the presence of leadership. Alternatively, only 2 out of the 6 configurations associated to LIDs and STRESS disturbances (see "lfd" configurations in models 1, 2 and 3) counted on the presence of leadership. This can again be related to the nature of

LFDs, as illustrated in the discussion about the role of leadership earlier in this section. The salience and recurrence of LFDs would facilitate the development of straightforward responses. In that context, leadership would be instrumental for the implementation of such responses. Alternatively, the uncertainty that accompany LIDs and STRESS disturbances would result in less straightforward courses of action and a higher dependency on a wider set of conditions that enhance information sharing and diagnosis capacity.

8. Conclusions

The findings of this study can be grouped by research questions. A first research question of this study was: Which types of disturbances have Spanish irrigation associations (WUAs) recently been confronted with? According to the evidence presented in the chapter, there is moderate diversity in the disturbances that the 5 WUAs under study have faced in the last 20 years. The most common disturbances across the systems were the long term trend of rural depopulation and decreased workforce in rural areas, the punctuated occurrence of droughts, and diverse forms of urbanization. Most of the disturbances threatened the systems' water allocation status quo, and only a few threatened the systems' infrastructure provision situation. This indicates that the irrigation systems face higher risks of collapse due to problems in the water allocation process than to failure to provide or maintain the necessary irrigation infrastructure. This is an interesting insight for governmental policies aiming at promoting the sustainability of the irrigation sector.

The characterization of disturbances with regard to their intensity and frequency proved to be feasible and useful. Disturbances were classified into three types: intense and frequent disturbances (LFDs), intense and infrequent disturbances (LIDs), and progressive disturbances (STRESS). According to the data, STRESS disturbances tended to be addressed by twice as many responses than LFDs and LIDs on average. This finding constitutes a first piece of evidence supporting the mediating effect of disturbance attributes on robustness processes (Carpenter 2001, Anderies et al. 2006, Cox 2010).

A second research question of this study was: Are there identifiable patterns in the way Spanish irrigation associations respond to different disturbances? According to the analysis, responses can be classified into 6 types of strategies: internal mitigation, bargaining with external entities, delegation on external entities, institutional development, infrastructure development, and both institutional and infrastructure development. In terms of collective action costs, the last three strategies are more demanding than the other three, and that seems to affect how the systems respond to disturbances. Although not conclusive, the data points to a tendency from the part of the WUAs under study to combine high- and low-cost strategies rather than investing only in high or low strategies. This finding highlights the importance of recognizing that communities face trade-offs when responding to disturbances due to transaction costs and limited time and resources (Janssen and Anderies 2007). The findings also show the interest of further exploring the implications of using collective action theory to understand robustness to disturbance (Anderies et al. 2004).

A final research question of this study was: How do governance and social factors affect the ability of Spanish irrigation associations to cope with different disturbances? As predicted by the theory of the commons (Poteete et al. 2010), responses that count on the presence of leadership, collective choice and cross-scale linkages and are developed in contexts of small or homogeneous systems can contribute to robustness. That said, some conditions are more sensitive to interaction effects than others. Leadership effects were the most robust among all conditions. The effects of collective choice were more dependent on the presence of leadership and/or the context of small systems.The effects of cross-scale linkages were also sensitive, particularly to the type of disturbance addressed and to the simultaneous presence of leadership and collective choice processes. Finally, the effect of size proved to be more sensitive to specific conditions than the effect of heterogeneity, which was almost as consistent as the effect of leadership.

The results also show that the simultaneous presence of all the factors posited by the theory of the commons is neither necessary for responses to contribute to robustness, nor the only path to robustness. Another important path is that combining the presence of leadership in the advent of LFDs, and given the presence of a few other conditions like small system's size and collective choice, or homogeneity. According to that path, disturbances that are salient and frequent enough would facilitate the emergence of a common understanding among farmers about the most effective and mutually beneficial course of action to follow. In that context, leadership would act as a low-cost means for the implementation and the ultimate effectiveness of such course of action.

Additionally, the data showed distinctive paths to robustness depending on the disturbance at hand. While responses to LFDs tended to cluster around the presence of leadership, LIDs and STRESS disturbances were addressed by a more diverse set of interacting conditions. These results support theoretical predictions about the role of disturbance salience and recurrence and its impact on the effectiveness of responses (Janssen and Anderies 2006), as well as the need to further explore the impact of different disturbance characteristics on robustness.

Finally, the analysis indicates that the causal process that explains robustness is asymmetric, i.e. that the configurations of conditions that enhance robustness to disturbance are not the same as the configurations of conditions that prevent robustness to disturbance. This suggests the relevance of investing further efforts in developing distinctive theories that explain lack of robustness.

Overall, the findings show the relevance of using a disturbance-response framework and a systematic study of interactions not only to understand robustness but also to refine the theory of the commons. As commented by scholars, the theory of the commons suffers from a lack of middle-ground theories that organize the myriad of factors that have been shown to contribute sustainability of local resource systems (Agrawal 2001, Poteete et al. 2010). One of the main findings of this study, i.e., the existence of different paths to robustness depending on disturbance characteristics, sheds light on an interesting venue to start filling that gap.

References

Agrawal, A. 2000. 'Small is beautiful, but is larger better? Forest-management institutions in the Kumaon Himalaya', in C. Gibson, M. McKean and E. Ostrom (ed)^(eds), *People and Forests: Communities, Institutions, and Governance*. Cambridge: MIT Press, pp. 57-86.

Anderies, J.M., M. Janssen and E. Ostrom 2004. ' A framework to analyze the robustness of social-ecological systems from an institutional perspective', *Ecology and Society*, **9**, 18.

Anderies, J.M., P. Ryan and B.H. Walker 2006. 'Loss of Resilience, Crisis, and Institutional Change: Lessons from an Intensive Agricultural System in Southeastern Australia', *Ecosystems*, **9**, 865-878.

Anderies, J.M., B.H. Walker and A.P. Kinzig 2006. 'Fifteen weddings and a funeral: case studies and resilience-based management', *Ecology and Society*, **11**, 21.

Baland, J.-M. and J.-P. Platteau 1999. 'The Ambiguous Impact of Inequality on Local Resource Management', *World Development*, **27**, 773-788.

Basurto, X. and J. Speer 2012. 'Structuring the Calibration of Qualitative Data as Sets for Qualitative Comparative Analysis (QCA)', *Field Methods*, **24**, 155-174.

Bennett, C.J. and M. Howlett 1992. 'The Lessons of Learning: Reconciling Theories of Policy Learning and Policy Change', *Policy Sciences*, **25**, 275-294.

Berkes, F. 2001. 'Cross-Scale Institutional Linkages: Perspectives from the Bottom Up', in E. Ostrom, T. Dietz, N. Dolsak, P.C. Stern, S. Stonich and E.U. Weber (ed)^(eds), *The Drama of the Commons*. Washington DC: National Academy Press.

Berkes, F., J. Colding and C. Folke eds. 2003. *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. New York, NY: Cambridge University Press.

Berkes, F. and C. Folke 1998. *Linking Social and Ecological Systems*. Cambridge: Cambridge University Press.

