Moving beyond modernization as a panacea: Pathways towards sustainable water use in communitybased irrigation management

Patrick Hoffmann

Moving beyond modernization as a panacea: Pathways towards sustainable water use in community-based irrigation management

Dissertation submitted for the degree of

Doctor of Philosophy in Environmental Science and Technology

by

Patrick Hoffmann

Director and Tutor: Sergio Villamayor Tomás

Institut de Ciència i Tecnologia Ambientals

Universitat Autònoma de Barcelona

September 2023

Acknowledgements

This doctoral thesis would not have been possible without the presence and contributions of a great number of great people. First and foremost, I want to express my sincerest gratitude to my supervisor, mentor, and friend Sergio Villamayor Tomás. If it was not for his support, encouragement, dedication, and willingness to spend countless hours in meetings and discussions, this thesis would not have been written. His expertise and insights shaped my academic formation and will have a lasting effect on my future in academia.

Having spent an essential part of my PhD at the Chair of Institutional Economics at the University of Marburg, Germany, I had the privilege to teach and supervise students in economics. I want to thank Elisabeth Schulte for giving me the opportunity to work at her chair, leaving me sufficient time to focus on my PhD work, and supporting my visits to Barcelona. I also want to thank my collogues in Marburg for the many moments we shared, talking about academic and non-academic topics alike. These friends are, in alphabetical order, Oliver Behn, Maximilian Burger, Nils Christian Hönow, Mathias Mayer, Marco Nilgen, Iryna Ivanets, Cat Lam Pham, Christoph Rößler, Ivo Steimanis, and Johannes Zahner.

I want to thank the many excellent academics that have, at some point of the journey, provided me with feedback, discussions, and food for thought on my work. These are, in alphabetical order: Jeroen C.J.M. van den Bergh, Filippos Exadactylos, Michael Leyer, Paula Novo, Ivan Savin, Elisabeth Schulte, and Anastasio J. Villanueva.

Special thanks to those people who played an important role in my life during the time of writing the thesis or who helped me with small and big favors: Liz Campoverde Pineda, Delf Friedrich Salgado, Philipp Hofmann, Jana Peters Solé, Simon Vaclahovsky, Alicia Vásquez Valdebenito, and Sara Velasquez Rojas.

To my brother, Dennis Hoffmann, who proved his excellent domination of the English language by grammar and spell checking this thesis, and who is on his way to becoming an exceptional academic in linguistics.

Moim rodzicom, Agacie i Hubertowi Hoffmann, których obecności nigdy nie brakowało podczas tej podróży i którzy nigdy nie przestali zapewniać mi domu i wsparcia, kiedy tylko go potrzebowałem.

Cover photo by Süleyman Şahan.

Summary

ENG

The modernization of irrigation systems, i.e., transforming traditional furrow into sprinkler or drip irrigation, increases the efficiency of water use in agriculture. On the one hand, such transformations augment the productivity of water and can therefore boost agricultural production. On the other hand, they are expected to conserve water for environmental functions, which are progressively jeopardized by growing water scarcity and climate change. However, considerable empirical evidence suggests that modernizing irrigation systems induces higher water consumption rates than prior, endangering the goal of sustainable water use in agriculture. This thesis addresses the issue by studying conditions under which modernization in contexts of community-based irrigation systems can contribute to more sustainable water use. Theoretically building on institutional economics and common pool resource theory, it contributes to better understanding how collective irrigation management and water use decisions are permeated by the uptake of modern irrigation technologies. Chapter 1 introduces the thesis by embedding it in its relevant context, describing the state of the art, outlining the research gaps, and formulating the main and sub-research questions. Chapter 2 employs a meta-analysis of case studies to identify distinct strategic decision-making situations and their interrelatedness with infrastructure modernization. Chapter 3 assesses the role of modernization among other conditions for successful drought management in Spanish water user associations. Chapter 4 presents a behavioral perspective on the effects of infrastructure modernization by examining whether farmers hold mental accounts depending on how they obtain water. Finally, chapter 5 concludes and ends with practical implications and an outlook on future research.

ESP

La modernización de los sistemas de riego, es decir, la transformación del riego tradicional por surcos en riego por aspersión o goteo, aumenta la eficiencia del uso del agua en la agricultura. Por un lado, tales transformaciones aumentan la productividad del agua y pueden, por tanto, impulsar la producción agrícola. Por otro, se espera que conserven el agua para funciones medioambientales, que se ven progresivamente amenazadas por la creciente escasez de agua y el cambio climático. Sin embargo, numerosos datos empíricos sugieren que la modernización de los sistemas de regadío induce tasas de consumo de agua superiores a las anteriores, lo que pone en peligro el objetivo del uso sostenible del agua en la agricultura. Esta tesis aborda dicha problemática estudiando las condiciones en las que la modernización en contextos de sistemas de regadío comunitarios puede contribuir a un uso más sostenible del agua. Basándose teóricamente en la economía institucional y en la teoría de los recursos comunes, contribuye a entender mejor cómo la gestión colectiva del riego y las decisiones sobre el uso del agua se ven influidas por la adopción de tecnologías modernas de riego. El capítulo 1 introduce la tesis situándola en su contexto pertinente, describiendo el estado de la cuestión, identificando las brechas de investigación y formulando las preguntas principales y secundarias de la investigación. El capítulo 2 emplea un metaanálisis de casos de estudio para identificar distintas situaciones de toma de decisiones estratégicas y su interrelación con la modernización de las infraestructuras. El capítulo 3 evalúa el papel de la modernización entre otras condiciones para el éxito de la gestión de la sequía en las asociaciones de usuarios de agua españolas. El capítulo 4 presenta una perspectiva basada en la economía de comportamiento sobre los efectos de la modernización de infraestructuras, examinando si los agricultores tienen cuentas mentales en función de cómo obtienen el agua. Por último, el capítulo 5 concluye y termina con implicaciones prácticas y una perspectiva sobre futuras investigaciones.

CAT

La modernització dels sistemes de reg, és a dir, la transformació del reg tradicional per solcs en reg per aspersió o degoteig, augmenta l'eficiència de l'ús de l'aigua en l'agricultura. D'una banda, tals transformacions augmenten la productivitat de l'aigua i poden, per tant, impulsar la producció agrícola. Per altra banda, s'espera que conservin l'aigua per a funcions ambientals, que es veuen progressivament amenaçades per la creixent escassetat d'aigua i el canvi climàtic. No obstant això, nombroses dades empíriques suggereixen que la modernització dels sistemes de regadiu indueix taxes de consum d'aigua superiors a les anteriors, la qual cosa posa en perill l'objectiu de l'ús sostenible de l'aigua en l'agricultura. Aquesta tesi aborda aquesta problemàtica estudiant les condicions en les quals la modernització en contextos de sistemes de regadiu comunitaris pot contribuir a un ús més sostenible de l'aigua. Basant-se teòricament en l'economia institucional i en la teoria dels recursos comuns, contribueix a entendre millor com la gestió col·lectiva del reg i les decisions sobre l'ús de l'aigua es veuen influïdes per l'adopció de tecnologies modernes de reg. El capítol 1 introdueix la tesi situant-la en el seu context pertinent, descrivint l'estat de la qüestió, identificant les bretxes de recerca i formulant les preguntes principals i secundàries de la recerca. El capítol 2 empra un metaanàlisis de casos d'estudi per a identificar diferents situacions de presa de decisions estratègiques i la seva interrelació amb la modernització de les infraestructures. El capítol 3 avalua el paper de la modernització entre altres condicions per a l'èxit de la gestió de la sequera en les associacions d'usuaris d'aigua espanyoles. El capítol 4 presenta una perspectiva basada en l'economia de comportament sobre els efectes de la modernització d'infraestructures, examinant si els agricultors tenen comptes mentals en funció de com obtenen l'aigua. Finalment, el capítol 5 conclou i acaba amb implicacions pràctiques i una perspectiva sobre futures recerques.

Contents

List of Figures

List of Tables

1. Introduction

“Thousands have lived without love, not one without water.”[1]

Water is one of the most, if not the most, valuable natural resource on earth. Although 71 percent of the planet’s surface is covered in water, only 2.5 percent is freshwater and therefore suitable to sustain human life. Thereof, almost 69 percent is frozen in icecaps and glaciers and almost 30 percent is stored as groundwater, leaving only slightly more than 1 percent as feasibly reachable surface water, i.e., water in lakes, reservoirs, and river systems (Gleick and Cooley, 2021; Shiklomanov, 1993). These freshwaters are necessary not only for human consumption, but provide also important services to aquatic ecosystems which maintain biodiversity and biological productivity (Humbert and Dorigo, 2005).

The majority of freshwater utilized by humans accumulates in agriculture, which exploits around 72 percent of yearly global freshwater withdrawals (compared to 16 percent in industrial and 12 percent in municipal use) (FAO, 2022). Within agricultural water use, roughly 90 percent accrue to irrigation (Hoogeveen et al., 2015). Irrigation, the active application of water to land to help to grow crops, constitutes a driving force for water depletion. This applies to arid and semi-arid regions and countries specifically, which heavily rely on irrigation to ensure agricultural production. Additionally, it creates competition over freshwater regarding environmental flows required to maintain aquatic ecosystems (Smakhtin, 2002). Coupled with the current trends of an increasing global population and stimulated economic growth, pressure on freshwater is set to grow further.

Moreover, serious consequences of the anthropogenic climate change are becoming noticeable at an accelerating rate. One that is particularly relevant for the agricultural sector is the increasing occurrence and severity of droughts (Padrón et al., 2020). Droughts can be defined as “temporary lack of water, which is, necessarily but not exclusively, caused by abnormal climate and which is damaging to an activity, group, or the environment” (Kallis, 2008, p.86). Particularly in recent decades, droughts have affected agricultural production, and they continue posing a severe threat to agricultural livelihoods and food security in many regions around the world.

The fact that the United Nations have declared the sustainable management of water as one of the seventeen sustainable development goals (UN General Assembly, 2015) shows that the necessity to rethink the use and management of water[2] towards more sustainable practices has gained public awareness and the consideration of high-level institutions and policymakers, especially given the

---

[1] W.H. Auden (1956), First Things First.

[2] For the remainder of this thesis, I will refer to ‘freshwater’ with ‘water’.

climatic and demographic developments. The agricultural sector, being the largest consumer of water, is frequently targeted by policies aiming to reduce its level of water consumption and to promote more sustainable water management. At the same time, it must build the capacity to adapt to the phenomenon of droughts, which exacerbate water scarcity for longer becoming periods of time. Adaptation to droughts revolves to a large extent around two strategies: increasing the supply of water or reducing the demand for it (Pereira et al., 2002). Supply-side oriented strategies in irrigation include increasing water storage capacity or resorting to desalinated or recycled water. Demand-side oriented strategies aim at reducing irrigation requirements, for example by adapting cropping varieties or decreasing water requirements by increasing the efficiency of water application or improving irrigation conveyance. The latter demand-side strategy is of particular importance for this thesis.

Modernization of irrigation systems with the objective to increase the efficiency of water application by means of converting traditional gravity (or furrow) systems to sprinkler or drip technologies has emerged as a pivotal concept to save water and increase agricultural production at the same time (Berbel et al., 2019; Lopez-Gunn et al., 2012; Playán and Mateos, 2006). Governments around the world, and particularly in Spain, have promoted and subsidized modernization processes, and increasing irrigation efficiency has been included into the sustainable development goal on water (UN General Assembly, 2015). However, the majority of the scientific community appears to refute the notion of a higher irrigation efficiency leading to water savings for the environmental good (Grafton et al., 2018; Pérez-Blanco et al., 2020; Perry et al., 2017), referring to it as a 'zombie idea' that persists despite the existence of scientific evidence (Pérez-Blanco et al., 2021). This phenomenon, frequently labelled as efficiency paradox or irrigation rebound effect, describes a situation in which a higher use-efficiency of a resource results in higher instead of lower consumption of that resource, and remains a core problem on the way to make irrigated agriculture more sustainable.

Understanding why real outcomes misalign with expectations around higher efficiencies in irrigation requires thorough attention to and assessment of the numerous elements of irrigation as a socio-ecological system that factor in its performance. Thus, this thesis puts a particular focus on *how* water is usually managed, and *why*. To understand *why*, it is first necessary to clarify the characteristics of water as a common-pool resource.

Common-pool resources represent a type of good that is, in economic terminology, non-excludable and rival. In other words, it is difficult (although not impossible) to exclude other individuals from accessing and using water, and any unit of water used by one individual cannot be used by another. These characteristics have key implications for water management considerations. Assuming a standard economic setting that is characterized a) by selfishly acting rational individuals and b) as free of institutional arrangements, resource overuse becomes the predicted equilibrium, an outcome that has famously been termed the "tragedy of the commons" (Hardin, 1968). This typical example of a social dilemma stems from the incentive structure of a single individual, rendering it irrational to preserve a resource while witnessing its appropriation by others.

Under real life conditions, however, there is substantial evidence of common-pool resource arrangements that do not lead to resource exhaustion and can therefore arguably be described as sustainable. Studying a multitude of such cases, researchers around Nobel Memorial Prize laureate Elinor Ostrom developed what is known as common pool resource (CPR) theory, which applies collective action theory to the management of local natural resources. This theory conceptualizes and studies the conditions under which groups of resource users, mainly organized in communities, coordinate and cooperate to develop strategies and arrangements to use and preserve common-pool resources over time (Cox et al., 2010; Ostrom, 1990; Ostrom et al., 1994; Poteete et al., 2010). Rooted in this theory, community-based natural resource management (CBNRM) is an approach which suggests that involving community members as stakeholders into decision-making processes at the lowest level possible contributes best to sustaining collective action and sustainable resource use over time.

In fact, many community-based irrigation systems worldwide have been identified as paradigmatic examples of successful CBNRM arrangements (Ostrom, 1990; Tang, 1992). These are typically found in countries where collective irrigation management has a long tradition, such as Spain, Nepal, or India, amongst many others. As state-led irrigation systems have frequently turned out to perform inefficiently, they were, on a global scale, transferred (back) to local communities of water users, insinuating a superiority of collective irrigation over other forms of management (Garces-Restrepo et al., 2007). Hence, water in irrigation systems is predominantly managed collectively (the *how*) because of the nature of water as a CPR (the *why*).

Returning to the issue of how to identify and assess the determinants of the outcomes of modernization processes and their potential to enable transitions to a more sustainable management of water resources in agriculture, it shows that any set of solutions will require considering the predominant form of irrigation governance, i.e., community-based, combined with the knowledge from collective action theory and CBNRM. Therefore, this thesis focuses on community-based irrigation systems in the context of modernization processes. The remainder of the introductory section splits into a brief overview of existing literature with the goal of pointing out the identified research gaps (Section 1.1), a theoretical foundation and contextualization of the research questions of the thesis (Section 1.2), and an overview of the outline of the thesis resuming the research questions and methodology (Section 1.3).

1.1. State of the art and research gaps

Extensive research on the effects of modernization on irrigation governance has been carried out by scholars from different disciplines and backgrounds. In the following, I will outline what I believe are the central strands of literature that have dealt with the effects of irrigation system modernization, mainly, but not exclusively, in the context of community-based irrigation management. I structure the state of the art into conceptual, theoretical, and empirical contributions, the latter divided into quantitative and qualitative studies. This should by no means be understood as an exhaustive or systematic summary of all existing literature, but an overview of what I consider have been the major directions of research, helping to discern a gap in current research.

Conceptual studies have contributed to nuance economic predictions in the water sector. For instance, Perry (2007) discusses the term *efficiency* in the context of a water accounting framework. The predominantly used definition of efficiency, originally coined by Israelsen in 1950, is the ratio of water consumed to water diverted to its purpose. However, refinements and improvements have been proposed over time, for which Perry (2007) outlines several proposals for a terminology to be used in the future. He furthermore highlights the important difference in water applied and water consumed, which has frequently been disregarded in the past. Tied to the Spanish context, Lopez-Gunn et al. (2012) trace the discourse of irrigation efficiency over time as it is accompanied by national modernization programs and initiatives, and demonstrate how the concept of efficiency is understood differently by different stakeholders. Another conceptual contribution to better understand the complexity of resource efficiency is made by Lankford (2013). He defines freed-up resources from efficiency increases as *paracommons*, i.e., as a common-pool resource to be treated as an analytically different dimension from "regular" commons. He argues that this conceptualization can contribute to better understand the uncertainty of efficiency interventions and outcomes, the destinations of 'freed-up' water, and the interconnectedness of users and systems. Dumont et al. (2013) contribute to the conceptual debate by deliberating whether the frequently referred parallelism of the irrigation rebound effect to the energy rebound effect is a useful concept, pointing out how they arguably differ. One notable distinction, for instance, is that inefficiency losses in energy are in fact lost, i.e., they do not serve any purpose, while water "losses" from inefficiency in irrigation can be used downstream or recharge aquifers as recoverable return flows, which constitute positive externalities.

A considerable number of theoretical contributions come from the discipline of economics. Numerous economic studies have investigated the effects of higher efficiencies on agricultural water and land use, typically relying on the standard economic assumption of profit maximization and cost minimization under rational choice, given economic variables as water prices and productivity scores (Berbel et al., 2018; Contor and Taylor, 2013; Gómez and Pérez-Blanco, 2014; Huffaker and Whittlesey, 2003; Lin Lawell, 2016). Building also on previous research from energy economics, the key message from theoretical economic modelling is that higher water efficiencies increase the propensity to consume more water, as a higher productivity per unit of water reduces its costs and therefore increases the purchasing power of the farmer (in economics termed *income effect*). Without policies that restrict farmers from translating this surge of productivity into the expansion of irrigated land or the shift towards more water-intensive crops, economic theory predicts higher water use compared to situations of lower efficiency.

The majority of research on the effects of modernization of irrigation systems, however, follows an empirical approach. Many of the theoretical economic models mentioned above have been tested and fed with simulated data (Berbel and Mateos, 2014; Gutiérrez-Martín and Gomez, 2011; Zhang et al., 2019) and real-world empirical data. Especially the latter approach has received considerable attention, analyzing effects on regional (Li and Zhao, 2018; Pfeiffer and Lin, 2014), national (Freire-González, 2019; Llop, 2008), or global (Doeffinger and Hall, 2020) scales. Furthermore, studies have employed quantitative analyses of secondary data to study the energy-water nexus, i.e., the increasing energy costs related to modernization (Espinosa-Tasón et al., 2020; González-Cebollada, 2015; Rodríguez-Díaz et al., 2011; Stambouli et al., 2014). Quantitative empirical studies have also aimed at assessing potential rebound effects after modernization (Fei et al., 2021; Wheeler et al., 2020). Nonetheless, systematic literature reviews on this topic are not conclusive. Reviewing theoretical and empirical studies, Berbel et al. (2015) assert that results on whether rebound effects occur are ambiguous. Perry et al. (2017) review evidence based not only on published literature, but also on information gathered from irrigation experts, technical specialists in international organizations, international research centers, and other high-profile agencies and personalities in the water sector. Based on the gathered evidence, they state that more efficient irrigation tends to increase local water consumption in most cases. The most recent systematic review of theoretical and empirical literature on the question whether water conservation technologies actually conserve water has been conducted by Pérez-Blanco et al. (2020). They reach conclusions similar to those of the previous authors, namely that making irrigation more efficient will lead to higher water consumption levels, except when modernization is accompanied by effective policy tools.

Next to the bulk of quantitative empirical work, scholars have thoroughly engaged in qualitative research. This type of research is mainly conducted on smaller scales and based on single case studies, using qualitative techniques, such as interviews and participatory workshops. For instance, a substantial body of research has looked at institutional, organizational, managerial, and social impacts of modernization on selected cases of irrigation communities (Albizua and Zaga-Mendez, 2020; Jobbins et al., 2015; Poblador et al., 2021; Sese-Minguez et al., 2017; van der Kooij et al., 2015; Venot et al., 2017). More precisely, studies have assessed technological problems for communities that arose with modernization (González-Pavón et al., 2020), the impact of the private sector in altering institutional arrangements (García-Mollá et al., 2020), or farmers ideas for post-modernization policies (Sanchis-Ibor et al., 2021). Other studies were concerned with the social justice dimension of technical modernization (Collett and Henry, 2014), how water use, irrigation costs, farmer practices and logic change after irrigation (Benouniche et al., 2014; Birkenholtz, 2017; Sanchis-Ibor et al., 2017; van der Kooij et al., 2017), and how discourses and frames of irrigation technology shape water use (Venot et al., 2014), frequently contradicting stated official goals (Molle and Tanouti, 2017). All this research demonstrates the diversity of approaches pursued by scholars and usually presents descriptive results of how modernization has left its mark in the community or area under study. Those results enhance the understanding of how modernization affects water management in irrigation and provides an insight into potential sustainable water management on a micro-scale.

Interestingly, the number of studies employing a CPR perspective when investigating the effects of modernization is rather scarce. Although some of the abovementioned studies acknowledge the CPR nature of irrigation water (e.g., Ortega-Reig et al., 2017), only few actively make use of the theoretical and practical knowledge from CPR theory. Collective action dynamics are particularly salient in decision-making processes of irrigation communities (Lam, 1998). It is essential to better understand how these processes are shaped by modernization to explain associated outcomes. In addition, this can contribute to the question on how modernization can lead to sustainable water use and conservation. Similarly, exploring the conditions under which modernization can contribute to a better performance of irrigation communities under drought conditions is relevant for understanding how climate change adaptation and sustainable water management can be realized simultaneously. Yet, there is little to no systematic understanding of said dynamics or conditions that promote sustainable water use after modernization in the literature, which I identify as a first research gap.

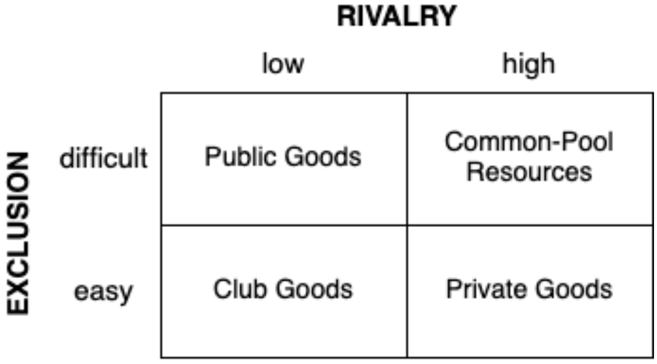
Second, reducing the amount of water used in agriculture coupled with highly efficient irrigation technologies requires avoiding potential rebound effects. So far, scholars have mainly suggested the design of water policies that complement modernization with reductions in water rights or restrictions to increase irrigated area (Berbel et al., 2019). This solution, although successful in some cases (e.g., Sanchis-Ibor et al., 2017), seems to fail as a panacea, as it faces farmer opposition and failure in other cases (e.g., Sampedro-Sánchez, 2022). Research in the area of the energy rebound effect indicates that the behavior of individuals in the context of increasing efficiencies is influenced by a number of behavioral factors (Exadaktylos and van den Bergh, 2021; Hahnel et al., 2020). Similarly, CPR theory has acknowledged the importance of not only considering pure rational choice as a driver for decision-making, but also incorporating behavioral factors and dynamics into the study of collective action problems (Ostrom, 1998; Poteete et al., 2010). Whether and how such factors play a role in the emergence of the irrigation rebound effect, however, remains rather unexplored, and has only been applied in studies on residential water use (Russell and Knoeri, 2020; Russell and Fielding, 2010). This is a second, clear gap in research, as the disclosure of psychological and behavioral factors affecting farmer's water use behavior following an increase in efficiency can yield valuable insights for the investigation of rebound effects.

In sum, although research on the multiple aspects of irrigation modernization and its effect on sustainable water governance has received substantial attention in the last decades, it is far from being conclusive or final. This thesis has the goal to contribute to the current literature by addressing the outlined gaps in research and advancing knowledge on the underlying forces and dynamics of infrastructure modernization in community-based irrigation systems.

1.2. Research questions and theoretical foundation

With the goal of addressing the abovementioned research gaps, I formulate the following overarching research question of the thesis: Under which conditions can modernization contribute to sustainable water use in the context of community-based irrigation management?

As a theoretical basis for my work, I primarily rely on institutional economics and common pool resource theory, and more precisely on the Bloomington School of public choice approach to natural resource management (Mitchell, 1988). Compared to other main strands of thinking in political science and public choice, the Bloomington school stands out for combining theoretical thinking and philosophy with empirical insights to formulate theories on collective choice (Mitchell, 1988). Hereby, it focuses specifically on the social dilemmas associated with common-pool resources, one of four types of goods (Figure 1.1). These are categorized based on two dimensions: rivalry and exclusion. Little to no rivalry exists for public and club goods. While public goods are neither rival in use nor can people be excluded from benefiting (e.g., national defense), club goods are not rival in use, but people can be excluded from benefiting (e.g., pay TV). Private goods are rival in use and people can be excluded from using them (e.g., a cellphone), common-pool resources are rival in use, but it is difficult or costly to exclude them from using them (e.g., river water). The management of CPRs usually faces so-called resource dilemmas.



EXCLUSION \ RIVALRY	low	high
difficult	Public Goods	Common-Pool Resources
easy	Club Goods	Private Goods

Figure 1.1 Typology of goods

Resource dilemmas are situations in which, following rational choice theory, short-term self-oriented behavior directed at resource appropriation or provision leads to socially or collectively suboptimal outcomes (i.e., the depletion or non-provision of a CPR) (Ostrom et al., 1994). This outcome owes to the previously described nature of CPRs, which incentivizes individuals to make use of a resource before it gets used by someone else. Decades of empirical research, however, have demonstrated that resource users hold the capability to overcome these dilemmas by designing rules and institutions that foster cooperation and collective action (Ostrom, 1990; Ostrom et al., 1994). Additionally, it has been shown that behavioral factors, as following established social norms or applying heuristics to cope with incomplete information, play a major role in the process (Ostrom, 1998; Poteete et al., 2010). In an attempt to formalize these dynamics into a theoretical "roadmap", scholars created the Institutional Analysis and Development (IAD) framework (Kiser and Ostrom, 1982; McGinnis, 2011a; Schlager and Villamayor-Tomas, 2023).

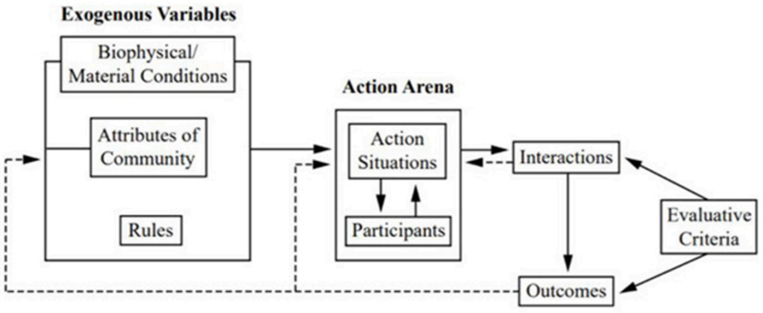


Figure 1.2 The IAD framework components. Source: Ostrom (2005)

The IAD is a conceptual tool for studying the dynamics between cooperation, institutions (i.e., management rules and their ability to promote cooperation among resource users), and natural resource use (Figure 1.2). At the core of the IAD lies the so-called action situation, which is characterized by two or more individuals or participants who face "a set of potential actions that jointly produce outcomes" (Ostrom, 2005: 32). Their decisions are influenced by several contextual factors (e.g., the biophysical context, the institutional arrangements in place, or attributes of the community) The interactions that result in the action situation create outcomes, which can be evaluated and which feed back to the contextual factors. Outcomes can, however, also affect the contextual conditions of other action situations. This allows the conceptualization of networks of action situations (Kimmich et al., 2020; McGinnis, 2011b). In Chapter 2 of the thesis, I rely on the theory of networks of action situations to fill the gap in understanding of how modernization dynamics affect strategic decision-making of water users by addressing the following two sub-questions: Which strategic decision situations and their linkages encompass the management of collective irrigation systems in modernization contexts? To which extent do those decisions allow us to understand the emergence of water-use rebound effects?

CPR theory, i.e., the identification of the institutional, social, and biophysical conditions that contribute to cooperative management of CPRs, has notably progressed in recent decades. As a result, the theory has now identified a considerable amount of potentially relevant variables. Despite apparent progress, scholars have also raised concerns about lack of knowledge about when different variables are more or less relevant (Agrawal, 2001; Villamayor-Tomas et al., 2020). Against this critique, scholars have started to study the explanatory power of combinations of variables rather than variables in isolation (Baggio et al., 2016; Poteete et al., 2010). This suggests that modernization as a variable influencing collective arrangements in water user associations needs to be understood for sensible water management decisions regarding water savings and the adaptation to droughts. Hence, Chapter 3 asks the following research question: Under which institutional, social, and biophysical conditions does modernization contribute to successful functioning of community-based irrigation systems during drought periods?

Another critique raised against CPR theory is its relatively narrow understanding of human decision-making and its limited observation of psychological processes questioning the rationale thereof. One of the theoretical foundations of this critique has been the science of behavioral economics. This sub-field of economics expands the rational choice model by acknowledging that psychological and cognitive factors influence human behavior (Camerer, 1999). Behavioral factors have been accounted for in common-pool resource theory for a long time to expand on the rational choice model (Ostrom, 1998; Poteete et al., 2010) but empirical work is still limited (Lambert et al., 2021; van Laerhoven et al., 2020). Advances in behavioral economics have enabled a better understanding of "irrational" decision-making regarding losses and gains (prospect theory; Kahneman and Tversky, 1979), how people's behavior can be influenced by subtle changes in their environment (nudge theory; Thaler and Sunstein, 2008), and how human decision-making is permeated by heuristics, biases and other cognitive effects (Kahneman, 2011). Insights from behavioral economics have been found to be useful contributors to explain rebound effects after efficiency increases (Hahnel et al., 2020). This holds particularly for the concept of mental accounting, which states that individuals tend to mentally categorize goods or resources into separate accounts, which has implications for an individual's attitude or perception towards those goods or resources (Thaler, 1985, 1999). Mental accounts can also be established based on psychological ownership of a good or resource, i.e., an individual's *perceived* right over using it regardless of legal status (Dawkins et al., 2017; Pierce et al., 2001). Chapter 4 of the thesis resorts to those theories and aims at answering the following sub-question: Is water resulting from efficiency gains perceived differently than water obtained through regular supply in the context of collective irrigation management?

Figure 1.3 visualizes how the outlined sub-research questions interrelate. Focal to the thesis, I postulate that irrigation modernization affects collective irrigation management, but it does so through more than one channel. Specifically, the research question from Chapter 2 (RQ 2) studies how strategic decision-making and collective action dynamics mediate the relationship between modernization and collective irrigation management. Embedded in the institutional setting of collective irrigation management, it aims at presenting a new perspective on irrigation rebound effects. The research question in Chapter 4 (RQ 4) focuses on how perceptions and beliefs, as theorized by mental accounting, mediate the relationship between modernization and collective irrigation management, contributing to the result of sustainable water use or potential rebound effects. Whether collective irrigation management leads to sustainable water use and successful drought adaptation is addressed in Chapter 3 (RQ 3). Here, I investigate contextual factors in how configurations of them result in satisfactory performance of water user associations during droughts.

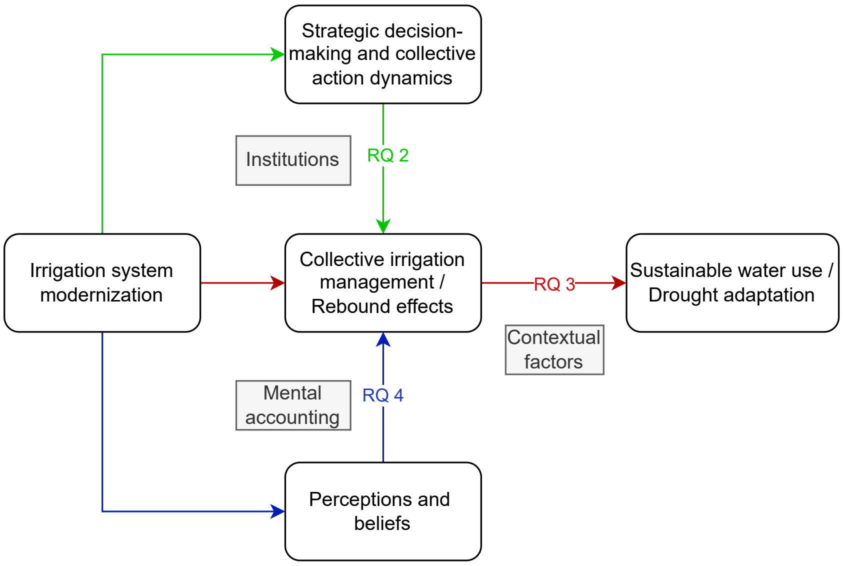


Figure 1.3 Visualization of research questions

1.3. Thesis outline

The remainder of the thesis is structured as follows. In Chapter 2, I ask the following specific research questions: Which strategic decision situations and their linkages encompass the management of collective irrigation systems in modernization contexts? To which extent do those decisions allow us to understand the emergence of water-use rebound effects? To answer these questions, I systematically analyze 37 case studies of modernization processes in collectively managed irrigation systems through the lens of Networks of Action Situations. The results of this meta-analysis enable a systematic perspective on the complex dynamics of modernization processes affecting strategic decision-making processes and demonstrate how rebound effects can be portrayed as the outcome of decisions in other domains of irrigation governance.

Chapter 3 engages in the following specific research question: Under which institutional, social, and biophysical conditions does modernization contribute to successful functioning of community-based irrigation systems during drought periods? To answer this question, I employ a qualitative comparative analysis of national-level survey data from Spain. The results show tendencies in configurations of community-internal conditions that lead to satisfactory performance of water user associations with key managerial functions during droughts.

Chapter 4 studies whether farmer's perceptions regarding how water is used and who it belongs to differ depending on how it is obtained. In this chapter, I pose the following question: Is water resulting from efficiency gains perceived differently than water obtained through regular supply in the context of collective irrigation management? Grounded on behavioral economic and psychologic theory, the chapter presents the results of a survey-based experiment conducted with representatives of Spanish water-user associations. The statistical analysis of the data shows that although mental accounting regarding water freed-up from efficiency gains does not manifest in the intention to use it, it does so in terms of psychological ownership. Finally, Chapter 5 summarizes the contributions of the conducted research and points out directions for future research.

1.4. References

Agrawal, A., 2001. Common property institutions and sustainable governance of resources. World Development 29, 1649–1672. https://doi.org/10.1016/S0305-750X(01)00063-8

Albizua, A., Zaga-Mendez, A., 2020. Changes in institutional and social–ecological system robustness due to the adoption of large-scale irrigation technology in Navarre (Spain). Environmental Policy and Governance 30, 167–181. https://doi.org/10.1002/eet.1882

Baggio, J.A., Barnett, A.J., Perez-Ibara, I., Brady, U., Ratajczyk, E., Rollins, N., Rubiños, C., Shin, H.C., Yu, D.J., Aggarwal, R., Anderies, J.M., Janssen, M.A., 2016. Explaining success and failure in the commons: The configural nature of Ostrom's institutional design principles. International Journal of the Commons 10, 417–439. https://doi.org/10.18352/ijc.634

Benouniche, M., Kuper, M., Hammani, A., Boesveld, H., 2014. Making the user visible: analysing irrigation practices and farmers' logic to explain actual drip irrigation performance. Irrigation Science 32, 405–420. https://doi.org/10.1007/s00271-014-0438-0

Berbel, J., Exposito, A., Gutierrez-Martin, C., Mateos, L., Expósito, A., Gutiérrez-Martín, C., Mateos, L., 2019. Effects of the Irrigation Modernization in Spain 2002–2015. Water Resources Management 33, 1835–1849. https://doi.org/10.1007/s11269-019-02215-w

Berbel, J., Gutiérrez-Martín, C., Expósito, A., 2018. Impacts of irrigation efficiency improvement on water use, water consumption and response to water price at field level. Agricultural Water Management 203, 423–429. https://doi.org/10.1016/j.agwat.2018.02.026

Berbel, J., Gutiérrez-Martín, C., Rodríguez-Díaz, J.A., Camacho, E., Montesinos, P., 2015. Literature Review on Rebound Effect of Water Saving Measures and Analysis of a Spanish

Case Study. Water Resources Management 29, 663–678. https://doi.org/10.1007/s11269-014-0839-0

Berbel, J., Mateos, L., 2014. Does investment in irrigation technology necessarily generate rebound effects? A simulation analysis based on an agro-economic model. Agricultural Systems 128, 25–34. https://doi.org/10.1016/j.agsy.2014.04.002

Birkenholtz, T., 2017. Assessing India's drip-irrigation boom: efficiency, climate change and groundwater policy. Water International 42, 663–677. https://doi.org/10.1080/02508060.2017.1351910

Camerer, C., 1999. Behavioral economics: Reunifying psychology and economics. Proceedings of the National Academy of Sciences 96, 10575–10577. https://doi.org/10.1073/pnas.96.19.10575

Collett, B., Henry, N., 2014. Water justice: exploring the social dimensions of new irrigation technologies in northern Victoria, Australia. Water Policy 16, 155–173. https://doi.org/10.2166/wp.2014.102

Contor, B.A., Taylor, R.G., 2013. Why improving irrigation efficiency increases total volume of consumptive use. Irrigation and Drainage 62, 273–280. https://doi.org/10.1002/ird.1717

Cox, M., Arnold, G., Villamayor-Tomas, S., 2010. A Review of Design Principles for Community-based Natural Resource Management. Ecology and Society 15, art38. https://doi.org/10.5751/ES-03704-150438

Dawkins, S., Tian, A.W., Newman, A., Martin, A., 2017. Psychological ownership: A review and research agenda. Journal of Organizational Behavior 38, 163–183. https://doi.org/10.1002/job.2057

Doeffinger, T., Hall, J.W., 2020. Water Stress and Productivity: An Empirical Analysis of Trends and Drivers. Water Resources Research 56. https://doi.org/10.1029/2019WR025925

Dumont, A., Mayor, B., López-Gunn, E., 2013. Is the Rebound Effect or Jevons Paradox a Useful Concept for better Management of Water Resources? Insights from the Irrigation Modernisation Process in Spain. Aquatic Procedia 1, 64–76. https://doi.org/10.1016/j.aqpro.2013.07.006

Espinosa-Tasón, J., Berbel, J., Gutiérrez-Martín, C., 2020. Energized water: Evolution of water-energy nexus in the Spanish irrigated agriculture, 1950–2017. Agricultural Water Management 233, 106073. https://doi.org/10.1016/j.agwat.2020.106073

Exadaktylos, F., van den Bergh, J., 2021. Energy-related behaviour and rebound when rationality, self-interest and willpower are limited. Nature Energy 6, 1104–1113. https://doi.org/10.1038/s41560-021-00889-4

FAO, 2022. The State of the World's Land and Water Resources for Food and Agriculture 2021 – Systems at breaking point. FAO, Rome, Italy. https://doi.org/10.4060/cb9910en

Fei, R., Xie, M., Wei, X., Ma, D., 2021. Has the water rights system reform restrained the water rebound effect? Empirical analysis from China's agricultural sector. Agricultural Water Management 246, 106690. https://doi.org/10.1016/j.agwat.2020.106690

Freire-González, J., 2019. Does Water Efficiency Reduce Water Consumption? The Economy-Wide Water Rebound Effect. Water Resources Management 33, 2191–2202. https://doi.org/10.1007/s11269-019-02249-0

Garces-Restrepo, C., Vermillion, D., Muñoz, G., 2007. Irrigation Management Transfer: Worldwide Efforts and Results, FAO Water Reports. Rome, Italy.

García-Mollá, M., Ortega-Reig, M., Boelens, R., Sanchis-Ibor, C., 2020. Hybridizing the commons. Privatizing and outsourcing collective irrigation management after technological change in Spain. World Development 132, 104983. https://doi.org/10.1016/j.worlddev.2020.104983

Gleick, P.H., Cooley, H., 2021. Freshwater Scarcity. Annual Review of Environment and Resources 46, 319–348. https://doi.org/10.1146/annurev-environ-012220-101319

Gómez, C.M., Pérez-Blanco, C.D., 2014. Simple Myths and Basic Maths About Greening Irrigation. Water Resources Management 28, 4035–4044. https://doi.org/10.1007/s11269-014-0725-9

González-Cebollada, C., 2015. Water and energy consumption after the modernization of irrigation in Spain. pp. 457–465. https://doi.org/10.2495/SD150401

González-Pavón, C., Arviza-Valverde, J., Balbastre-Peralta, I., Carot Sierra, J.M., Palau-Salvador, G., 2020. Are Water User Associations Prepared for a Second-Generation Modernization? The Case of the Valencian Community (Spain). Water 12, 2136. https://doi.org/10.3390/w12082136

Grafton, R.Q., Williams, J., Perry, C.J., Molle, F., Ringler, C., Steduto, P., Udall, B., Wheeler, S.A., Wang, Y., Garrick, D., Allen, R.G., 2018. The paradox of irrigation efficiency. Science 361, 748–750. https://doi.org/10.1126/science.aat9314

Gutiérrez-Martín, C., Gomez, C.M., 2011. Assessing irrigation efficiency improvements by using a preference revelation model. Spanish Journal of Agricultural Research 9, 1009. https://doi.org/10.5424/sjar/20110904-514-10

Hahnel, U.J.J.J., Chatelain, G., Conte, B., Piana, V., Brosch, T., 2020. Mental accounting mechanisms in energy decision-making and behaviour. Nature Energy 5, 952–958. https://doi.org/10.1038/s41560-020-00704-6

Hardin, G., 1968. The Tragedy of the Commons. Science 162, 1243–1248. https://doi.org/10.1126/science.162.3859.1243

Hoogeveen, J., Faurès, J.-M., Peiser, L., Burke, J., van de Giesen, N., 2015. GlobWat – a global water balance model to assess water use in irrigated agriculture. Hydrology and Earth System Sciences 19, 3829–3844. https://doi.org/10.5194/hess-19-3829-2015

Huffaker, R., Whittlesey, N., 2003. A Theoretical Analysis of Economic Incentive Policies Encouraging Agricultural Water Conservation. International Journal of Water Resources Development 19, 37–53. https://doi.org/10.1080/713672724

Humbert, J.-F., Dorigo, U., 2005. Biodiversity and aquatic ecosystem functioning: A mini-review. Aquatic Ecosystem Health & Management 8, 367–374. https://doi.org/10.1080/14634980500457773

Jobbins, G., Kalpakian, J., Chriyaa, A., Legrouri, A., El Mzouri, E.H., 2015. To what end? Drip irrigation and the water–energy–food nexus in Morocco. International Journal of Water Resources Development 31, 393–406. https://doi.org/10.1080/07900627.2015.1020146

Kahneman, D., 2011. Thinking, Fast and Slow. Farrar, Straus and Giroux, New York.

Kahneman, D., Tversky, A., 1979. Prospect Theory : An Analysis of Decision under Risk. Econometrica 47, 263–292.

Kallis, G., 2008. Droughts. Annual Review of Environment and Resources 33, 85–118. https://doi.org/10.1146/annurev.environ.33.081307.123117

Kimmich, C., Ehlers, M.-H., Kellner, E., Oberlack, C., Thiel, A., Villamayor-Tomas, S., 2020. Networks of action situations in social-ecological systems research. Sustainability Science 15, 1009–1010. https://doi.org/10.1007/s11625-020-00814-w

Kiser, L.L., Ostrom, E., 1982. The Three Worlds of Action: A Metatheoretical Synthesis of Institutional Approaches, in: Ostrom, E. (Ed.), Strategies of Political Inquiry. Sage Publications, Beverly Hills.

Lam, W.F., 1998. Governing irrigation systems in Nepal: institutions, infrastructure, and collective action. Institute for Contemporary Studies.

Lambert, J., Epstein, G., Joel, J., Baggio, J., 2021. Identifying Topics and Trends in the Study of

Common-Pool Resources Using Natural Language Processing. International Journal of the Commons 15, 206. https://doi.org/10.5334/ijc.1078

Lankford, B., 2013. Resource Efficiency Complexity and the Commons: The paracommons and paradoxes of natural resource losses, wastes and wastages, 1st Editio. ed. Routledge, London, UK. https://doi.org/10.4324/9780203520888

Li, H., Zhao, J., 2018. Rebound Effects of New Irrigation Technologies: The Role of Water Rights. American Journal of Agricultural Economics 100, 786–808. https://doi.org/10.1093/ajae/aay001

Lin Lawell, C.-Y.C., 2016. The Management of Groundwater: Irrigation Efficiency, Policy, Institutions, and Externalities. Annual Review of Resource Economics 8, 247–259. https://doi.org/10.1146/annurev-resource-100815-095425

Llop, M., 2008. Economic impact of alternative water policy scenarios in the Spanish production system: An input–output analysis. Ecological Economics 68, 288–294. https://doi.org/10.1016/j.ecolecon.2008.03.002

Lopez-Gunn, E., Zorrilla, P., Prieto, F., Llamas, M.R., 2012. Lost in translation? Water efficiency in Spanish agriculture. Agricultural Water Management 108, 83–95. https://doi.org/10.1016/j.agwat.2012.01.005

McGinnis, M.D., 2011a. An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework. Policy Studies Journal 39, 169–183. https://doi.org/10.1111/j.1541-0072.2010.00401.x

McGinnis, M.D., 2011b. Networks of Adjacent Action Situations in Polycentric Governance. Policy Studies Journal 39, 51–78. https://doi.org/10.1111/j.1541-0072.2010.00396.x

Mitchell, W.C., 1988. Virginia, Rochester, and Bloomington: Twenty-five years of public choice and political science. Public Choice 56, 101–119. https://doi.org/10.1007/BF00115751

Molle, F., Tanouti, O., 2017. Squaring the circle: Agricultural intensification vs. water conservation in Morocco. Agricultural Water Management 192, 170–179. https://doi.org/10.1016/j.agwat.2017.07.009

Ortega-Reig, M., Sanchis-Ibor, C., Palau-Salvador, G., García-Mollá, M., Avellá-Reus, L., 2017. Institutional and management implications of drip irrigation introduction in collective irrigation systems in Spain. Agricultural Water Management 187, 164–172. https://doi.org/10.1016/j.agwat.2017.03.009

Ostrom, E., 2005. Understanding institutional diversity. Princeton University Press, Princeton, NJ.

Ostrom, E., 1998. A Behavioral Approach to the Rational Choice Theory of Collective Action: Presidential Address, American Political Science Association, 1997. American Political Science Review 92, 1–22. https://doi.org/10.2307/2585925

Ostrom, E., 1990. Governing the commons: the evolution of institutions for collective action, Political Economy Of Institutions and Decisions. Cambridge University Press, Cambridge. https://doi.org/10.2307/3146384

Ostrom, E., Gardner, R., Walker, J., 1994. Rules, Games, and Common-Pool Resources, Rules, Games, and Common-Pool Resources. University of Michigan Press, Ann Arbor, MI. https://doi.org/10.3998/mpub.9739

Padrón, R.S., Gudmundsson, L., Decharme, B., Ducharne, A., Lawrence, D.M., Mao, J., Peano, D., Krinner, G., Kim, H., Seneviratne, S.I., 2020. Observed changes in dry-season water availability attributed to human-induced climate change. Nature Geoscience 13, 477–481. https://doi.org/10.1038/s41561-020-0594-1

Pereira, L.S., Oweis, T., Zairi, A., 2002. Irrigation management under water scarcity. Agricultural Water Management 57, 175–206. https://doi.org/10.1016/S0378-3774(02)00075-6

Pérez-Blanco, C.D., Hrast-Essenfelder, A., Perry, C., 2020. Irrigation Technology and Water Conservation: A Review of the Theory and Evidence. Review of Environmental Economics and Policy 14, 216–239. https://doi.org/10.1093/reep/reaa004

Pérez-Blanco, C.D., Loch, A., Ward, F., Perry, C., Adamson, D., 2021. Agricultural water saving through technologies: a zombie idea. Environmental Research Letters 16, 114032. https://doi.org/10.1088/1748-9326/ac2fe0

Perry, C., 2007. Efficient irrigation; inefficient communication; flawed recommendations. Irrigation and Drainage 56, 367–378. https://doi.org/10.1002/ird.323

Perry, C., Steduto, P., Karajeh, F., 2017. Does improved irrigation technology save water? A review of the evidence (No. 42), Food and Agriculture Organization of the United Nations, Food and Agriculture Organization of the United Nations. Cairo.

Pfeiffer, L., Lin, C.-Y.C., 2014. Does efficient irrigation technology lead to reduced groundwater extraction? Empirical evidence. Journal of Environmental Economics and Management 67, 189–208. https://doi.org/10.1016/j.jeem.2013.12.002

Pierce, J.L., Kostova, T., Dirks, K.T., 2001. Toward a Theory of Psychological Ownership in Organizations. Academy of Management Review 26, 298–310. https://doi.org/10.5465/amr.2001.4378028

Playán, E., Mateos, L., 2006. Modernization and optimization of irrigation systems to increase water productivity. Agricultural Water Management 80, 100–116. https://doi.org/10.1016/j.agwat.2005.07.007

Poblador, N.N., Sanchis-Ibor, C., Kuper, M., 2021. The Landing of Parachuted Technology: Appropriation of Centralised Drip Irrigation Systems by Irrigation Communities in the Region of Valencia (Spain). Water Alternatives 14, 228–247.

Poteete, A.R., Janssen, M.A., Ostrom, E., 2010. Working together: Collective action, the commons, and multiple methods in practice, Working Together: Collective Action, the Commons, and Multiple Methods in Practice. Princeton University Press, Princeton and Oxford.

Rodríguez-Díaz, J.A., Pérez-Urrestarazu, L., Camacho-Poyato, E., Montesinos, P., 2011. The paradox of irrigation scheme modernization: more efficient water use linked to higher energy demand. Spanish Journal of Agricultural Research 9, 1000. https://doi.org/10.5424/sjar/20110904-492-10

Russell, S., Fielding, K., 2010. Water demand management research: A psychological perspective. Water Resources Research 46. https://doi.org/10.1029/2009WR008408

Russell, S. V., Knoeri, C., 2020. Exploring the psychosocial and behavioural determinants of household water conservation and intention. International Journal of Water Resources Development 36, 940–955. https://doi.org/10.1080/07900627.2019.1638230

Sampedro-Sánchez, D., 2022. Can Irrigation Technologies Save Water in Closed Basins? The effects of Drip Irrigation on Water Resources in the Guadalquivir River Basin (Spain). Water Alternatives 15, 501–522.

Sanchis-Ibor, C., García-Mollá, M., Avellà-Reus, L., 2017. Effects of drip irrigation promotion policies on water use and irrigation costs in Valencia, Spain. Water Policy 19, 165–180. https://doi.org/10.2166/wp.2016.025

Sanchis-Ibor, C., Ortega-Reig, M., Guillem-García, A., Carricondo, J.M., Manzano-Juárez, J., García-Mollá, M., Royuela, Á., 2021. Irrigation Post-Modernization. Farmers Envisioning Irrigation Policy in the Region of Valencia (Spain). Agriculture 11, 317. https://doi.org/10.3390/agriculture11040317

Schlager, E., Villamayor-Tomas, S., 2023. The IAD Framework and Its Tools for Policy and Institutional Analysis, in: Weible, C.M. (Ed.), Theories Of The Policy Process. Routledge, New York, pp. 196–229. https://doi.org/10.4324/9781003308201-8

Sese-Minguez, S., Boesveld, H., Asins-Velis, S., van der Kooij, S., Maroulis, J., 2017.

Transformations accompanying a shift from surface to drip irrigation in the Cànyoles Watershed, Valencia, Spain. Water Alternatives.

Shiklomanov, I.A., 1993. World fresh water resources, in: Gleick, P.H. (Ed.), Water in Crisis: A Guide to the World's Fresh Water Resources. Oxford University Press, pp. 93–126.

Smakhtin, V., 2002. Environmental water needs and impacts of irrigated agriculture in river basins: A framework for a new research program (No. 42), International Water Management Institute.

Stambouli, T., Faci, J.M.M., Zapata, N., 2014. Water and energy management in an automated irrigation district. Agricultural Water Management 142, 66–76. https://doi.org/10.1016/j.agwat.2014.05.001

Tang, S.Y., 1992. Institutions and collective action: Self-governance in irrigation. ICS Press, San Francisco, CA.

Thaler, R., 1985. Mental Accounting and Consumer Choice. Marketing Science 4, 199–214. https://doi.org/10.1287/mksc.4.3.199

Thaler, R.H., 1999. Mental accounting matters. Journal of Behavioral Decision Making 12, 183–206. https://doi.org/10.1002/(SICI)1099-0771(199909)12:3<183::AID-BDM318>3.0.CO;2-F

Thaler, R.H., Sunstein, C.R., 2008. Nudge: Improving Decisions About Health, Wealth and Happiness. Yale University Press, New Haven, CT.

UN General Assembly, 2015. Transforming our world : the 2030 Agenda for Sustainable Development. A/RES/70/1.

van der Kooij, S., Kuper, M., Zwarteveen, M.Z., de Fraiture, C.M.S., 2017. A user-centred approach to irrigation performance: drip irrigation in the Khrichfa area, Morocco. Water International 42, 794–809. https://doi.org/10.1080/02508060.2017.1373319

van der Kooij, S., Zwarteveen, M., Kuper, M., 2015. The material of the social: the mutual shaping of institutions by irrigation technology and society in Seguia Khrichfa, Morocco. International Journal of the Commons 9, 129–150. https://doi.org/10.18352/ijc.539

van Laerhoven, F., Schoon, M., Villamayor-Tomas, S., 2020. Celebrating the 30th Anniversary of Ostrom's Governing the Commons: Traditions and Trends in the Study of the Commons, Revisited. International Journal of the Commons 14, 208–224. https://doi.org/10.5334/ijc.1030

Venot, J.-P., Kuper, M., Zwarteveen, M., 2017. Drip irrigation for agriculture: Untold stories of efficiency, innovation and development. Taylor & Francis.

Venot, J.-P., Zwarteveen, M., Kuper, M., Boesveld, H., Bossenbroek, L., Kooij, S. Van Der, Wanvoeke, J., Benouniche, M., Errahj, M., Fraiture, C. De, Verma, S., 2014. Beyond the promises of technology: a review of the discourses and actors who make drip irrigation. Irrigation and Drainage 63, 186–194. https://doi.org/10.1002/ird.1839

Villamayor-Tomas, S., Oberlack, C., Epstein, G., Partelow, S., Roggero, M., Kellner, E., Tschopp, M., Cox, M., 2020. Using case study data to understand SES interactions: a model-centered meta-analysis of SES framework applications. Current Opinion in Environmental Sustainability 44, 48–57. https://doi.org/10.1016/j.cosust.2020.05.002

Wheeler, S.A., Carmody, E., Grafton, R.Q., Kingsford, R.T., Zuo, A., 2020. The rebound effect on water extraction from subsidising irrigation infrastructure in Australia. Resources, Conservation and Recycling 159, 104755. https://doi.org/10.1016/j.resconrec.2020.104755

Zhang, L., Ma, Q., Zhao, Y., Wu, X., Yu, W., 2019. Determining the influence of irrigation efficiency improvement on water use and consumption by conceptually considering hydrological pathways. Agricultural Water Management 213, 674–681. https://doi.org/10.1016/j.agwat.2018.11.016

2. Irrigation modernization and the efficiency paradox: a meta-study through the lens of Networks of Action Situations[3]

2.1. Introduction

Despite repeated warnings, the climate and ecological crises have only deepened over the last decades (Ripple et al., 2021). With it, research and calls for the transformation of socio-ecological and -technical systems towards more sustainable modes of production and consumption have become increasingly salient (El Bilali, 2019; Köhler et al., 2019; Markard et al., 2012). In the irrigation sector, the transformation of irrigation systems through the modernization of infrastructure and technology (e.g., via investments in water storage, or sprinkler/drip irrigation) has been portrayed as the main way to move to more sustainable water use. Modernization sets the goal to increase water-use efficiency, which, in turn, is expected to contribute to alleviating water scarcity by reducing agricultural water-use. However, a growing body of literature indicates that water consumption increases rather than decreases after the implementation of modernization measures (Freire-González, 2019; Grafton et al., 2018; McCarthy et al., 2020; Pérez-Blanco et al., 2020; Perry et al., 2017; Sears et al., 2018; Wang et al., 2020; Wheeler et al., 2020). This seemingly paradoxical effect, known as the *efficiency paradox* or *rebound effect*, reveals a conflict with the goal of conserving water-dependent ecosystems and demonstrates how well-intended interventions in socio-technical systems can produce unanticipated and undesirable consequences. That conflict is particularly important given the growing world population, the associated increase in demand for food, and climate change (FAO, 2017; World Bank, 2020). Scholars have tended to justify the efficiency paradox mostly based on economic theory, which predicts that an increase in irrigation efficiency results in an income effect, permitting farmers to increase production by expanding irrigated area or by switching to more valuable and water-consuming crops (Contor and Taylor, 2013; Pfeiffer and Lin, 2014; Ward and Pulido-Velazquez, 2008). The income effect can also be the result of other processes, like decreases in operation and maintenance (Gómez and Pérez-Blanco, 2014) or energy costs (Stambouli et al., 2014). Additionally, as I argue in this chapter, the efficiency paradox may owe to collective action dynamics and strategic decision-making, just like other

---

[3] This chapter has been published as Hoffmann, P., Villamayor-Tomas, S., 2023. Irrigation modernization and the efficiency paradox: a meta-study through the lens of Networks of Action Situations. Sustainability Science 18, 181–199.

unattended effects of infrastructure investments in irrigation systems (Lam, 1998; Sanchis-Ibor et al., 2017a).

There is little systematic understanding on collective action dynamics and strategic decision-making as they relate to the efficiency paradox, particularly in the context of collectively managed irrigation systems, where said dynamics and decision-making are particularly salient among farmers. Considering this gap, this chapter addresses the following research questions: Which strategic decision situations and their linkages encompass the management of collective irrigation systems in modernization contexts? To which extent do those decisions allow us to understand the emergence of water-use rebound effects? To address these questions, I rely on the theory of Networks of Action Situations (McGinnis, 2011a) which understands the management of irrigation systems as a series of strategic decision-making situations, the outcomes of which affect each other and social and ecological outcomes. The contribution of this chapter is thus to start delving into the complex behavioral dynamics behind the efficiency paradox and to provide a basis to systematize the so far scattered knowledge about it in the irrigation sector.

Methodologically, I conduct a meta-analysis of 37 case studies of irrigation modernization in community-managed systems. In the coding process, I first identified and named key action situations. Further, the same strategy was used for linkages among dyads of action situations. In the analysis I unveil collective action problems potentially associated to the situations, with particular attention to what I name the water-saving situation.

The chapter is structured as follows: Section 2.2 introduces the literature on the institutional analysis lens that inspires the theory of Networks of Action Situations. Section 2.3 explains the methodology. Section 2.4 presents the results in three subsections. First, I provide a descriptive summary of the case studies used in the meta-analysis. Second, I describe the set of identified action situations that characterize the studied irrigation systems in modernization contexts. Finally, I explore institutional, physical, and informational linkages among dyads of action situations. Section 2.5 discusses the implications of the findings, reconstructs the analytic narratives behind two of the NAS coded, and highlights gaps for future research. In the conclusion I recap on the main findings.

2.2. Background

Despite the growing literature on the *irrigation rebound effect* (Berbel et al., 2019; Grafton et al., 2018; Pérez-Blanco et al., 2020; Perry et al., 2017; Wang et al., 2020), few studies consider that irrigation systems are managed collectively by farmers via water-user associations (WUAs). This is not trivial because user-managed irrigation systems are widespread in many rural areas of the world, and many of them have operated with remarkable success over decades and centuries (Bardhan, 1993; Wade, 1987; Ward et al., 2020). More importantly, the functioning and success of such collective systems is pervaded by collective action dynamics, the exploration of which can complement our knowledge on the drivers of the rebound effect. Irrigation systems are a typical example of a common-pool resource (CPR), the management of which faces collective action problems associated to its depletability and difficult excludability, as well as to the strategic decision-making of users (Ostrom et al., 1994). Decades of research have shown the capacity of farmers to overcome those collective action problems to manage irrigation systems, and adapt to scarcity situations (Lam and Chiu, 2016; Ma'Mun et al., 2020; Ostrom, 1993; Poteete et al., 2010; Villamayor-Tomas, 2014). They have accomplished this via rules that comprise water allocation, financial contributions, or monitoring and sanctioning mechanisms, as well as the creation of WUAs with the power to design and modify said rules.

The increase in productivity associated with efficiency-enhancing modernizations is likely to affect farmer's water-use decisions, as well as the way WUAs manage the irrigation systems (i.e., the abovementioned rules) (Bandaragoda, 1998; Ortega-Reig et al., 2017; van der Kooij et al., 2015). Yet, there is still little research that addresses modernization processes with an eye on the collective management dynamics within those systems. In an early study of small-scale irrigation systems in Nepal, Lam (1996) found that externally imposed infrastructure investments were unlikely to achieve irrigation efficiency levels if local conditions and institutions were not taken into account, an argument that was further supported in a follow up study of the performance of irrigation modernization (Lam and Ostrom, 2010). García-Mollá et al. (2014) illustrate how modernization in a collective irrigation scheme in Spain translated into water savings but also in an increase of water fees the association charged to its members (to finance the new infrastructure). Albizua and Zaga-Mendez (2020) assess in a Spanish irrigation system how collective management conditions changed before and after a modernization project. They find that the technological conversion led to a decrease in farmers' autonomy to self-organize but also to tighter monitoring due to the externalization of this task to an external company.

In this chapter, I rely on the Institutional Analysis and Development (IAD) framework (Kiser and Ostrom, 1982; McGinnis, 2011b). Its focal units of analysis are action situations which capture decision-making points for two or more individuals whose decisions jointly produce outcomes (Ostrom, 2005). Irrigation scholars using the IAD lenses have tended to focus on two typical action situations: the water appropriation situation (whereby farmers decide how much water to use), and the infrastructure maintenance situation (how much to maintain the infrastructure) (Ostrom et al., 1994). Action situations are affected by contextual factors as well as biophysical, socioeconomic, and institutional conditions. Their outcomes can in turn feedback to the contextual factors of other action situations (see Figure A 2.1 in the Appendix). For example, how well the irrigation infrastructure is maintained will affect efficiency of water conveyance and the amount ultimately needed to satisfy farmers' needs and cope with scarcity (Tang, 1992; Villamayor-Tomas and García-López, 2017). To account for this interdependence, McGinnis (2011b) coined the approach of Networks of Action Situations (NAS). Linkages between action situations can be categorized into types depending on which of the contextual factors of one action situation (and therefore strategic decisions) are altered by the outcome of another. According to Kimmich (2013), linkages can be biophysical, institutional, actor-based, or informational. Physical linkages are, for example, changes in water availability or consumption; and institutional linkages are, for instance, water allocation rules. In sum, a linked set of action situations can be displayed as a network. The analysis can then be carried by focusing on one action situation (the focal action situation) and exploring how it is affected by all others and their linkages.

2.3. Methodology

In the last years, a growing number of scholars have applied the NAS approach to single and comparative case studies, including irrigation management cases (Kimmich, 2013; Kimmich and Villamayor-Tomas, 2019; Möck et al., 2019; Villamayor-Tomas et al., 2015). I complement that literature by conducting a meta-analysis of case studies that cover irrigation modernization and its effects in the context of collective irrigation management systems. The variables of interest are action situations and their respective linkages, but I also coded for geographical, biophysical, and technological variables (the complete list of variables can be found in Table A 2.1 in the Appendix). Many irrigation studies do not explicitly mention NAS but contain information about linkages, nevertheless. After a first exploratory phase (see S1 for more details), I collected case studies from two complementary sources: a database from Pérez-Blanco et al. (2020)'s review on water conservation technologies, and a database resulting from a systematic literature search via Scopus. The first database provides a collection of 230 empirical studies analyzing the effect of water conservation technologies, which I narrowed down to a subset of cases with sufficient and relevant information, resulting in 152 studies reported in 139 articles. For the second database, I ran a document search with Scopus by applying the "related documents" algorithm based on four preselected papers which I considered exemplary applications of the NAS approach in the irrigation sector and/or modernization effects. I carried out one search per each of the 4 selected papers. For each search I selected the 50 most relevant results, mostly to guarantee a representative but still manageable size of articles. Aggregating the resulting 200 articles and deleting duplicates resulted in a second database of 182 documents, which, together with the first database, returned a database of 321 articles. These were then filtered by applying a set of exclusion and inclusion criteria related to the availability (i.e., accessible), document type (e.g., not grey literature), methods (e.g., not modelling studies or theoretical papers), and substantive information (i.e., on collective irrigation management and modernization) (Figure 2.1).

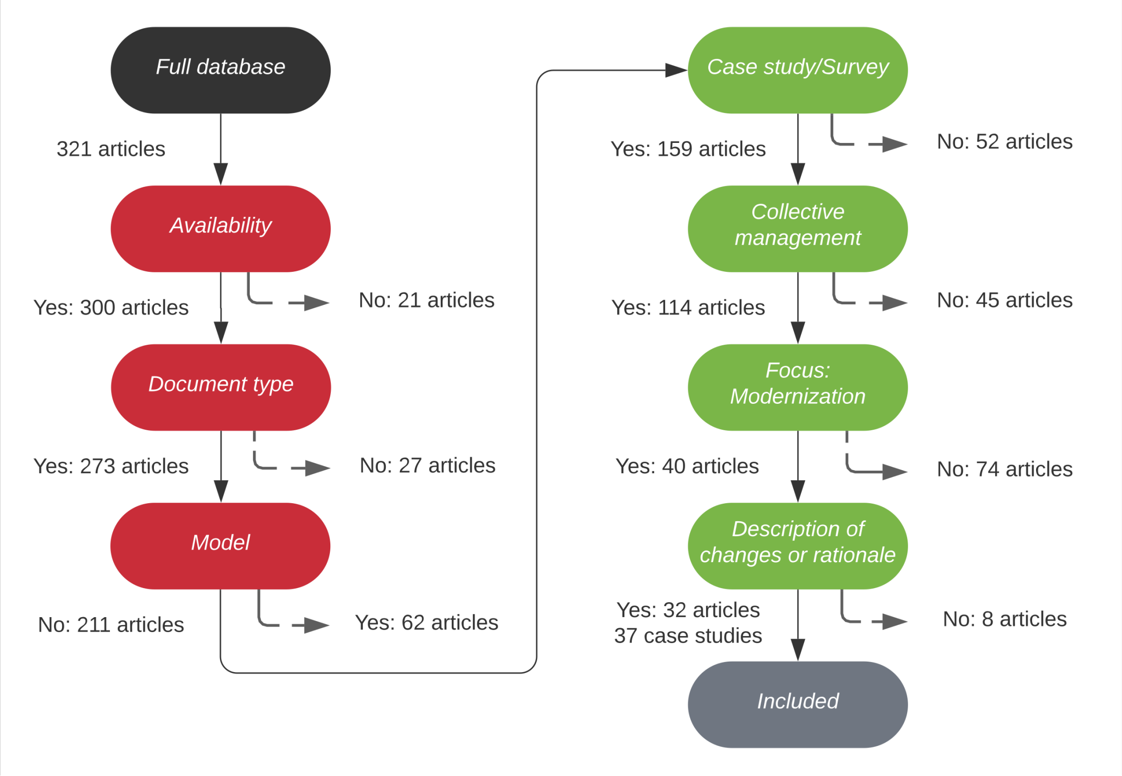


Figure 2.1 Selection process of studies according to the applied exclusion (red) and inclusion (green) criteria

The goal of the coding process was to identify action situations and linkages between them. Several action situations in the context of irrigation management have already been identified by Kimmich (2013) and Kimmich and Villamayor-Tomas (2019). For the analysis, I built on the set of action situations from the latter study and complemented it with new action situations based on the information found in the reviewed cases. The identification of linkage types was mostly inductive although inspired by Kimmich (2013)'s distinction between biophysical, institutional, actor-based, and informational linkages.

The exploratory phase revealed sufficient evidence in the studies to code for dyads of action situations, as expressed in causal effects between pairs of variables. For example, the statement "Energy tariff impacts timing of water pumped" indicated that the outcome of an energy allocation situation affects decisions in a water allocation situation (further examples for such statements are listed in Table A 2.2 in the Appendix). Since connecting those dyads into a NAS for each of the studies would have required interpretation (e.g., about the direction of effects throughout the network), I decided to stick to the coding of causal dyads.

Finally, although seeking for empirically supported statements, I also coded theory-informed statements that were relevant and directly connected to the cases (as when an author uses premises or interprets findings based on strong theory).

2.4. Results

2.4.1. Descriptive summary

Geographically, the 37 selected case studies cover a range of 11 countries. Most of the cases are based in Spain (24) while the remaining 13 are spread over 10 countries from all continents except Oceania.[4] Spain is the only European country featured in this analysis, and its overrepresentation can be explained by the fact that it is a country that has a long history and recognition for collective irrigation management (Lopez-Gunn, 2003), and has experienced large-scale modernization processes in the last decades (Berbel et al., 2019). Also, 3 of the 4 articles used in the Scopus search were located in Spain, which could partially explain the overrepresentation of this country. The size of irrigation systems studied is heterogeneous, with the smallest irrigated acreage being 67 ha and the largest being 800,000 ha. The water source in most of the cases is surface water (e.g., water diverted from rivers) (Figure 2.2).

Figure 2.2 Water source used for irrigation (n=37)

The cases put forth various reasons for the engagement in a modernization process (Figure 2.3). Saving water was by far the most frequently indicated goal, followed by increasing the system's productivity, saving water, and increasing productivity simultaneously, as well as increasing the water supply in the system, among others.

---

[4] The remaining studies are based in Tanzania, Chile, USA, Ecuador, Philippines, Mexico, China, Algeria, and Morocco.

Figure 2.3 Reasons for modernization (n=37)

Looking at the impacts of modernization, the information on whether modernizing the system leads to actual savings is only provided by 17 case studies, most of which negate water savings (Figure 2.4). Also, less than half of the cases compare water use levels before and after the investment (Figure 2.5). In 7 of them water use decreased, while in 10 water use increased.

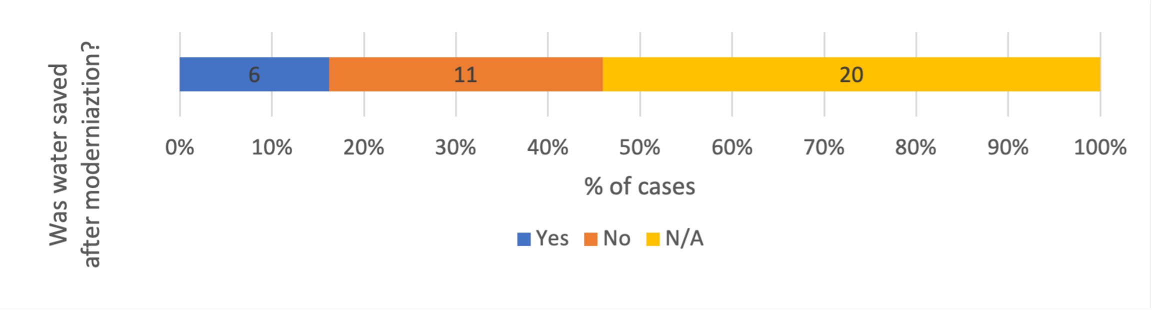


Figure 2.4 Cases with reported actual water savings (n=37)

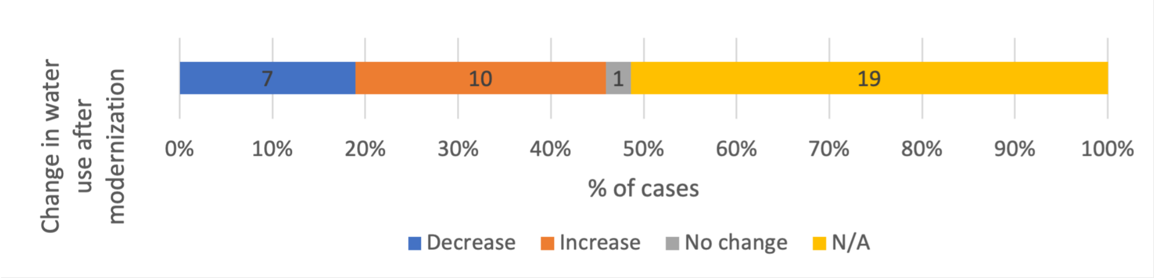


Figure 2.5 Changes in water use after modernization (n=37)

2.4.2. Action situations

Overall, the review resulted in the identification of 12 action situations relevant for irrigation modernization contexts. On average, I found 5 situations per case (standard deviation of 2.4). Below, I describe each of the action situations, i.e., the main decision involved and stakes at hand.

2.4.2.1. Typical action situations

I start with the four basic action situations that are already known from the NAS literature in the irrigation context (Kimmich and Villamayor-Tomas, 2019; Ostrom et al., 1994).