Blomquist, W., A. Dinar and K. Kemper 2005. 'Comparison of Institutional Arrangements for River Basin Management in Eight Basins'(ed)^(eds), *Policy Research Working Paper Series*. Washington DC: The World Bank.

Bolea Foradada, J.A. 1986. *Los riegos de Aragon*. Huesca, Spain: Grupo Parlamentario Aragones Regionalista de las Cortes de Aragon.

Carlson, J.M. and J. Doyle 2002. 'Complexity and robustness', *Proceedings of the National Academy of Sciences of the United States of America*, **99**, 2538-2545.

Carpenter, S., B. Walker, J.M. Anderies and N. Abel 2001. 'From metaphor to measurement: resilience of what to what?', *Ecosystems*, **4**, 765-781.

Cavero, J. and J. Hernandez 1987. 'Evaluacion y Viabilidad Economica del Riego por Aspersion en un Secano Arido en Aragon'(ed)^(eds), *Serie Economia*. Madrid: Instituto Nacional de Investigaciones Agrarias.

CESA 2009. 'Informe sobre la Situacion Economica y Social de Aragon'(ed)^(eds). Zaragoza: Consejo Economico y Social de Aragon.

CHE 2010. 'Planificacion Hidrologica: Banco de Datos'(ed)^(eds). Zaragoza.

Costeja, M. 2009. 'Adaptabilidad Insitucional: Dinámicas en la evolución de los sistemas socio-ecológicos de uso del agua en España'(ed)^(eds), *Departamento de Ciencia Politica*. Barcelona: Universidad Autonoma de Barcelona.
Cox, M. 2010. 'Exploring the Dynamics of Social-Ecological Systems: The Case of the Taos Valley Acequias'(ed)^(eds), *Workshop in Political Theory and Policy Analysis*. Bloomington: Indiana University.
Cox, M., G. Arnold and S. Villamayor Tomás 2010. 'A review of design principles for community-based natural resource management', *Ecology and Society*, **15**.
Cox, M. and J.M. Ross 2011. 'Robustness and vulnerability of community irrigation systems: The case of the Taos valley acequias', *Journal of Environmental Economics and Management*, **61**, 254-266.
Fleischman, F., K. Boening, G. Garcia-Lopez, S. Mincey, M. Schmitt-Harsh, K. Daedlow, M.C. Lopez, X. Basurto, B. Fischer and e. Ostrom 2010. 'Disturbance, Response, and Persistence in Self-Organized Forested Communities: Analysis of Robustness and Resilience in Five Communities in Southern Indiana', *Ecology and Society*, **14**.
George, A.L. and A. Bennett 2005. *Case Studies and Theory Development*. Cambridge: MIT press.
Glaser, B.G. and A.L. Strauss 1999. *The Discovery of Grounded Theory: Strategies for Qualitative Research* N.J.: New Brunswick AldineTransaction.
Glick, T. 1970. *Irrigation and Society in Medieval Valencia*. Cambridge, Mass.: Harvard University Press.
Gupta, R. and S. Tiwari 2002. 'At the Crossroads: Continuity and Change in the Traditional Irrigation Practices of Ladakh.'(ed)^(eds), *9th Biennial Conference of the IASCP*. Victoria Falls, Zimbabwe.
Hardin, G. 1968. 'The Tragedy of the Commons', *Science*, **162**, 1243-1248.
Janssen, M. and J.M. Anderies 2007. 'Robustness Trade-offs in Social-Ecological Systems', *International Jounal of the Commons*, **1**.
Kiser, L.L. and E. Ostrom 1982. 'The three worlds of action: A metatheoretical synthesis of institutional approaches', in M.D. McGinnis (ed)^(eds), *Polycentric Games and Institutions: Readings from the Workshop in Political Theory and Policy Analysis*. Ann Arbor: University of Michigan Press, pp. 56-89.
Lam, W.F. 1998. *Governing Irrigation Systems in Nepal*. San Francisco: CA: ICS Press.
Lam, W.F. 2006. 'Foundations of a robust social-ecological system: irrigation institutions in Taiwan', *Journal of Institutional Economics*, **2**, 203-226.
Lecina, S., D. Isidoro, E. Playán and R. Aragüés 2010. 'Irrigation modernization and water conservation in Spain: The case of Riegos del Alto Aragón', *Agricultural Water Management*, **97**, 1663-1675.
Lee, K.N. 1999. . 'Appraising adaptive management', *Conservation Ecology*, **3**, 3.
Lopez Galvez, J. and J.M. Naredo eds. 1997. *La Gestion del Agua de Riego*. Madrid: Fundacion Argentaria.
Lubell, M., M. Schneider, J.T. Scholz and M. Mete 2002. 'Watershed partnerships and the emergence of collective action institutions', *American Journal of Political Science*, **46**, 148-163.
McGinnis, M.D. 2011. 'Networks of Adjacent Action Situations in Polycentric Governance', *Policy Studies Journal*, **39**, 51-78.
Meinzen-Dick, R., K.V. Raju and A. Gulati 2002. 'What affects organization and collective action for managing resources? Evidence from canal Irrigation systems in India', *World Development*, **30**, 649-666.
Merino de Diego, A. 2006. *La Gestion Colectiva del Agua de Riego*. Zaragoza: Institucion Fernando el Catolico.
MOPT 1994. *Catalogo General de Comunidades de Regantes*. Madrid: Ministerio de Obras Publicas y Transporte.
Morgan, D.L. 1997. *Focus Groups as Qualitative Research*. London: SAGE.
Olson, M. 1965. *The Logic of Collective Action*. Cambridge: Massachussetts: Harvard University Press.
OMEL 2012. (ed)^(eds).

Osés-Eraso, N., F. Udina and M. Viladrich-Grau 2008. 'Environmental versus Human-Induced Scarcity in the Commons: Do They Trigger the Same Response?', *Environmental and Resource Economics*, **40**, 529-550.

Ostrom, E. 1990. *Governing The Commons*. New York: Cambridge University Press.

Ostrom, E. 2003. 'How Types of Goods and Property Rights Jointly Affect Collective Action', *Journal of Theoretical Politics*, **15**, 239-270.

Ostrom, E. 2005. *Understanding Institutional Diversity*. Princeton, NJ: Princeton University Press.

Ostrom, E. 2007. 'A diagnostic approach for going beyond panaceas', *Proceedings of the National Academy of Sciences*, **104**, 15181-15187.

Ostrom, E. 2010. 'Beyond Markets and States: Polycentric Governance of Complex Economic Systems', *American Economic Review*, **100**, 641-672.

Ostrom, E., R. Gardner and J. Walker 1994. *Rules, Games and Common Pool Resources*. Michigan: Michigan University Press.

Ostrom, V. and E. Ostrom 1977. 'A Theory of Institutional Analysis of Common Pool Problems', in G. Hardin and J.A. Baden (ed)^(eds), *Managing the Commons*. San Francisco: Freeman, pp. 157-172.

Pinilla Navarro, V. and L.A. Saez Perez 2009. *Tendencias recientes en la evolucion de las comarcas aragonesas*. Zaragoza: Publicaciones de Rolde de Estudios Aragoneses.