Water allocation (WAL)

Even in contexts where water is abundant, infrastructure constraints (e.g., the limited carrying capacity of conveyance canals) can prevent individual demands to be met at all times across the irrigation system. This is particularly the case for surface irrigation systems and makes water allocation a central action situation in these systems. In this situation, farmers face a coordination problem, i.e., one that requires the ordering of irrigation. I identified the water allocation situation in 21 of the cases reviewed, for example when authors made statements like "water usage is regulated by water use turns and irrigation schedules" (Dessalegn and Merrey 2014:13), or "water users smartly adapted to the rotational water distribution" (van der Kooij et al. 2017:6). Typical water allocation rules in the reviewed papers include turns, irrigation schedules, or timed irrigation, the appropriateness of which depended on the dominant irrigation technology in the systems (Dinar et al., 1997; Ortega-Reig et al., 2017), biophysical aspects (van der Kooij et al., 2015), or the availability of groundwater (Cox and Ross, 2011).

Water application[5] (WAP)

More frequently than not, water is scarce, and farmers face the challenge of deciding how much of it they should use. Throughout the irrigation campaign, farmers seek to apply the optimal amount of water to satisfy their crop requirements. This decision confronts them with the typical CPR appropriation dilemma, especially if their water needs are being higher than water available. I coded this action situation in 21 cases, i.e., whenever authors referred to changes in water withdrawals (e.g., Sanchis-Ibor et al. 2017b), or water use (e.g., Lopez-Gunn et al. 2012a). Additionally, I

---

[5] Although institutional analyses of irrigation management refer to water appropriation, most of the studies here reviewed refer to water application. Also, in those analyses, water appropriation has the connotation of water being consumed; however, as explained by recent irrigation studies, it is important to separate water used from water effectively consumed (see water-saving situation below).

included cases informing about changes (frequently increases) in irrigated area (e.g., Sese-Minguez et al. 2017).

Infrastructure operation and maintenance (IMNT)

In many irrigation communities, operation and maintenance of the system are carried out by farmers themselves via community work or collectively paid laborers (Communal et al., 2016; Kimmich and Villamayor-Tomas, 2019; Lankford, 2004). Yet, collective maintenance efforts are not trivial as the infrastructure itself is a local public good. To cope with free rider issues, water associations usually condition water application to compliance with maintenance rules and engagement in monitoring (Ostrom, 1993). I identified this action situation in 23 of the cases whenever authors referred to "operation practices" or "maintenance of the system". As illustrated in some of these papers, ongoing technological advancements have led to operation and maintenance being outsourced in some occasions to private companies, and financed through fees collected from farmers (Molle and Sanchis-Ibor, 2019; Sanchis-Ibor et al., 2017a).

Monitoring compliance (MON)

As mentioned above, monitoring of rule compliance and/or resource conditions is an essential action situation for successful collective action in irrigation and other CPR contexts (Cox et al., 2010; Tang, 1992). However, the provision of monitoring is also confronted with a public goods problem. Since the benefits from monitoring accrue to the community as a whole, individual farmers lack the incentive to contribute towards it. This action situation was coded from 8 cases, e.g., when studies pointed to the commissioning of guards or ditch riders by the WUAs (Lecina et al., 2005), collective investments in remote monitoring (Lecina et al., 2010a), or monitoring activities carried out by farmers themselves (van der Kooij et al., 2015). As was also illustrated in the papers, monitoring effort is highly contingent on the irrigation technology (e.g., metered water or water in open ditches is easier to track than otherwise) and water sources (e.g., aquifer conditions and extractions are less visible than surface water conditions and extractions) (Lopez-Gunn, 2003; van der Kooij et al., 2015).

2.4.2.2. Focal action situations in the modernization context

Here I introduce the two focal action situations relevant for an analysis of the modernization context.

Infrastructure investment (IINV)

Investing in the improvement or construction of new infrastructure usually involves collective efforts (Lam and Ostrom, 2010; Ostrom et al., 2011). The conversion of flood to sprinkler or drip irrigation, for example, typically involves investments at the system level, such as water storage works and equipment to pressurize water throughout the system, all of which would require collective action among irrigators (Blanke et al., 2007). Similar to in the infrastructure maintenance or the monitoring situations, system level investments benefit the community (to the extent that they, e.g., improve water efficiency or control), which is a disincentive for farmers to contribute to their financing or implementation.[6] I coded for this action situation whenever a study reported on a (collective) modernization decision, which was the case in almost all studies (note that the search strategy required the cases to involve some sort of modernization). Typical investments reviewed included headworks and in-system water storage works, the conversion from flood to sprinkler or drip irrigation, and the lining of canals (Lopez-Gunn et al., 2012; Sese-Minguez et al., 2017; Stambouli et al., 2014).

Water-saving (SAV)

This action situation sheds light on whether modernization investments lead to water savings or not. Water savings can remain within the boundaries of the system (which is mostly the case for groundwater), or flow to the outside environment or external water users (e.g., urban or industrial uses, or other water users), i.e., their value for the community depends on the systems' biophysical conditions. Everything being equal, an increase in irrigation efficiency reduces the amount of water applied per crop, hence freeing up a fraction of the water used before. Lankford (2013:1) proposes labeling this freed-up fraction *paracommons*, i.e., “commons of the material gains from efficiency improvements”. I follow this distinction to trace water savings analytically, finding sufficient evidence in the reviewed cases where water savings were mentioned apart from overall application rates.

The decision to distinguish the water-saving situation from the WAP situation is further supported by the theory of mental accounting (Thaler, 1999). This concept suggests that individuals' decision-making on expenditures and savings depends on separate mental accounts that they hold for financial and material endowments. Applied to the underlying context, I assume that farmers keep distinct mental accounts on the water they are endowed with and the water that is freed-up after an increase in efficiency.

---

[6] More precisely, the modernized system is an impure public good, as farmers enjoy also private benefits from an investment.

Thus, the decision on how to allocate water savings confronts irrigators with a social dilemma, essentially like the dilemma in the WAP situation. Using the freed-up water benefits the water user directly given that they can effectively put that "extra" water to work and increase agricultural production (Berbel and Mateos, 2014; van der Kooij et al., 2015). Alternatively, saving water could allow other irrigators within or outside the system to use it, or sustain the environment. Water does not only have an agronomic function but also contributes to sustaining freshwater ecosystems and the biophysical environment at large, both of which are public goods (Chiesura and de Groot, 2003; Martin-Ortega et al., 2015). For the individual farmer, the benefit from increased crop production likely exceeds the benefit from contributing to the public good (Molle and Tanouti, 2017). Thus, farmers may be more willing to use the freed-up water than to save it, even if the benefits of environmental conservation offset private ones overall. This aligns with the observation that farmers perceive modernization rather as a means to increase production and yield rather than as a means to save water (Benouniche et al., 2014; Ortega-Reig et al., 2017). Overall, I found evidence of this action situation in 15 cases, i.e., whenever authors referred to "water consumed" or "water saved".

2.4.2.3. Modernization-specific action situations

The following action situations are considered auxiliary as they were less frequently reported. However, they can be salient in the context of modernization.

Modernization policy (POL)

In the context of self-governed irrigation systems, governments usually take responsibility for coordinating operations across said systems (Frey et al., 2016). Hence, governmental policies can also influence the incentives of farmers regarding other decisions, like those associated with infrastructure. A modernization-supporting policy was mentioned in 22 of the cases, most of which referred to governmental subsidies towards modernization (Berbel et al., 2019; Mollinga and Bolding, 2004; Renault, 1998). As pointed out by some of the studies, the stakes of government officials at releasing modernization subsidies can be high if these are understood to increase political clout or votes (Molle and Sanchis-Ibor, 2019); especially if irrigators also lobby for them (Kimmich, 2016; Zeitoun et al., 2012). Agricultural policies are more frequently than not shaped by the farm lobby in favor or against certain policies; however, I did not find evidence for action situations related to lobbying activities in the reviewed studies.

Cropping (CRO)

This action situation captures farmers' cropping decisions at the beginning of the cultivation cycle. It was coded when the studies provided information about cropping patterns (Lecina et al., 2010b), cropping calendars (Delos Reyes and Schultz, 2021), or other crop-related decisions. I found this action situation in 22 cases.

As is shown in the reviewed studies, cropping decisions are usually driven by changes in crop prices or input costs; however, changes in water availability (e.g., in the aftermath of modernization investments) can also motivate them (Graveline et al., 2014; Soto-García et al., 2013; Stambouli et al., 2014), which tightly links this action situation to the WAP situation. In dry environments, the availability of irrigation water may encourage farmers to water winter crops or switch to summer crops for their higher productivity or economic returns (Lecina et al., 2010b). Ultimately, if too many farmers within a system grow high water demand crops, issues of water availability and compliance with management rules may arise. Interestingly enough, irrigation associations usually do not have the authority to tell farmers what to grow, even though there are exceptions (Villamayor-Tomas and García-López, 2017).

Energy application and allocation (EAL)

This action situation was found in 12 cases, e.g., whenever energy or electricity costs were mentioned. As shown in the studies, in the context of transitions from flood to drip or sprinkler irrigation, many surface systems have become dependent on energy to pump water into pressurized pipes (e.g., in Spain see Molle and Sanchis-Ibor 2019). This can result in a rise in electricity costs, depending on, e.g., the elevation of the system or the existence of a water storage facility (Jackson et al., 2010; Rodríguez-Díaz et al., 2011). In the context of collective irrigation, energy costs are shared to some degree, which makes energy a CPR and confronts farmers with a similar dilemma to that of the WAP situation. Also, there are infrastructure limitations (i.e., power limitations) that prevent the use of energy simultaneously by any number of farmers. This confronts farmers with a coordination problem that is very similar to that of the WAL situation. The energy application dilemma and coordination problem are evident when the irrigation association collectively owns an energy generation plant, as well as when WUAs sign collective contracts with electricity suppliers that provide energy according to scheduled tariffs (Kimmich and Villamayor-Tomas, 2019; Stambouli et al., 2014; Villamayor-Tomas, 2018)

Water market (MKT)

In some cases, users can exchange water concessions in formal or informal markets. Water markets are supposed to add flexibility to water-use concessions and allocate water to its most productive use (van der Kooij et al., 2015; Wheeler et al., 2020). This includes the possibility for farmers to sell concessions to the government, which can then allocate water towards other productive or environmental uses (Berbel et al., 2015). I found this action situation to be relevant only in one case study (van der Kooij et al., 2015).

Management improvement/adaptation (MIP)

WUAs need to revise managerial practices and adjust them to changing conditions (Playán and Mateos, 2006; van der Kooij et al., 2015). This can also be the case in the aftermath of modernization processes, as existing rules and practices need to be reviewed to adapt to the new technologies (Molle and Sanchis-Ibor, 2019). Some authors argue that managerial improvements are as important as technical improvements to enable sustainable and efficient water management (Lecina et al., 2010a). Changes in management rules, however, are not smooth processes. They require cooperation among farmers, e.g., to diagnose problems and come up with amendments to existing practices (Ostrom, 1990). Moreover, changes in rules usually create winners and losers. That is why some authors have pointed to the importance that said changes are better accomplished whenever stakes at water-use are low (Fernandez and Rainey, 2006; Villamayor-Tomas et al., 2020a). This action situation was found in 9 cases when, e.g., authors included descriptions of institutional reforms associated to modernization projects, such as the establishment of new thematic committees within the WUA (Lankford, 2004) or the automation of administrative processes (Soto-García et al., 2013).

Fertigation (FER)

The change of irrigation practices also affects the choice of fertigation. Fertigation is the injection of fertilizers into irrigation water to save the additional step of applying fertilizer at the field level. In collectively used infrastructures, members must agree on the amount of fertilizer to be injected into the water at the irrigation head, which bears potential for conflict (Ortega-Reig et al., 2017). I coded this action situation in 5 studies, i.e., whenever the possibility for collective fertigation management was mentioned.

2.4.3. Linking the action situations

Table 2.1 displays the count of links for each pair of action situations; the direction of the linkages is from the action situation in the row to the action situation in the column. The linkage matrix with all links characterized qualitatively is provided in S2.

Table 2.1 Numbers of linkages per action situation. Direction of a linkage: from row to column

	WAL	WAP	CRO	IMNT	**IINV**	MON	POL	EAL	MKT	MIP	FER	SAV	***sum***
WAL		2	3		1	1		1					8
WAP	1		3	2	1	1		3				1	12
CRO	2	5			1							3	11
IMNT	4												4
IINV	9	14	14	25		7		7	1	7	6	8	98
MON													0
POL	1	4	2	1	21					2		1	32
EAL	3	2	3	4									12
MKT	1												1
MIP	3		2	3	2								10
FER													0
SAV		2	2										4
sum	24	29	29	35	26	9	0	11	1	9	6	13	192

Abbreviations: WAL=Water allocation, WAP=Water application, CRO=Cropping, IMNT=Infrastructure maintenance and operation, IINV=Infrastructure investment, MON=Monitoring, POL=Policy, EAL=Energy allocation, MKT=Water market, MIP=Management improvement, FER= Fertigation, SAV=Water-saving

Expectedly, I did not find links between all action situations (see blank cells in Table 2.1). The focal action situation, the water-saving situation (SAV), was affected by four other action situations in 13 cases (see also Figure 2.6). A direct link from the infrastructure modernization investment action situation (IINV) to SAV was reported in 8 cases. Out of these, three connect water use efficiency increase to increases in water consumption or depletion, which provides evidence for the rebound effect. In contrast, two cases assert water savings, in one case helping to recharge an aquifer. The remaining three cases are ambiguous, as they acknowledge a fraction of freed-up water associated to modernization without making claims on whether it is allocated towards consumption or conservation. In another 5 cases, SAV was linked to the outcomes of other action situations, including the cropping (CRO), state policy (POL), and water application (WAP) situations.

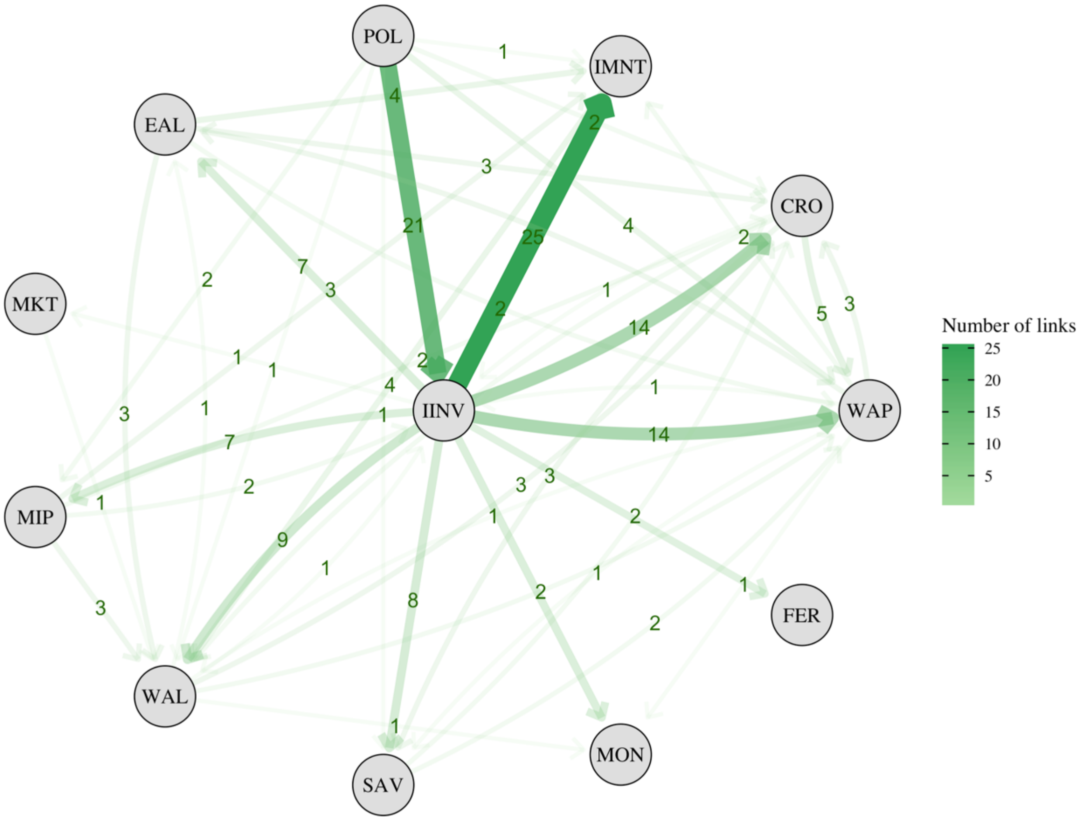


Figure 2.6 Dyads of linked action situations represented as a network. The thickness of the arrows represents the number of studies reporting on that link. Abbreviations: WAL=Water allocation, WAP=Water application, CRO=Cropping, IMNT=Infrastructure maintenance and operation, IINV=Infrastructure investment, MON=Monitoring, POL=Policy, EAL=Energy allocation, MKT=Water market, MIP=Management improvement, FER= Fertigation, SAV=Water-saving

The highest number of links identified (98) originate in the IINV situation. This can be attributed to my explicit focus on modernization studies. The link mentioned by the largest number of cases (25) is that between the IINV and the infrastructure maintenance (IMNT) action situations. In 8 of the 25 cases, the link speaks about an increase in operation and maintenance costs after modernization. Six other cases describe how irrigators had to employ technical staff or a private company for operation and maintenance due to the need for technical expertise; and 5 other cases mention a change in operation and maintenance practices for irrigators themselves. The remaining cases point towards changes in operation rules, improved working conditions, and the introduction of new communication devices such as remote control.

A relatively high number of studies also report links from IINV to the water allocation (WAL), cropping (CRO), and water application (WAP) situations. Links to the WAL situation are recognized in 9 cases. Six out of these report changes in the allocation procedure, mostly (4) from "turns" to "on-demand" allocation. The other three links are associated with cases where modernization led to improved compliance to distribution rules, the requirement for additional coordination effort, and an improved scheduling of water volumes, respectively. Links from the IINV to the cropping (CRO) situation are reported in 14 studies. Nine of them state changing cropping patterns in general or for specific crops, two cases estimate the crops after modernization to be of higher value, and another 2 cases describe the movement towards more intensive cropping or more productive crop. I also found links from the IINV to the water application (WAP) situation in 14 cases. Eight of them point to the expansion of irrigated land, four remark a reduction in water applied (without referring to water consumption), one case describes a reduction in quantities of water supplied, and another case states that the timing of extractions changed after modernization.

IINV was also linked to the monitoring (MON), energy allocation (EAL), and management improvement (MIP) situations in 7 cases each. Linkages typically report changes to automated monitoring or metering systems, increases in energy costs, and institutional and managerial reforms, respectively. The studies also provide linkages from the IINV to the fertigation (FER) situation, pointing to changes in fertilizer management (4 cases) and changes in fertigation costs (2 cases). IINV was linked to the market (MKT) situation in only one case study (van der Kooij et al., 2015): modernization enabled a better control over water allocation and use and this facilitated water exchanges among farmers within the system.

Importantly, authors report an influence of the modernization policy action situation (POL) on the IINV situation in 21 cases. All the cases mentioned governmental (or, in one case, NGO) support for modernizing the irrigation system through subsidies. Conversely, I could not identify links directed at POL, although many authors acknowledge the role of influential groups and lobby organizations in shaping agricultural policies (e.g., Dessalegn and Merrey 2014; van der Kooij et al. 2015; see also discussion).

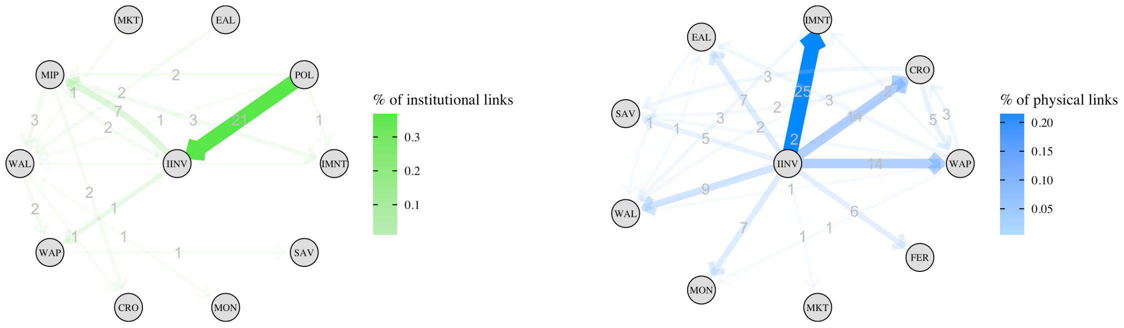


Figure 2.7 Dyads of linked action situations categorized according to their institutional (left) and physical (right) nature. The number shows the count of each link while the thickness and opacity represent their relative occurrence within each category. The network of informational links is omitted here due to the low frequencies.

The exploration of types of linkages reveals additional insights (see Figure 2.7). Overall, out of the 192 links in the database, 29% and 62% are represented by institutional and physical linkages, respectively. The most salient linkages for each category are the subsidies that incentivize modernization investments (institutional; POL → IINV) and the infrastructural modifications that affect operation and maintenance aspects (physical; IINV → IMNT), including working conditions, remote control services, and the hiring of technical staff or the outsourcing of certain tasks.

Institutional links connect 11 out of the 12 action situations, showing the relevance of rules and property rights in collective irrigation governance. This is telling, given that most of the studies reviewed are not institutional analyses per se. Other than modernization subsidies that link POL to IINV (38% of the institutional linkages network), more than three linkages only exist between IINV and MIP (13%), which include mostly institutional reforms of practices.

Physical links are mainly the outcome of the infrastructural change and therefore depart most frequently from IINV to 9 other action situations. Other than the abovementioned links between IINV and IMNT (22% of the physical linkages network) non-deniable links are also identified between IINV and WAP, as e.g., when the new technology allows increases in water application rates and/or irrigated acreage; or between IINV and CRO, as e.g., when the new technology allows for cropping high-value crops.

Additionally, I found only 17 informational links (9% of all links). This may relate to the difficulties that I found in finding linkages that were purely informative and not institutional or physical (see

S2 for examples). Finally, I did not find actor-based linkages; farmers were the main actors involved in all the action situations identified, except for the POL situation. None of the studies reported on, e.g., whether certain organizations or leaders played any role in connecting situations.

2.5. Discussion

Studies addressing the effects and consequences of modernization processes have grown in number over the last years. Much of this literature is based on modelling approaches which simulate the performance of infrastructural and technological reforms under different scenarios (Pérez-Blanco et al., 2020). In this study, I focus on actual evidence on water-use and consumption changes in an attempt to shed new light on the rebound effects associated to said reforms.

2.5.1. A diversity of action situations

Several of my findings illustrate strengths and deficits in the literature on irrigation rebound effects. Although a fair number of studies identify the reasons for modernization improvements, only half measure how water-use was affected by modernization, and only 17 report whether water was saved. These variables need be considered more thoroughly in future research. Among the cases that assess water-use changes, most of them do consider changes in both water application rates and environmental returns, which is good news considering the tendency in the past to ignore the distinction between water use and consumption (Dumont et al., 2013). An important finding of the study is the relatively high and diverse number of action situations that I found per case, which illustrates the need to look at modernization effects from beyond a one to one relationship between the infrastructure investments and water savings (Perry et al., 2017; Sears et al., 2018). Two other findings I want to highlight in this section refer to the potential of pathways thinking and the distinctiveness of the water-saving situation.

2.5.2. The potential of NAS for pathway thinking

The process of linking dyads of action situations has proven itself useful to start uncovering the complexity of modernization investments and their effects on water savings. As explained in the methods, I did not code for networks of action situations due to the difficulties of doing it without much interpretation.

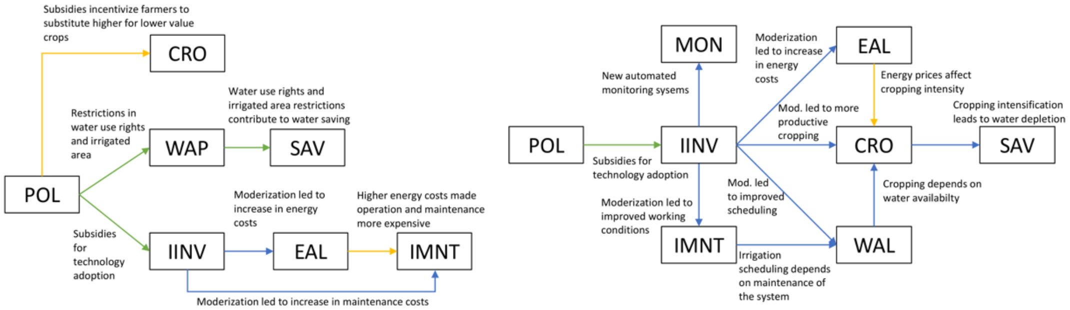


Figure 2.8 Networks of Action Situations for Berbel et al. (2015), left, and Lecina et al. (2010a), right. Note: The networks have been reconstructed by "putting together" the dyads identified for the main analysis. Green arrows represent institutional linkages; blue arrows represent physical linkages; and yellow arrows represent informational linkages.

Thus, although the data shows how studies linked water saving to modernization and to other situations, it does not show whether and how all those situations were interrelated. Despite this, I can still make some speculations about those cross-situational pathways or networks. One example of such a pathway, and an illustration of achieved water savings (Figure 2.8), builds on Berbel et al. (2015). Here, the government partially subsidized the investment costs for installing micro-irrigation (POL → IINV) in the Guadalquivir River basin, Spain. However, farmers needed to comply with certain conditions to receive the subsidies, including the reduction of their water rights and a proscription to increase the irrigated area (POL → WAP). As pointed out by the authors, these constraints contributed to actual water savings (POL→ WAP; WAP → SAV), which are used by the government to fulfill environmental flow standards. Additionally, the case also describes farmers changing cropping patterns (towards crops of higher value, as citrus and vegetable crops) as a result of the policy (POL → CRO), likely because of the reduction in water rights. Moreover, the increased electricity costs after modernization led to higher operation and maintenance costs (IINV→ EAL; EAL → IMNT). Nevertheless, no links connect these action situations to SAV.

On the contrary, Lecina et al. (2010a) illustrates how subsidized investments in sprinkler irrigation (POL → IINV) in the Ebro River basin, Spain, resulted in an increase in the proportion of high-value, high-water demand crops (IINV → CRO) like horticultural crops, orchards, and summer crops; and how these resulted in an increase in evapotranspiration (CRO → SAV) (Figure 2.8). As the authors further illustrate, pressurized irrigation also comes with automated monitoring systems (IINV → MON); and allows for more fine-grained irrigation scheduling (IINV → WAL), which favors increases in crop productivity (WAL → CRO). That being said, the control over irrigation scheduling depends on system maintenance (IMNT → WAL), which is affected by improvements in labor conditions associated to the modernization (IINV → IMNT); and changes in energy prices (among other agricultural input prices) (IINV → EAL) affected the willingness of farmers to intensify cropping (EAL → CRO).

The two examples above demonstrate that the data allow to build analytic narratives in terms of networks of action situations (Kimmich, 2016). As shown above, the networks can vary notably across case studies even if relying on a similar set of action situations. At the same time, it is likely that there are different pathways leading to similar outcomes and quite similar pathways that lead to different outcomes. Further research should identify and test those patterns (see Villamayor-Tomas et al. 2020b for a method that could be adapted for that purpose). This would inform not only better irrigation water-saving practices but also the knowledge on sustainability transitions of socio-technical systems more broadly (Markard et al., 2012). Water-saving policies are promising levers to transition towards more resilient and sustainable irrigation systems (Pérez-Blanco et al., 2020). As illustrated here, governmental policies in the form of infrastructure improvement subsidies can be quite effective at initiating said transitions and result not only in water savings but also in improvements in water allocation and infrastructure maintenance and management.

2.5.3. The distinctiveness of the water-savings situation

The results also show that conceptualizing the water-saving situation as a distinctive situation offers analytical traction to further understand behavioral dynamics behind the rebound effect. Specifically, I posit that water users perceive water savings as a "separate" resource, which is in line with the concepts of the paracommons (Lankford, 2013) and mental accounting (Thaler, 1999). Inherently, the decision of how to allocate the freed-up fraction of water takes the form of a social dilemma. Modernization investments open the possibility to save water for environmental conservation or for other water users; however, farmers perceive modernization as a means to increase production and yield rather than to conserve water (Benouniche et al., 2014). This makes the dilemma of saving vs. using the water nontrivial and calls for policy interventions. Policymakers should consider redistributing the incentives between promoting higher efficiencies and encouraging water conservation, as it has been done, for example, through payment for ecosystem service schemes (Fisher et al., 2010; Lima et al., 2019). Furthermore, CPR theory suggests that social dilemmas in natural resource use can be overcome by collective action and strong institutions (Ostrom, 1990; Poteete et al., 2010). Collective action in irrigation communities is realized by adherence to rules and norms, bottom-up participation in decision-making processes, and collaboration in collective tasks. Thus, water-saving as a goal might be easier to achieve if the community as a whole is persuaded to take ownership over the need to self-organize and to promote water-conserving behavior. The case of the Eastern La Mancha aquifer in Spain, for instance, shows that even in a context of severe overexploitation and mistrust, inducing cooperative behavior among farmers is possible through the promotion of self-regulation by the government, collective control of extractions (monitoring), and cultivation plans (Esteban and Albiac, 2012; Lopez-Gunn, 2003). Similar approaches may work when planning for modernization processes, even though the choice of the correct solution needs to be considered carefully depending on the situation at hand (Villamayor-Tomas et al., 2019).

An interesting point to consider regarding the water-saving situation is the role of biophysical conditions. Whether farmers appropriate water from a surface or groundwater pool might be a relevant biophysical factor influencing the efficiency paradox, as groundwater inherits the characteristics of a local common good and surface water those of a global common good (Stern, 2011).

The data are limited to explain this connection. My review includes 20 surface irrigation cases and 4 groundwater cases. The number of cases where actual water savings were reported is 1 and 2, respectively. Although difficult to interpret, these results trigger some reflections about the role of resource system characteristics. By default, groundwater systems are less visible and therefore incentives for saving water might be lower; however, the incentives for water users in surface systems could also depend on their location along the basin. Further research shall thus explore this and other related conjectures and their influence on the water-saving situation.

2.5.4. Limitations and further research

The study also sheds light on data gaps that should be addressed in further research. First, the only action situation being influenced by IINV and not affecting any other action situations in my review is the monitoring situation MON. This was surprising, as monitoring is a key action situation in the management of CPRs at large (Slough et al., 2021). Further primary research shall explore whether my findings are an artifact of the empirical choices made by the authors of the reviewed studies or are indeed worth explaining.

Second, about half of the studies reviewed do not report water savings, which limits the ability to draw quantitative conclusions about the efficiency paradox. Qualitatively, however, the few studies that do report on water savings can provide interesting insights through the NAS lenses about pathways that would explain the complexities behind the rebound effect. As shown here, the modernization investments on water savings are mediated by what farmers do vis-à-vis water allocation, infrastructure maintenance, monitoring, or energy allocation, and would indeed be key to better understand the origins and potential solutions to the rebound effect.

Third, a blind spot in irrigation research are power dynamics and their influential role in (strategic) decisions. The results show unidirectional linkages from modernization policies POL to other action situations, but not vice versa. Revisiting the case studies from the sample and conducting a keyword search for 'power' and 'lobby*', I found 6 cases that acknowledge power dynamics but fail to establish a direct link between them and modernization policies. Such linkages need to be recognized and incorporated more thoroughly into institutional analyses, as has already been proposed by other scholars (Bennett et al., 2018; Clement, 2010).

The selected approach and choices are also subject to several limitations. First, 24 of the studies included in the review assess Spanish irrigations systems. This is mostly due to my search strategy, which partially relied on 4 preselected studies, 3 of which were based in Spain. Thus, my findings may not be entirely generalizable to a wide diversity of contexts. At the same time, they would apply quite well to the Spanish one. This is not ideal but neither that limiting. The fact that 3 out of the 4 preselected studies were located in Spain is telling of the quality and the momentum of irrigation modernization and rebound studies in this country. It also indirectly speaks about the cutting-edge work that Spanish practitioners and researchers have been carrying out irrigation over the years.

Second, in this study I focused on WUAs that have quite some managerial autonomy with regard to key irrigation management tasks (e.g., water allocation, maintenance, investments etc.); however, it is not unusual that WUAs share some of those tasks with public authorities or others (Frey et al., 2016; Hunt, 1989). Further research shall explore more in detail whether the action situations and linkages identified here would still be relevant in co-managed systems or similar governance arrangements.

Third, although I excluded modelling studies from this study, I recognize the value of this analysis to conceptualize future models that formalize and explore different sets of the linkages presented here. Sensitivity analyses could be quite informative of the cascading effects of different water-saving interventions across action situations (see Kimmich and Villamayor-Tomas 2019 for a similar diagnostic approach).

Fourth, I only identified the existence of linkages from one action situation to another, but not whether the outcome of one action situation had a negative or positive effect on the outcome of the adjacent situation. As was shown, modernization investments affected energy allocation through increased energy costs in a fair number of cases but not in all of them (in one case the effect was the opposite). An explanation of the direction of outcomes needs to be addressed through more thorough analyses of the contextual factors that shape decisions within the action situations, and in particular the modernization and saving situations.

Fifth, finding evidence on informational links was challenging. I found it difficult to disentangle institutional and biophysical links from informational links (as information can refer to both institutions and biophysical conditions). In the end, only the evidence I could not categorize as institutional or biophysical was classified as informational links. Further research should better conceptualize and operationalize informational links as compared to the other types.

Sixth, based on data availability, I decided to include decisions associated with cultivated acreage into the water application situation, and collapsed the energy application and allocation situations into one. This rather inductive approach to draw the boundaries of action situations should, however, be tested and complemented with more deductive approaches, e.g., based on existing archetypes of games (Bruns and Kimmich, 2021; Kimmich and Villamayor-Tomas, 2019).

Finally, I have focused on identifying action situations and linkages. I have not featured the situations themselves (e.g., farmer's decisions and the factors that shape them within each situation) for lack of data. Identifying the situations was indeed already quite challenging because the authors barely get into behavioral dynamics and just focus on variables and outcomes. Thus, the results should be taken with caution: although I am positive about the linkages between the action situations, I cannot say much about the actual decisional dynamics within each, or even whether some of the non-typical action situations here identified (like the cropping, fertigation, or management improvement situations) are totally relevant with regard to strategic decision-making.

2.6. Conclusion

Rebound effects in water consumption in the aftermath of modernization investments in irrigation systems are part of complex processes that have yet to be fully understood. This is all the more important given current pressures around transitioning towards more sustainable agricultural practices (El Bilali, 2019). In principle, the rebound effect can be explained according to the argument that a higher water use efficiency leads to higher productivity, which translates into farmers expanding their irrigated area, intensifying their production, or switching to higher value but also higher water-demand crops. To better frame and understand the behavioral dynamics involved in that process, I conducted a meta-analysis of 37 case studies describing irrigation modernization processes and their effects in collectively managed irrigation systems. I organized the coding around the idea of adjacent action situations in an attempt to shed light on the strategic decision-making situations that farmers are confronted with as they participate in modernization investments and adapt to the new infrastructure.

As shown in the results, it is possible to meaningfully understand relevant variables as either outcomes of or factors in strategic decision-making situations (action situations). Here I identified 12 of those situations, and 192 institutional, physical, and informational links that connect them. Also, the findings illustrate that the connection between modernization and water savings is not as straight forward as frequently portrayed. First, although some studies report on linkages between the modernization investment and water-saving situations, many other studies also link those two situations to situations not strictly connected with modernization processes but to the collective management of irrigation systems (like the water application, infrastructure maintenance, or monitoring situations). Second, a number of those situations potentially involve social dilemmas and coordination problems that need to be integrated in analyses. Here, I pay special attention to the water-saving situation, which I frame as a public goods dilemma that confronts farmers with the decision of reusing the freed-up water (private benefits) or conserving it for reuse by others (common-pool benefits) or environmental purposes (public benefits). The evidence about increases of water-use in the aftermath of modernization processes aligns with economic predictions about the inability of farmers and governments to overcome the dilemma. By the same token, however, this understanding also calls for a more active involvement of farmers and irrigation associations in the management of the dilemma, as they have done already in the context of other collective irrigation management situations. Overall, it would be desirable to incorporate collective action dynamics and institutional analysis more systematically in the study of the manifold drivers of and potential solutions to the rebound effect. This should in turn contribute to more realistic water-saving policies in the sector.