Poteete, A.R. and E. Ostrom 2004. 'Heterogeneity, group size and collective action: The role of institutions in forest management', *Development and Change*, **35**, 435-461.

Poteete, A.R., E. Ostrom and M. Janssen 2010. *Working Together*. Princeton, NY: Princeton University Press.

Ragin, C. 2000. *Fuzzy-Set Social Science*. Chigaco: The University of Chicago Press.

Ragin, C. 2008. *Redesigning Social Inquiry: Fuzzy Sets and Beyond*. Chicago University of Chicago Press.

Ragin, C.C., K.A. Drass and S. Davey 2006. 'Fuzzy-Set/Qualitative Comparative Analysis 2.0'(ed)^(eds). Tucson, Arizona: Department of Sociology, University of Arizona.

Rihoux, B. and C. Ragin 2009. *Configurational Comparative Methods*. Thousand Oaks, CA: SAGE.

Rutte, C.G., H.A.M. Wilke and D.M. Messick 1987. 'Scarcity or abundance caused by people or the environment as determinants of behavior in the resource dilemma', *Journal of Experimental Social Psychology*, **23**, 208-216.

Salafsky, N., D. Salzer, A.J. Stattersfield, C. Hilton-Taylor, R. Neugarten, S.H.M. Butchart, B. Collen, N. Cox, L.L. Master, S. O'Connor and D. Wilkie 2008. 'A Standard Lexicon for Biodiversity Conservation: Unified Classifications of Threats and Actions', *Conservation Biology*, **22**, 897-911.

Sancho Martí, J. 1984. *El Espacio Perirubano de Zaragoza.* . Zaragoza: Ayuntamiento de Zaragoza.

Schneider, C.Q. and C. Wagemann 2006. 'Reducing complexity in Qualitative Comparative Analysis (QCA): Remote and proximate factors and the consolidation of democracy', *European Journal of Political Research*, **45**, 751-786.

Schneider, C.Q. and C. Wagemann 2010. 'Standards of Good Practice in Qualitative Comparative Analysis (QCA) and Fuzzy-Sets', *Comparative Sociology*, **9**, 397-418.

Schoon, M. 2008. 'Building robustness to disturbance: Governance in southern African peace parks'(ed)^(eds). Bloomington: Indiana University.

Sekhon, J.S. 2004. 'Quality meets quantity: case studies, conditional probability, and counterfactuals', *Perspectives on Politics*, **2**, 281-293.

Speer, J. 2011. 'Participatory Governance, Accountability, andvResponsiveness: A Comparative Study of Local Public Service Provision in Rural Guatemala'(ed)^(eds), *Department of Agriculture and Horticulture*. Berlin, Germany: Humboldt University.

Subramanian, A., N.V. Jagannathan and R. Meinzen−Dick 1997. 'User Organizations for Sustainable Water Services'(ed)^(eds). Washington DC: The World Bank.

Theesfeld, I. 2009. 'The Downgrading Effect of Abuse of Power on Trust and Collective Action in Bulgaria’s Irrigation Sector Institutions and Sustainability', in V. Beckmann and M. Padmanabhan (ed)^(eds): Springer Netherlands, pp. 223-242.

Tucker, C.M., H. Eakin and E.J. Castellanos 2010. 'Perceptions of risk and adaptation: Coffee producers, market shocks, and extreme weather in Central America and Mexico', *Global Environmental Change*, **20**, 23-32.

UN/ISDR 2004. 'Living with Risk: A Global Review of the International Strategy for Disaster Reduction'(ed)^(eds).

Varughese, G. and E. Ostrom 2001. 'The Contested Role of Heterogeneity in Collective Action: Some Evidence from Community Forestry in Nepal', *World Development*, **29**.

Vedeld, T. 2000. 'Village Politics: Heterogeneity, Leadership and Collective Action', *Journal of Development Studies*, **36**, 105.

Zadeh, L.A. 1965. 'Fuzzy Sets', *Information Control*, **8**, 338-353.

Appendix

Table A1: Measurement of outcome and conditions

Outcome and causal conditions	Measures	Justification for the Measure	Aggregation function	Data collection and sources
Robustness	Lack of complaints or concerns at any general assembly meeting about how the organization coped with the disturbance. (*satisf*)	Issues that reach some relevance are usually brought to a general assembly meeting	ROBUST: Maximum of the values for *satisfy* and *mitigate;* average of values from resulting measure and *nospill and time*	Content analysis of the general assembly meetings of the irrigation associations
	Contribution of the response to mitigate the impact of the disturbance (*mitigate*)	Farmers (particularly those holding organizational positions) are expected to have a good sense of the performance of their system vis a vis the disturbance.		Interviews with current and previous members of the executive committee, guards and secretaries, and with old time and more recent famers
	Whether there were unattended and unaddressed negative effects of the response or the disturbance (*nospill*)	The existence of negative unexpected effects reduces the net benefits of the response to the disturbance	ROBUST2: Average of the values for *satisfy*, and *mitigate*; average between resulting measure, *nospill* and *time*	Interviews with current and previous members of the executive committee, guards and secretaries, and with old time and more recent famers Content analysis of the general assembly meetings of the irrigation associations
	Timeliness of the response (*time*)	The earlier a disturbance is tackled, the more chances the response has to be effective in mitigating the impact		
Disturbance: Frequency and intensity	Frequency: Number of times that the disturbance hit the community in the last 20 years (*freq*)	The frequency of an event provides opportunities for feedback and learningfrom previous responses and (Anderies et al. 2006) 20 years is the maximum time frame for which information was available or recoverable via interviews	LFD: If freq and intens =1, then LFD=1, else lfd=0 STRESS: If freq = 0 and intens=0, then STRESS=1, else STRESS=0. LID: if freq=0, intens=1, then LID=1, else LID=0	Governmental data (*Confederacion Hidrografica del Ebro*), secondary sources (*Comunidad General de Riegos del Alto Aragon*). Content analysis of the general assembly and executive committee meetings of the irrigation communities (1980-2009). Focus groups, and interviews with members of the executive committee, staff and old timers of the associations.
	Intensity of the disturbance: magnitude of the disturbance within the time frame of one irrigation campaign (*intens*)	Intensity is magnitude over time. Magnitude alone would not capture the difference between large changes that occur over a short period vs. a long period of time. Planning decisions in the WUAs are usually		