As a final reflection, the collected data shows that there is sufficient material in the literature to speculate about causal pathways that connect modernization investments and water savings. As illustrated here, it is possible to build networks of action situations after a first identification of dyads of them. Advances in this direction will require expanding primary research on the behavioral dynamics within specific situations or pairs of them, as well as new meta-analyses that synthesize primary research.

2.7. References

Albizua, A., Zaga-Mendez, A., 2020. Changes in institutional and social–ecological system robustness due to the adoption of large-scale irrigation technology in <scp>Navarre (Spain)</scp>. Environmental Policy and Governance 30, 167–181. https://doi.org/10.1002/eet.1882

Bandaragoda, D.J., 1998. Need for institutional impact assessment in planning irrigation system modernization, Research Report 21 (IWMI). Colombo, Sri Lanka.

Bardhan, P., 1993. Symposium on Management of Local Commons. Journal of Economic Perspectives. https://doi.org/10.1257/jep.7.4.87

Bennett, A., Acton, L., Epstein, G., Gruby, R.L., Nenadovic, M., 2018. Embracing conceptual diversity to integrate power and institutional analysis: Introducing a relational typology. International Journal of the Commons 12, 330. https://doi.org/10.18352/ijc.819

Benouniche, M., Kuper, M., Hammani, A., Boesveld, H., 2014. Making the user visible: analysing irrigation practices and farmers' logic to explain actual drip irrigation performance. Irrigation Science 32, 405–420. https://doi.org/10.1007/s00271-014-0438-0

Berbel, J., Expósito, A., Gutiérrez-Martín, C., Mateos, L., 2019. Effects of the Irrigation Modernization in Spain 2002–2015. Water Resources Management 33, 1835–1849. https://doi.org/10.1007/s11269-019-02215-w

Berbel, J., Gutiérrez-Martín, C., Rodríguez-Díaz, J.A., Camacho, E., Montesinos, P., 2015. Literature Review on Rebound Effect of Water Saving Measures and Analysis of a Spanish Case Study. Water Resources Management 29, 663–678. https://doi.org/10.1007/s11269-014-0839-0

Berbel, J., Mateos, L., 2014. Does investment in irrigation technology necessarily generate rebound effects? A simulation analysis based on an agro-economic model. Agricultural Systems 128, 25–34. https://doi.org/10.1016/j.agsy.2014.04.002

Blanke, A., Rozelle, S., Lohmar, B., Wang, J., Huang, J., 2007. Water saving technology and saving water in China. Agricultural Water Management 87, 139–150. https://doi.org/10.1016/j.agwat.2006.06.025

Bruns, B., Kimmich, C., 2021. Archetypal games generate diverse models of power, conflict, and cooperation. Ecology and Society 26, 2. https://doi.org/10.5751/ES-12668-260402

Chiesura, A., de Groot, R., 2003. Critical natural capital: a socio-cultural perspective. Ecological

Economics 44, 219–231. https://doi.org/10.1016/S0921-8009(02)00275-6

Clement, F., 2010. Analysing decentralised natural resource governance: proposition for a "politicised" institutional analysis and development framework. Policy Sciences 43, 129–156. https://doi.org/10.1007/s11077-009-9100-8

Communal, T., Faysse, N., Bleuze, S., Aceldo, B., 2016. Effects at Farm and Community Level of the Adoption of Sprinkler Irrigation in the Ecuadorian Andes. Irrigation and Drainage 65, 559–567. https://doi.org/10.1002/ird.2063

Contor, B.A., Taylor, R.G., 2013. Why improving irrigation efficiency increases total volume of consumptive use. Irrigation and Drainage 62, 273–280. https://doi.org/10.1002/ird.1717

Cox, M., Arnold, G., Villamayor-Tomas, S., 2010. A Review of Design Principles for Community-based Natural Resource Management. Ecology and Society 15, art38. https://doi.org/10.5751/ES-03704-150438

Cox, M., Ross, J.M., 2011. Robustness and vulnerability of community irrigation systems: The case of the Taos valley acequias. Journal of Environmental Economics and Management 61, 254–266. https://doi.org/10.1016/j.jeem.2010.10.004

Delos Reyes, M.L.F., Schultz, B., 2021. An assessment of farmers' perspective in support of the modernization of national irrigation systems in the Philippines. Irrigation and Drainage 70, 207–223. https://doi.org/10.1002/ird.2537

Dessalegn, M., Merrey, D.J., 2014. Is 'Social Cooperation' for traditional irrigation, while 'Technology' is for motor pump irrigation? Colombo, Sri Lanka. https://doi.org/10.5337/2015.201

Dinar, A., Rosegrant, M.W., Meinzen-Dick, R., 1997. Water Allocation Mechanisms: Principles and Examples, Policy Research Working Papers. The World Bank. https://doi.org/10.1596/1813-9450-1779

Dumont, A., Mayor, B., López-Gunn, E., 2013. Is the Rebound Effect or Jevons Paradox a Useful Concept for better Management of Water Resources? Insights from the Irrigation Modernisation Process in Spain. Aquatic Procedia 1, 64–76. https://doi.org/10.1016/j.aqpro.2013.07.006

El Bilali, H., 2019. Research on agro-food sustainability transitions: A systematic review of research themes and an analysis of research gaps. Journal of Cleaner Production 221, 353–364. https://doi.org/10.1016/j.jclepro.2019.02.232

Esteban, E., Albiac, J., 2012. The problem of sustainable groundwater management: the case of La

Mancha aquifers, Spain. Hydrogeology Journal 20, 851–863. https://doi.org/10.1007/s10040-012-0853-3

FAO, 2017. Rome Statement on Water Scarcity in Agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy.

Fernandez, S., Rainey, H.G., 2006. Managing Successful Organizational Change in the Public Sector. Public Administration Review 66, 168–176. https://doi.org/10.1111/j.1540-6210.2006.00570.x

Fisher, B., Kulindwa, K., Mwanyoka, I., Turner, R.K., Burgess, N.D., 2010. Common pool resource management and PES: Lessons and constraints for water PES in Tanzania. Ecological Economics 69, 1253–1261. https://doi.org/10.1016/j.ecolecon.2009.11.008

Freire-González, J., 2019. Does Water Efficiency Reduce Water Consumption? The Economy-Wide Water Rebound Effect. Water Resources Management 33, 2191–2202. https://doi.org/10.1007/s11269-019-02249-0

Frey, U.J., Villamayor-Tomas, S., Theesfeld, I., 2016. A continuum of governance regimes: A new perspective on co-management in irrigation systems. Environmental Science & Policy 66, 73–81. https://doi.org/10.1016/j.envsci.2016.08.008

García-Mollá, M., Ortega-Reig, M., Sanchis-Ibor, C., Avellà-Reus, L., 2014. The effects of irrigation modernization on the cost recovery of water in the Valencia Region (Spain). Water Supply 14, 414–420. https://doi.org/10.2166/ws.2013.215

Gómez, C.M., Pérez-Blanco, C.D., 2014. Simple Myths and Basic Maths About Greening Irrigation. Water Resources Management 28, 4035–4044. https://doi.org/10.1007/s11269-014-0725-9

Grafton, R.Q., Williams, J., Perry, C.J., Molle, F., Ringler, C., Steduto, P., Udall, B., Wheeler, S.A., Wang, Y., Garrick, D., Allen, R.G., 2018. The paradox of irrigation efficiency. Science 361, 748–750. https://doi.org/10.1126/science.aat9314

Graveline, N., Majone, B., Van Duinen, R., Ansink, E., 2014. Hydro-economic modeling of water scarcity under global change: an application to the Gállego river basin (Spain). Regional Environmental Change 14, 119–132. https://doi.org/10.1007/s10113-013-0472-0

Hunt, R.C., 1989. Appropriate social organization? Water user associations in bureaucratic canal irrigation systems. Human Organization 48, 79–90. https://doi.org/10.17730/humo.48.1.r508511u785x280v

Jackson, T.M., Khan, S., Hafeez, M., 2010. A comparative analysis of water application and energy consumption at the irrigated field level. Agricultural Water Management 97, 1477–1485. https://doi.org/10.1016/j.agwat.2010.04.013

Kimmich, C., 2016. Can Analytic Narrative Inform Policy Change? The Political Economy of the Indian Electricity–Irrigation Nexus. The Journal of Development Studies 52, 269–285. https://doi.org/10.1080/00220388.2015.1093119

Kimmich, C., 2013. Linking action situations: Coordination, conflicts, and evolution in electricity provision for irrigation in Andhra Pradesh, India. Ecological Economics 90, 150–158. https://doi.org/10.1016/j.ecolecon.2013.03.017

Kimmich, C., Villamayor-Tomas, S., 2019. Assessing Action Situation Networks: A Configurational Perspective on Water and Energy Governance in Irrigation Systems. Water Economics and Policy 05, 1850005. https://doi.org/10.1142/S2382624X18500054

Kiser, L.L., Ostrom, E., 1982. The Three Worlds of Action: A Metatheoretical Synthesis of Institutional Approaches, in: Ostrom, E. (Ed.), Strategies of Political Inquiry. Sage Publications, Beverly Hills.

Köhler, J., Geels, F.W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M.S., Nykvist, B., Pel, B., Raven, R., Rohracher, H., Sandén, B., Schot, J., Sovacool, B., Turnheim, B., Welch, D., Wells, P., 2019. An agenda for sustainability transitions research: State of the art and future directions. Environmental Innovation and Societal Transitions 31, 1–32. https://doi.org/10.1016/j.eist.2019.01.004

Lam, W.F., 1998. Governing irrigation systems in Nepal: institutions, infrastructure, and collective action. Institute for Contemporary Studies.

Lam, W.F., 1996. Improving the performance of small-scale irrigation systems: The effects of technological investments and governance structure on irrigation performance in Nepal. World Development 24, 1301–1315. https://doi.org/10.1016/0305-750X(96)00043-5

Lam, W.F., Chiu, C.Y., 2016. Institutional nesting and robustness of self-governance: the adaptation of irrigation systems in Taiwan. International Journal of the Commons 10, 953. https://doi.org/10.18352/ijc.638

Lam, W.F., Ostrom, E., 2010. Analyzing the dynamic complexity of development interventions: lessons from an irrigation experiment in Nepal. Policy Sciences 43, 1–25. https://doi.org/10.1007/s11077-009-9082-6

Lankford, B., 2013. Resource Efficiency Complexity and the Commons: The paracommons and paradoxes of natural resource losses, wastes and wastages, 1st Editio. ed. Routledge, London, UK. https://doi.org/10.4324/9780203520888

Lankford, B., 2004. Irrigation improvement projects in Tanzania; scale impacts and policy implications. Water Policy 6, 89–102. https://doi.org/10.2166/wp.2004.0006

Lecina, S., Isidoro, D., Playán, E., Aragüés, R., 2010a. Irrigation modernization in Spain: Effects on water quantity and quality-a conceptual approach. International Journal of Water Resources Development 26, 265–282. https://doi.org/10.1080/07900621003655734

Lecina, S., Isidoro, D., Playán, E., Aragüés, R., 2010b. Irrigation modernization and water conservation in Spain: The case of Riegos del Alto Aragón. Agricultural Water Management 97, 1663–1675. https://doi.org/10.1016/j.agwat.2010.05.023

Lecina, S., Playán, E., Isidoro, D., Dechmi, F., Causapé, J., Faci, J.M., 2005. Irrigation evaluation and simulation at the Irrigation District V of Bardenas (Spain). Agricultural Water Management 73, 223–245. https://doi.org/10.1016/j.agwat.2004.10.007

Lima, L.S. de, Ramos Barón, P.A., Villamayor-Tomas, S., Krueger, T., 2019. Will PES Schemes Survive in the Long-term Without Evidence of Their Effectiveness? Exploring Four Water-related Cases in Colombia. Ecological Economics 156, 211–223. https://doi.org/10.1016/j.ecolecon.2018.09.005

Lopez-Gunn, E., 2003. The Role of Collective Action in Water Governance: A Comparative Study of Groundwater User Associations in La Mancha Aquifers in Spain. Water International 28, 367–378. https://doi.org/10.1080/02508060308691711

López-Gunn, E., Mayor, B., Dumont, A., 2012. Implications of the modernization of irrigation systems, Water, Agriculture and the Environment in Spain: Can We Square the Circle? CRC Press.

Lopez-Gunn, E., Zorrilla, P., Prieto, F., Llamas, M.R.R., 2012. Lost in translation? Water efficiency in Spanish agriculture. Agricultural Water Management 108, 83–95. https://doi.org/10.1016/j.agwat.2012.01.005

Ma'Mun, S.R., Loch, A., Young, M.D., 2020. Robust irrigation system institutions: A global comparison. Global Environmental Change 64, 102128. https://doi.org/10.1016/j.gloenvcha.2020.102128

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: An emerging field of research and its prospects. Research Policy 41, 955–967. https://doi.org/10.1016/j.respol.2012.02.013

Martin-Ortega, J., Ferrier, R.C., Gordon, I.J., Khan, S., 2015. Water Ecosystem Services, Water Ecosystem Services: A Global Perspective. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9781316178904

McCarthy, B., Anex, R., Wang, Y., Kendall, A.D., Anctil, A., Haacker, E.M.K., Hyndman, D.W., 2020. Trends in Water Use, Energy Consumption, and Carbon Emissions from Irrigation: Role of Shifting Technologies and Energy Sources. Environmental Science & Technology. https://doi.org/10.1021/acs.est.0c02897

McGinnis, M.D., 2011a. Networks of Adjacent Action Situations in Polycentric Governance. Policy Studies Journal 39, 51–78. https://doi.org/10.1111/j.1541-0072.2010.00396.x

McGinnis, M.D., 2011b. An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework. Policy Studies Journal 39, 169–183. https://doi.org/10.1111/j.1541-0072.2010.00401.x

Möck, M., Vogeler, C.S., Bandelow, N.C., Schröder, B., 2019. Layering Action Situations to Integrate Spatial Scales, Resource Linkages, and Change over Time: The Case of Groundwater Management in Agricultural Hubs in Germany. Policy Studies Journal. https://doi.org/10.1111/psj.12377

Molle, F., Sanchis-Ibor, C., 2019. Irrigation Policies in the Mediterranean: Trends and Challenges, in: Molle, F., Sanchis-Ibor, C., Avellá-Reus, L. (Eds.), Irrigation in the Mediterranean. Global Issues in Water Policy. Springer, Cham, pp. 279–313. https://doi.org/10.1007/978-3-030-03698-0_10

Molle, F., Tanouti, O., 2017. Squaring the circle: Agricultural intensification vs. water conservation in Morocco. Agricultural Water Management 192, 170–179. https://doi.org/10.1016/j.agwat.2017.07.009

Mollinga, P., Bolding, A., 2004. The politics of irrigation reform. Contested policy formulation and implementation in Asia, Africa and Latin America. Ashgate, Aldershot.

Ortega-Reig, M., Sanchis-Ibor, C., Palau-Salvador, G., García-Mollá, M., Avellá-Reus, L., 2017. Institutional and management implications of drip irrigation introduction in collective irrigation systems in Spain. Agricultural Water Management 187, 164–172. https://doi.org/10.1016/j.agwat.2017.03.009

Ostrom, E., 2005. Understanding institutional diversity. Princeton University Press, Princeton, NJ.

Ostrom, E., 1993. Design principles in long-enduring irrigation institutions. Water Resources Research 29, 1907–1912. https://doi.org/10.1029/92WR02991

Ostrom, E., 1990. Governing the commons: the evolution of institutions for collective action, Political Economy Of Institutions and Decisions. Cambridge University Press, Cambridge. https://doi.org/10.2307/3146384

Ostrom, E., Gardner, R., Walker, J., 1994. Rules, Games, and Common-Pool Resources, Rules, Games, and Common-Pool Resources. University of Michigan Press, Ann Arbor, MI. https://doi.org/10.3998/mpub.9739

Ostrom, E., Lam, W.F., Pradhan, P., 2011. Improving irrigation in Asia: Sustainable performance of an innovative intervention in Nepal. Edward Elgar Publishing.

Pérez-Blanco, C.D., Hrast-Essenfelder, A., Perry, C., 2020. Irrigation Technology and Water Conservation: A Review of the Theory and Evidence. Review of Environmental Economics and Policy 14, 216–239. https://doi.org/10.1093/reep/reaa004

Perry, C., Steduto, P., Karajeh, F., 2017. Does improved irrigation technology save water? A review of the evidence (No. 42), Food and Agriculture Organization of the United Nations, Food and Agriculture Organization of the United Nations. Cairo.

Pfeiffer, L., Lin, C.-Y.C., 2014. Does efficient irrigation technology lead to reduced groundwater extraction? Empirical evidence. Journal of Environmental Economics and Management 67, 189–208. https://doi.org/10.1016/j.jeem.2013.12.002

Playán, E., Mateos, L., 2006. Modernization and optimization of irrigation systems to increase water productivity. Agricultural Water Management 80, 100–116. https://doi.org/10.1016/j.agwat.2005.07.007

Poteete, A.R., Janssen, M.A., Ostrom, E., 2010. Working together: Collective action, the commons, and multiple methods in practice, Working Together: Collective Action, the Commons, and Multiple Methods in Practice. Princeton University Press, Princeton and Oxford.

Renault, D., 1998. Modernization of irrigation systems: a continuing process, In Modernization of Irrigation System Operations. Maharashtra (India). 28-30 Oct 1998. Rome, Italy.

Ripple, W.J., Wolf, C., Newsome, T.M., Gregg, J.W., Lenton, T.M., Palomo, I., Eikelboom, J.A.J., Law, B.E., Huq, S., Duffy, P.B., Rockström, J., 2021. World Scientists' Warning of a Climate Emergency 2021. BioScience 71, 894–898. https://doi.org/10.1093/biosci/biab079

Rodríguez-Díaz, J.A., Pérez-Urrestarazu, L., Camacho-Poyato, E., Montesinos, P., 2011. The paradox of irrigation scheme modernization: more efficient water use linked to higher energy demand. Spanish Journal of Agricultural Research 9, 1000. https://doi.org/10.5424/sjar/20110904-492-10

Sanchis-Ibor, C., Boelens, R., García-Mollá, M., 2017a. Collective irrigation reloaded. Re-collection and re-moralization of water management after privatization in Spain. Geoforum 87, 38–47. https://doi.org/10.1016/j.geoforum.2017.10.002

Sanchis-Ibor, C., García-Mollá, M., Avellà-Reus, L., 2017b. Effects of drip irrigation promotion policies on water use and irrigation costs in Valencia, Spain. Water Policy 19, 165–180. https://doi.org/10.2166/wp.2016.025

Sears, L., Caparelli, J., Lee, C., Pan, D., Strandberg, G., Vuu, L., Lin Lawell, C.-Y., 2018. Jevons' Paradox and Efficient Irrigation Technology. Sustainability 10, 1590. https://doi.org/10.3390/su10051590

Sese-Minguez, S., Boesveld, H., Asins-Velis, S., van der Kooij, S., Maroulis, J., 2017. Transformations accompanying a shift from surface to drip irrigation in the Cànyoles Watershed, Valencia, Spain. Water Alternatives.

Slough, T., Rubenson, D., Levy, R., Alpizar Rodriguez, F., Bernedo del Carpio, M., Buntaine, M.T., Christensen, D., Cooperman, A., Eisenbarth, S., Ferraro, P.J., Graham, L., Hartman, A.C., Kopas, J., McLarty, S., Rigterink, A.S., Samii, C., Seim, B., Urpelainen, J., Zhang, B., 2021. Adoption of community monitoring improves common pool resource management across contexts. Proceedings of the National Academy of Sciences 118, e2015367118. https://doi.org/10.1073/pnas.2015367118

Soto-García, M., Martínez-Alvarez, V., García-Bastida, P.A., Alcon, F., Martin-Gorriz, B., 2013. Effect of water scarcity and modernisation on the performance of irrigation districts in south-eastern Spain. Agricultural Water Management 124, 11–19. https://doi.org/10.1016/j.agwat.2013.03.019

Stambouli, T., Faci, J.M., Zapata, N., 2014. Water and energy management in an automated irrigation district. Agricultural Water Management 142, 66–76. https://doi.org/10.1016/j.agwat.2014.05.001

Stern, P.C., 2011. Design principles for global commons: Natural resources and emerging technologies. International Journal of the Commons 5, 213. https://doi.org/10.18352/ijc.305

Tang, S.Y., 1992. Institutions and collective action: Self-governance in irrigation. ICS Press, San Francisco, CA.

Thaler, R.H., 1999. Mental accounting matters. Journal of Behavioral Decision Making 12, 183–206. https://doi.org/10.1002/(SICI)1099-0771(199909)12:3<183::AID-BDM318>3.0.CO;2-F van der Kooij, S., Kuper, M., Zwarteveen, M.Z., de Fraiture, C.M.S., 2017. A user-centred approach to irrigation performance: drip irrigation in the Khrichfa area, Morocco. Water International 42, 794–809. https://doi.org/10.1080/02508060.2017.1373319

van der Kooij, S., Zwarteveen, M., Kuper, M., 2015. The material of the social: the mutual shaping of institutions by irrigation technology and society in Seguia Khrichfa, Morocco. International Journal of the Commons 9, 129–150. https://doi.org/10.18352/ijc.539

Villamayor-Tomas, S., 2018. Polycentricity in the water-energy nexus: A comparison of polycentric governance traits and implications for adaptive capacity of water user associations in Spain. Environmental Policy and Governance 28, 252–268. https://doi.org/10.1002/eet.1813

Villamayor-Tomas, S., 2014. Cooperation in common property regimes under extreme drought conditions: Empirical evidence from the use of pooled transferable quotas in Spanish irrigation systems. Ecological Economics 107, 482–493. https://doi.org/10.1016/j.ecolecon.2014.09.005

Villamayor-Tomas, S., García-López, G., 2017. The influence of community-based resource management institutions on adaptation capacity: A large-n study of farmer responses to climate and global market disturbances. Global Environmental Change 47, 153–166. https://doi.org/10.1016/j.gloenvcha.2017.10.002

Villamayor-Tomas, S., Grundmann, P., Epstein, G., Evans, T., Kimmich, C., 2015. The water-energy-food security nexus through the lenses of the value chain and the institutional analysis and development frameworks. Water Alternatives 8, 735–755.

Villamayor-Tomas, S., Iniesta-Arandia, I., Roggero, M., 2020a. Are generic and specific adaptation institutions always relevant? An archetype analysis of drought adaptation in Spanish irrigation systems. Ecology and Society 25. https://doi.org/10.5751/ES-11329-250132

Villamayor-Tomas, S., Oberlack, C., Epstein, G., Partelow, S., Roggero, M., Kellner, E., Tschopp, M., Cox, M., 2020b. Using case study data to understand SES interactions: a model-centered meta-analysis of SES framework applications. Current Opinion in Environmental Sustainability 44, 48–57. https://doi.org/10.1016/j.cosust.2020.05.002

Villamayor-Tomas, S., Thiel, A., Amblard, L., Zikos, D., Blanco, E., 2019. Diagnosing the role of the state for local collective action: Types of action situations and policy instruments. Environmental Science & Policy 97, 44–57. https://doi.org/10.1016/j.envsci.2019.03.009

Wade, R., 1987. The Management of Common Property Resources: Finding a Cooperative Solution. The World Bank Research Observer 2, 219–234.

https://doi.org/10.1093/wbro/2.2.219

Wang, Y., Long, A., Xiang, L., Deng, X., Zhang, P., Hai, Y., Wang, J., Li, Y., 2020. The verification of Jevons' paradox of agricultural Water conservation in Tianshan District of China based on Water footprint. Agricultural Water Management 239, 106163. https://doi.org/10.1016/j.agwat.2020.106163

Ward, F.A., Pulido-Velazquez, M., 2008. Water conservation in irrigation can increase water use. Proceedings of the National Academy of Sciences 105, 18215–18220. https://doi.org/10.1073/pnas.0805554105

Ward, P.S., Alvi, M.F., Makhija, S., Spielman, D.J., 2020. Cooperation and the management of local common resources in remote rural communities: Evidence from Odisha, India (No. 1940), IFPRI discussion papers.

Wheeler, S.A., Carmody, E., Grafton, R.Q., Kingsford, R.T., Zuo, A., 2020. The rebound effect on water extraction from subsidising irrigation infrastructure in Australia. Resources, Conservation and Recycling 159, 104755. https://doi.org/10.1016/j.resconrec.2020.104755

World Bank, 2020. Water in Agriculture [WWW Document]. URL https://www.worldbank.org/en/topic/water-in-agriculture (accessed 7.22.20).

Zeitoun, M., Allan, T., Al Aulaqi, N., Jabarin, A., Laamrani, H., 2012. Water demand management in Yemen and Jordan: addressing power and interests. The Geographical Journal 178, 54–66. https://doi.org/10.1111/j.1475-4959.2011.00420.x

2.8. Appendix

Figure A 2.1 Extended IAD framework. The thick arrows depict stylized examples for a connection between the outcome of Action Situation (AS) 1 and the contextual factors of Action Situation (AS) 2. Examples are presented in italic. Source: own elaboration.

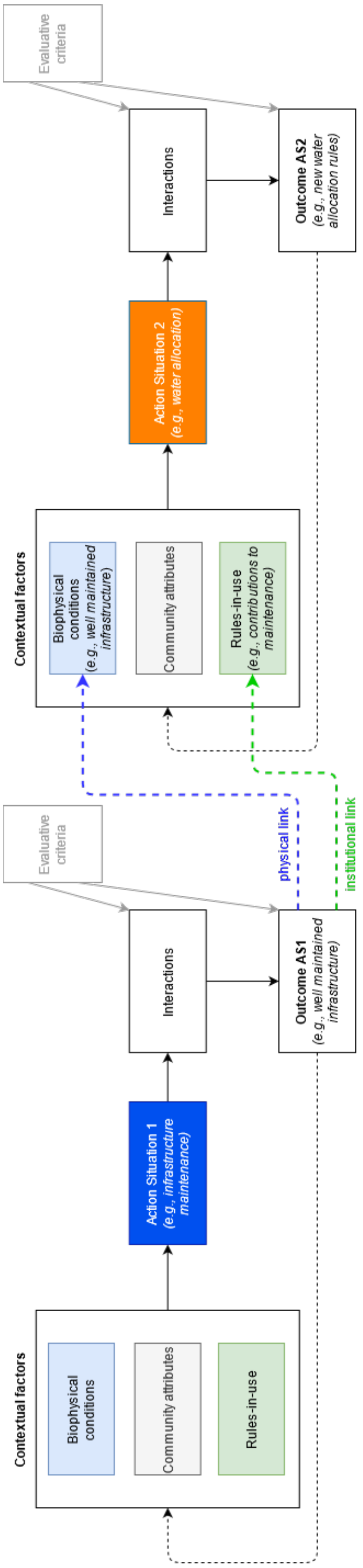


Table A 2.1 List of variables.

	Variable	Definition	Answer
General information			
	Country	Country where the study is located	Name of the country
	Country region	Country region/s where the study is located	Name of the country region/s
	Water basin	Name of the studied water basin/s	Name of the basin/s, n/a
	Irrigation district	Name of the studied irrigation district/s	Name of the district/s, n/a
Biophysical variables			
	Water source	Type of source of the water used in the agricultural production process	Surface water, groundwater, treated wastewater
	Water supply	Quantity of water supplied to the system (per year)	m^3/year, n/a
	Irrigated area	Area of land under irrigation	ha, n/a
Infrastructural and technological characterizations			
A	Technology0	Irrigation technology used before modernization	Furrow, sprinkler, drip
	Technology1	Irrigation technology used after modernization	Furrow, sprinkler, drip
B	Improvement	Type of infrastructural improvement of an existing technology that improves water use efficiency, and which parts of the system it concerns	Canal lining, Capacity increase
	Purpose	Stated purpose of the modernization	Water saving, productivity, supply increase, development
Outcomes			
	Water use	How did water use change after modernization?	Increase, deacrease, no change, n/a
	Water saving	Was water saved after modernization?	Yes, no, n/a
Action Situations			
	WAL	Does the case inform about farmers engaged in interdependent water allocation decisions?	0, 1 (0 for no, 1 for yes)
	WAP	Does the case inform about farmers engaged in interdependent water application decisions?	0, 1

	CRO	Does the case inform about farmers engaged in interdependent cropping decisions?	0, 1
	IMNT	Does the case inform about farmers engaged in collective operation and maintenance decisions?	0, 1
	IINV	Does the case inform about farmers engaged in collective modernization investment decisions?	0, 1
	MON	Does the case inform about farmers engaged in collective monitoring decisions?	0, 1
	POL	Does the case inform about state policies that have a direct effect on decision-making processes?	0, 1
	EAL	Does the case inform about farmers engaged in interdependent energy allocation decisions?	0, 1
	MKT	Does the case inform about the existence of a water market?	0, 1
	MIP	Does the case inform about farmers engaged in interdependent management improvement decisions?	0, 1
	FER	Does the case inform about farmers engaged in collective fertigation decisions?	0, 1
	SAV	Does the case inform about farmers interdependently deciding upon allocating water savings due to efficiency gains?	0, 1

Table A 2.2 Examples for coded linkages.

Information found in article	**Interpretation**
The volume of water flows depends on the maintenance of the structures. (study id:14a, p.273)	One can identify a link between the action situations WAL and IMNT, namely that the outcome of IMNT affects the WAL.
Energy tariff impacts timing of water pumped. (16a, p.71)	The choice of the energy tariff in a collective irrigation system is described by EAL, whose outcome changes the water allocation rule and therefore the WAL.
This higher cost was due to new operating and maintenance costs, particularly because the cost of energy increased from an average of 25 % of total water costs before the investment, to around 43 % after the conversion. (1b, p.666)	As a consequence of the technological conversion from furrow to drip (IINV), operation and maintenance (IMNT) was affected by higher costs. Furthermore, higher energy costs will affect the situation of choosing an energy tariff in EAL, which in turn affects IMNT.

3. The role of irrigation modernization in drought adaptation of water-user associations: A qualitative comparative analysis of the Spanish irrigation sector[7]

3.1. Introduction

With progressing anthropogenic climate change, periods of drought are occurring with increased frequency and severity, resulting in serious consequences for the availability of water resources worldwide (Padrón et al., 2020). The phenomenon of recurring droughts affects particularly countries with low water availability but high needs for water, for example Spain. In the last decade, droughts have become a major problem for Spanish agriculture, as the absence of rainfall over long periods of time exacerbates the already high pressure on freshwater resources for irrigation and other uses. In response, the Spanish government has been a strong advocate for irrigation modernization, replacing many traditional furrow systems with drip or sprinkler irrigation (Berbel et al., 2019; Lopez-Gunn et al., 2012). Such technologies allow farmers to increase the efficiency of water use by augmenting the precision of water application. Since irrigation in Spain is organized via community-based irrigation associations (Thuy et al., 2014), the modernization of infrastructure has implications not only on a technical level, but also on a range of social and institutional dimensions that stem from the collective nature of irrigation water management (Bandaragoda, 1998; Hoffmann and Villamayor-Tomas, 2023; Lopez-Gunn, 2003). In turn, the contribution of infrastructure modernization to successful drought adaptation will equally be shaped by the social and institutional conditions inherent to collective irrigation governance. A noticeable amount of research has addressed the effects of infrastructure modernization on collective irrigation governance on a local level using case studies and from multiple perspectives (e.g., Albizua and Zaga-Mendez, 2020; Garcia-Molla et al., 2020; Poblador et al., 2021; Sese-Minguez et al., 2017; van der Kooij et al., 2015). However, the interaction of modernization and other contextual variables on a more general scale, and in the background of droughts, has received less attention. In this chapter, I use national-level data from Spain to study the conditions under which modernized irrigation systems perform successfully according to their key governance functions in the event of

---

[7] This chapter has been submitted for publication to *Regional Environmental Change* on the 20.09.2023 as: Hoffmann, P., Villamayor-Tomas, S.: The role of irrigation modernization in drought adaptation of water-user associations: A qualitative comparative analysis of the Spanish irrigation sector.

drought. By applying a qualitative comparative analysis (QCA), I aim to answer the following research question: Under which institutional, social, and biophysical conditions does modernization contribute to successful functioning of community-based irrigation systems during drought periods?

The results show differences in the conditions that lead modern and traditional systems to report high satisfaction with WUA functioning during droughts. Modern systems employ a relatively low number of adaptation measures and focus on supply-side strategies. At the same time, traditional systems resort to demand-side measures and experience higher participation to assemblies when a large number of measures is applied. These findings advocate for a consideration of nuanced drought responses of WUAs for policy design. Also, efforts to modernize should consider effects of high efficiencies on path dependencies, collective action dynamics, and environmental goals. The chapter is structured as follows: Section 3.2. reviews the literature regarding community-based common-pool resource management and collective action with a focus on drought adaptation in agriculture. Section 3.3. introduces the QCA methodology and the handling of data. Subsequently in Section 3.4., I present the results. Section 3.5. discusses their interpretation in the light of the reviewed literature, recaps on limitations of the study, and points at avenues for future research. The last section summarizes and concludes this chapter.

3.2. Background

Irrigation systems have received a substantial amount of attention as a paramount example of common-pool resource systems, which hold the capacity for successful self-governance by resource user groups without the intervention of private or state actors (Ostrom, 1990; Tang, 1992). Considerable research endeavor has been dedicated to understanding the conditions that enable successful community-based natural resource management (CBNRM) (Agrawal, 2001; Cox et al., 2010; Ostrom, 1990), and how these conditions interact with each other and further contextual variables of the socio-ecological system at hand (Baggio et al., 2016; Wang and Chen, 2021). Given the present circumstances of climate change, prospective climatic disturbances are expected to have an impact on CBNRM arrangements. In the case of irrigation systems, the increasing frequency and severity of droughts is a major disturbance in this regard (Jiménez-Donaire et al., 2020; Padrón et al., 2020). Consequently, research on the intersection between irrigation governance and drought adaptation has emerged, aiming to understand the conditions under which CBNRM can adequately react to such disturbances (Garrick, 2018; Villamayor-Tomas et al., 2020; Villamayor-Tomas and García-López, 2017). A central theme in CBNRM is the capability of resource users to engage in collective action in order to overcome the dilemmas associated with common-pool resource management in general (Gardner et al., 1990; Poteete et al., 2010) and regarding adaptive responses to droughts and other climatic disturbances in particular (Bisaro and Hinkel, 2016; Villamayor-Tomas, 2018). Many irrigation systems worldwide are managed collectively by water user associations (WUAs) (Garces-Restrepo et al., 2007), whose main tasks are to design rules for water allocation, infrastructure conservation, and conflict resolution. As a direct form of collective action, farmers, as members of these associations, are involved in collective decision-making processes, for instance, via participation in assemblies (Lopez-Gunn, 2003; Thuy et al., 2014; Valero de Palma, 2021). Regarding the response to droughts, possible actions, as for example, temporarily changing cropping plans or water allocation rules (Cody, 2018; Urquijo and De Stefano, 2016; Villamayor-Tomas et al., 2020), building pools to retain water or transferring water from other systems to their own (Chong and Sunding, 2006), require coordination and cooperation among community members (Villamayor-Tomas, 2018). Strategies dealing with water scarcity, as mentioned above, can generally be divided into supply- or demand-oriented strategies (Pereira et al., 2002). Supply-oriented strategies include increasing storage capacity (e.g., by building pools) or developing new sources of water (e.g., by "producing" freshwater via processes of saltwater desalinization or wastewater recycling, or trading via water markets). Demand-oriented strategies aim at reducing irrigation requirements, for example by adapting cropping varieties or decreasing water requirements by increasing the efficiency of water application or improving irrigation conveyance (e.g., by cleaning canals). Scholars usually recommend diversification between both types of strategies, although tradeoffs and interdependencies exist (Iglesias and Garrote, 2015; Pereira et al., 2002).

One demand-side measure which has received particular attention in the last decades is the modernization of irrigation infrastructure with the goal to increase the efficiency of water use. This stipulates transforming traditional gravity irrigation systems into more efficient systems, such as sprinkler or drip. Such technologies lower agricultural water requirements and reduce the negative impacts of droughts by, ceteris paribus, decreasing the demand for water. Demand-oriented policies in form of investments for infrastructure improvements have become particularly popular in Spain, where various waves of technological modernization have been launched in the 1990s as a response to the severe droughts of that decade (Berbel et al., 2019). These transformations induced numerous changes in the institutional sphere of collective irrigation governance (García-Mollá et al., 2020; Ortega-Reig et al., 2017; Poblador et al., 2021), and entailed also some unexpected consequences. Generating water savings for the purpose of ecosystem maintenance as a stated goal occurred only under specific circumstances (Berbel et al., 2015; Sanchis-Ibor et al., 2017b), while water depletion has increased after modernization in other cases (González-Cebollada, 2015; Sampedro-Sánchez, 2022). Similarly, many WUAs have seen an explosion of energy needs to run the pressurized systems, leading to an unforeseen rise in electricity costs (Espinosa-Tasón et al., 2020; Rodriguez-Diaz et al., 2011). Infrastructure improvements have also affected other decision-making processes in the context of collective governance, such as water allocation and application, cropping, fertigation, monitoring, and management improvement (Hoffmann and Villamayor-Tomas, 2023).