		made from one irrigation campaign (i.e., year) to another.		
Response: Cross Scale Linkages	State embeddedness: Embeddedness of the WUA's response and regional and/or national regulations created to cope with the disturbance. (*embedstate*)	Embeddedness captures the synergy between the WUA's responses on the one hand, and external institutions that shape interactions between farmers on the other (Lam 2006). Complementarity captures the existence of mutually beneficial division of labor between the WUA's responses on hand, and external institutions that shape interactions between WUAs on the other (Lam 2006). External institutions can have their origin at higher levels of governance (i.e., regional and national governments) or at similar levels of governance (i.e., the GCRAA or local governments).	CROSS: Average of values for embedstate, embedloc, compstate and comploc (institutional nesting); average between maximum of values for medstate and decstate, and maximum of values for medloc and decloc (co-management); average of values for restate and resloc (external resources; maximum between value for institutional nesting, co-management, and external resources	Governmental data (*Confederacion Hidrografica del Ebro*), secondary sources (*Comunidad General de Riegos del Alto Aragon*). Content analysis of the general assembly and executive committee meetings of the irrigation associations (1980-2009). Focus groups and interviews with members of the executive committee, staff and old timers of the associations.
	Local embeddedness: Embeddedness of the WUA's response into municipal regulations and/or regulations of the GCRAA created to cope with the disturbance. (*embedloc*)			
	State complementarity: Complementarity between the WUA's response and regional and/or national regulations created to cope with the disturbance. (*compstate*)			
	Local complementarity: Complementarity of the WUA's response and regulations of the GCRAA and/or municipal regulations created to cope with the disturbance. (*compleloc*)			
	State mediation: Mediation role played by the water agency or the regional government as part of the WUA's response to the disturbance (*medstate*)	Two important functions of cross-scale linkages are the resolution of disagreements and the coordination of actions between actors at different or similar governance levels (Ostrom 1990, Lam 2006). That mediation role can be fulfilled both by local and regional/national actors.	CROSS2: Average of values for *embedstate*, *embedloc*, *compstate* and *comploc* (institutional nesting); average between maximum of values for *medstate* and *decstate*, and maximum of values	
	Local mediation: Mediation role played by the GCRAA or the local government as part of the WUA's response to the disturbance (*medloc*)			
	State co-decision: Co-decision	Co-management is a paradigmatic example		

	making between national or regional external actors and the WUA as part of the WUA's response to the disturbance (*decstate*)	of cross-scale linkages (Carlsson and Berkes 2005). Shared decision making between the WUA and local or regional/national actors in the context of coping with a disturbance would be an instance of co-management.	for *medloc* and *decloc* (co-management); average of values for *restate* and *resloc* (external resources); average of values for institutional nesting, co-management, and external resources	
	Local co-decision: Co-decision making between local external actors and the WUA as part of the WUA's response to the disturbance (*decloc*)			
	State resources: Financial support provided by the national or regional government as part of the WUA's response to the disturbance (*resstate*)	The availability of financial resources is a factor that contributes to the operational performance of WUAs (Agrawal. 2001, Merino de Diego 2006). These resources can be provided externally by the local or regional/national entities.		
	Local resources: Financial support provided by the GCRAA or the local government as part of the WUA's response to the disturbance (*resloc*)			
Response: Bottom-up collective choice	Unanimity: Existence of consensus at the general assembly level about the course of action followed in response to the disturbance (*collunam*)	The general assembly meetings are the main decision making arena in the WUAs under study. The existence of unanimity about a response gives legitimacy to the corresponding course of action	CHOICE: Interaction of values for *colldelib* and *attend*; average of resulting measure and *collbottom* and *collunam* CHOICE2: Average of values for *collunam*, *collbottom* and *colldelib*; interaction of resulting measure and *attend*.	Governmental data (*Confederacion Hidrografica del Ebro*), secondary sources (*Comunidad General de Riegos del Alto Aragon*). Content analysis of the general assembly and executive committee meetings of the irrigation associations (1980-2009). Focus groups, and interviews with members of the executive committee, staff and old timers of the associations.
	Bottom-up: Lowest collective choice level at which the WUA's response to the disturbance was elaborated (*collbottom*)	Disaggregated collective choice processes (i.e. at the municipality or secondary canal level), enable tailoring responses to the heterogeneity of interests within a WUA, which can increase the legitimacy and effectiveness of the responses (Ostrom 1990)		
	Deliberation: Discussion of the disturbance and/or the response in general assembly meetings (*colldelib*)	Whether the disturbance or the response is brought to one or more general assembly meetings before a decision is made proxies for the degree that the response was built on the collective knowledge of farmers		
	Attendance: Average percentage attendance of	The general assembly meetings are the main decision making arena in the WUAs under		

	farmers to the WUA's general assembles in the last 20 years (*attend*)	study. Level of attendance to those meetings reflects the importance that the WUA gives to farmers' participation in collective decisions, which moderates the positive effects that collective choice can have on the quality and legitimacy of responses.		
Response: Leadership	Monitoring and sanctioning role of the president or a person under his authority in the elaboration/implementation of the response (*leadm&s*)	Monitoring & sanctioning plays a key role in common property regimes (Cox et al. 2010). The ability of leaders to monitor and sanction the behavior of WUA members may contribute to the proper implementation of collective responses	LEAD: Maximum of values for *leadm&s*, *leadrepr*, *leadcoor* and *leadmob* (leadership role); maximum of *presexp* and *presiedu* (leadership ability); interaction of leadership role and leadership ability LEAD2: Maximum of values for *leadm&s*, *leadrepr*, *leadcoor* and *leadmob* (leadership role); average of *presexp* and *presiedu* (leadership ability); interaction of leadership role and leadership ability	Governmental data (*Confederacion Hidrografica del Ebro*), secondary sources (*Comunidad General de Riegos del Alto Aragon*). Content analysis of the general assembly and executive committee meetings of the irrigation associations (1980-2009). Focus groups,and interviews with members of the executive committee, staff and old timers of the associations.
	Representation role of the president or a person under his authority in the implementation of the response (*leadrepr*)	The WUAs under study have a hierarchical structure that makes the president the main representative of the associations The representation role reflects the ability of a leader to put a voice to the interests of the WUA vis a vis external actors who may be the source of disturbances or have the authority or interests to resolve them.		
	Coordination and/or mobilization role of the president or a person under his authority in the elaboration/implementation of the response. (*leadcoor*)	Coordination is a key component of collective action (Ostrom et al. 1994) The coordination role reflects the ability of a leader to shape emerging individual reactions to disturbances into collective responses.		
	Mobilization role of the president or a person under his authority in the elaboration of the response (*leadmob*)	The mobilization role reflects the ability of a leader to speed up collective decision processes by proposing and promoting courses of action, which can facilitate the ultimate emergence of collective responses (Ostrom 1990)		
	Expertise: Average tenure in number of years of the presidents of a WUAsince 1980 (*presexp*)	The tenure of the person fulfilling the president position reflects to some extent his experience, which can help him to navigate the WUA through difficulties in responding to a disturbance or through the elaboration of an appropriate response.		
	Education: Average education	The education of the person fulfilling the		

	level of presidents in the WUA since 1980 (*presedu*)	president position reflects to some extent his potential ability to navigate the WUA through difficulties of responding to a disturbance or through the elaboration of an appropriate response.		
System: Size	Average area of the irrigation systems in hectares since 2000 (*size*)	Spatial size is a relevant dimensions of size vis a vis the transaction costs of collective enterprises. The number of irrigable hectares per system has not dramatically changed from 2000 to 2010. It is thus expected that those figures did not change much in previous decades. Reports from interviewees also point in that direction.	---	Databases and spatial data from *Confederacion Hidrografica del Ebro, Regional Government of Aragon* and *Comunidad General de Riegos del Alto Aragon*
System: Heterogeneity	Endowment heterogeneity: Gini-Simpson index (Gibbs and Martin 1962) of number of hectares that belong to small (<30 has.) vs. large farms. (2000-2010). (*hete*)	The Gini-Simpson index reflects the chances that two random farms are small (<30 has.) and large (>30 has.) respectively. The time frame was chosen according to data availability	---	Databases and spatial data from *Confederacion Hidrografica del Ebro, Regional Government of Aragon* and *Comunidad General de Riegos del Alto Aragon*

Note: Aggregation rules: *Interaction* is used when one of the variables moderates the impact of the other within a process (i.e. like deliberation and attendance to meetings; or like leadership roles and leadership expertise and education). *Average* is used when: (1) the measures are assumed to be complementary, i.e., the higher the values of all of them, the higher the effect of the construct (see leader's expertise and education in the construct of leadership, or see embeddedness and complementarity of state/local institutions). The *maximum* criterion is used when: (1) variables are assumed to be mutually exclusive (see the mediation vs. co-decision role of the state or of local entities); or (2) variables are assumed to be not complementary, i.e., the higher values of one of them the higher the construct, regardless of the values of the other measures.
Note 2: the default aggregations are designed according to theory and knowledge of the cases; the alternative aggregations relax some of the assumptions so measures are more conservative.