Despite some if its unintended negative drawbacks, irrigation modernization remains a major strategy in preparing the Spanish agricultural sector for future periods of drought (Gómez-Espín, 2019). Ideally, the effectiveness of modernization should translate into improved water management and the ability of WUAs to perform regarding key governance functions, such as water allocation, infrastructure management, as well as relatively low levels of conflict. To better assess the contribution of modernization to drought adaptation, it is therefore necessary to understand the contextual conditions, in which the system operates. There is not much knowledge, however, about what those conditions are. In this chapter, I uncover some of the conditions that lead to satisfactory performance of WUAs during droughts with and without a high degree of modernization. I am interested in unveiling how modernization associates with factors such as number and type of drought adaptation measures, participation rates in collective decision-making processes, and availability of water sources in shaping satisfaction of water users with the key governance tasks of WUAs during droughts. Understanding such factors can guide the design of targeted and efficient strategies towards collective drought adaptation in irrigation.

3.3. Methods and Data

3.3.1. Qualitative Comparative Analysis

Given the interest in exploring how modernization interacts with other contextual conditions, such as the number and type of drought adaptation measures, participation in collective decision-making and availability of water sources, for successful irrigation governance, this chapter applies a qualitative comparative analysis (QCA). QCA is a technique applicable to analyze empirical data based on set-theoretic considerations. It allows for causal interpretation of independent variables in their conjoint effect (compared to inferring isolated effects via regression analysis) on an outcome variable and is particularly useful for analyzing small to medium n-sized datasets (Vis, 2012). Due to the nature of the data (see further below), I chose the crisp-set version of QCA (csQCA) for the analysis. Rooted in set-theory and Boolean logic, cases are assigned to be either inside or outside of a set, which are, as put by Mahoney (2010:7, cited by Schneider and Wagemann, 2012), "boundaries that define zones of inclusion and exclusion". Each case potentially belongs to many sets, depending on how many of the set's characteristics can possibly be determined. It is the task of the researcher to conclude on the sets of interest for the analysis. Once the membership of the observed cases in each corresponding set has been established, the goal of the analysis is to identify which conditions (i.e., set memberships), or configurations thereof, are necessary or sufficient for the outcome of interest. Hence, this method specifically looks at configurations of variables in their joint effect on an outcome, rather than their effect in isolation (Rihoux and Ragin, 2009; Schneider and Wagemann, 2012).

The analysis of sufficiency, the core analysis of QCA, unfolds by constructing a truth table. The truth table displays all theoretically possible combinations of conditions (2^k with k being the number of conditions) together with information on whether these combinations are represented by the cases. Unrepresented combinations are called *logical reminders*. Based on the truth table, the next step involves logical minimization, which aims at finding the simplest possible expression associated with the outcome. Three types of solutions can be generated: the conservative (or complex), the parsimonious, and the intermediate solution. The conservative solution considers only those configurations of conditions for which the outcome is present and excludes logical reminders and contradictions. In contrast, the minimization algorithm for the parsimonious solution includes all logical reminders into the minimization process. Hence, it treats all logical reminders as if they were to produce the outcome, did they manifest in reality (Dusa, 2019). As implied by the name, the intermediate solution attempts to settle for a middle ground by including logical reminders that align with theoretical directional expectations and excluding logical reminders that consist of incoherent or untenable configurations.

In the past, QCA has received notable attention in the field of common-pool resource theory. For instance, Ragin et al. (2003) applied QCA to expand on Wade's (1989) analysis of factors for successful collective action in rural India. Lam and Ostrom (2010) study under which conditions improved irrigation infrastructure contributes to irrigation performance over time in Nepal, and Soliman et al. (2021) analyze the institutional performance of shared pumping systems as a form of collective action in Egyptian irrigation systems. QCA has further been applied to study the robustness of Ostrom's design principles for CBNRM (Baggio et al., 2016; Ma'Mun et al., 2020) and coordination in polycentric water governance systems (Pahl-Wostl and Knieper, 2023). Closest to this chapter, Villamayor-Tomas et al. (2020) investigate how different paths or combinations of adaptation institutions contribute to successful drought adaptation in Spanish irrigation systems.

For this analysis, I resort to two medium-n-sized databases of survey data. The data were collected at the XIV and XV National Congresses of Spanish Water User Associations, which took place in 2018 and 2022, respectively. Throughout the duration of the two congresses, the data were collected via in-person surveys using pen and paper with participants of the congress (mainly representatives of Spanish WUAs), who were selected randomly based on convenience sampling and with the goal to maximize sample size. In total, 80 individuals completed the survey in 2018, and 63 in 2022. The surveys encompassed topics such as WUA's responses to droughts, dynamics of water use and administration, irrigation related energy use, participation in social movements, and satisfaction with WUA management. The time required to complete the survey was approximately 15 minutes.

3.3.2. Variable selection

The two surveys were almost identical, and the identification of variables shared by both surveys was based on theoretical and practical considerations. Eventually, I selected six variables for the analysis, which are described hereafter and summarized in Table 3.2. The corresponding survey questions can be found in Table A 3.1 in the Appendix. The final dataset used for the analysis counts 61 observations after eliminating missing values and duplicates.

Outcome: Performance as measured by satisfaction with WUA functioning (SATISF)

The overall satisfaction of community members with the operations of the WUA during droughts regarding some of its main governance tasks as a measure of performance was chosen as the outcome variable. Previous research has identified a strong relationship between user satisfaction and collective action (Kadirbeyoglu and Özertan, 2015; Naiga, 2021). This allows an interpretation of the average satisfaction score as a measure of how well a WUA can function in its overall responsibilities during droughts. In this case, the overall satisfaction score is determined based on the satisfaction with water allocation, infrastructure conservation, the ability to acquire resources from other communities, and internal electricity management, all precisely during droughts. In the survey, the satisfaction with each of the aspects was retrieved on a 5-point Likert-scale and overall satisfaction was calculated as the average of the sum of the scores attributed to each of the four aspects. If a WUA indicated that they do not use electricity, the average score was calculated based on the first three managerial aspects, as the fourth did not apply.

Number of collective drought adaptation measures (MEAS)

This variable counts the number of collective adaptation measures that the WUA typically organizes to cope with droughts. In general, it can be assumed that the higher the number of adaptation measures available to a WUA, the higher the effectiveness in adapting to droughts and the more satisfied farmers are. On the contrary, many measures increase the cost of coordination and cooperation (Villamayor-Tomas, 2018), and could also indicate that a WUA faces challenges in identifying the most suitable approach to adapt and therefore needs to implement various instruments, while low numbers of measures might work well for other WUAs.

Degree of modernization (MODERN)

This variable accounts for the degree of modernization, which is the presence of sprinkler or drip irrigation technology in a WUA. It therefore distinguishes between WUAs with mainly traditional (furrow) infrastructure and WUAs with mainly modern (sprinkler/drip) systems. It is also possible for a single WUA to incorporate a combination of all three systems. High levels of technification affect operation and maintenance of the irrigation system and pose additional cooperation and coordination challenges for farmers (Ortega-Reig et al., 2017; Poblador et al., 2021). To avoid confusion with WUAs that modernize (fully or partially) as a drought adaptation measure, I henceforth refer to WUAs that are already modernized (i.e., more than 50% of the system is sprinkler or drip) as "*modern*". Contrarily, WUAs with a modernization rate of 50% or less will be referred to as *"traditional"*.

Demand vs. supply measures (DMAJ)

As outlined previously, drought adaptation measures are usually divided into demand and supply measures (Pereira et al., 2002; Urquijo and De Stefano, 2016). I created a binary variable indicating whether a WUA chooses predominantly demand measures or supply measures (see Calibration). Table 3.1 below presents how the measures were categorized into supply- and demand.

Table 3.1 List of supply and demand measures included in the survey.

Supply	***Demand***		
River water pumping	Leaving land uncultivated	Canal improvement	Changes in water allocation
Utilization of "drought wells" (*pozos de sequia*)	Reduction of high-water consuming crop	Ground levelling	Water exchanges within the community
Utilization of desalinated water	Introduction of new crop	Pool construction	
Utilization of recycled/treated water	Restricting more than one harvest per year	Switching to drip or sprinkler irrigation	

Assistance to assemblies (ASIST)

Collective decision-making in WUAs is usually done during assemblies to which all members are invited (and expected) to participate. These assemblies have the objective to allow farmers to decide upon and control the activities of the WUA, and raise important topics and pressing issues regarding current developments (Valero de Palma, 2021). The rate of participation in the assemblies is therefore a point of reference for community engagement and involvement. Especially during droughts, high participation can potentially indicate two situations. On the one hand, higher participation could have a positive impact on satisfaction if it allows the community to better resolve pressing issues. On the other hand, high participation could also be a sign for low satisfaction with matters, motivating farmers that usually abstain from assemblies to show up. In the survey, the representatives were asked whether the assistance to assemblies increases, decreases, or does not change during droughts, i.e., whether droughts are an incentive for higher rates of collective action.

Availability of water sources (FUENTE)

Finally, the capacity of WUAs to adapt to drought periods also depends on how many sources of water are at their disposal. The availability of multiple sources of water provides the community with alternatives in cases the supply shortages of one source which increases their adaptive capacity, but can also influence related water costs (Urquijo and De Stefano, 2016).

3.3.3. Calibration

Although there are some drawbacks associated with the use of crisp-sets, for example the loss of information as a result of dichotomization or more sensitivity with regards to the decisions made by the researcher (Schneider and Wagemann, 2012; Skaaning, 2011), I chose csQCA for two reasons. First, two of the selected variables for the analysis are binary by nature, reducing the potential loss of empirical information from dichotomization. Second, Rihoux (2006) contends that dichotomized data is the preferred approach for small and medium-n analyses when working with case-based knowledge as opposed to other techniques. This aligns with the conditions of this study.

CsQCA implies calibrating non-binary variables into a dichotomized version, i.e., assigning them for each case to be either inside or outside the corresponding set. For the four non-binary variables, I first visualized their distribution (see Appendix A2) and set the calibration threshold according to context-dependent considerations. Table 3.2 summarizes the selected variables and how they were calibrated. The result of this process yields the calibrated data matrix. A detailed description of the calibration process and the corresponding tables and figures are presented in the Appendix (A2). This calibrated data matrix is the basis for the subsequently presented analyses of necessity and sufficiency, which were conducted using version 3.18 of the "QCA" package (Dusa, 2019) in R Version 4.2.1 (R Core Team, 2022).

Table 3.2 Variable information.

Variable	**Summary**	**Calibration value**	
		0 if	**1 if**
SATISF	Satisfaction calculated as the average satisfaction score from 4 (or 3) Likert-score responses	2.9 or less on the average satisfaction score	3 or more on the average satisfaction score
MEAS	Number of collective drought adaptation measures executed by the WUA	3 or less collective measures	4 or more collective measures
DMAJ	Indicates whether demand or supply measures dominate WUA responses to drought	more supply than demand measures or tied	more demand than supply measures
ASIST	Indicates whether the assistance to assemblies changes during droughts	assistance decreased or remained unchanged	assistance increased
MODERN	Degree of modernization of the WUA	50% or more of the irrigation system are gravity systems	more than 50% of the irrigation system are sprinkler or drip systems
FUENTE	Number of water sources available to the WUA	only one water source available	more than one water source available

3.4. Results

In the following, I present the results of the analysis for the joint dataset of the years 2018 and 2022. For completeness, the same analysis for the two years separately is presented in Appendix A5. Similarly, Appendix A6 reports on the analysis of the absence of outcome.

3.4.1. Analysis of necessity

The analysis of necessity for each condition and both the presence and absence of the outcome is presented in Table 3.3. In order to be accounted for as necessary, consensus among QCA scholars recommends consistency scores to be at least 0.9 (Ragin, 2006). As the scores in Table 3.3 show, the variable DMAJ reaches a consistency score of 0.944 for the absence of the outcome variable. Hence, employing a majority of demand-side measures is a necessary condition for low satisfaction with WUA performance during droughts. At the same time, its coverage is relatively low (0.347), indicating that DMAJ and ~SATISF appear together only in 34.7% of the occurrences of DMAJ, making DMAJ a rather irrelevant necessary condition. The same variable, however, reaches a non-deniable consistency score of 0.744 and a coverage of 0.653 for the presence of the outcome.

Table 3.3 Analysis of necessity.

	Presence of outcome (SATISF)		**Absence of outcome (~SATISF)**	
	Consistency (inclN)	Coverage (covN)	Consistency (inclN)	Coverage (covN)
MEAS	0.442	0.633	0.611	0.367
DMAJ	0.744	0.653	**0.944**	0.347
ASIST	0.535	0.657	0.667	0.343
MODERN	0.488	0.677	0.556	0.323
FUENTE	0.256	0.733	0.222	0.267
~MEAS	0.558	0.774	0.389	0.226
~DMAJ	0.256	0.917	0.056	0.083
~ASIST	0.465	0.769	0.333	0.231
~MODERN	0.512	0.733	0.444	0.267
~FUENTE	0.744	0.696	0.778	0.304

3.4.2. Analysis of sufficiency

The truth table (Table 3.4) shows how the 61 observations group into 23 rows (the 9 logical reminders are omitted from the table). 15 out of the 23 configurations found in my data are unambiguous, while 8 constitute potential contradictions, i.e., they can equally lead to the presence and the absence of an outcome. Rihoux and Ragin (2009:48) suggest best practices on how to deal with these cases. Similar to Villamayor-Tomas et al. (2020) and in line with the suggestion by Rihoux and Ragin (2009), I count configurations with an inclusion score of 0.75 or higher as sufficient for the outcome, and configurations with an inclusion score of 0.25 or lower as not causing the outcome. This resolves four contradictory rows (9, 11, 15 and 29). The remaining 4 contradicting configurations (rows 12, 13, 25 and 31) have inclusion scores of 0.5 and 0.6. These can hardly be resolved and will be omitted from the minimization process.

Table 3.4 Truth table. Logical reminders omitted. Contradictions in grey.

#row	**Variables**						**n**	**incl**	**Cases (WUA)**
	MEAS	DMAJ	ASIST	MODERN	FUENTE	OUT			
1	0	0	0	0	0	1	2	1	2, 4
3	0	0	0	1	0	1	1	1	33
4	0	0	0	1	1	1	1	1	25
7	0	0	1	1	0	1	1	1	58
8	0	0	1	1	1	1	2	1	16, 21
9	0	1	0	0	0	1	6	0.83	3, 5, 7, 48, 50, 57
10	0	1	0	0	1	1	2	1	30, 54
11	0	1	0	1	0	1	4	0.75	10, 18, 43, 60
12	*0*	*1*	*0*	*1*	*1*	*C*	*2*	*0.5*	*9, 42*
13	*0*	*1*	*1*	*0*	*0*	*C*	*5*	*0.6*	*29, 39, 40, 44, 61*
14	0	1	1	0	1	0	1	0	24
15	0	1	1	1	0	1	4	0.75	1, 15, 17, 56
17	1	0	0	0	0	1	1	1	13
18	1	0	0	0	1	0	1	0	22
22	1	0	1	0	1	1	2	1	11, 32
24	1	0	1	1	1	1	1	1	52
25	*1*	*1*	*0*	*0*	*0*	*C*	*4*	*0.5*	*14, 19, 45, 59*
27	1	1	0	1	0	1	1	1	31
28	1	1	0	1	1	1	1	1	12
29	1	1	1	0	0	1	5	0.8	27, 36, 46, 53, 55
30	1	1	1	0	1	1	1	1	26
31	*1*	*1*	*1*	*1*	*0*	*C*	*12*	*0.5*	*6, 8, 20, 23, 28, 34, 35, 37, 38, 41, 47, 49*
32	1	1	1	1	1	0	1	0	51

I choose to report the conservative (or complex) solution as it makes the least assumptions about logical remainders. For completeness, the (enhanced) parsimonious and intermediate solutions are shown and commented on in Appendix A3. The minimization, carried out by the Quine-McCluskey algorithm, yields an overall inclusion score of 0.886 and a coverage score of 0.721 for the solution formula, while consisting of seven configurations that cover 31 cases (excluding the four contradictory cases 43, 15, 50, and 55). The single configurations that lead to the outcome, each representing one solution, are displayed in Table 3.5. Coverage scores for the individual solutions range from 0.186 (i.e., 18.6% of the cases with present outcome are covered by the solution) to 0.047. The identification of WUAs covered by the solution configurations is presented in Table A 3.8 in the Appendix.

Table 3.5 Conservative solution. (**) marks contradictory cases.

	Configuration	Inclusion	Coverage	Cases (WUA)
1	~MEAS*MODERN*~FUENTE	0.8	0.186	33, 58, 10, 18, 43**, 60, 1, 15**, 17, 56
2	+ ~MEAS*DMAJ*~ASIST*~MODERN	0.875	0.163	3, 5, 7, 48, 50**, 57, 30, 54
3	+ ~MEAS*~DMAJ*MODERN	1	0.116	33, 25, 58, 16, 21
4	+ MEAS*DMAJ*ASIST*~MODERN	0.833	0.116	27, 36, 46, 53, 55**, 26
5	+ MEAS*~DMAJ*ASIST*FUENTE	1	0.07	11, 32, 52
6	+ ~DMAJ*~ASIST*~MODERN*~FUENTE	1	0.07	2, 4, 13
7	+ MEAS*DMAJ*~ASIST*MODERN	1	0.047	31, 12

To account for relevance, I focus the description and discussion of results only on those solution configurations that cover at least 5 cases or have a coverage above 10%, hence on solution terms 1-4, which encompass 22 WUAs.

The first solution combines the absence of MEAS and FUENTE with the presence of MODERN. Thus, the cases covered by this configuration are modern WUAs that, during droughts, do not carry out more than three collective drought adaptation measures and that count on one sole source of water. This configuration contains two contradictory cases (inclS = 0.8) but covers 18.6% of the cases with high satisfaction. Solution configuration 2 contains the absence of MEAS, ASIST, and MODERN, and the presence of DMAJ. This describes the high satisfaction of traditional WUAs, which rely primarily on a low number of demand-side oriented adaptation measures and exhibit a low to normal rate of participation to assemblies during droughts. This configuration includes one contradictory case (inclS = 0.875) and covers 16.3% of the cases with present outcome. Configurations 1 and 2 have the highest coverage scores within the complete solution. The third configuration consists of the absence of conditions MEAS and DMAJ, but the presence of MODERN. This is reflected in the situation of 5 modern WUAs that implement no more than three collective measures, which are rather supply-oriented. This solution covers 11.6% of satisfied communities and does not include contradictory cases (inclS = 1). Finally, solution 4 also covers 11.6% of the cases with high performance and constitutes of the presence of MEAS, DMAJ, ASIST and the absence MODERN. Hence, it comprises traditional WUAs that apply more than three measures, which are by majority demand-oriented, and that experience an increased participation to assemblies during droughts.

Looking at the geographical distribution of the communities represented by each solution, I find that the results are spatially robust since, except for one configuration, there is no clear pattern after which the WUAs cluster relating to their location (Figure 3.1). The exception are WUAs grouping in solution configuration 3 (green dots in Figure 3.1) which scatter particularly around the East of Spain. Hence, in this sample, particularly eastern WUAs characterize as modern and with a low number of drought adaptation measures, which are mainly supply-oriented.

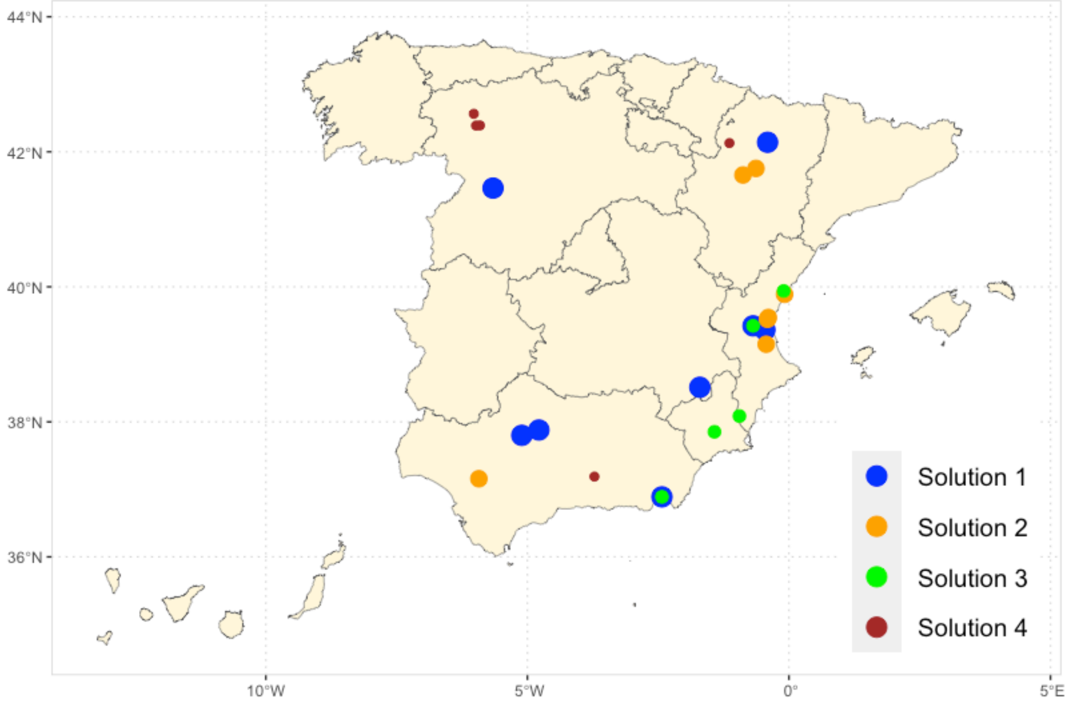


Figure 3.1 Geographical location of the WUAs covered by each solution within Spain. The size of the dots decreases with the coverage of the solutions to visualize overlaps. The map was created using the "mapSpain" R package, version 0.8.0 (Hernangómez, 2023).

3.5. Synthesis and Discussion

The results allow observing some interesting patterns. I find that both modern and traditional WUAs appear in the four major solution configurations, which means that neither type inherently outperforms the other during droughts. The modern systems represented in configurations 1 and 3 are characterized by resorting to a comparatively small number of measures (i.e., absence of MEAS). This absence of a high number of measures could indicate that having a modern irrigation system reduces the need for multiple measures during droughts, which aligns with the goal of modernization programs to support climate change adaptation (Berbel et al., 2019). Conversely, modernization has justified the centralization of management, including the hiring of new, specialized professionals (Poblador et al., 2021; Sanchis-Ibor et al., 2017a). This centralization can, in turn crowd out the initiative of farmers to engage collectively in drought adaptation measures (Garrick, 2018).

An in-depth exploratory revision of the measures reveals the number and type of measures that both modern and traditional systems from the main solution configurations have reported to engage in (Table 3.6). I divide the demand-side measures into three categories: cropping strategies, institutional change, and infrastructure improvements. Cropping strategies include leaving parts of the land uncultivated, switching to less water-consuming crop, or restricting the number of harvests per year. Institutional change strategies refer to drought-related alterations of the rules-in-use, such as allocation turns and water exchanges within the community (internal water markets). Infrastructure improvements aim at increasing the efficiency of water use or conveyance by improving canals, levelling ground, installing sprinkler or drip irrigation, or constructing pools to regulate water flow. As confirmed in Table 3.6, modern systems rely relatively more on supply than demand-side measures overall, while the opposite is true for traditional systems. Within the demand-side measures, those related to institutional change are the only ones that remain relatively equal across the two WUA types.

Table 3.6 Specification of adaptation measures. Modern systems are represented by configurations 1 and 3 (11 cases), traditional systems are represented by configurations 2 and 4 (12 cases).

	Modern systems	***Traditional systems***
Supply-side measures		
River pumping	0	0
Drought wells	2	4
Use of desalinated water	3	0
Use of recycled/treated water	2	0
TOTAL	*7*	*4*
Demand-side measures		
Cropping strategies		
Leaving land uncultivated	2	4
Reducing high-water consuming crop	1	7
Introduction of new cropping varieties	0	0
Restricting more than one harvest per year	0	2
Institutional change		
Changes in water allocation	7	7
Water exchanges within the community	1	2
Infrastructure improvements		
Canal improvement	0	5
Ground levelling	0	1
Pool construction	1	3
Sprinkler or drip installation	6	4
TOTAL	*18*	*33*

Many demand-side measures, especially infrastructural improvements, have the goal to increase the efficiency of an irrigation system, and modern irrigation system can reach theoretical efficiencies of up to 95% (van der Kooij et al., 2013). Thus, increasing efficiency in these kinds of systems is more difficult than doing so in less efficient ones (e.g., furrow-dominated systems), making supply-side strategies a necessary alternative. If these supply-side strategies imply augmenting the use of groundwater via wells, this can have negative repercussions on the availability of water for environmental purposes. Moreover, many of the modern systems have been modernized with the goal to increase productivity (Berbel et al., 2019; Hoffmann and Villamayor-Tomas, 2023; Lopez-Gunn et al., 2012). The sole focus on a specific development trajectory (in this case modernization and intensification with the goal of productivity maximization) can reduce a system's flexibility to react to social, political, or biophysical changes, and can therefore create path dependencies towards maintaining this goal. Ultimately, path dependencies can reduce the resilience and adaptive capacity of the system in the long term (Anderies et al., 2006). The factors mentioned explain why modern systems are more likely to resort to supply-side measures than furrow-dominated systems.

The traditional systems characterized by solution configurations 2 and 4 depict a different scenario. In both configurations, WUAs resort primarily to demand rather than supply-side measures (Table 3.6). However, the two solutions differ in terms of the assistance to assemblies and the number of drought adaptation measures. In configuration 2 (7 cases), WUAs employ few measures and do not observe an increase in assistance to assemblies, while in configuration 4 (5 cases), they do implement more than three measures and observe an increase in assistance to assemblies. I ascribe this observation to the possibility that a higher number of measures requires a high degree of coordination effort and participation (Villamayor-Tomas, 2018). Alternatively, it is also possible that the higher number of measures reflects struggles to cope with droughts and therefore conflicts, which would, in turn, justify enhanced communication among farmers (i.e., via assemblies).

Previous research has categorized WUAs into Asian and American types. Villamayor-Tomas et al. (2020) undertake such a distinction and find that, on the one hand, Asian type WUAs are characterized by small irrigation systems with low levels of technification and relatively informal or customary-based management rules, but with high levels of social capital. One the other hand, American type WUAs rely less on social capital and inter-personal relationships to coordinate and rely more on formal rules, centralized coordination and high degrees of professionalization and technification (García-Mollá et al., 2020; Sanchis-Ibor et al., 2017a). My results, which distinguish WUAs in configurations 1 and 3 from those in configurations 2 and 4 in their degree of modernization and their propensity toward different adaptation strategies, echo the findings from Villamayor-Tomas et al. (2020).

In general, three of the four major solution configurations (1-3) indicate that a lower number of collective adaptation measures is rather associated with satisfaction than a high number thereof. From a theoretical perspective, a high number of measures can be interpreted in two ways: On the one hand, a greater number and variety provides a more diverse toolkit for WUAs to react to droughts, which has been associated with the ability to cope with droughts (Urquijo and De Stefano, 2016). On the other hand, transaction costs increase with the management of a higher number of measures (Villamayor-Tomas, 2018). In this case, one or few measures might be sufficient (i.e., more transaction cost efficient) for a particular WUA to cope well with drought periods. My findings tend to support the latter conjecture.

Finally, although appearing as a condition in configuration 1, the interpretation of the FUENTE variable is ambiguous. In theory, more diversity in water supply should expectedly increase adaptive capacity to droughts and therefore satisfaction with drought management. The major solution terms, however, include only the absence of the FUENTE condition, i.e., WUAs disposing of only one source of water (which makes sense regarding to the relatively high consistency [0.744] and coverage [0.696] scores in the analysis of necessity). This could be attributed to the notion that more sources can lead to higher water costs (Urquijo and De Stefano, 2016). Alternatively, based on the data, it could be due to the skewed distribution of the variable, as almost 75% of the WUAs reported having only one source at their disposal. It also shows that having "only" one source of water does not constitute a problem for WUAs to cope with droughts, and my results demonstrate some of the conditions, under which WUAs with only one source can reach high satisfaction.

Limitations and future research

Although this study is a first step into identifying contextual conditions around modernization conducive to satisfaction with water governance during droughts, the results are far from conclusive. There is an almost uncountable number of contextual variables which potentially influence the success of collective action for drought adaptation (Agrawal, 2001; Wang and Chen, 2021). This study covers only a small number of conditions that I considered relevant and had access to, given the limited possibility to extract data via surveys. Future research could explore more contexts and include other variables that researchers might consider important, such as physical (e.g., water consumption), institutional (e.g., water allocation mechanisms, monitoring rules), socio-economic (e.g., WUA income), or cognitive (e.g., frames and perceptions) variables. Evidently, this listing is far from exhaustive, and researchers should choose variables based on availability and practical relevance in the context of their study. Furthermore, and particularly relevant for future applications of QCA, researchers should collaborate closer with WUAs to extract more qualitative information that can better inform the solutions generated by the analysis. These solutions can be reported back to the WUAs involved, giving them the possibility to discuss the solutions in general assemblies. Although my study aimed at illustrating the results with qualitative insights, survey data is limited in its possibility to provide it. Other methods, e.g., focus groups or participatory research practices, could increase the richness of qualitative data and therefore of the results of QCA. Finally, I acknowledge that the sampling was not purely random. This might raise questions about generalizability and representation of my sample regarding the entirety of WUAs in Spain. Although the mapping of the major solution cases did not show spatial concentration, future efforts could attempt different methods of data collection.

3.6. Conclusion

Improving our understanding of drought adaptation in agriculture in the context of climate change is crucial for a sustainable functioning of the sector. The aim of this chapter was to identify configurations of selected conditions that contribute to the performance of WUAs (as measured by the satisfaction of farmers) during droughts. To this end, I applied csQCA on national-level survey data from Spain. My results advance existing knowledge in various directions. First, modern WUAs in this sample show high satisfaction rates in configuration with relatively few but supply-side measures. While these strategies may offer short-term relief, they can also put a system's environmental sustainability into question. Moreover, as efficiency gains in already modernized WUAs face diminishing returns, improving efficiency even further is challenging to attain. Nevertheless, many modern systems were modernized with the goal to increase productivity. Sticking to this goal can create path dependencies of water use intensification and preclude environmental goals together with degrading resilience and adaptive capacity.

Traditional WUAs do not encounter these issues. The traditional WUAs in my sample show high satisfaction scores in combination with predominantly demand-side measures. Compared to modern ones, traditional WUAs can resort to various efficiency-increasing demand-side measures more easily (as efficiency increases are more easily achievable). This shows that modernization is not a unique solution to drought adaptation for furrow-dominated irrigation systems. In turn, a large number of adaptation measures may face high transaction costs associated with their coordination. Future research could expand on the association between transaction costs and collective drought adaptation. Identifying such costs and making them more tangible can be useful in supporting cost-benefit analysis of relevant policies. Also, further research could delve into how traditional WUAs cope with those transaction costs as their reliance on a higher number of measures does not seem to be associated with low satisfaction.

My attempt to map WUAs according to their characterization by the solution configurations motivates further exploration on whether spatial patterns can be detected and confirmed, which could help tailoring policy recommendations to geographical areas. Moving forward, policymaking should consider the nuanced responses of modern and traditional WUAs. Targeted policy interventions could encourage different strategies and objectives for modern WUAs, potentially enhancing their resilience to drought. Lastly, efforts to modernize WUAs should carefully consider their impact on collective action dynamics and on the availability of ecological stocks and flows, ensuring that the benefits of enhanced efficiency do not undermine community engagement and environmental goals. In essence, this chapter contributes valuable insights into the intricate interplay between modern and traditional WUAs, drought adaptation strategies, institutional dynamics, and community engagement. These findings provide a foundation for refining water resource management policies that are responsive to diverse needs and promote sustainable practices in response to growing water challenges.

3.7. References

Agrawal, A., 2001. Common property institutions and sustainable governance of resources. World Development 29, 1649–1672. https://doi.org/10.1016/S0305-750X(01)00063-8

Albizua, A., Zaga-Mendez, A., 2020. Changes in institutional and social–ecological system robustness due to the adoption of large-scale irrigation technology in Navarre (Spain). Environmental Policy and Governance 30, 167–181. https://doi.org/10.1002/eet.1882

Anderies, J.M., Ryan, P., Walker, B.H., 2006. Loss of Resilience, Crisis, and Institutional Change: Lessons from an Intensive Agricultural System in Southeastern Australia. Ecosystems 9, 865–878. https://doi.org/10.1007/s10021-006-0017-1

Baggio, J.A., Barnett, A.J., Perez-Ibara, I., Brady, U., Ratajczyk, E., Rollins, N., Rubiños, C., Shin, H.C., Yu, D.J., Aggarwal, R., Anderies, J.M., Janssen, M.A., 2016. Explaining success and failure in the commons: The configural nature of Ostrom's institutional design principles. International Journal of the Commons 10, 417–439. https://doi.org/10.18352/ijc.634

Bandaragoda, D.J., 1998. Need for institutional impact assessment in planning irrigation system modernization, Research Report 21 (IWMI). Colombo, Sri Lanka.

Berbel, J., Exposito, A., Gutierrez-Martin, C., Mateos, L., Expósito, A., Gutiérrez-Martín, C., Mateos, L., 2019. Effects of the Irrigation Modernization in Spain 2002–2015. Water Resources Management 33, 1835–1849. https://doi.org/10.1007/s11269-019-02215-w

Berbel, J., Gutiérrez-Martín, C., Rodríguez-Díaz, J.A., Camacho, E., Montesinos, P., 2015. Literature Review on Rebound Effect of Water Saving Measures and Analysis of a Spanish Case Study. Water Resources Management 29, 663–678. https://doi.org/10.1007/s11269-014-0839-0

Bisaro, A., Hinkel, J., 2016. Governance of social dilemmas in climate change adaptation. Nature Climate Change 6, 354–359. https://doi.org/10.1038/nclimate2936

Chong, H., Sunding, D., 2006. Water Markets and Trading. Annual Review of Environment and Resources 31, 239–264. https://doi.org/10.1146/annurev.energy.31.020105.100323

Cody, K.C., 2018. Flexible water allocations and rotational delivery combined adapt irrigation systems to drought. Ecology and Society 23, art47. https://doi.org/10.5751/ES-10193-230247

Cox, M., Arnold, G., Villamayor-Tomas, S., 2010. A Review of Design Principles for Community-based Natural Resource Management. Ecology and Society 15, art38. https://doi.org/10.5751/ES-03704-150438

Dusa, A., 2019. QCA with R. A Comprehensive Resource. Springer International Publishing, Cham, Switzerland. https://doi.org/10.1007/978-3-319-75668-4

Espinosa-Tasón, J., Berbel, J., Gutiérrez-Martín, C., 2020. Energized water: Evolution of water-energy nexus in the Spanish irrigated agriculture, 1950–2017. Agricultural Water Management 233, 106073. https://doi.org/10.1016/j.agwat.2020.106073

Garces-Restrepo, C., Vermillion, D., Muñoz, G., 2007. Irrigation Management Transfer: Worldwide Efforts and Results, FAO Water Reports. Rome, Italy.