Table A2. Calibration of fuzzy set values for outcome, qualitative and quantitative measures

Measures	Sub-measures	Definitions of fuzzy set values
Outcome		
Robustness	*mitigate*	1: The response contributed notably to reduce the impact of the disturbance on the functioning of the system 0.5:The response contributed marginally to reduce the impact of the disturbance on the functioning of the system 0: The response did not contribute to reduce the impact of the disturbance on the functioning of the system
	satisf	1: There were no complaints/concerns pointing to the effectiveness of the response in any general assembly meeting since the response was implemented. 0.5: There were complaints/concerns pointing to the response in at least 1 general assembly meeting since the response was implemented but those complaints were solved; or there were complaints/concerns pointing to the response in 1 general assembly meeting since the response was implemented and the complaints are to be addressed. 0: There were complains/concerns pointing to the effectiveness of the response in at least 1 general assembly meeting since the response was implemented and most of those complaints have not been addressed.
	nospill	1: There were no unattended consequences/spill-overs of the disturbance or the response that affected the system negatively. 0.5: There were at least one unattended consequence/ spill-overs of the disturbance or the response that affected the system negatively but it was addressed. 0: There were at least one unattended consequence spill-overs of the disturbance or the response that affected the system negatively and was not addressed.
	time	1: There was no relevant time gap between the recognition of the disturbance and the implementation of the response; or the response preexisted to the disturbance (i.e. it had been developed preventively in the absence of the disturbance). 0: There was a relevant time gap between the recognition of the disturbance and the implementation of the response. “Relevant time gap” = One irrigation campaign for disturbances that developed within a year’s time frame; or more than 5 years for disturbances that developed over a 10 year time frame or more.
Qualitative Measures		
Disturbance: Intensity	*intens*	1: The disturbance manifested as the deviation of a variable out of its normal range of variation within the time frame of an irrigation campaign 0: The disturbance did not manifest as the deviation of a variable out of its normal range of variation within the time frame of an irrigation campaign
Response: Cross-scale linkages	State embeddedness (*embedstate*)	1: The WUA used national/regional institutions that had been designed to cope with the disturbance and affected interactions among farmers 0: The community did not use national/regional institutions that had been designed to cope with the disturbance and affected interactions among farmers
	State complementarity	1: The WUA used national/regional institutions that had been designed to cope with the disturbance and affected interactions among WUAs 0: The WUA did not use national/regional institutions that had been designed to cope with the disturbance and affected interactions among WUAs

	(*complestate*)	
	Local embeddedness (*embedloc*)	1: The WUA enjoyed institutions from a second order organization and/or municipal institutions that had been designed to cope with the disturbance and affected interactions among farmers 0: The WUA did not enjoy institutions from a second order organization or municipal institutions that had been designed to cope with the disturbance and affected interactions among farmers
	Local complementarity (*compleloc*)	1: The WUA enjoyed institutions from a second order organization and/or municipal institutions that had been designed to cope with the disturbance and affected interactions among WUAs 0: The WUA did not enjoy institutions from a second order organization or municipal institutions that had been designed to cope with the disturbance and affected interactions among WUAs
	State mediation (*medstate*)	1: National or regional public authorities paid attention to complaints or mediation petitions of the WUA, *and* (1) set the communication space to solve disagreements between WUA members or the WUA and other organizations, or (2) accompanied/represented the WUA at supra-WUA levels of decision making 0.5: National or regional public authorities paid attention to complaints or mediation petitions of the WUA *but did not* pursue any further action to solve the situation. 0: National or regional public authorities did not pay attention to complaints or mediation petitions of the WUA, or no complaints or petitions were made.
	State resources: (*resstate*)	1: National or regional organizations/companies covered *more than half* of the financial costs of *long-term* investments made by the WUA in response to the disturbance, *or* made the investments directly. 0.66: National or regional organizations/companies covered *less than half* of the financial costs of *long term* investments made by the WUA to cope with the disturbance. 0.33: National or regional organizations/companies covered less *than half or more than half of the financial costs of short term investments* made by the WUA to cope with the disturbance, or made the investments directly. 0: National or regional organizations did not cover the financial costs of short or long term investments made by the WUA to cope with the disturbance, nor made any investments directly. "Long term investments": investments in infrastructure that remain over time; "short term investment": investments mostly to solve ad-hoc issues, like the cleaning of the infrastructure.
	State co-decision (*decstate*)	1: The WUA was *consulted and its input was taken into account* in decisions made by national or regional organizations/companies to cope with the disturbance, *or* the WUA and national or regional organizations coordinated their actions to cope with the disturbance 0.5: The WUA *was consulted but its input was not taken into account* in decisions made by national or regional organizations/companies to cope with the disturbance 0: The WUA was not consulted in decisions made by national or regional organizations to cope with the disturbance, or no decisions by national or regional organizations were made.
	Local mediation (*mediatloc*)	1: Municipal public authorities or a second order organization paid attention to complaints, or mediation petitions of the WUA, *and* (1) set the communication space to solve disagreements between WUA members or the WUA and other organizations, or (2) accompanied/represented the WUA at supra-WUA levels of decision making 0.5: Municipal public authorities or a second order organization paid attention to complaints or mediation petitions of the WUA *but did not* pursue any further action to solve the situation.