García-Mollá, M., Ortega-Reig, M., Boelens, R., Sanchis-Ibor, C., 2020. Hybridizing the commons. Privatizing and outsourcing collective irrigation management after technological change in Spain. World Development 132, 104983. https://doi.org/10.1016/j.worlddev.2020.104983

Gardner, R., Ostrom, E., Walker, J.M., 1990. The Nature of Common-Pool Resource Problems. Rationality and Society 2, 335–358. https://doi.org/10.1177/1043463190002003005

Garrick, D.E., 2018. Decentralisation and drought adaptation: Applying the subsidiarity principle in transboundary river basins. International Journal of the Commons 12, 301–331. https://doi.org/10.18352/ijc.816

Gómez-Espín, J.M., 2019. Modernización de regadíos en España: experiencias de control, ahorro y eficacia en el uso del agua para riego. Agua y Territorio 69–76. https://doi.org/10.17561/at.13.3972

González-Cebollada, C., 2015. Water and energy consumption after the modernization of irrigation in Spain. pp. 457–465. https://doi.org/10.2495/SD150401

Hernangómez, D., 2023. mapSpain: Administrative Boundaries of Spain. https://doi.org/10.5281/zenodo.5366622

Hoffmann, P., Villamayor-Tomas, S., 2023. Irrigation modernization and the efficiency paradox: a meta-study through the lens of Networks of Action Situations. Sustainability Science 18, 181–199. https://doi.org/10.1007/s11625-022-01136-9

Iglesias, A., Garrote, L., 2015. Adaptation strategies for agricultural water management under climate change in Europe. Agricultural Water Management 155, 113–124. https://doi.org/10.1016/j.agwat.2015.03.014

Jiménez-Donaire, M. del P., Giráldez, J.V., Vanwalleghem, T., 2020. Impact of Climate Change on Agricultural Droughts in Spain. Water 12, 3214. https://doi.org/10.3390/w12113214

Kadirbeyoglu, Z., Özertan, G., 2015. Power in the Governance of Common-Pool Resources: A comparative analysis of irrigation management decentralization in Turkey. Environmental Policy and Governance 25, 157–171. https://doi.org/10.1002/eet.1673

Lam, W.F., Ostrom, E., 2010. Analyzing the dynamic complexity of development interventions: lessons from an irrigation experiment in Nepal. Policy Sciences 43, 1–25. https://doi.org/10.1007/s11077-009-9082-6

Lopez-Gunn, E., 2003. The Role of Collective Action in Water Governance: A Comparative Study of Groundwater User Associations in La Mancha Aquifers in Spain. Water International 28, 367–378. https://doi.org/10.1080/02508060308691711

Lopez-Gunn, E., Zorrilla, P., Prieto, F., Llamas, M.R., 2012. Lost in translation? Water efficiency in Spanish agriculture. Agricultural Water Management 108, 83–95. https://doi.org/10.1016/j.agwat.2012.01.005

Ma'Mun, S.R., Loch, A., Young, M.D., 2020. Robust irrigation system institutions: A global comparison. Global Environmental Change 64, 102128. https://doi.org/10.1016/j.gloenvcha.2020.102128

Naiga, R., 2021. Determinants of User Satisfaction and the Implications on Collective Action in Demand-driven Water Governance in Rural Uganda. International Journal of Rural Management 17, 93–119. https://doi.org/10.1177/0973005220968957

Ortega-Reig, M., Sanchis-Ibor, C., Palau-Salvador, G., García-Mollá, M., Avellá-Reus, L., 2017. Institutional and management implications of drip irrigation introduction in collective irrigation systems in Spain. Agricultural Water Management 187, 164–172. https://doi.org/10.1016/j.agwat.2017.03.009

Ostrom, E., 1990. Governing the commons: the evolution of institutions for collective action, Political Economy Of Institutions and Decisions. Cambridge University Press, Cambridge. https://doi.org/10.2307/3146384

Padrón, R.S., Gudmundsson, L., Decharme, B., Ducharne, A., Lawrence, D.M., Mao, J., Peano, D., Krinner, G., Kim, H., Seneviratne, S.I., 2020. Observed changes in dry-season water availability attributed to human-induced climate change. Nature Geoscience 13, 477–481. https://doi.org/10.1038/s41561-020-0594-1

Pahl-Wostl, C., Knieper, C., 2023. Pathways towards improved water governance: The role of polycentric governance systems and vertical and horizontal coordination. Environmental Science and Policy 144, 151–161. https://doi.org/10.1016/j.envsci.2023.03.011

Pereira, L.S., Oweis, T., Zairi, A., 2002. Irrigation management under water scarcity. Agricultural Water Management 57, 175–206. https://doi.org/10.1016/S0378-3774(02)00075-6

Poblador, N.N., Sanchis-Ibor, C., Kuper, M., 2021. The Landing of Parachuted Technology: Appropriation of Centralised Drip Irrigation Systems by Irrigation Communities in the Region of Valencia (Spain). Water Alternatives 14, 228–247.

Poteete, A.R., Janssen, M.A., Ostrom, E., 2010. Working together: Collective action, the commons, and multiple methods in practice, Working Together: Collective Action, the Commons, and Multiple Methods in Practice. Princeton University Press, Princeton and Oxford.

R Core Team, 2022. R: A language and environment for statistical computing.

Ragin, C.C., 2006. Set Relations in Social Research: Evaluating Their Consistency and Coverage. Political Analysis 14, 291–310. https://doi.org/10.1093/pan/mpj019

Ragin, C.C., Shulman, D., Weinberg, A., Gran, B., 2003. Complexity, Generality, and Qualitative Comparative Analysis. Field Methods 15, 323–340. https://doi.org/10.1177/1525822X03257689

Rihoux, B., 2006. Qualitative Comparative Analysis (QCA) and Related Systematic Comparative Methods. International Sociology 21, 679–706. https://doi.org/10.1177/0268580906067836

Rihoux, B., Ragin, C.C., 2009. Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) and Related Techniques. SAGE Publications, Inc., 2455 Teller Road, Thousand Oaks California 91320 United States. https://doi.org/10.4135/9781452226569

Rodriguez-Diaz, J.A., Perez-Urrestarazu, L., Camacho-Poyato, E., Montesinos, P., Rodríguez-Díaz, J.A., Pérez-Urrestarazu, L., Camacho-Poyato, E., Montesinos, P., 2011. The paradox of irrigation scheme modernization: more efficient water use linked to higher energy demand. Spanish Journal of Agricultural Research 9, 1000. https://doi.org/10.5424/sjar/20110904-492-10

Sampedro-Sánchez, D., 2022. Can Irrigation Technologies Save Water in Closed Basins? The effects of Drip Irrigation on Water Resources in the Guadalquivir River Basin (Spain). Water Alternatives 15, 501–522.

Sanchis-Ibor, C., Boelens, R., García-Mollá, M., 2017a. Collective irrigation reloaded. Re-collection and re-moralization of water management after privatization in Spain. Geoforum 87, 38–47. https://doi.org/10.1016/j.geoforum.2017.10.002

Sanchis-Ibor, C., García-Mollá, M., Avellà-Reus, L., 2017b. Effects of drip irrigation promotion policies on water use and irrigation costs in Valencia, Spain. Water Policy 19, 165–180. https://doi.org/10.2166/wp.2016.025

Schneider, C.Q., Wagemann, C., 2013. Doing Justice to Logical Remainders in QCA: Moving Beyond the Standard AnalysisSchneider, C.Q., Wagemann, C., 2013. Doing Justice to Logical Remainders in QCA: Moving Beyond the Standard Analysis. Political Research Quarterly 66, 211–220. https://doi.org/. Political Research Quarterly 66, 211–220. https://doi.org/10.1177/1065912912468269

Schneider, C.Q., Wagemann, C., 2012. Set-Theoretic Methods for the Social Sciences. Cambridge University Press. https://doi.org/10.1017/CBO9781139004244

Sese-Minguez, S., Boesveld, H., Asins-Velis, S., van der Kooij, S., Maroulis, J., 2017. Transformations accompanying a shift from surface to drip irrigation in the Cànyoles Watershed, Valencia, Spain. Water Alternatives.

Skaaning, S.-E., 2011. Assessing the Robustness of Crisp-set and Fuzzy-set QCA Results. Sociological Methods & Research 40, 391–408. https://doi.org/10.1177/0049124111404818

Soliman, A., Thiel, A., Roggero, M., 2021. Institutional Performance of Collective Irrigation Systems: A Fuzzy Set Qualitative Comparative Analysis in the Nile Delta of Egypt. Sustainability 13, 1103. https://doi.org/10.3390/su13031103

Tang, S.Y., 1992. Institutions and collective action: Self-governance in irrigation. ICS Press, San Francisco, CA.

Thuy, L.A.D.R., de Palma, J. V, López-Gunn, E., 2014. The institutional organization of irrigation in Spain and other Mediterranean countries, in: Martinez-Santos, P., Aldaya, M.M., Llamas, R. (Eds.), Integrated Water Resources Management in the 21st Century: Revisiting the Paradigm. CRC Press, pp. 277–301.

Urquijo, J., De Stefano, L., 2016. Perception of Drought and Local Responses by Farmers: A Perspective from the Jucar River Basin, Spain. Water Resources Management 30, 577–591. https://doi.org/10.1007/s11269-015-1178-5

Valero de Palma, J., 2021. Gestión y gobernanza de las comunidades de regantes, in: Jornada: La Gestión de Las Comunidades de Regantes. Madrid.

van der Kooij, S., Zwarteveen, M., Boesveld, H., Kuper, M., 2013. The efficiency of drip irrigation unpacked. Agricultural Water Management 123, 103–110. https://doi.org/10.1016/j.agwat.2013.03.014

van der Kooij, S., Zwarteveen, M., Kuper, M., 2015. The material of the social: the mutual shaping of institutions by irrigation technology and society in Seguia Khrichfa, Morocco. International Journal of the Commons 9, 129–150. https://doi.org/10.18352/ijc.539

Villamayor-Tomas, S., 2018. Disturbance features, coordination and cooperation: an institutional economics analysis of adaptations in the Spanish irrigation sector. Journal of Institutional Economics 14, 501–526. https://doi.org/10.1017/S1744137417000285

Villamayor-Tomas, S., García-López, G., 2017. The influence of community-based resource management institutions on adaptation capacity: A large-n study of farmer responses to climate and global market disturbances. Global Environmental Change 47, 153–166. https://doi.org/10.1016/j.gloenvcha.2017.10.002

Villamayor-Tomas, S., Iniesta-Arandia, I., Roggero, M., 2020. Are generic and specific adaptation institutions always relevant? An archetype analysis of drought adaptation in Spanish irrigation systems. Ecology and Society 25. https://doi.org/10.5751/ES-11329-250132

Vis, B., 2012. The Comparative Advantages of fsQCA and Regression Analysis for Moderately Large-N Analyses, Sociological Methods and Research. https://doi.org/10.1177/0049124112442142

Wade, R., 1989. Village Republics: economic conditions for collective action in South India. Cambridge University Press.

Wang, R.Y., Chen, T., 2021. Integrating Institutions with Local Contexts in Community-Based Irrigation Governance: A Qualitative Systematic Review of Variables, Combinations, and Effects. International Journal of the Commons 15, 320. https://doi.org/10.5334/ijc.1108

3.8. Appendix

A1. Survey questions for selected variables

Table A 3.1 Survey questions for selected variables

Variable	Survey question (Spanish - *original*)	Survey question (English - *translated*)
SATISF (OUTCOME)	¿Del 1 al 5 cuán satisfecho cree que los regantes de su comunidad están con los siguientes aspectos relativos a la administración de la comunidad? (1= muy insatisfechos, 5= muy satisfechos). Marcar NA si no aplica. ▪ Reparto de agua ▪ Conservación de la infraestructura ▪ Conseguir recursos de otras entidades ▪ Gestión de la electricidad	From 1 to 5 how satisfied do you think the irrigators in your community are with the following aspects related to the administration of the community (1= very dissatisfied, 5= very satisfied). Mark NA if not applicable ▪ Water distribution ▪ Infrastructure maintenance ▪ Obtaining resources from other entities ▪ Electricity management
MEAS	¿Qué medidas de las de más abajo *ha organizado la comunidad de regantes* para hacer frente a las sequías? Marque con una X todas las que apliquen. [Listado de medidas]	Which of the measures below has the irrigation community organized to cope with droughts? Mark with an X all that apply. [List of measures]
MODERN	¿Qué porcentaje de la superficie de su comunidad se riega por...? ▪ Inundación ▪ Aspersión ▪ Goteo (Nota: tiene que sumar 100%)	What percentage of your community's surface area is irrigated by…? ▪ Furrow ▪ Sprinkler ▪ Drip (Note: must add up to 100%)
DMAJ	-	-
ASIST	¿Durante sequías, cambia el número de miembros que asisten a las asambleas?	During droughts, does the number of members attending assemblies change?
FUENTE	¿Qué fuentes de agua utiliza su comunidad durante años de disponibilidad normal de agua?	What water sources does your community use during years of normal water availability?

A2. Calibration process and rationale

The initial raw data matrix is presented in Table A 3.2.

Table A 3.2 Raw data matrix

ID	WUA	SATISF	ASIST	MODERN	FUENTE	MEAS	DMAJ
1	Tamarite La Concepcion	3,3	1	65	1	3	1
2	Junta de Acendados de la Huerta de Murcia	3	0	0	1	3	0
3	Villamayor	3	0	0	1	2	1
4	Canal de Castellon	3,3	0	0	1	2	0
5	Alzira	4	0	50	1	3	1
6	Sector IV	3,8	1	100	1	4	1
7	Burjasot, Godella y Rocafort	3,3	0	0	1	3	1
8	Colectividad Puente Genil	2	1	100	1	4	1
9	Benferri	2,5	0	100	2	3	1
10	Sectores X y XI	5	0	100	1	3	1
11	Acequia de tormos	3	1	0	2	5	0
12	Palazote la Herrera	4	0	100	2	5	1
13	Favara	3	0	0	1	6	0
14	Acequia Arabuelia	2	0	10	1	6	1
15	Zairin	2,2	1	85	1	3	1
16	San Onofre Torromendo	3,5	1	100	4	3	0
17	Canal de la margen izquierda del Genil	4,8	1	80	1	3	1
18	Juan Partinez Parras	4	0	100	1	3	1
19	Llanos de Camarera	2,7	0	10	1	11	1
20	CG Regantes del Canal del Paramo de Leon	4	1	80	1	4	1
21	CR de Alhama de Murcia	3,3	1	80	2	3	0
22	Margen Derecha Segura	2,8	0	50	5	4	0
23	CR Godolleta	1,8	1	100	1	4	1
24	Sindicato de Riegos Canal de Tauste	2,7	1	5	2	3	1
25	Canal de la Cota 100 Margen derecho del rio Mijos	4,5	0	70	2	1	0
26	CG Bardenas	3,3	1	28	2	5	1
27	SC Embalse Villameca	3,3	1	40	1	4	1
28	Benacher y Faitanar	2,8	1	60	1	5	1
29	Canal Imperial Aragon	4,5	1	0	1	2	1
30	CR Bajo Guadalquivir	4	0	50	2	2	1
31	CR Casinos	4,7	0	100	1	5	1
32	CR Tajo Segura Librilla	5	1	25	2	6	0
33	Cuatro Vegas Almeria	4	0	100	1	1	0
34	CR de Guadiana	3,5	1	100	1	7	1
35	CUAS Mancha Occidental II	1,5	1	100	1	7	1
36	CR Ciudad de Santa Fe	3,8	1	40	1	4	1
37	CR Montijo	4	1	75	1	5	1

38	Santa Maria del Paramo Alto	3,2	1	85	1	4	1
39	Sector Nr. 5	3	1	25	1	3	1
40	Canal de Castañon	2	1	10	1	2	1
41	Presa Cerrajera	2,8	1	65	1	6	1
42	CR Sector 2 Los Tollos	4,8	0	100	2	2	1
43	CR del Paramo Alto	2,5	0	80	1	3	1
44	CR Pantano del Rumblar	2	1	40	1	2	1
45	Sector Nr. 3	4	0	0	1	6	1
46	CR del Canal alto de Villares	4,7	1	30	1	5	1
47	Sindicato de Riegos de Soller	3,2	1	60	1	4	1
48	Sindicato de Riegos de Rabal	3,7	0	0	1	3	1
49	CR El Ferial	1,5	1	100	1	5	1
50	CR Urdan (CR Nuez de Ebro)	1,5	0	0	1	2	1
51	CR Presa de la Manga	2	1	70	2	5	1
52	CR Totana	3,5	1	92	3	5	0
53	CR de Tres Consejo	4,7	1	30	1	5	1
54	Real Acequia Moncada	4	0	0	2	3	1
55	CR Presa de la Vega de Abajo	1	1	30	1	4	1
56	CR de la Margen Izquierda del Rio Bembezar	4	1	100	1	3	1
57	CR de Burriana	3,7	0	2	1	3	1
58	CR San Pedro Apostol de Godilleta	4,5	1	100	1	2	0
59	CR Villadangos del Paramo	3,7	0	10	1	6	1
60	CR La Virgen del Aviso	5	0	100	1	2	1
61	CR Losa del Obispo	3,3	1	5	1	2	1

The variable DMAJ and ASIST are binary by nature and therefore do not require calibration. The calibration of the remaining variables into binary form was based on their visualizations (see Figure A 3.1) and theoretical considerations. The rationale behind each selected threshold is briefly explained in the following.

SATISF

The average satisfaction score over the governance related aspects ranges from 1 to 5. Overall satisfaction on average was higher than the arithmetic mean of 2.5. I therefore opted for a cutoff value of 3, i.e., a score of 3 or more accounts for the presence of satisfaction, and a score below 3 for the absence of satisfaction. This is justified based on the distribution of the data points, ensuring variation in the dataset, and based on the consideration that 3 is the neutral value on a 5-point Likert scale, suggesting that scores below 3 typically represent dissatisfaction, and values above 3 represent satisfaction.

MEAS

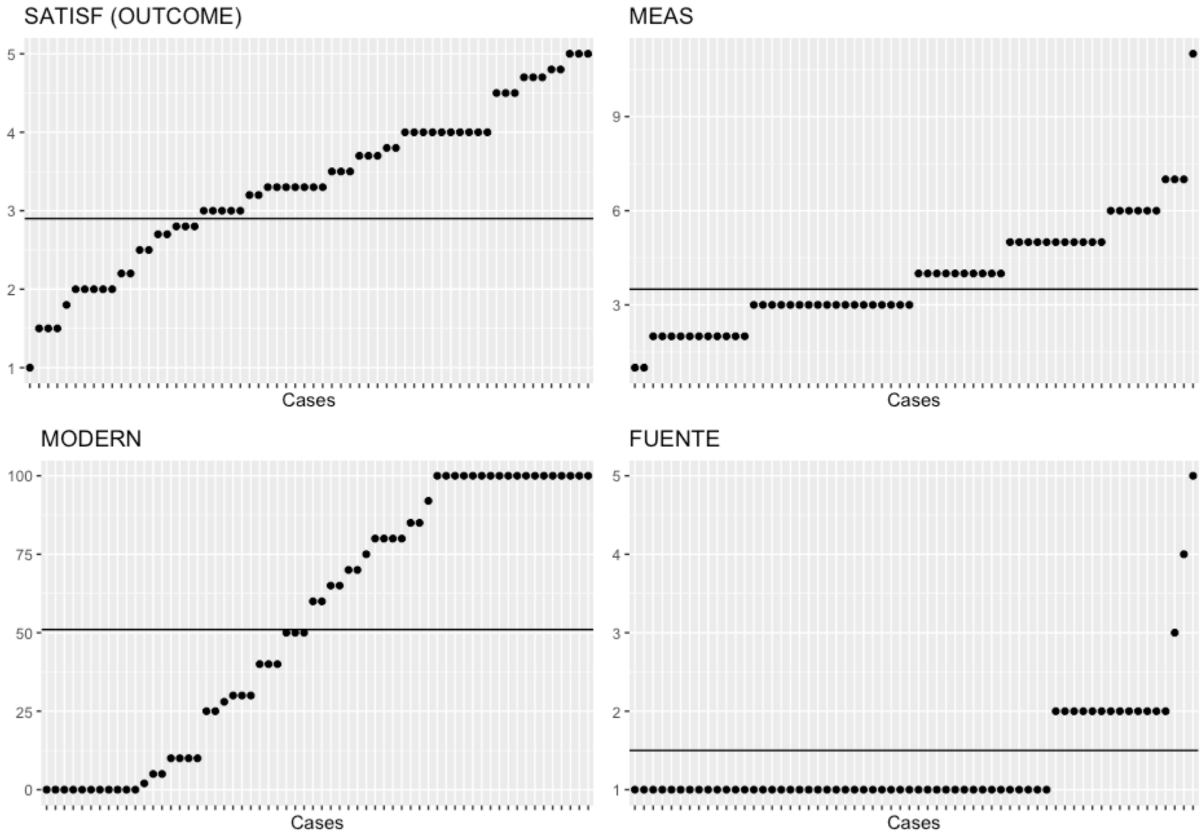
The cutoff value for what counts as "many" and "few" adaptation measures is difficult to justify by theory. Therefore, I opted for a value that splits the dataset into approximately equal parts to allow for variation. Although this choice might not be generalized to other cases, it does represent well what "many" and "few" mean relative to my dataset.

MODERN

It is fair to assume that an irrigation system can be called modernized, if at least the majority of its infrastructure has been converted to drip and/or sprinkler irrigation. Therefore, the threshold for modernized irrigation systems has been set to 51%, meaning that if at least 51% of the irrigation is done via sprinkler and drip irrigation, the case belongs to the modernized irrigation systems. On the other hand, at least 50% of irrigation being traditional furrow irrigation means absence of modernization. This also aligns well with the distribution of the data.

FUENTE

The scope to choose a threshold for the number of water sources is quite limited, as the clear majority of the included cases only dispose of one source. Therefore, I count only one source of water supply as the absence of a diversity of water sources, and more than one source as the presence of a diversity of water sources.


SATISF (OUTCOME)

MEAS

MODERN

FUENTE

Figure A 3.1 Visualization of calibration thresholds

Table A 3.3 Calibrated data matrix

ID	WUA	SATISF	ASIST	MODERN	FUENTE	MEAS	DMAJ
1	Tamarite La Concepcion	1	1	1	0	0	1
2	Junta de Acendados de la Huerta de Murcia	1	0	0	0	0	0
3	Villamayor	1	0	0	0	0	1
4	Canal de Castellon	1	0	0	0	0	0
5	Alzira	1	0	0	0	0	1
6	Sector IV	1	1	1	0	1	1
7	Burjasot, Godella y Rocafort	1	0	0	0	0	1
8	Colectividad Puente Genil	0	1	1	0	1	1
9	Benferri	0	0	1	1	0	1
10	Sectores X y XI	1	0	1	0	0	1
11	Acequia de tormos	1	1	0	1	1	0
12	Palazote la Herrera	1	0	1	1	1	1
13	Favara	1	0	0	0	1	0
14	Acequia Arabuelia	0	0	0	0	1	1
15	Zairin	0	1	1	0	0	1
16	San Onofre Torromendo	1	1	1	1	0	0
17	Canal de la margen izquierda del Genil	1	1	1	0	0	1
18	Juan Partinez Parras	1	0	1	0	0	1

19	Llanos de Camarera	0	0	0	0	1	1
20	CG Regantes del Canal del Paramo de Leon	1	1	1	0	1	1
21	CR de Alhama de Murcia	1	1	1	1	0	0
22	Margen Derecha Segura	0	0	0	1	1	0
23	CR Godolleta	0	1	1	0	1	1
24	Sindicato de Riegos Canal de Tauste	0	1	0	1	0	1
25	Canal de la Cota 100 Margen derecho del rio Mijos	1	0	1	1	0	0
26	CG Bardenas	1	1	0	1	1	1
27	SC Embalse Villameca	1	1	0	0	1	1
28	Benacher y Faitanar	0	1	1	0	1	1
29	Canal Imperial Aragon	1	1	0	0	0	1
30	CR Bajo Guadalquivir	1	0	0	1	0	1
31	CR Casinos	1	0	1	0	1	1
32	CR Tajo Segura Librilla	1	1	0	1	1	0
33	Cuatro Vegas Almeria	1	0	1	0	0	0
34	CR de Guadiana	1	1	1	0	1	1
35	CUAS Mancha Occidental II	0	1	1	0	1	1
36	CR Ciudad de Santa Fe	1	1	0	0	1	1
37	CR Montijo	1	1	1	0	1	1
38	Santa Maria del Paramo Alto	1	1	1	0	1	1
39	Sector Nr. 5	1	1	0	0	0	1
40	Canal de Castañon	0	1	0	0	0	1
41	Presa Cerrajera	0	1	1	0	1	1
42	CR Sector 2 Los Tollos	1	0	1	1	0	1
43	CR del Paramo Alto	0	0	1	0	0	1
44	CR Pantano del Rumblar	0	1	0	0	0	1
45	Sector Nr. 3	1	0	0	0	1	1
46	CR del Canal alto de Villares	1	1	0	0	1	1
47	Sindicato de Riegos de Soller	1	1	1	0	1	1
48	Sindicato de Riegos de Rabal	1	0	0	0	0	1
49	CR El Ferial	0	1	1	0	1	1
50	CR Urdan (CR Nuez de Ebro)	0	0	0	0	0	1
51	CR Presa de la Manga	0	1	1	1	1	1
52	CR Totana	1	1	1	1	1	0
53	CR de Tres Consejo	1	1	0	0	1	1
54	Real Acequia Moncada	1	0	0	1	0	1
55	CR Presa de la Vega de Abajo	0	1	0	0	1	1
56	CR de la Margen Izquierda del Rio Bembezar	1	1	1	0	0	1
57	CR de Burriana	1	0	0	0	0	1
58	CR San Pedro Apostol de Godilleta	1	1	1	0	0	0
59	CR Villadangos del Paramo	1	0	0	0	1	1
60	CR La Virgen del Aviso	1	0	1	0	0	1
61	CR Losa del Obispo	1	1	0	0	0	1

A3. (Enhanced) Parsimonious and intermediate solutions for the presence of the outcome.

It is a standard of good practice to present all three types of solutions that can result from QCA. Since the conservative, or complex, solution is reported in the main text, I present here the parsimonious and intermediate solutions. While the parsimonious solution includes all logical reminders as if they caused the presence of the outcome, the intermediate solution does so only according to consistent and intuitive directional expectations (i.e., expectations about whether to expect rather the presence or the absence of each variable to cause the outcome). Both solutions can be further "improved” into enhanced versions (Schneider and Wagemann, 2013). These enhanced parsimonious and intermediate solutions differ from their normal counterparts by excluding contradictory simplifying assumptions, simultaneous subset relations, and incoherent configurations (Dusa, 2019). In the following, all four solutions are shown.

Table A 3.4 Parsimonious solution

	Configuration	**Inclusion**	**Coverage**	**Cases (WUA)**
1	~DMAJ*MODERN	1	0.140	33, 25, 58, 16, 21, 52
2	+ ~DMAJ*~FUENTE	1	0.116	2, 4, 33, 58, 13
3	+ ~MEAS*MODERN*~FUENTE	0.8	0.186	33, 58, 10, 18, 43, 60, 1, 15, 17, 56
4	+ MEAS*~ASIST*MODERN	1	0.047	31, 12
5	+ MEAS*ASIST*~MODERN	0.875	0.163	11, 32, 27, 36, 46, 53, 55, 26
6	+ ~MEAS*~ASIST*~MODERN	0.9	0.209	2, 4, 3, 5, 7, 48, 50, 57, 30, 54

Table A 3.5 Intermediate solution

	Configuration	**Inclusion**	**Coverage**	**Cases (WUA)**
1	~DMAJ*MODERN	1	0.140	33, 25, 58, 16, 21, 52
2	+ ~DMAJ*~FUENTE	1	0.116	2, 4, 33, 58, 13
3	+ ~MEAS*MODERN*~FUENTE	0.8	0.186	33, 58, 10, 18, 43, 60, 1, 15, 17, 56
4	+ MEAS*~ASIST*MODERN	1	0.047	31, 12
5	+ MEAS*ASIST*~MODERN	0.875	0.163	11, 32, 27, 36, 46, 53, 55, 26
6	+ ~MEAS*DMAJ*~ASIST*~MODERN	0.875	0.163	3, 4, 7, 48, 50, 57, 30, 54

Parsimonious and intermediate solution are equal for configurations 1-5 and differ only in configuration 6. The spotted difference is that the intermediate solution includes DMAJ to the configuration and the parsimonious does not. The WUAs they represent, however, are similar.

Table A 3.6 Enhanced parsimonious solution

	Configuration	Inclusion	Coverage	Cases (WUA)
1	~MEAS*~DMAJ*MODERN	1	0.116	33, 25, 58, 16, 21
2	+ ~MEAS*DMAJ*~ASIST*~MODERN	0.875	0.163	3, 5, 7, 48, 50, 57, 30, 54
3	+ ~DMAJ*ASIST*FUENTE	1	0.116	16, 21, 11, 32, 52
4	+ MEAS*DMAJ*~ASIST*MODERN	1	0.047	31, 12
5	+ MEAS*DMAJ*ASIST*~MODERN	0.833	0.116	27, 36, 46, 53, 55, 26
6	+ ~DMAJ*~ASIST*~MODERN*~FUENTE	1	0.070	2, 4, 13

Table A 3.7 Enhanced intermediate solution

	Configuration	Inclusion	Coverage	Cases (WUA)
1	~MEAS*~DMAJ*MODERN	1	0.116	33, 25, 58, 16, 21
2	+ ~MEAS*DMAJ*~ASIST*~MODERN	0.875	0.163	3, 5, 7, 48, 50, 57, 30, 54
3	+ MEAS*~DMAJ*ASIST*FUENTE	1	0.070	11, 32, 52
4	+ MEAS*DMAJ*~ASIST*MODERN	1	0.047	31, 12
5	+ MEAS*DMAJ*ASIST*~MODERN	0.833	0.116	27, 36, 46, 53, 55, 26
6	+ ~DMAJ*~ASIST*~MODERN*~FUENTE	1	0.070	2, 4, 13

Enhanced parsimonious and enhanced intermediate solution are also equal for configurations 1, 2, 4, 5, and 6 and differ only in configuration 3. The difference here is that the intermediate solution includes MEAS in the configuration and the parsimonious does not. The WUAs they represent, however, are also here similar.

With respect to the conservative solution from the main text, I find little difference. The conservative solution resembles closer the enhanced versions of the parsimonious and intermediate solutions. This is not surprising as the number of logical reminders used for minimization is gradually reduced. Comparing the conservative solution with the other two enhanced solutions, I find that configurations 2, 3, 4, 6, and 7 are equal, while only configurations 1 and 5 are slightly different. I interpret this as proof for the robustness of the results.

A4. WUA names of solution terms

Table A 3.8 WUA names of solution terms from the joint analysis (main text)

Configuration	Cases (WUA)	WUA names
1	33, 58, 10, 18, 43*, 60, 1, 15*, 17, 56	Cuatro Vegas Almeria, CR San pedro apostol de godilleta, sectores X y XI, Juan Martinez Parras, CR del paramo alto*, CR la virgen del aviso, tamarite_la concepcion, zairin*, canal de la margen izquierda del genil, CR de la margen izquierda del rio bembezar
2	3, 5, 7, 48, 50*, 57, 30, 54	villamayor, alzira, "burjasot, godella y rocafort", Sindicato de riegos de Rabal, CR Urdan (CR Nuez de Ebro)*, CR de Burriana, C.R. Bajo Guadalquivir, Real Acequia Moncada
3	33, 25, 58, 16, 21	Cuatro Vegas Almeria, Canal de la cota 100 Margen derecho del rio Mijos, CR San pedro apostol de godilleta, san onofre torromendo, Comunidad de Regantes de Alhama de Murcia
4	27, 36, 46, 53, 55*, 26	S.C. Embalse Villameca, CR ciudad de santa fe, CR del canal alto de Villares, CR de tres consejo, CR Presa de la Vega de abajo*, C.G. Bardenas
5	11, 32, 52	acequia de tormos, C.R. Tajo Segura Librilla, CR Totana
6	2, 4, 13	junta de acendados de la huerta de murcia, canal de castellon, favara
7	31, 12	C.R. Casinos, palazote la herrera

Note: "Cuatro Vegas Almeria" (WUA 33) and "CR San pedro apostol de godilleta" (58) repeat in solutions 1 and 3.

A5. Separate analysis for the 2018 and 2022 datasets

Analysis of necessity

The analysis of necessity is presented simultaneously for both years (Table A 3.9). For the 2018 dataset, no condition reaches the consistency score of 0.9 in order to be accounted for as necessary (although DMAJ comes close with a consistency score of 0.889 for the absence of the outcome). For the 2022 dataset, however, DMAJ reaches a consistency of 0.895 for the presence of the outcome and full consistency for the absence of the outcome. This means, that DMAJ is present in most (or all) cases where the outcome is present (or absent). For the presence of the outcome, the coverage score is relatively high (0.654), making it a relevant necessary condition. The relatively low coverage score (0.346) for the absence, however, indicates that DMAJ is a rather irrelevant necessary condition, because there are comparatively many more cases where DMAJ is present than cases where SATISF is absent.

Table A 3.9 Analysis of necessity (separate analysis)

	Presence of outcome (SATISF)				**Absence of outcome (~SATISF)**			
	Consistency (inclN)		*Coverage (covN)*		*Consistency (inclN)*		*Coverage (covN)*	
	2018	*2022*	*2018*	*2022*	*2018*	*2022*	*2018*	*2022*
MEAS	0.357	0.526	0.625	0.667	0.667	0.556	0.375	0.333
DMAJ	0.643	**0.895**	0.692	0.654	0.889	**1.000**	0.308	0.346
ASIST	0.429	0.632	0.706	0.632	0.556	0.778	0.294	0.368
MODERN	0.536	0.474	0.750	0.643	0.556	0.556	0.250	0.357
FUENTE	0.393	0.158	0.786	0.750	0.333	0.111	0.214	0.250
~MEAS	0.643	0.474	0.857	0.692	0.333	0.444	0.143	0.308
~DMAJ	0.357	0.105	0.909	**1.000**	0.111	0.000	0.091	0.000
~ASIST	0.571	0.368	0.800	0.778	0.444	0.222	0.200	0.222
~MODERN	0.464	0.526	0.765	0.714	0.444	0.444	0.235	0.286
~FUENTE	0.607	0.842	0.696	0.739	0.667	0.889	0.261	0.333

Analysis of sufficiency

Generally, the analyses presented here follow the same specifications (as e.g., cutoff points) as the analysis presented in the main text.

2018

The minimization yields four models that group the sufficient configurations for the outcome. Since they all show the same inclusion score of 1 (stating that 100% of cases with present outcome are covered by the model), I only present the first model. Configurations 1-5 are the same for all models, while configurations 6-8 vary between models.

Table A 3.10 Conservative solution, 2018 data

	Configuration	**Inclusion**	**Coverage**	**Cases (WUA)**
1	~MEAS*DMAJ*~ASIST*~MODERN	1	0.179	3, 5, 7, 28, 33
2	+ ~MEAS*~DMAJ*MODERN*FUENTE	1	0.143	24, 26, 16, 21
3	+ MEAS*ASIST*~MODERN*FUENTE	1	0.107	11, 35, 29
4	+ ~DMAJ*~ASIST*~MODERN*~FUENTE	1	0.107	2, 4, 13
5	+ DMAJ*ASIST*~MODERN*~FUENTE	1	0.071	32, 30
6	+ ~MEAS*~ASIST*~FUENTE	1	0.321	2, 4, 37, 3, 5, 7, 10, 18, 27
7	+ MEAS*DMAJ*~ASIST*MODERN	1	0.071	34, 12
8	+ MEAS*DMAJ*ASIST*FUENTE	1	0.071	29, 36

As presented in Table A 3.10, all configurations have an inclusion score of 1, denoting that no contradictory cases were included in the minimization process. Configurations. 1, 2, and 6 together explain 64.3% of cases. Comparing these solutions to those in the main text, it is possible to identify similarities. Configuration 1 from the 2018 analysis corresponds to configuration 2 from the joint analysis in the main text. Furthermore, configuration 3 from the joint analysis is expanded by the FUENTE variable to build configuration 2 in the 2018 analysis. Overall, the variable FUENTE tends to appear more frequently in the 2018 data analysis.

2022

Table A 3.11 presents the conservative solution which has an overall inclusion score of 0.909 and consists of four sufficient configurations, whereof only the first can be considered somewhat important, as it covers more than 26% of the cases where the outcome is present.

Table A 3.11 Conservative solution, 2022 data

	Configuration	**Inclusion**	**Coverage**	**Cases (WUA)**
1	MEAS*DMAJ*~MODERN*~FUENTE	0.833	0.263	12, 26, 3, 13, 20, 22*
2	+ ~MEAS*DMAJ*~ASIST*FUENTE	1	0.105	21, 9
3	+ ~MEAS*ASIST*MODERN*~FUENTE	1	0.105	25, 23
4	+ MEAS*~DMAJ*ASIST*MODERN*FUENTE	1	0.053	19

Comparison to overall solution

Comparing the solution presented in the main text, I observe that the 2018 data replicates one of its configurations (configuration 1) exactly and one closely (configuration 2). These are also the configurations with the highest coverage scores from the 2018 analysis. For the 2022 data, the most important configuration in terms of coverage (configuration 1) does not replicate in the joint analysis. However, it differs only in one variable (~FUENTE in 2022 compared to ASSIST in the joint analysis).