		0: Municipal public authorities or a second order organization did not pay attention to complaints or mediation petitions of the WUA, or no complaints or petitions were made.
	Local resources (*resourcloc*)	1: Municipal public authorities or other local-level organizations covered *more than half* of the costs of *long-term* investments made by the WUA in response to the disturbance, *or* made the investments directly. 0.66: Municipal public authorities or other local-level organizations covered *less than half* of the costs of *long term* investments made by the WUA to cope with the disturbance. 0.33: Municipal public authorities or other local-level organizations covered less *than half or more than half of short term investments* made by the WUA to cope with the disturbance, or made the investments directly. 0: Municipal public authorities or other local-level organizations did not cover short or long term investments made by the WUA to cope with the disturbance, nor made any investments directly.
	Local co-decision (*decloc*)	1: The WUA's *requests or input were taken into account* in decisions made by Municipal public authorities or other local-level organizations to cope with the disturbance, or the WUA and national or regional organizations coordinated their actions to cope with the disturbance 0.5: The WUA *was consulted but its input was not taken into account* in decisions made by municipal public authorities or other local-level organizations to cope with the disturbance 0: The WUA was not consulted in decisions made by municipal public authorities or other local-level organizations to cope with the disturbance, or no decisions by municipal public authorities or other local-level organizations were made.
Response: Bottom-up collective choice	Unianimity (*collunam*)	1: A voting procedure *was not* used in a general assembly meeting of the WUA but there were no formal objections to the decision (e.g. via complaint letters or interpellations addressed in general assembly meetings or to external organizations); *or* formal voting was used and there was *unanimity* 0.5: A voting procedure *was* used in a general assembly meeting of the WUAand there was *not unanimity*, but the result was *not formally questioned* before its implementation 0: A voting procedure was used, there was not unanimity and the decision was formally questioned before its implementation
	Bottom-up (*collbottom*)	1: Farmers at *lower organization levels than the general assembly meeting of the WUA* (e.g., at the secondary canal level or municipality level) made their decisions about how to cope with the disturbance. 0.66: The response was decided in a general assembly meeting of the WUA 0.33: The response was decided in an executive committee meeting and ratified in a general assembly meeting of the WUA after or during its implementation. 0: The response was decided outside the community collective choice arenas (general assembly and executive committee)
	Deliberation (*colldelib*)	1: The response was discussed in *more than one* general assembly meeting of the WUA or meetings at lower organizational levels before the decision was made. 0.5: The response was discussed and a decision was made in the same general assembly meeting of the WUA or meetings at lower organizational levels. 0: The response was not discussed in *any* general assembly meeting of the WUA or meetings at lower organizational levels before the decision was made.
Response: Leadership	Monitoring role (*leadm&s*)	1: Members of the executive committee and/or the secretary and/or the guard fulfilled a monitoring & sanctioning function in the implementation of the response to the disturbance 0: Members of the executive committee and/or the secretary and/or the guard did not fulfill any coordination or monitoring

		in the implementation of the response to the disturbance
	Coordination role (*leadcoor*)	1: A member of the executive committee or the guard organized meetings among farmers at lower levels of organization and/or coordinated their appropriation or provision actions as part of the elaboration or implementation of the response 0: No member of the executive committee or the guard organized meetings among farmers at lower levels of organization or coordinated their appropriation or provision actions as part of the elaboration or implementation of the response
	Representation role (*leadrepr*)	1: Members of the executive committee and/or the secretary personally represented the WUA in bargaining processes, conflict-solving or administrative processes as part of the elaboration or implementation of the response 0: Members of the executive committee and/or the secretary personally did not represent the WUA in bargaining processes, conflict-solving or administrative processes as part of the elaboration or implementation of the response
	Mobilization role (*leadmob*)	1: Members of the executive committee brought information about the disturbance and *promoted* the response in one or more general assembly meetings of the WUA by bringing extra information and organizing new meetings at the general assembly and lower organizational levels until it was approved by the chapter 0.5: Members of the executive committee brought information about the disturbance and *proposed* the response in one or more general assembly meetings of the WUA, *or* just the later. 0: Members of the executive committee brought information about the disturbance in one or more general assembly meetings of the WUA but did not proposed or promoted a response.
	Education (*presedu*)	1: The president had a university degree 0.5: The president had a secondary degree 0:The president had a primary degree

Quantitative measures

Measures	**Sub-measures**	**Anchor points for Direct calibration of Fuzzy-Sets**
Disturbance: frequency	*freq*	1: The disturbance had occurred at more than once more within the 20 year time frame 0: The disturbance occurred only once within the 20 year time frame
System: Size	Hectares (*size*)	1: More than average extension in the area of study (1,600 hectares) 0: Less than average extension in the area of study
System: Heterogeneity	Endowment heterogeneity (*hete*)	1: The chances that two random hectares belong to different categories of farm size (more vs. less than 30 hectares) are higher than 32% (average in the area of study) 0.5: The chances that two random hectares belong to different categories of farm size (more vs. less than 30 hectares) are equal to 32% 0: The chances that two random hectares belong to different categories of farm size (more vs. less than 30 hectares) are lower than 32%
Response: Leadership	Tenure (*presexp*)	1: The average tenure of the WUA presidents for the period under study was more than two election terms (more than 8 years) 0.5: The average tenure of the WUA presidents for the period under study was one election term (4 years) 0: The average tenure of the WUA presidents for the period under study was less than one election term (less than 4 years)
Response: Collective choice	Attendance (*atten*)	1:More than 60% of the land is represented in the chapter meetings on average 0.5:Between 30% and 60% of the land is represented in the chapter meetings on average 0: Less than 30% of the land is represented in the chapter meetings on average

Table A3. Fuzzy set values of conditions and outcome

Id	System	Disturbance	Response type	Size	Heterogeneity	LFD	Choice	Cross	Leadership	Robustness
1	SXI	Drought	Investment & rule	0.65	0.67	1	0.55	0.5	0.9	0.17
2	SXI	Drought	Investment & rule	0.65	0.67	1	0.82	0.5	0.9	0.65
3	SXI	Drought	Rule development/use	0.65	0.67	1	0.64	1	0.9	1
4	SXI	Crop intensification	Investment & rule	0.65	0.67	0	0.67	0.5	0.9	1
5	SXI	Crop intensification	Rule development/use	0.65	0.67	0	0.82	0.5	0.9	0.91
6	SXI	Crop intensification	Investment & rule	0.65	0.67	0	0.82	0.5	0.9	0.38
7	SXI	Crop intensification	Delegation on external entity	0.65	0.67	0	0.33	0.5	0.9	0.83
8	SXI	Crop intensification	Delegation on external entity	0.65	0.67	0	0.33	0.5	0.9	0.23
9	SXI	Crop intensification	Delegation on external entity	0.65	0.67	0	0.33	0.5	0.9	0.74
10	SXI	Crop intensification	Delegation on external entity	0.65	0.67	0	0.33	0.5	0.9	0.83
11	SXI	Crop intensification	Rule development/use	0.65	0.67	0	0.64	0.25	0.9	1
12	SXI	Lack of labor factor	Investment & rule	0.65	0.67	0	0.55	0.33	0.9	0.49
13	SXI	Energy prices	Rule development/use	0.65	0.67	0	0.55	0	0.5	0.73
14	SXI	Energy prices	Bargaining with external entities	0.65	0.67	0	0.33	0.5	0.9	0.63
15	SXI	Debtors	Rule development/use	0.65	0.67	0	0.7	0.5	0.9	0.56
16	SXI	Debtors	Ad-hoc mitigation strategy	0.65	0.67	0	0.44	0	0.5	1
17	JC	Drought	Rule development/use	0.29	0.34	1	0.71	1	0.9	1
18	JC	Drought	Investment & rule	0.29	0.34	1	0.84	0.75	0.9	0.67
19	JC	Crop intensification	Rule development/use	0.29	0.34	0	0.81	0	0.9	0.91
20	JC	Crop intensification	Delegation on external entity	0.29	0.34	0	0.33	0.5	0.9	0.74
21	JC	Crop intensification	Delegation on external entity	0.29	0.34	0	0.33	0.5	0.9	0.47
22	JC	Crop intensification	Investment & rule	0.29	0.34	0	0.84	0.75	0.9	0.82
23	JC	Railway construction	Bargaining with external entities	0.29	0.34	1	0.96	0.5	0.9	0.74
24	JC	New users	Bargaining with external entities	0.29	0.34	1	0.44	1	0.9	0.74
25	JC	New users	Rule development/use	0.29	0.34	1	0.44	0.5	0.9	1
26	JC	Lack of labor factor	Ad-hoc mitigation strategy	0.29	0.34	0	0.44	0	0.9	0.73
27	JC	Lack of labor factor	Investment & rule	0.29	0.34	0	0.96	1	0.9	1
28	JC	Canal breakages	Ad-hoc mitigation strategy	0.29	0.34	1	0.33	1	0.9	0.83

29	JC	Canal breakages	Delegation on external entity	0.29	0.34	1	0.33	0.5	0.9	0.83
30	CV	Drought	Rule development/use	0.23	0.14	1	0.59	0.5	0.82	1
31	CV	Lack of labor factor	Ad-hoc mitigation strategy	0.23	0.14	0	0.44	0	0.82	0.73
32	CV	Lack of labor factor	Investment & rule	0.23	0.14	0	0.73	0.5	0.82	0.83
33	CV	Highway construction	Bargaining with external entities	0.23	0.14	0	0.73	0.5	0.82	0.83
34	CV	Urbanization	Bargaining with external entities	0.23	0.14	0	0.62	0.5	0.82	0.58
35	CV	Urbanization	Ad-hoc mitigation strategy	0.23	0.14	0	0.44	0.5	0.82	1
36	CV	Landslides	Ad-hoc mitigation strategy	0.23	0.14	1	0.44	0	0.82	1
37	CV	Landslides	Delegation on external entity	0.23	0.14	1	0.44	0	0.82	0.33
38	CV	Infrastructure erosion	Investment	0.23	0.14	0	0.73	0.5	0.82	0.83
39	CV	River flood	Investment	0.23	0.14	0	0.7	0.5	0.82	1
40	CV	Highway construction	Delegation on external entity	0.23	0.14	0	0.44	0.5	0.82	0.56
41	SA	Drought	Delegation on external entity	0.23	0.2	1	0.44	0.45	1	0.49
42	SA	Lack of labor factor	Rule development/use	0.23	0.2	0	0.44	0	0.55	0.63
43	SA	Lack of labor factor	Ad-hoc mitigation strategy	0.23	0.2	0	0.11	0	1	0.17
44	SA	New users	Delegation on external entity	0.23	0.2	0	0.33	0.5	1	0.67
45	SA	New users	Delegation on external entity	0.23	0.2	0	0.33	0.5	1	0.83
46	SA	Faulty infrastructure design	Investment	0.23	0.2	0	0.79	0.5	1	0.47
47	SA	Faulty infrastructure design	Ad-hoc mitigation strategy	0.23	0.2	0	0.8	0	0	0.82
48	SA	Lake flood	Bargaining with external entities	0.23	0.2	0	0.68	1	1	0.67
49	SA	Lake flood	Investment	0.23	0.2	0	0.79	0.33	1	0.08
50	SA	Landslides	Ad-hoc mitigation strategy	0.23	0.2	1	0.44	0	1	1
51	SA	Landslides	Delegation on external entity	0.23	0.2	1	0.44	0.45	1	0.33
52	FVT	Lack of labor factor	Ad-hoc mitigation strategy	0.57	0.06	0	0.44	0	0	0.63
53	FVT	Lack of labor factor	Ad-hoc mitigation strategy	0.57	0.06	0	0.11	0	0.51	0.33
54	FVT	Lack of labor factor	Investment & rule	0.57	0.06	0	0.39	0.5	0.51	0.23
55	FVT	Internal conflict	Delegation on external entity	0.57	0.06	0	0.33	0.5	0	1
56	FVT	Internal conflict	Ad-hoc mitigation strategy	0.57	0.06	0	0.11	0.5	0.51	1
57	FVT	River flood	Ad-hoc mitigation strategy	0.57	0.06	1	0.44	0.33	0.51	1
58	FVT	River flood	Delegation on external entity	0.57	0.06	1	0.44	0.5	0.51	1

59	FVT	River flood	Delegation on external entity	0.57	0.06	1	0.33	0.5	0	0.91
60	FVT	Algae proliferation	Ad-hoc mitigation strategy	0.57	0.06	1	0.44	0	0.51	0.91
61	FVT	Highway construction	Bargaining with external entities	0.57	0.06	1	0.84	0.5	0.51	1

Table A4. Summary statistics of membership scores by conditions

	Mean	St. Dev.	Min.	Max.
Outcome				
Robustness	0.73	0.26	0.8	1
Robustness2	0.65	0.30	0	1
Disturbance conditions				
Intense & Frequent (LFD)	0.67	0.48	0	1
Response conditions				
Collective Choice	0.53	0.21	0.11	0.96
Collective Choice 2	0.32	0.21	0.06	0.87
Leadership	0.78	0.26	0	1
Leadership2	0.57	0.18	0	0.71
Cross-scale linkages	0.43	0.29	0	1
Cross-scale linkages2	0.25	0.19	0	0.67
System conditions				
Heterogeneity	0.13	0.13	0.03	0.34
Size	0.55	0.14	0.39	0.73

Note: The disturbance attributes are measured on a binary scale (0, 1). Thus, the mean scores also represent the proportion of disturbances that contain the attribute. That is not the case for the other attributes.

Note: Alternative measures result from more conservative aggregation strategies.