A6. Analysis of sufficiency for the absence of outcome (~SATISF)

The analysis of sufficiency for the absence of SATISF yields a truth table with a large number of contradictions (Table A 3.12). Contradictions are highlighted by red font. Without making strong assumptions about cutoff values, this result yields only three “clean” cases: WUAs 22, 24, and 51 (highlighted in bold and green font).

Table A 3.12 Truth Table for the outcome being the absence of satisfaction (~SATISF)

MEAS	**DMAJ**	**ASIST**	**MODERN**	**FUENTE**	**OUT**	**n**	**incl**	**PRI**	**cases**
0	0	0	0	0	0	2	0	0	2, 4
0	0	0	1	0	0	1	0	0	33
0	0	0	1	1	0	1	0	0	25
0	0	1	1	0	0	1	0	0	58
0	0	1	1	1	0	2	0	0	16, 21
0	1	0	0	0	0	6	0.167	0.167	3, 5, 7, 48, 50, 57
0	1	0	0	1	0	2	0	0	30, 54
0	1	0	1	0	C	4	0.25	0.25	10, 18, 43, 60
0	1	0	1	1	C	2	0.5	0.5	9, 42
0	1	1	0	0	C	5	0.4	0.4	29, 39, 40, 44, 61
0	1	1	0	1	1	1	1	1	24
0	1	1	1	0	C	4	0.25	0.25	1, 15, 17, 56
1	0	0	0	0	0	1	0	0	13
1	0	0	0	1	1	1	1	1	22
1	0	1	0	1	0	2	0	0	11, 32
1	0	1	1	1	0	1	0	0	52
1	1	0	0	0	C	4	0.5	0.5	14, 19, 45, 59
1	1	0	1	0	0	1	0	0	31
1	1	0	1	1	0	1	0	0	12
1	1	1	0	0	0	5	0.2	0.2	27, 36, 46, 53, 55
1	1	1	0	1	0	1	0	0	26
1	1	1	1	0	C	12	0.5	0.5	6, 8, 20, 23, 28, 34, 35, 37, 38, 41, 47, 49
1	1	1	1	1	1	1	1	1	51

Since neither the conservative nor the intermediate solution can simplify the three cases by more than the case configurations themselves, there is no scope for a sensible analysis. This shows that, as the WUAs have nothing in common that could be minimized, it is not possible to express the absence of satisfaction in a more parsimonious way.

4. Does modernization of irrigation infrastructure create mental accounts? Insights from an exploratory experiment with Spanish water user associations[8]

4.1. Introduction

Many governments in arid and semi-arid regions have responded to water scarcity and degraded aquatic ecosystems by promoting new technologies that increase the efficiency of water use in irrigation (Turral et al., 2010). Proponents of such modernization investments argue that efficient water use allows for higher productivity and quality of output while conserving water for the environment simultaneously. However, empirical evidence suggests that increases in water productivity rarely lead to increased environmental flows due to the so-called rebound effect or efficiency paradox (Grafton et al., 2018; Pérez-Blanco et al., 2020; Sampedro-Sánchez, 2022). The irrigation rebound effect occurs when changes in water use offset the higher efficiencies gained with the infrastructure improvements (Grafton et al., 2018; Perry et al., 2017; Sears et al., 2018), which can manifest in various ways. As, ceteris paribus, higher efficiencies free up a fraction of the water used beforehand, farmers can save this water for future irrigation periods, expand their irrigated area, or replace their crop with more water consuming varieties (which frequently promise higher economic returns). At the same time, a more efficient application of water reduces (environmentally beneficial) return flows, which, from an ecological perspective, constitute a positive externality (Gómez and Pérez-Blanco, 2014). This poses a serious threat to the sustainability of aquatic ecosystems and future food security.

To counteract this phenomenon, scholars have pointed out that the design of water conservation policies could strongly benefit from a profound understanding of the drivers of water user behavior (Grafton et al., 2018). With advancing research on the rebound effect in other fields, it is becoming increasingly evident that the rebound effect is not only explained by the rational agent model (Binswanger, 2001; Contor and Taylor, 2013), but also affected by a number of behavioral factors, such as moral licensing, peer influence, or mental accounting (Dorner, 2019; Exadaktylos and van den Bergh, 2021). In fact, psychological and behavioral aspects have already been pointed out as indispensable for understanding and promoting water conservation behavior in similar areas, as

---

[8] This chapter has been submitted for publication to *Ecological Economics* on the 29.03.2023 as: Hoffmann, P., Villamayor-Tomas, S.: Does modernization of irrigation infrastructure create mental accounts? Insights from an exploratory experiment with Spanish water user associations.

e.g., residential water use (Russell and Knoeri, 2020; for a review see Russell and Fielding, 2010). In the literature on irrigation water management, which relies considerably on insights from collective action and community-based irrigation management theory, such behavioral factors have yet to be integrated into analyses of water use. Their consideration could be helpful to better understand irrigation rebound effects from a behavioral perspective. This research investigates the behavioral concept and applicability of mental accounting in the irrigation sector. Mental accounting is a cognitive strategy that resource users apply to optimize their consumption according to their preferences, and has previously been identified as one driver for rebound effects (Hahnel et al., 2020). Researchers have also pointed out that farmer's perceptions and preferences play an essential role in their participation in water markets (Palomo-Hierro et al., 2015) and their water use behavior (Kafle and Balasubramanya, 2022). In addition, studies have argued that policies should integrate knowledge on farmer's actions and perceptions alongside irrigation efficiency increases (Grafton et al., 2018). Mental accounting further expands the potential to make use of advances in other behavioral interventions, as e.g., nudging, in targeting policies to specific mental budgets.

This study tests whether mental accounting matters for water users and their water use decisions in the context of irrigation associations and thus provides a complementary perspective on the rebound effect in irrigation. More specifically, I ask the question whether water users create different mental accounts based on two different ways water can be obtained, which I refer to as the "origin" of water: water received by natural supply and water freed-up from efficiency gains. Here, I understand farmer's decisions as fundamentally rational and following a "water budget" reasoning, according to which they can only use the water that is available and accessible to them via the irrigation infrastructure and the result of collective allocation decisions (Healy et al., 2007; Richter and Orr, 2017). Collective irrigation management is particularly prominent within the context of this study, as Spain is known for its tradition and strength of water user associations (WUAs) (Lopez-Gunn, 2003; Ostrom, 1990). Collective action dynamics and strategic decision-making can thus be expected to play a role in shaping farmer's preferences and behaviors.

I ask the following research question: Is water resulting from efficiency gains perceived differently than water obtained through regular supply in the context of collective irrigation management? To address this question, I rely on a scenario-based experimental survey (Holbrook and Lavrakas, 2019) which combines ideas from the literature on mental accounting and psychological ownership (Pierce et al., 2003; Thaler, 1999). As proxies for mental accounting (i.e., the dependent variable), I use the intention to use water and the perception of ownership (or psychological ownership) of water. Additionally, I explore the strategic nature of farmers' decisions by observing what they believe others will do and whether this has an impact on their own intended behavior.

The experimental results suggest that water gains resulting from efficiency increases are more likely to be perceived as owned by the farmers but are not used differently than water gains by additional supply. With that being said, while the effect of said origin on psychological ownership is significant, it is not significant on the intention to use. Furthermore, I observe that the perception of how other farmers within the same WUA would utilize the water strongly correlates with one's own intention for water use, implying the decision's strategic nature. Contextual conditions, such as the degree of modernization, the type of crop produced, and the size of the WUA do not seem to influence mental accounts. The remainder of the chapter has the following structure: Section 2 introduces the relevant theoretical concepts and presents the research model and hypotheses. Section 3 describes method and data collection. Section 4 presents the results of the data analysis. Section 5 discusses and interprets them in the context of community-based irrigation management. Finally, Section 6 concludes and offers suggestions for more sustainable irrigation practices and associated public policies.

4.2. Theory

This study builds on the theories of mental accounting and psychological ownership and combines these two concepts into a research model that reflects how the origin of water in irrigation is expected to affect the creation of mental accounts.

4.2.1. Mental Accounting

Mental accounting refers to the observation that individuals tend to mentally categorize goods or resources into separate accounts, with implications for the individual's attitude or perception towards those goods or resources (Thaler, 1985, 1999). For example, financial income is mentally categorized depending on whether it is regular income or, for instance, a tax rebate or bonus (Antonides et al., 2011). Although breaking the standard economic assumption of fungible money (Thaler, 1999), keeping such accounts helps people to decide on how to allocate or spend their financial resources. Established originally in the financial domain, mental accounting has found increasing application also in non-financial domains, such as energy (Exadaktylos and van den Bergh, 2021; Hahnel et al., 2020) and food consumption (Antonides, 2022; Huang et al., 2020).

Mental accounts in finance have been argued to stem from sources and uses of funds, or sets of choices and outcomes (Zhang and Sussman, 2018). The former suggests that mental accounts manifest as a result of differing channels, through which an income or resource is received (i.e., based on its origin), and its propensity to be consumed (Antonides et al., 2011; Heath and Soll, 1996; Zhang and Sussman, 2018). In other words, the way we obtain a good or resource prompts a mental account, while the association thereof subsequently influences our decision on how we use or spend it. For instance, studies have found that people value equal objects differently depending on whether they were obtained by chance or effort (Cherry and Shogren, 2008; Loewenstein and Issacharoff, 1994). In other studies, monetary gains were either spent unequally depending on whether they were displayed as dividends or capital gains (Baker et al., 2006), or consumers' spending increased when a fraction of it was redeemed in the form of coupons (Milkman and Beshears, 2009). In the energy sector, consumers were found to be prone to make energy-related decisions based on how previous energy-savings have been achieved (Hahnel et al., 2020). Apart from one study which applies mental accounting theory to understand farmer's reluctance to pay agricultural water fees in China (Zhang et al., 2016), research on mental accounting in agricultural water use is scarce to non-existent. To my knowledge, this is the first attempt to introduce this approach to the domain of agricultural water use.

4.2.2. Psychological ownership

Another justification of mental accounts is psychological ownership. Psychological ownership refers to an individual's perceived rights over using a good or service, regardless of legal status (Dawkins et al., 2017; Pierce et al., 2001), and arises via three major experiences: controlling the ownership target, knowing the target intimately, and investing the self in the target (Pierce et al., 2003). The context of origin can also be counted as an influential factor for psychological ownership (Pierce et al., 1991). Originating in organizational economics research, the concept has recently received attention in natural common pool resource contexts. For instance, psychological ownership was found to foster the management of public goods and natural resources (Matilainen et al., 2017; Peck et al., 2021), and strengthen commitment towards the environment (Jiang et al., 2019). To date, only one study explicitly relates psychological ownership directly to mental accounting: conducting a set of choice experiments, Sharma et al. (2021) provide evidence that psychological ownership of money differs across payment forms (i.e., whether money is borrowed as a credit or a loan), affecting its assignment to mental accounts and propensity to be spent. Building on this connection, I look at psychological ownership as a dimension mental accounting in the forthcoming.

4.2.3. Collective water management in Spain

Irrigation systems are a well-known example of a common-pool resource system. In Spain, water is publicly owned and water rights (which only allow for using but not buying or selling the water) are assigned by river basin authorities to farmers on a collective basis. Water users have to organize themselves into WUAs and manage the water collectively via common property regimes (Gómez-Limón et al., 2021; Villamayor-Tomas et al., 2020). With a longstanding tradition in the country, farmers in WUAs have learned to cope with the social dilemmas inherent to the provision of irrigation infrastructure and the allocation of water relatively well (Lopez-Gunn, 2003; Ostrom, 1990). Hence, informal rules, such as social norms or peer pressure, play a predominant role in farmer perceptions and decision-making within this institutional context (Ostrom, 1993). Moreover, the creation of mental accounts might also be influenced by such factors (Krishnamurthy and Prokopec, 2010).

4.2.4. Hypotheses

Based on the literature presented above, I theorize that an individual's psychological ownership and intention to use of a resource vary with the origin of the resource, and that intention to use and psychological ownership are connected (Lee et al., 2019; Strahilevitz and Loewenstein, 1998).

More specifically, I am interested in unveiling alternating perceptions of water contingent upon whether it is freed-up after efficiency-driven water savings or obtained due to increases in water availability (see next section for a detailed description). A theoretical distinction of water depending on its source has already been proposed by Lankford (2013), who argues that water savings from higher efficiencies (so called paracommons) should be treated conceptually different than "raw" water (commons). Following this distinction, and in order to provide empirical support to this assertion and simultaneously improve our understanding of the rebound effect, I formulate the following research hypotheses:

H1: The materialization of water affects the intention to use it.

H2: The materialization of water affects the psychological ownership of it.

H3: Psychological ownership affects the intention to use.

The hypotheses illustrate connections between the origin of water and the two proposed dimensions of mental accounting as synthesized in Figure 4.1.

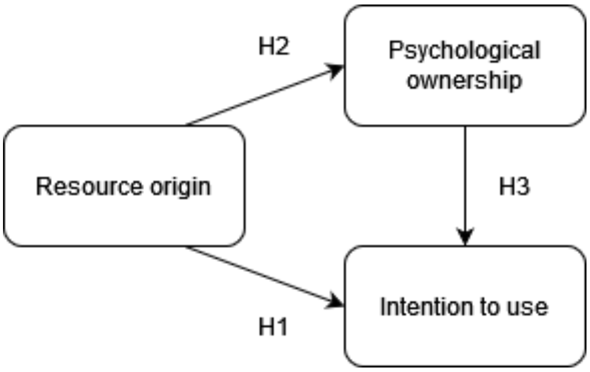


Figure 4.1 Research model showing the relationships to be tested by hypotheses H1 to H3.

4.3. Methodology

The data for this study were collected at the XV National Congress of Spanish Water User Associations, which took place in León, Spain from May 30 to June 3, 2022, by conducting in-person surveys with congress participants who were representatives of Spanish WUAs. Survey participants were selected following convenience sampling among those attending the congress. Answers, as well as qualitative comments made by the respondents, were written down on paper. 63 surveys were completed at the end of the congress in total (M_{age} = 62.8 years, SD = 10.5, 97% male, rejection rate 10%). The survey was split into two parts. The first part consisted of a scenario-based experiment, which presented each participant one of two hypothetical situations followed by three closed questions. The second part of the survey entailed closed and open questions about how WUAs cope with droughts, whether administration and management are affected by droughts, energy-related problems, participation in social movements, and satisfaction with administrative aspects. Completion time for the survey was approximately 15 minutes per participant.

In the experiment, participants were randomly assigned to one of the two hypothetical situations. In the baseline, participants were asked to imagine that favorable biophysical conditions had led to an increase in water supply by 20% based on the water they usually receive and use. In the treatment, participants were asked to imagine that due to a (cost-free) infrastructure modernization investment, the higher efficiency reduced their water requirements by 20%. It was also emphasized that this change would apply to all water users of the corresponding WUA. Subsequently, the participants were asked three questions regarding: a) their intended individual use of the additional 20%, b) their expectations regarding the intended use of other water users in the WUA, and c) their perceived ownership of the additional 20%. For questions a) and b), the participants were instructed to distribute the 20% among three possible options: individual use, communal use, and environmental use. For question c), participants had to state whether they felt that the 20%

belonged to themselves, to the community, or to the environment (i.e., to no one). The questions were closed but participants were allowed to qualify their answer verbally, which was documented additionally. Furthermore, the participants were asked their WUA's degree of modernization (i.e., how much of the irrigation system consists of sprinkler or drip irrigation), the dominantly cultivated crop (herbaceous, woody, and vegetables), and the size of their WUA. The former variable captures a relevant distinction, because previous studies have demonstrated that modern irrigation technologies can shape institutions and management practices over time (Benouniche et al., 2014; Ortega-Reig et al., 2017; van der Kooij et al., 2017). Farmers working in modernized irrigation systems may develop different perceptions and believes regarding water use and ownership compared to farmers in predominantly traditional irrigation systems. The distinction between woody (e.g., citrus or olives) and arable (herbaceous or vegetable) crops can also be relevant as woody plants cannot be easily replaced from one period to another, constraining the flexibility of farmers to adapt to changes in water availability. Lastly, size is a relevant variable as it usually affects professionalization (Villamayor-Tomas et al., 2020) and degree of modernization, which in turn might impact perceptions about collective decision-making processes and water use (Araral, 2009; Meinzen-Dick et al., 2002). The survey design was preregistered on aspredicted.org (see Supplementary Materials).

I analyze the data in two steps: First, I conduct a descriptive analysis based on frequency counts and test for differences across treatments with Fisher's exact and Kruskal-Wallis tests. Second, I run a binomial logistic regression model to further test relationships while controlling for contextual variables.

4.4. Results

In total, 62 water users answered one of the two treatments[9]: 33 did it for the baseline and 29 for the treatment. It should be noted that although the participants had the possibility to distribute the 20% excess water freely, most of them (n = 52) assigned the full percentage to only one category. Given this highly skewed distribution towards the extremes (see Figure A 4.1 and Figure A 4.2 in the Appendix), I opted to dichotomize the responses by assigning the value of the variable to the category with the highest percentage. In the case of the intention to use, both "individual use", as well as "communal use", refer to "investing" the water for economic activity (i.e., irrigation). Hence, I dichotomized those responses into "economic use" to compare it with "environmental

---

[9] I excluded one participant from the sample who claimed not to be a water user but a technician of a WUA.

use”. The same logic holds for the other’s intention to use and psychological ownership, which was clustered into “non-environmental” (i.e., individual, communal, or other) and “environmental”. Lastly, I also dichotomized the type of technology used and type of crop cultivated predominantly. A system is classified as traditional if more than 50% of its area is irrigated by gravity, and modern if more than 50% of its area is irrigated by drip or sprinkler.

In this process, 4 observations were omitted due to participants splitting the excess water equally among two or more destinations. The results are therefore based on a subsample of 58 observations (33 in the baseline and 25 in the treatment). The following table summarizes the variables included in the analysis (Table 4.1).

Table 4.1 Description of variables

Variable	**Values**	**Mean**
Dependent variables		
Intention to use	Economic (0), Environmental (1)	0.22
Psychological ownership	Non-environmental (0), Environmental (1)	0.22
Independent variables		
Treatment	Baseline (0), Treatment (1)	0.43
Other’s intention to use	Economic (0), Environmental (1)	0.17
Technology	Traditional (0), Modern (1)	0.52
Type of crop	Arable/Non-woody (0), Woody (1)	0.48
WUA size	200 – 120000 ha (SD = 20424.1)	7483.6

4.4.1. Descriptive analysis

Figure 4.2 shows the distribution of responses to the question “*How would you use the extra 20% water?*” across scenarios.

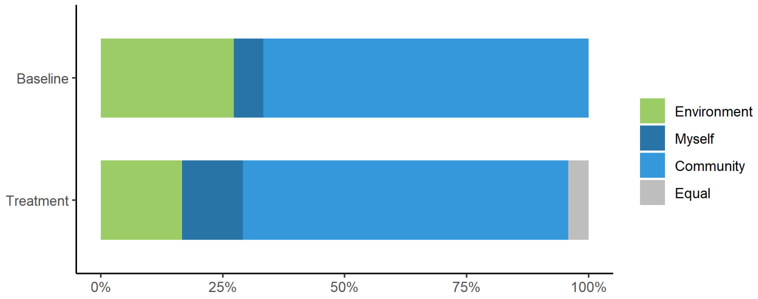


Figure 4.2 Frequency bar chart based on the individual's intention to use. Fisher's exact test between environmental and economic use: p = 0.52 (Kruskal-Wallis p = 0.54).

The results demonstrate that participants were most likely to leave the extra water for use within the community (i.e., distribute it within the community), regardless of scenario. To a much lesser extent, the second and third most frequent intended use was to leave it for the environment and keep it for oneself, respectively. Only one respondent opted for "distributing" freed-up water among all potential uses. As explained previously, I used the dichotomized version of the variable for the statistical tests (the clustering is demonstrated in the Figures by using blue colored vs. green colored bars). While more assignments to the environment in the baseline compared to the treatment can be observed, this difference is not statistically significant.

Figure 4.3 shows the frequency of responses to the question "*How would other farmers from your community decide?*".

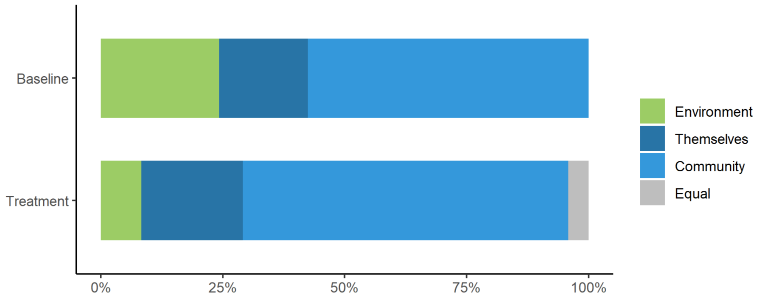


Figure 4.3 Frequency bar chart based on the expected other's intention to use. Fisher's exact test between environmental and economic use: p = 0.17 (Kruskal-Wallis p = 0.11).

The findings depict a similar scenario as for the previous question; allocations to the environment were not significantly different in the baseline compared to the treatment. However, it shows that, in the treatment, more participants expected other water users from their community to use the additional water for themselves, rather than leave it for the environment. This difference, nevertheless, is neither statistically significant (Fisher's exact p > 0.25).

The overall distribution of responses with regards to psychological ownership of the additional 20% water is similar to the intention to use: the majority perceives additional water as belonging to the community, regardless of the scenario (Figure 4.4). However, the number of respondents who state that the additional water belongs to the environment in the baseline, compared to the treatment, is significantly larger.

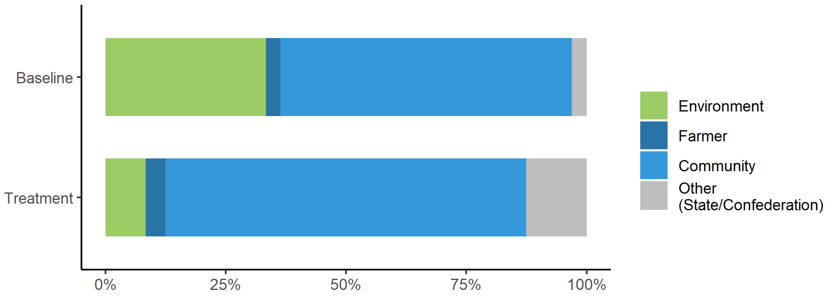


Figure 4.4 Frequency bar chart based on psychological ownership. Fisher's exact test between environmental and economic use: p = 0.03 (Kruskal-Wallis p = 0.02).

Examining the relationship between the two dimensions of mental accounting, I find alignments across intended use and psychological ownership responses (Figure 4.5, Fisher's exact and Kruskal-Wallis both p = 0.00): 69,2% (= 9/13) of those participants who stated that the environment is the owner of the extra water also preferred leaving it for environmental use. Further, 91,1% (= 41/45) of the participants that said that the community or individual farmer owned the extra water preferred keeping it for community or themselves for economic use. This association is shown graphically in Figure 4.5. The top left rectangle represents responses where environmental use was associated with environmental ownership and the bottom right rectangle shows responses where economic use was associated with non-environmental ownership.

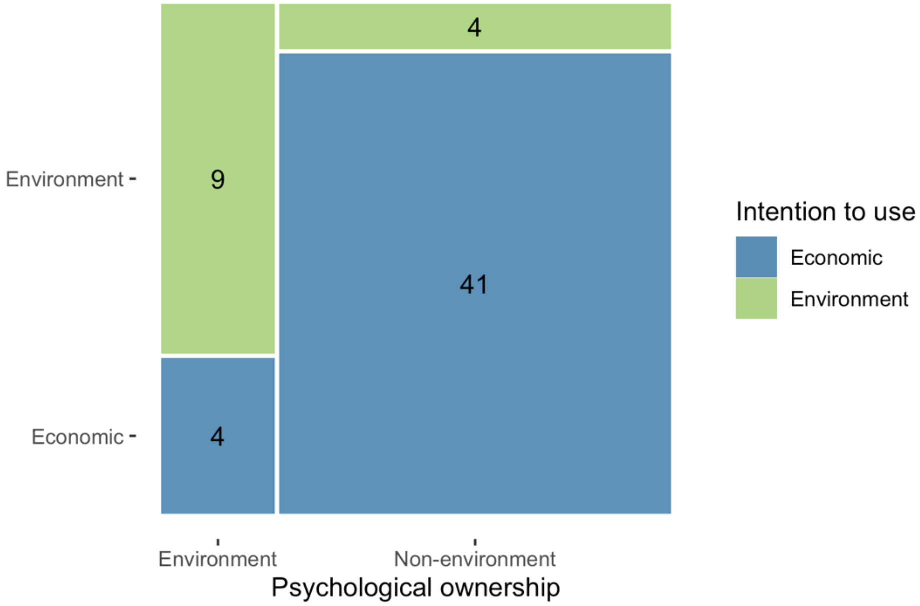


Figure 4.5 Mosaic plot of the dimension consistency between intention to use and psychological ownership. The numbers within the rectangles are frequency counts of participants perception of psychological ownership (environment vs. non-environment) and their own intention to use (economic vs. environment).

Finally, I find strong correlation between one's own intention to use and the expected intention to use of others (Pearson's correlation coefficient $\varrho = 0.98$), i.e., 98% of the individual intention to use responses align with what is expected to be done by others.

4.4.2. Regression analysis

To further test my hypotheses, I ran a binomial logistic regression. The model shows that the odds of the intention to use being leaving water for the environment decrease by the factor 0.51 (95% CI [0.12 – 1.81]); i.e., by 49% for the treatment compared to the baseline. However, this effect is statistically not significant ($z = -1.01$, $p = 0.313$) and consistent across model specifications (columns 2 and 3 of Table 4.2). Hence, this confirms the finding that the treatment cannot explain the differences in the intention to use (lack of support for H1).

For the other dependent variable, it was found that the treatment decreases the odds of assigning ownership to the environment by a factor of 0.17 (95% CI [0.03 – 0.74]). In other words, the odds of feeling that the additional water belongs to the environment are 83% lower in the treatment compared to the baseline. While the base odds of believing the water belongs to the environment stand at 0.5 in the baseline, these are reduced to only 0.087 in the treatment. Similar to the descriptive results, this effect is significant at the 5% level ($z = -2.12$, $p = 0.034$), and remains consistent across different model specifications, further supporting hypothesis H2.

The regression also confirms the strong relationship between the two dependent variables ($p \leq 0.001$) (supporting hypothesis H3) and indicates that none of the contextual variables has a significant effect on any of the dependent variables. In sum, the regression model confirms the results from the descriptive analysis which leads to the rejection hypothesis H1 and confirmation of hypotheses H2 and H3.

Table 4.2 Full regression results

	Intention to use						Psychological Ownership					
	(1)		(2)		(3)		(4)		(5)		(6)	
Predictors	*Odds Ratios*	*p*	*Odds Ratios*	*p*	*Odds Ratios*	*p*	*Odds Ratios*	*p*	*Odds Ratios*	*p*	*Odds Ratios*	*p*
(Intercept)	0.38	**0.012**	0.08	**0.001**	0.09	**0.038**	0.50	0.061	0.17	**0.002**	0.24	0.139
Treatment (origin)	0.51	0.313	1.59	0.615	1.37	0.764	0.17	**0.034**	0.13	**0.048**	0.09	**0.048**
Psych. Ownership [env]			27.99	**<0.001**	32.14	**0.001**						
Modernized [modern]					0.17	0.072					1.22	0.835
Crop [woody]					1.76	0.552					0.43	0.377
WUA size					1.00	0.495					1.00	0.449
Intention to use [env]									27.99	**<0.001**	24.32	0.083
Other's intention to use [env]					*omitted due to high collinearity*						1.06	0.976
Observations	58		58		56		58		58		56	
R^2 Tjur	0.018		0.364		0.373		0.091		0.453		0.431	

4.5. Discussion

4.5.1. Mental accounting

The main hypothesis of the study posited that water users categorize water into different mental accounts based on how water is materialized, on the one hand, and that this manifests in varying intentions to use the resource and psychological ownership over it, on the other hand. Contrary to previous findings from financial and energy-related studies (Hahnel et al., 2020; Zhang and Sussman, 2018), I do not find a statistically significant effect of the treatment on the intention to use. However, the results show a significant effect of the treatment on psychological ownership, which aligns with findings from the respective literature (Pierce et al., 1991; Sharma et al., 2021). Moreover, I find psychological ownership to be strongly correlated with the intention to use. Hence, the results can be interpreted as a first indication for mental accounts of water budgets.

The dominance of community use and ownership in the responses of the participants is particularly striking. To understand this outcome, it is worthwhile to recall the institutional context, in which water users (inter-)act, and its potential impact on mental accounting. The fact that water is governed collectively limits the capability of individual farmers to freely decide on the quantity of water they want to apply, which in turn shapes their perceptions and believes of ownership. This could explain why there were almost no "selfish", i.e., individual use, responses in the sample. It is worth noting that some farmers might have individual access to water via their own wells, while others depend fully on collective water distribution mechanisms. While one would expect this to affect the creation of mental accounts as well, the sample did not allow for testing this hypothesis as there was almost no variation in the indicated water sources used by the WUA representatives. This finding can become relevant for addressing the efficiency paradox in collectively managed irrigation systems, given the ubiquity of community-based irrigation management systems worldwide (Gany et al., 2019; Garces-Restrepo et al., 2007).

Relatedly, participants in this study frequently raised the argument that WUAs need to save any surplus or freed-up water resources for upcoming periods of drought, as their water rights are frequently not met during these periods. This constitutes a strong incentive for WUAs to not contribute to environmental flows. More importantly, some participants explained that allocating any additional water to the community was environmentally beneficial because any unused water would be "lost", while the community could regulate it to maintain runoffs in water scarcity periods. This helps to understand the relatively few allocations to the environmental option in this study and reflects the persisting idea among farmers that any water not used in agriculture is lost and that sustainability is seen as a form of agricultural profitability (Baccar et al., 2020). In other words, farmers seem to create a "false" environmental account (Grüner and Hirschauer, 2016) when allocating water to the community. In this case, mental accounting would be reinforcing water use as users "book" resources into the community account under the believe that their collective consumption does not impact the ecosystem or does so positively (Hahnel et al., 2020).

4.5.2. The collective rebound effect

The finding that there is only a negligible number of water allocations to individual use illustrates, in my understanding, the ability of farmers in the sampled WUAs to overcome common pool resource dilemmas associated with the incentive for individuals to free-ride on other farmer's water conservation efforts (Ostrom et al., 1994; Villamayor-Tomas, 2014). At the same time, the results suggest that the public goods dilemma regarding the potential impact of irrigation water use on the environment and other potential water users (Villamayor-Tomas et al., 2019b) remains salient and unresolved. This is seen in the low number of "pro-environmental" responses, meaning that contributions to the ecosystem, which constitutes a global public good, do not appear to be a major concern. These findings confirm literature on nested social dilemmas, which highlights how sustainable local resource management requires solving collective action problems at different levels and with regard to different management tasks (Bisaro and Hinkel, 2016; Villamayor-Tomas et al., 2021). Moreover, it shows how users are more likely to cooperate with their peers and in the presence of external competition for the resources than otherwise (Wit and Kerr, 2002). It is therefore possible that resolving the dilemma at the irrigation system level is to some extent at odds with solving it at the global public good level. Keeping the extra water for the community illustrates farmer's capacity for cooperation (and for defending their collective interests) but also conflicts with freeing water for other uses. This would explain why efficiency increases do not automatically translate into water savings in the WUA management context. Any efforts in trying to reduce water consumption after efficiency increases should therefore be more effective when targeted at the collective rather than the individual level, which is an important implication for future policy design (Hoffmann and Villamayor-Tomas, 2022).

4.5.3. Implications for water conservation policies

After at least two decades of promoting infrastructure modernization of irrigation systems worldwide, policy makers are now concerned about the need to curb rebound effects that undermine the contribution of efficiency gains to water conservation. Reaching such objectives is further hindered by the increasing occurrence of drought as a consequence of global climate change. Although cutting water rights appears to be a relatively successful measure in some cases (e.g., Berbel et al., 2015), its implementation faces strong farmer opposition more frequently than not (Garrick et al., 2013) and does not always lead to a direct or visible increase in ecological flows (Sampedro-Sánchez, 2022). The results show that, although farmers are capable of holding different mental accounts of water, their perceptions are strongly influenced by prevalent WUA institutions and collective action beliefs (Lubell, 2003). Several recommendations emerge from this finding; all of them point to similar directions but each emphasizes different policy instruments. A first straightforward means to convey water saving strategies would involve assigning shared responsibility of said savings to WUAs and emphasizing the necessity to accommodate competition over water resources at the basin level. In Spain, and many other countries, WUAs are represented in decision-boards of river basin organizations; however, to my knowledge, these boards have not seriously treated structural water conservation priorities (Schütze et al., 2022). WUAs possess not only the formal authority to regulate farmers' behavior at the local level, but also the legitimacy, monitoring capacity, and firsthand expertise to enforce these regulations effectively.

Second, since beliefs constitute an important determinant of water conservation behavior (Russell and Fielding, 2010), the potential advantages of reshaping them to motivate water conservation are evident. One such common belief is that water retained and used by the WUA is considered the ecologically 'best' option, disregarding the importance of environmental flows. In order to counteract this belief, a progressive approach could involve the promotion of participatory processes within the WUAs to question and deliberate around this idea. Equally, farmers might revise their beliefs based on demonstration projects that illustrate the connection between consumptive uses of water and ecological flows for aquatic ecosystems. Such ideas could be introduced as part of the growing literature on participatory research (e.g., Sanchis-Ibor et al., 2021).

Finally, the results also show that individuals tend to act in accordance with peer behavior (or at least what they believe other farmers would do), which suggests the importance of social norms in Spanish WUAs. The importance of so called "neighborhood effects", i.e., peer pressure or conformity behavior, on conservation behavior has already been shown in other conservation contexts (e.g., Chen et al., 2009; Villamayor-Tomas et al., 2019a). Therefore, farmers might be inclined to reduce consumption within certain mental budget accounts, if a reference group does so similarly (Krishnamurthy and Prokopec, 2010); and WUAs could promote said learning via regular feedback to their members (Tiefenbeck et al., 2019). Future research could explore how reference levels from successfully water-saving farmers and WUAs can be communicated effectively within and across WUAs.

4.5.4. Limitations

The study has three limitations. First and likely foremost, I acknowledge the possibility of hypothetical bias in the responses given by the participants (Loomis, 2011). Since the survey was not incentivized, there is a risk that farmers leaned towards altruism, resulting in an overestimation of environmental water allocations. Also, the hypothetical scenarios might have appeared unrealistic for some WUA representatives. For instance, an additional increase in efficiency of 20% for an already modernized system is difficult to reach, and a sudden increase in 20% of natural supply is equally unrealistic in cumulative years of drought. Hence, one cannot rule out the possibility that farmers gave responses that deviate from their actual behavior in real-world contexts. I expect this hypothetical bias, however, to affect mainly one own's assignment but not psychological ownership or beliefs of other's decisions.

Second, I had to work with a relatively small sample size. This has to be attributed to the chosen approach of in-person surveys at an event. Conducting online-surveys remains challenging due to the low use of technologies among farmers (in the sample, less than 50% of respondents estimated email usage by farmers within their WUAs to be above 50%), and comparably low response rates (Glas et al., 2019). Additionally, the small sample size raises concerns due to the lack of homogeneous preferences among irrigators when it comes to water use or the manner in which improved water supply is obtained (Guerrero-Baena et al., 2019; Villanueva and Glenk, 2021). Although the sample is homogenous in a sense that it only includes representatives of WUAs, the characteristics of the WUA can be quite heterogenous, shaping the perceptions and believes of their representatives. To overcome this problem, research with larger sample sizes and other case studies will be required. Although the small sample size mostly undermines the power of the statistical analysis and the risk of Type II error, it does not undermine the direction of findings. The findings are not conclusive about mental accounting effects of water origin on intention to use but are relatively so regarding psychological ownership.

Third, this study did not include data from farmers operating in irrigation systems that are not managed by WUAs. The finding about the strong influence of the collective management institutions on mental accounting points, however, to the interest of exploring other institutional contexts. To be sure, I believe the results to be quite generalizable given the widespread dominance of community-based irrigation systems worldwide (Garces-Restrepo et al., 2007). That being said, other forms of governance (i.e., state-led or market-based governance) might underlie different behavioral dynamics. Also, considerable institutional diversity exists even among community-based irrigation systems worldwide (Wang and Chen, 2021), and in Spain (Villamayor-Tomas et al., 2020).