Table A5. Base Results and Robustness Checks for the Analysis of Sufficiency

Type of Specification	Solutions for the Presence of the Outcome (consistency cutoff = 0.7)
robust = *f* (*hete*, *size*)	Hete + SIZE
Strictrer aggregation function for the measures of robustness (outcome: *robust2*)	Hete + SIZE
robust = *f* (*lfd*, *choice*, *cross*, *lead*)	LEAD*CHOICE*CROSS + LDF*LEAD*choice + lfd*cross
Strictrer aggregation function for the measures of robustness (outcome: *robust2*)	LEAD*CHOICE*CROSS + LDF*LEAD*choice + lfd*cross
Second strictrer aggregation function for the measures of robustness (outcome: *robust3*)	LEAD*CHOICE*CROSS + LDF*LEAD*choice + lfd*cross
Strictrer aggregation function for the measures of leadership (*lead2*)	LEAD*CHOICE*CROSS + LDF*LEAD*choice + lfd*cross
Strictrer aggregation function for the measures of collective choice (*choice2*)	LEAD*CHOICE*CROSS + LDF*LEAD*choice + lfd*cross
Strictrer aggregation function for the measures of cross-scale linkages (*cross2*)	LEAD*CHOICE + cross*choice + LFD*LEAD + lfd*cross
robust = *f* (*lfd*, *lead*, *choice*, *cross*, *hete*)	LEAD*CHOICE*CROSS*hete + LFD*LEAD*choice*hete + LFD*LEAD*CHOICE*CROSS + lfd*cross*hete + lfd*cross*CHOICE*LEAD
Strictrer aggregation function for the measures of robustness (outcome: *robust2*)	LEAD*CHOICE*CROSS*hete + LFD*LEAD*choice*hete + LFD*LEAD*CHOICE*CROSS + lfd*cross*hete + lfd*cross*CHOICE*LEAD
Strictrer aggregation function for the measures of collective choice (*choice2*)	LEAD*CHOICE*CROSS*hete + LEAD*cross*choice*hete + LFD*LEAD*choice*hete + LFD*LEAD*CHOICE*CROSS + lfd*cross*lead + lfd*cross*CHOICE
Strictrer aggregation function for the measures of cross-scale linkages (*cross2*)	LEAD*CHOICE*hete + choice*cross*hete + LFD*LEAD*CHOICE + LFD*LEAD*hete + lfd*cross*hete + lfd*choice*hete
Strictrer aggregation function for the measures of leadership (*lead2*)	LEAD*CHOICE*CROSS*hete + LEAD*cross*choice*hete + LFD*LEAD*choice*hete + LFD*LEAD*CHOICE*CROSS + lfd*cross*lead + lfd*cross*CHOICE
robust = *f* (*lfd*, *lead*, *choice*, *cross*, *size*)	LEAD*CHOICE*CROSS*size + LEAD*choice*cross + LDF*LEAD*CHOICE*CROSS + LDF*LEAD*CHOICE*size + lfd*cross*LEAD + lfd*cross*CHOICE*size + lfd*cross*choice*SIZE
Strictrer aggregation function for the	LEAD*CHOICE*CROSS*size + LEAD*choice*cross + LDF*LEAD*CHOICE*CROSS +

measures of robustness (outcome: *robust2*)	LDF*LEAD*CHOICE*size + lfd*cross*LEAD + lfd*cross*CHOICE*size + lfd*cross*choice*SIZE
Strictrer aggregation function for the measures of collective choice (*choice2*)	LEAD*CHOICE*CROSS*size + LDF*LEAD*choice + lfd*cross*LEAD*size + lfd*cross*CHOICE*size + lfd*cross*choice*SIZE
Strictrer aggregation function for the measures of cross-scale linkages (*cross2*)	LEAD*CHOICE*size + choice*cross*size + LFD*LEAD*size + LFD*LEAD*CHOICE* + lfd*cross*choice*SIZE
Strictrer aggregation function for the measures of leadership (*lead2*)	LEAD*CHOICE*CROSS*size + LEAD*choice*cross + LDF*LEAD*CHOICE*CROSS + LDF*LEAD*CHOICE*size + lfd*cross

Note: only displayed combinations that are different from the base specification in one condition.

Table A6. First step of QCA: Remote conditions associated to *absence* of robustness[13]

Model: **robust** = *f* (*size*, *hete*)			
Parsimonious Solution[14]	Raw Coverage	Unique Coverage	Consistency
SIZE	0.73	0.73	0.5
Solution coverage: 0.73 Solution consistency: 0.5			

Table A6 shows that the size condition also contributes to lack of robustness, i.e. that responses elaborated in the context of large irrigation systems can also fail to contribute to robustness. This result does not invalidate the findings from table 8.a but indicates the need to further specify the conditions under which size contributes to robustness. It may be possible that size translates in increased transaction costs and/or the possibility to develop economies of scale depending on other intervening factors.

Table A7. Second step of QCA: Configurations of proximate conditions associated to *absence* of robustness

Model: robust = *f* (*lfd*, *choice*, *cross*, *lead*)			
Complex Solution	Raw Coverage	Unique Coverage	Consistency
lfd*cross	0.65	0.14	0.44
lfd*choice*LEAD	0.55	0.03	0.47
Solution coverage: 0.69 Solution consistency: 0.39			

According to table A7, one of the configurations contributing to robustness is also associated with the lack of robustness (see lfd*cross). A second configuration (lfd*choice*LEAD) is similar to one of the configurations associated to robustness (LFD*choice*LEAD). Interestingly enough, the path associated to LFDs contributes to robustness, while the path associated to progressive/infrequent disturbances does not lead to robustness.

[13] A low (0.5) consistency threshold was chosen for this exercise and the other models in tables A7 to A9. The threshold of 0.5 was chosen for representing the lowest threshold possible from a logical point of view (if more than half of the cases representing a configuration of conditions are also associated to the lack of robustness I considered that configuration as leading to the lack of robustness). The decision to use a 0.5 threshold decision was made in an attempt to further double-check whether any of the conditions found to lead to robustness were also associated to the lack of robustness.

[14] "Formula", or "solution", refers to the combination and logical minimization of all configurations of conditions that are associated to the outcome. In the formulas the multiplication sign (*) corresponds to the logical operator of "and", and indicates that the conditions or configurations of conditions interact. Similarly, the addition (+) sign and corresponds to the operator of "or", and indicates that the conditions or configurations of conditions are exclusive.

Table A8. Second step of QCA: Configurations of proximate and remote conditions associated to *absence* of robustness

Model: robust = *f* (*lfd*, *choice*, *cross*, *lead*, *hete*)			
Complex Solution	Raw Coverage	Unique Coverage	Consistency
lfd*cross*hete	0.61	0.13	0.52
lfd*CHOICE*LEAD*hete	0.51	0.02	0.52
lfd*cross*CHOICE*LEAD	0.51	0.02	0.57
LFD*CROSS*COLCHOIC*LEAD*HETE	0.15	0.15	0.52
Solution coverage: 0.82 Solution consistency: 0.47			

According to table A8, none of the configurations contributing to robustness is also associated with the lack of robustness. Specifically, the solution consists of four configurations. The results are similar to those from model 1. Most of the configurations are associated to progressive/infrequent disturbances. Two of those paths include also the presence of collective choice and leadership suggesting some incompatibility between these conditions and the nature of the disturbances. Finally, there is a condition that includes all variables of interest but also heterogeneity (LFD*CROSS*COLCHOIC*LEAD*HETE). This goes in line with the findings from the stage one of the analysis regarding the relevance of the heterogeneity condition to understand robustness and the lack of it.

Table A9. Second step of QCA: Configurations of proximate and remote conditions associated to *absence* of robustness

Model: robust = *f* (*lfd*, *choice*, *cross*, *lead*, *size*)			
Complex Solution	Raw Coverage	Unique Coverage	Consistency
lfd*CHOICE*LEAD*SIZE	0.54	0.02	0.53
lfd*cross*SIZE	0.63	0.13	0.51
Solution coverage: 0.66 Solution consistency: 0.48			

According to table A9, none of the configurations contributing to robustness is also associated with the lack of robustness. Specifically, the solution consists of a two configurations. Both of them are associated to progressive/infrequent disturbances and to large irrigation systems. One of them also includes collective choice and leadership, pointing to the potential lack of effect of those variables when combined with large size and progressive/infrequent disturbances.

Table A10. Tests of necessity for remote and proximate conditions

Condition	Consistency score
LFD	0.37
Leadership	*0.82*
Collective choice	0.66
Cross-scale linkages	0.53
Size	0.51
Heterogeneity	0.40

Note: consistency threshold for necessity = 0.7