Further research should therefore address mental accounting and rebound effects in different institutional contexts.

4.6. Conclusion

The goal of this study was to identify whether mental accounting plays a role in water use rebound effects after irrigation efficiency increases. For that matter, a scenario-based survey experiment with representatives from Spanish WUAs was conducted, asking them about intention to use and sense of ownership under two different water origin scenarios. Although the majority of the respondents claimed the intention to allocate any type of water to their community and perceived water usually as owned by the community, I found a significant difference in psychological ownership across the two treatment scenarios. Additionally supplied water is significantly more likely to be perceived as owned by the environment than water that is freed-up from efficiency gains by water users. While the treatment effect was not significant for the intention to use, I still find a strong correlation between the two proposed dimensions of mental accounting. Overall, I interpret this as evidence for mental accounting processes and emphasize the importance of understanding these processes to better address water use rebound effects more effectively. Furthermore, the data suggest that an individual's intention to use strongly correlates with expectations or beliefs about what other water users within the WUA would do. Although this cannot be interpreted without speculation, it suggests that conformity and other forms of peer pressure or identity-based loyalty also play an important role. Moreover, the results suggest that community-based management institutions (e.g., the conformity of farmers with collective management rules and norms) are likely to have a substantial influence on shaping the perceptions of water users, demonstrating the key role of WUAs and prevalence of collective action dynamics in the Spanish irrigation sector. This study is meant to be a first exploration towards better understanding the behavioral consequences of irrigation modernization investments and should lay the groundwork for future research on behavioral dynamics in community-based irrigation systems.

4.7. References

Antonides, G., 2022. The Behavioral Economics of Healthy and Sustainable Food Consumption, in: Altman, M. (Ed.), Constructing a More Scientific Economics. Springer Nature Switzerland, pp. 169–195. https://doi.org/10.1007/978-3-030-83928-4_9

Antonides, G., Manon de Groot, I., Fred van Raaij, W., 2011. Mental budgeting and the management of household finance. Journal of Economic Psychology 32, 546–555. https://doi.org/10.1016/j.joep.2011.04.001

Araral, E., 2009. What Explains Collective Action in the Commons? Theory and Evidence from the Philippines. World Development 37, 687–697. https://doi.org/10.1016/j.worlddev.2008.08.002

Baccar, M., Bouaziz, A., Dugué, P., Gafsi, M., Le Gal, P.-Y., 2020. Sustainability Viewed from Farmers' Perspectives in a Resource-Constrained Environment. Sustainability 12, 8671. https://doi.org/10.3390/su12208671

Baker, M., Nagel, S., Wurgler, J., 2006. The Effect of Dividends on Consumption. Cambridge, MA. https://doi.org/10.3386/w12288

Benouniche, M., Kuper, M., Hammani, A., Boesveld, H., 2014. Making the user visible: analysing irrigation practices and farmers' logic to explain actual drip irrigation performance. Irrigation Science 32, 405–420. https://doi.org/10.1007/s00271-014-0438-0

Berbel, J., Gutiérrez-Martín, C., Rodríguez-Díaz, J.A., Camacho, E., Montesinos, P., 2015. Literature Review on Rebound Effect of Water Saving Measures and Analysis of a Spanish Case Study. Water Resources Management 29, 663–678. https://doi.org/10.1007/s11269-014-0839-0

Binswanger, M., 2001. Technological progress and sustainable development: what about the rebound effect? Ecological Economics 36, 119–132. https://doi.org/10.1016/S0921-8009(00)00214-7

Bisaro, A., Hinkel, J., 2016. Governance of social dilemmas in climate change adaptation. Nature Climate Change 6, 354–359. https://doi.org/10.1038/nclimate2936

Chen, X., Lupi, F., He, G., Liu, J., 2009. Linking social norms to efficient conservation investment in payments for ecosystem services. Proceedings of the National Academy of Sciences 106, 11812–11817. https://doi.org/10.1073/pnas.0809980106

Cherry, T.L., Shogren, J.F., 2008. Self-interest, sympathy and the origin of endowments. Economics Letters 101, 69–72. https://doi.org/10.1016/j.econlet.2008.04.007

Contor, B.A., Taylor, R.G., 2013. Why improving irrigation efficiency increases total volume of consumptive use. Irrigation and Drainage 62, 273–280. https://doi.org/10.1002/ird.1717

Dawkins, S., Tian, A.W., Newman, A., Martin, A., 2017. Psychological ownership: A review and research agenda. Journal of Organizational Behavior 38, 163–183. https://doi.org/10.1002/job.2057

Dorner, Z., 2019. A behavioral rebound effect. Journal of Environmental Economics and Management 98, 102257. https://doi.org/10.1016/j.jeem.2019.102257

Exadaktylos, F., van den Bergh, J., 2021. Energy-related behaviour and rebound when rationality, self-interest and willpower are limited. Nature Energy 6, 1104–1113. https://doi.org/10.1038/s41560-021-00889-4

Gany, A.H.A., Sharma, P., Singh, S., 2019. Global Review of Institutional Reforms in the Irrigation Sector for Sustainable Agricultural Water Management, Including Water Users' Associations. Irrigation and Drainage 68, 84–97. https://doi.org/10.1002/ird.2305

Garces-Restrepo, C., Vermillion, D., Muñoz, G., 2007. Irrigation Management Transfer: Worldwide Efforts and Results, FAO Water Reports. Rome, Italy.

Garrick, D., Whitten, S.M., Coggan, A., 2013. Understanding the evolution and performance of water markets and allocation policy: A transaction costs analysis framework. Ecological Economics 88, 195–205. https://doi.org/10.1016/j.ecolecon.2012.12.010

Glas, Z.E., Getson, J.M., Gao, Y., Singh, A.S., Eanes, F.R., Esman, L.A., Bulla, B.R., Prokopy, L.S., 2019. Effect of Monetary Incentives on Mail Survey Response Rates for Midwestern Farmers. Society & Natural Resources 32, 229–237. https://doi.org/10.1080/08941920.2018.1530815

Gómez-Limón, J.A., Gutiérrez-Martín, C., Montilla-López, N.M., 2021. Priority water rights. Are they useful for improving water-use efficiency at the irrigation district level? Agricultural Water Management 257, 107145. https://doi.org/10.1016/j.agwat.2021.107145

Gómez, C.M., Pérez-Blanco, C.D., 2014. Simple Myths and Basic Maths About Greening Irrigation. Water Resources Management 28, 4035–4044. https://doi.org/10.1007/s11269-014-0725-9

Grafton, R.Q., Williams, J., Perry, C.J., Molle, F., Ringler, C., Steduto, P., Udall, B., Wheeler, S.A., Wang, Y., Garrick, D., Allen, R.G., 2018. The paradox of irrigation efficiency. Science 361, 748–750. https://doi.org/10.1126/science.aat9314

Grüner, S., Hirschauer, N., 2016. An experimental investigation of mental accounting in environmental economics. International Journal of Agricultural Resources, Governance and Ecology 12, 18–26.

Guerrero-Baena, M.D., Villanueva, A.J., Gómez-Limón, J.A., Glenk, K., 2019. Willingness to pay for improved irrigation water supply reliability: An approach based on probability density functions. Agricultural Water Management 217, 11–22. https://doi.org/10.1016/j.agwat.2019.02.027

Hahnel, U.J.J.J., Chatelain, G., Conte, B., Piana, V., Brosch, T., 2020. Mental accounting mechanisms in energy decision-making and behaviour. Nature Energy 5, 952–958. https://doi.org/10.1038/s41560-020-00704-6

Healy, R.W., Winter, T.C., LaBaugh, J.W., Franke, O.L., 2007. Water Budgets: Foundations for Effective Water-Resources and Environmental Management. U.S. Geological Survey Circular Vol. 1308, Reston, VA.

Heath, C., Soll, J.B., 1996. Mental Budgeting and Consumer Decisions. Journal of Consumer Research 23, 40. https://doi.org/10.1086/209465

Hoffmann, P., Villamayor-Tomas, S., 2022. Irrigation modernization and the efficiency paradox: a meta-study through the lens of Networks of Action Situations. Sustainability Science. https://doi.org/10.1007/s11625-022-01136-9

Holbrook, A., Lavrakas, P.J., 2019. Vignette Experiments in Surveys, in: Experimental Methods in Survey Research. Wiley, pp. 369–370. https://doi.org/10.1002/9781119083771.part8

Huang, J., Antonides, G., Nie, F., 2020. Is mental accounting of farm produce associated with more consumption of own-produced food? Journal of Behavioral and Experimental Economics 88, 101594. https://doi.org/10.1016/j.socec.2020.101594

Jiang, M., Wang, H., Li, M., 2019. Linking Empowering Leadership and Organizational Citizenship Behavior Toward Environment: The Role of Psychological Ownership and Future Time Perspective. Frontiers in Psychology 10. https://doi.org/10.3389/fpsyg.2019.02612

Kafle, K., Balasubramanya, S., 2022. Can perceptions of reduction in physical water availability affect irrigation behaviour? Evidence from Jordan. Climate and Development 1–13. https://doi.org/10.1080/17565529.2022.2087587

Krishnamurthy, P., Prokopec, S., 2010. Resisting That Triple-Chocolate Cake: Mental Budgets and Self-Control. Journal of Consumer Research 37, 68–79. https://doi.org/10.1086/649650

Lankford, B., 2013. Resource Efficiency Complexity and the Commons: The paracommons and paradoxes of natural resource losses, wastes and wastages, 1st Editio. ed. Routledge, London, UK. https://doi.org/10.4324/9780203520888

Lee, J., Lee, D., Park, Y., Lee, S., Ha, T., 2019. Autonomous vehicles can be shared, but a feeling of ownership is important: Examination of the influential factors for intention to use autonomous vehicles. Transportation Research Part C: Emerging Technologies 107, 411–422. https://doi.org/10.1016/j.trc.2019.08.020

Loewenstein, G., Issacharoff, S., 1994. Source dependence in the valuation of objects. Journal of Behavioral Decision Making 7, 157–168. https://doi.org/10.1002/bdm.3960070302

Loomis, J., 2011. What's to know about hypothetical bias in stated preference valuation studies? Journal of Economic Surveys 25, 363–370. https://doi.org/10.1111/j.1467-6419.2010.00675.x

Lopez-Gunn, E., 2003. The Role of Collective Action in Water Governance: A Comparative Study of Groundwater User Associations in La Mancha Aquifers in Spain. Water International 28, 367–378. https://doi.org/10.1080/02508060308691711

Lubell, M., 2003. Collaborative Institutions, Belief-Systems, and Perceived Policy Effectiveness. Political Research Quarterly 56, 309–323. https://doi.org/10.1177/106591290305600306

Matilainen, A., Pohja-Mykrä, M., Lähdesmäki, M., Kurki, S., 2017. "I feel it is mine!" – Psychological ownership in relation to natural resources. Journal of Environmental Psychology 51, 31–45. https://doi.org/10.1016/j.jenvp.2017.03.002

Meinzen-Dick, R., Raju, K.., Gulati, A., 2002. What Affects Organization and Collective Action for Managing Resources? Evidence from Canal Irrigation Systems in India. World Development 30, 649–666. https://doi.org/10.1016/S0305-750X(01)00130-9

Milkman, K.L., Beshears, J., 2009. Mental accounting and small windfalls: Evidence from an online grocer. Journal of Economic Behavior & Organization 71, 384–394. https://doi.org/10.1016/j.jebo.2009.04.007

Ortega-Reig, M., Sanchis-Ibor, C., Palau-Salvador, G., García-Mollá, M., Avellá-Reus, L., 2017. Institutional and management implications of drip irrigation introduction in collective irrigation systems in Spain. Agricultural Water Management 187, 164–172. https://doi.org/10.1016/j.agwat.2017.03.009

Ostrom, E., 1993. Design principles in long-enduring irrigation institutions. Water Resources Research 29, 1907–1912. https://doi.org/10.1029/92WR02991

Ostrom, E., 1990. Governing the commons: the evolution of institutions for collective action, Political Economy Of Institutions and Decisions. Cambridge University Press, Cambridge. https://doi.org/10.2307/3146384

Ostrom, E., Gardner, R., Walker, J., 1994. Rules, Games, and Common-Pool Resources, Rules, Games, and Common-Pool Resources. University of Michigan Press, Ann Arbor, MI. https://doi.org/10.3998/mpub.9739

Palomo-Hierro, S., Gómez-Limón, J., Riesgo, L., 2015. Water Markets in Spain: Performance and Challenges. Water 7, 652–678. https://doi.org/10.3390/w7020652

Peck, J., Kirk, C.P., Luangrath, A.W., Shu, S.B., 2021. Caring for the Commons: Using Psychological Ownership to Enhance Stewardship Behavior for Public Goods. Journal of Marketing 85, 33–49. https://doi.org/10.1177/0022242920952084

Pérez-Blanco, C.D., Hrast-Essenfelder, A., Perry, C., 2020. Irrigation Technology and Water Conservation: A Review of the Theory and Evidence. Review of Environmental Economics and Policy 14, 216–239. https://doi.org/10.1093/reep/reaa004

Perry, C., Steduto, P., Karajeh, F., 2017. Does improved irrigation technology save water? A review of the evidence (No. 42), Food and Agriculture Organization of the United Nations, Food and Agriculture Organization of the United Nations. Cairo.

Pierce, J.L., Kostova, T., Dirks, K.T., 2003. The State of Psychological Ownership: Integrating and Extending a Century of Research. Review of General Psychology 7, 84–107. https://doi.org/10.1037/1089-2680.7.1.84

Pierce, J.L., Kostova, T., Dirks, K.T., 2001. Toward a Theory of Psychological Ownership in Organizations. Academy of Management Review 26, 298–310. https://doi.org/10.5465/amr.2001.4378028

Pierce, J.L., Rubenfeld, S.A., Morgan, S., 1991. Employee Ownership: A Conceptual Model of Process and Effects. The Academy of Management Review 16, 121. https://doi.org/10.2307/258609

Richter, B., Orr, S., 2017. Water Budgets to Inform Sustainable Water Management, in: Water for the Environment. Elsevier, pp. 347–360. https://doi.org/10.1016/B978-0-12-803907-6.00016-4

Russell, S., Fielding, K., 2010. Water demand management research: A psychological perspective. Water Resources Research 46. https://doi.org/10.1029/2009WR008408

Russell, S. V., Knoeri, C., 2020. Exploring the psychosocial and behavioural determinants of household water conservation and intention. International Journal of Water Resources Development 36, 940–955. https://doi.org/10.1080/07900627.2019.1638230

Sampedro-Sánchez, D., 2022. Can Irrigation Technologies Save Water in Closed Basins? The effects of Drip Irrigation on Water Resources in the Guadalquivir River Basin (Spain). Water Alternatives 15, 501–522.

Sanchis-Ibor, C., Ortega-Reig, M., Guillem-García, A., Carricondo, J.M., Manzano-Juárez, J., García-Mollá, M., Royuela, Á., 2021. Irrigation Post-Modernization. Farmers Envisioning Irrigation Policy in the Region of Valencia (Spain). Agriculture 11, 317. https://doi.org/10.3390/agriculture11040317

Schütze, N., Thiel, A., Villamayor-Tomas, S., 2022. Coordination across the policy cycle: Uncovering the political economy of river basin management in Spain. Environmental Science & Policy 135, 182–190. https://doi.org/10.1016/j.envsci.2022.05.007

Sears, L., Caparelli, J., Lee, C., Pan, D., Strandberg, G., Vuu, L., Lin Lawell, C.-Y., 2018. Jevons' Paradox and Efficient Irrigation Technology. Sustainability 10, 1590. https://doi.org/10.3390/su10051590

Sharma, E., Tully, S., Cryder, C., 2021. Psychological Ownership of (Borrowed) Money. Journal of Marketing Research 58, 497–514. https://doi.org/10.1177/0022243721993816

Strahilevitz, M.A., Loewenstein, G., 1998. The Effect of Ownership History on the Valuation of Objects. Journal of Consumer Research 25, 276–289. https://doi.org/10.1086/209539

Thaler, R., 1985. Mental Accounting and Consumer Choice. Marketing Science 4, 199–214. https://doi.org/10.1287/mksc.4.3.199

Thaler, R.H., 1999. Mental accounting matters. Journal of Behavioral Decision Making 12, 183–206. https://doi.org/10.1002/(SICI)1099-0771(199909)12:3<183::AID-BDM318>3.0.CO;2-F

Tiefenbeck, V., Wörner, A., Schöb, S., Fleisch, E., Staake, T., 2019. Real-time feedback promotes energy conservation in the absence of volunteer selection bias and monetary incentives. Nature Energy 4, 35–41. https://doi.org/10.1038/s41560-018-0282-1

Turral, H., Svendsen, M., Faures, J.M., 2010. Investing in irrigation: Reviewing the past and looking to the future. Agricultural Water Management 97, 551–560. https://doi.org/10.1016/j.agwat.2009.07.012

van der Kooij, S., Kuper, M., Zwarteveen, M.Z., de Fraiture, C.M.S., 2017. A user-centred approach to irrigation performance: drip irrigation in the Khrichfa area, Morocco. Water International 42, 794–809. https://doi.org/10.1080/02508060.2017.1373319

Villamayor-Tomas, S., 2014. Cooperation in common property regimes under extreme drought conditions: Empirical evidence from the use of pooled transferable quotas in Spanish irrigation systems. Ecological Economics 107, 482–493. https://doi.org/10.1016/j.ecolecon.2014.09.005

Villamayor-Tomas, S., Iniesta-Arandia, I., Roggero, M., 2020. Are generic and specific adaptation institutions always relevant? An archetype analysis of drought adaptation in Spanish irrigation systems. Ecology and Society 25. https://doi.org/10.5751/ES-11329-250132

Villamayor-Tomas, S., Sagebiel, J., Olschewski, R., 2019a. Bringing the neighbors in: A choice experiment on the influence of coordination and social norms on farmers' willingness to accept agro-environmental schemes across Europe. Land Use Policy 84, 200–215. https://doi.org/10.1016/j.landusepol.2019.03.006

Villamayor-Tomas, S., Sagebiel, J., Rommel, J., Olschewski, R., 2021. Types of collective action problems and farmers' willingness to accept agri-environmental schemes in Switzerland. Ecosystem Services 50, 101304. https://doi.org/10.1016/j.ecoser.2021.101304

Villamayor-Tomas, S., Thiel, A., Amblard, L., Zikos, D., Blanco, E., 2019b. Diagnosing the role of the state for local collective action: Types of action situations and policy instruments. Environmental Science & Policy 97, 44–57. https://doi.org/10.1016/j.envsci.2019.03.009

Villanueva, A.J., Glenk, K., 2021. Irrigators' preferences for policy instruments to improve water supply reliability. Journal of Environmental Management 280, 111844. https://doi.org/10.1016/j.jenvman.2020.111844

Wang, R.Y., Chen, T., 2021. Integrating Institutions with Local Contexts in Community-Based Irrigation Governance: A Qualitative Systematic Review of Variables, Combinations, and Effects. International Journal of the Commons 15, 320. https://doi.org/10.5334/ijc.1108

Wit, A.P., Kerr, N.L., 2002. "Me versus just us versus us all" categorization and cooperation in nested social dilemmas. Journal of Personality and Social Psychology 83, 616–637. https://doi.org/10.1037/0022-3514.83.3.616

Zhang, C.Y., Sussman, A.B., 2018. Perspectives on mental accounting: An exploration of budgeting and investing. Financial Planning Review 1, e1011. https://doi.org/10.1002/cfp2.1011

Zhang, W., Fu, X., Lu, J., Zhang, L., Michael, K., Liu, G., Yang, F., Liu, Y., 2016. Understanding Farmers' Decision-Making in Agricultural Water Fee Payment in China: The Role of Mental Accounting. Water 8, 375. https://doi.org/10.3390/w8090375

4.8. Appendix

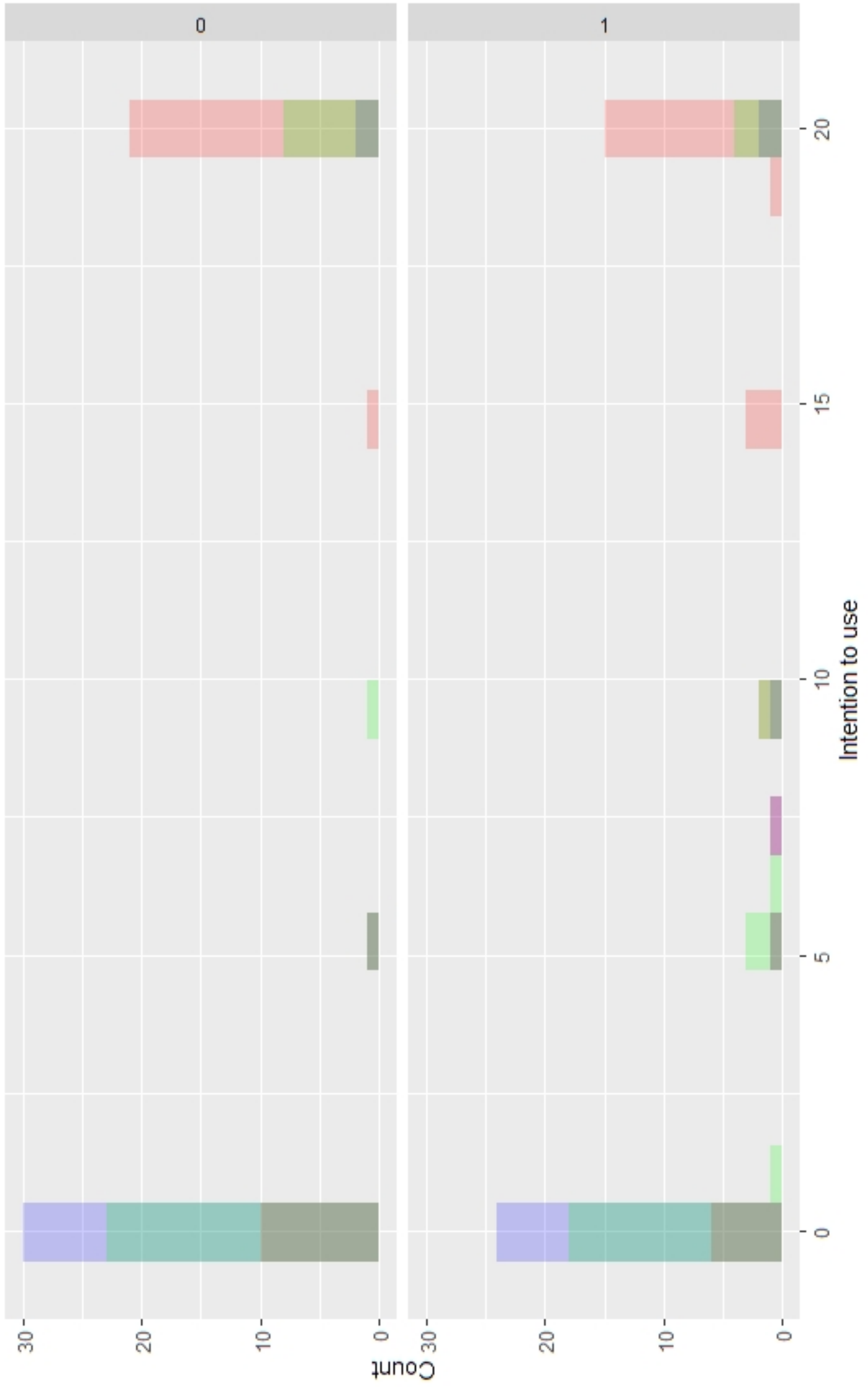


Figure A 4.1 Distribution of responses with regards to (own) intention to use. Red shade represents communal use, green environmental use, and blue individual use. 0 = Baseline, 1 = Treatment

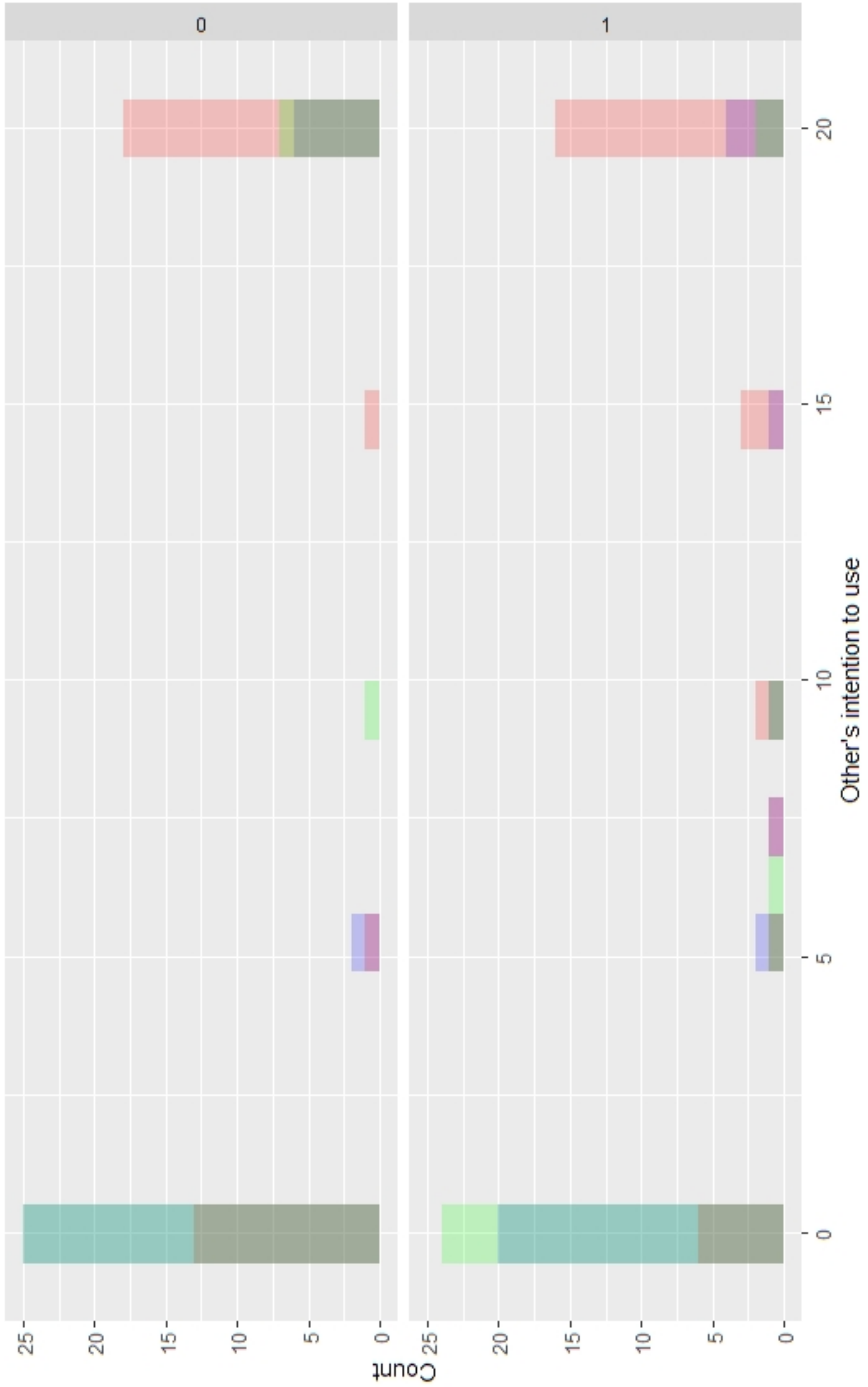


Figure A 4.2 Distribution of responses with regards to other’s intention to use. Red shade represents communal use, green environmental use, and blue individual use. 0 = Baseline, 1 = Treatment

5. Conclusion

Ensuring availability and sustainable management of water is crucial for sustaining future generations. Reaching this goal is a challenging endeavor, especially in the light of climate change and a growing world population. Few will disagree that it will this will require a sustainable transformation of the agricultural sector. This thesis has focused on the modernization of irrigation systems, which has become a priority measure to make water use more efficient. In principle, higher irrigation efficiencies bear the potential to free-up water from agricultural use in favor of, for example, environmental uses. Reality, however, is more complex. In community-based irrigation systems changes in infrastructure have implications not only on a technical level, but on a logical and institutional level as well. My thesis addresses these implications by looking at the effects of efficient irrigation technologies on community-based water resource management, sustainability, and the adaptation to droughts. It builds for this purpose on theories of collective action, community-based natural resource management, and behavioral economics. It aims at responding to the following overarching research question: Under which conditions can modernization contribute to sustainable water use in the context of community-based irrigation management?

In chapter 2, I contribute to the overarching research question by studying how the decision to invest in modernization shapes collective irrigation management via other community-internal decision-making processes and institutions. There, I ask the following research questions: Which strategic decision situations and their linkages encompass the management of collective irrigation systems in modernization contexts? To which extent do those decisions allow us to understand the emergence of water-use rebound effects? Chapter 3 aims at uncovering the role of a set of contextual conditions that are conducive to sustainable management of Spanish water user associations during drought by asking the following research question: Under which institutional, social, and biophysical conditions does modernization contribute to successful functioning of community-based irrigation systems during drought periods? Finally, Chapter 4 studies whether farmer's perceptions regarding how water is used and who it belongs to differ depending on how it is obtained. It poses the following research question: Is water resulting from efficiency gains perceived differently than water obtained through regular supply in the context of collective irrigation management? In the remainder of this chapter, I summarize the main results presented in the chapters and end with an outlook on future ways forward.

5.1. Summary

Chapter 2 presents a qualitative meta-analysis of 37 case studies of irrigation modernization in collectively managed systems. Building on the theory of Networks of Action Situations, it identifies 12 distinct strategic decision-making situations with collective outcomes (action situations), and the institutional, physical, and informational linkages that connect them. This approach helped me to uncover the interconnectedness of typical decisions made by farmers in the context of community-based irrigation management. It adds to the irrigation rebound effect literature by outlining how the strategic nature of farmer's water-use decisions and related collective action dynamics can contribute to better understand rebound effects. As I found, changes in water consumption are usually the outcome of a chain of linked action situations. For example, an increase of water consumption can be described as the outcome of the cropping decision, which is affected by changes in water and energy allocation, which are, in turn, results of a new technology. In sum, the various case studies examined show numerous pathways that can help explain rebound effects.

Chapter 3 conducts a qualitative comparative analysis based on survey data collected from representatives of Spanish water user associations. It studies whether selected variables, i.e., contextual factors, contribute, in isolation or in configurations, to satisfactory performance of water user associations during droughts. The results illustrate a relationship between the degree of modernization of a system and the type of drought adaptation measures it favors. Interestingly, modern, i.e., drip or sprinkler dominated, systems show high satisfaction rates when relatively few collective adaptation measures are employed during droughts. In those cases, the chosen measures are primarily supply-side strategies (as resorting to additional groundwater pumping via drought wells or buying desalinated/recycled water). As outlined in the chapter, this can be interpreted as a successful contribution of modernization to drought adaptation in these irrigation communities, but also indicate as reduced rate of collective action in these systems. Furthermore, the lack of possibilities for modernized communities to increase efficiency even further could explain their reliance on supply-side adaptation. Contrarily, traditional, or furrow-dominated, systems have more scope for increasing efficiency and the respective results indicate relatively more demand-side measures as a condition for satisfactory performance for most traditional communities. Remarkably, in those communities a relatively high number of measures is associated with an increase in assistance to assemblies. This result suggests that transaction costs, embodied in the active participation in assembly meetings, are an important factor to consider in association with collective drought adaptation measures.

Finally, chapter 4 introduces a behavioral perspective on the effects of infrastructure modernization. It does so by examining whether farmer's perceptions regarding how water is used and who it belongs to differ depending on how it is obtained. Methodologically, this chapter builds on a survey-based experiment conducted with representatives of Spanish water user associations. Given two different water-origin scenarios, the results show no significant difference in participants' stated intention to use. However, responses in terms of psychological ownership do vary significantly between treatments. Thereafter, water users are significantly more likely to perceive additionally supplied water as owned by the environment than water that is freed-up from efficiency gains. Another noteworthy result from this chapter is the manifestation of a strong sense of collective thinking among Spanish water users. Opposing the common assumption of selfish or individualistic behavior, the majority of responses regarding the intention to use and psychological ownership were dominated by "community" instead of "individual" use and ownership. This finding serves as further evidence for the strong prevalence of collective thinking among locally organized users of natural common-pool resources.

5.2. Policy implications and outlook on future research

Moving towards a sustainable trajectory for future agricultural water management is a challenging endeavor. In the following, I will outline how my thesis contributes to this effort by delineating implications for policymaking and suggesting inroads for further research. My research results underscore the critical need for a multifaceted approach to promote sustainable water use in the agricultural sector. One general suggestion that arises is that stakeholder involvement needs to be more actively promoted and directed at the large-scale dilemma of conserving water to maintain ecosystem stability. Although there is a vast literature on community-based natural resource management, my results illustrate it in the context of infrastructure modernization. As I show in the first chapter, the failure to conserve water for environmental purposes after efficiency increases in irrigation can be conceptualized as the result of a social dilemma. Social dilemmas permeate the collective management of water as a CPR on many levels, but the emphasis on the dilemma of how to deal with freed-up water from higher efficiencies (i.e., paracommons) has yet been rather neglected. Making irrigation communities co-responsible of such environmental conservation, e.g., as part of conditions for subsidies, could enhance their motivation to reassess water use practices. Furthermore, future modernization efforts should consider the many strategic decision-making situations that are affected by modernization and include them in the planning and assessment of investments.

Secondly, policies aimed at conserving water and preparing irrigation communities for drought should consider the nuanced responses of the different types of irrigation systems. Targeted policy interventions could encourage different strategies and objectives for different water user associations, potentially enhancing their resilience to drought. Although the results clearly indicate that traditional systems can adapt well to droughts, this can come at a cost of comparatively high transaction costs. Policies shall therefore not only focus on promoting modernization, but also on reducing transaction costs, e.g., via the digitalization of operations and decision-making.

A third implication centers on the prospect of reshaping beliefs regarding the environmental value of water as a determinant of conservation behavior. Currently, farmers frequently view retaining and using water within their community as its most sustainable, and water saved from efficiency increases as their property. To address this perception, participatory processes could be initiated to deliberate on the importance of environmental flows and revise beliefs regarding ecosystem services. This shift in perspective can lead to more environmentally conscious decision-making, and, on the collective level, help overcome the above-mentioned dilemma.

In addition to the practical implications, the results suggest new inroads for future research. First, future research should consider the collective action dynamics that exist in the context of efficiency increases in community-based water resource management. Chapter 2 has demonstrated the importance of such dynamics for better understanding which types of decision-making situations are influenced by technological change and how their outcomes, in turn, are potential drivers of irrigation rebound effects. Building on this knowledge, future research could identify how different policies or intervention strategies interact with the numerous action situations. The suggested approach of pathways thinking along networks of action situations could prove useful, and future research could collect evidence from case studies to inform causal chains, i.e., the direction of linkages between action situations. Advancing research in this direction has the potential to inform policymakers in their effort to design policies to mitigate unintended effects of infrastructure modernization.

Another way forward could be the identification of spatial patterns of water user associations according to their characteristics. Chapter 3 presented a first attempt to map associations according to the QCA solution configuration they were represented by. Future studies that strive to uncover commonalities among irrigation systems could include the geographical location in the analysis. Such mapping can contribute to tailoring policies to the diversity of types of irrigation systems. Moreover, future research could center around the role of transaction costs in drought adaptation and expand further on the identified association between number of collective drought adaptation measures and assistance to assemblies. Identifying transaction costs and making them more tangible would be a useful endeavor that could serve to inform the design and feasibility of relevant policies.

Finally, a relatively novel research avenue is the investigation of behavioral economic principles in irrigation water conservation. Researchers can explore how various incentive mechanisms, such as financial incentives or behavioral nudges, influence perceptions and beliefs regarding water-saving behavior in the aftermath of efficiency-increases. As discussed in Chapter 4, collective thinking and social norms inherent to many community-based irrigation systems create a strong influence of peer behavior on individual behavior. Future research could explore how to harness the power of these forces to encourage sustainable practices. This may involve strategies to promote social norms in favor of water conservation or identify reference groups for individuals to compare themselves against. The currently growing use of participatory research methods could be one tool to investigate the most effective ways to provide feedback on individual and group behavior into communities to facilitate behavioral change.

In summary, the implications of my thesis highlight the need for continuous collective efforts from researchers, policymakers, and stakeholders to create practical solutions for sustainable water resource management. Engaging in the search for such solutions, it is possible to design sustainable and effective strategies for addressing resource dilemmas on local, regional, and global scales, ultimately paving the way for a more secure and equitable water future for all.