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Who owns saved water? Exploring psychological ownership of efficiency gains in irrigation

Patrick Hoffmann ^{a,b} and Sergio Villamayor-Tomas ^b

^aCentre for Climate Resilience and Faculty of Business and Economics, University of Augsburg, Augsburg, Germany; ^bInstitute of Environmental Science and Technology, Autonomous University of Barcelona, Cerdanyola del Vallès, Spain

ABSTRACT

Although cognitive and behavioural factors are crucial for understanding rebound effects, their role in irrigation modernization remains underexplored. This study reports a survey experiment conducted with 183 Spanish farmers to examine psychological ownership, distribution beliefs and use preferences of water savings. We find no difference across theorized knowledge and investment routes to psychological ownership. However, our data show that farmers assign ownership of water savings predominantly to their water user association, that modernization is associated with stronger environmental ownership beliefs, and that these beliefs are related to pro-social preferences.

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KEYWORDS

Rebound effect; agriculture; survey experiment; modernization; Spain

Introduction

Modernizing irrigation systems is a key strategy for the agricultural sector to adapt to increasing water scarcity (EC, 2023; Hoffmann & Villamayor-Tomas, 2023). Governments worldwide promote modernization through substantial subsidy programmes aimed at enhancing agricultural productivity and conserving water for environmental and urban uses (Flörke et al., 2018). Modernization usually implies the replacement of furrow or flood irrigation with sprinkler or drip technologies, enabling a more precise application of water to meet crop irrigation needs with less water (Turrall et al., 2010). However, ample empirical evidence suggests that the goal of achieving water savings with more efficient irrigation is rarely met; on the contrary, in many cases, water consumption increases, reducing ecologically valuable return flows (Grafton et al., 2018; Pérez-Blanco et al., 2020; Perry, 2007). This phenomenon is known as the irrigation rebound effect or efficiency paradox (Sears et al., 2018; Wheeler et al., 2020). Irrigation rebound effects have been reported in various countries that have committed to modernizing their irrigation systems, such as Australia (Wheeler et al., 2020), China (Fang et al., 2020) and Spain (Sampedro-Sánchez, 2022). The mechanism behind this effect can be ascribed to an

CONTACT Patrick Hoffmann  patrick.hoffmann@uni-a.de

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economic income effect: the higher efficiency of water application increases the productivity of water (i.e., gains per drop), which, given water supply is unchanged after modernization, allows farmers to expand irrigated area, switch to more water-intensive crops or increase irrigation frequency (e.g., by double harvesting; Contor & Taylor, 2013; Ward & Pulido-Velazquez, 2008). Governmental modernization programmes and subsidies often assume theoretical water savings, not accounting for the behavioural responses of water users (Grafton et al., 2018). This underscores the necessity to consider complementary governance measures to generate actual water savings for ecological ends.

One potential measure to curb rebound effects in agriculture is by reducing water rights of agricultural actors. In Australia, for example, where water rights are held by individual farmers, governments tie subsidies for modernization to the agreement that a fraction of the estimated water savings is transferred as entitlements to the government (Wheeler et al., 2020). In Spain, another prominent example of a country investing heavily in irrigation modernization (Berbel et al., 2019), water use rights for surface water are mostly assigned to water user associations (WUAs), which manage irrigation collectively (Sanchis-Ibor et al., 2022). It is also the WUAs that collectively apply for government subsidies. To receive subsidies, WUAs need to demonstrate potential theoretical water savings based on model estimations (Schütze, 2025), and water use rights need to be updated; however, there is no enforcement of such right reforms (Berbel et al., 2015; Sanchis-Ibor et al., 2024). This is due to coordination problems between authorities (Schütze, 2025; Schütze et al., 2022), political conflicts with the promotion of irrigation modernization as a measure for rural development (Sampedro-Sánchez, 2022) or predominant imaginaries of irrigation expansion and intensification for development (Hoogesteger et al., 2023).

The difficulty in implementing effective water rights reductions also stems from the limited understanding of how farmers perceive irrigation modernization and resulting water savings, and how these perceptions relate to their water use behaviour (Guo et al., 2021; Zhang et al., 2020). By gaining insight into how farmers perceive the modernization process, the associated irrigation technology, and the potential water savings it incurs, policymakers and stakeholders could better promote modernization adoption while encouraging behaviours that contribute to water conservation (Albizua et al., 2019; Poblador et al., 2021).

This study investigates how farmers perceive water savings in terms of ownership, distribution and use, and tests whether these perceptions are influenced by theory-informed scenarios of hypothetical water savings. We build on the theory of psychological ownership, which posits that feelings of ownership over an object or target, independent of legal ownership, arise via three routes: investment, knowledge and control (Dawkins et al., 2017; Pierce & Jussila, 2011; Wang et al., 2022). We ask the following two research questions: Do the three theoretical routes of psychological ownership induce a sense of ownership with respect to water savings? Does psychological ownership affect water conservation behaviour and related behaviours and attitudes? We address these questions by analysing responses from a pre-registered survey experiment involving 202 agricultural water users, primarily from northern Spain.

The main analysis yields no significant difference between the theorized routes in strengthening a sense of ownership. The routes of psychological ownership also do not significantly affect water conservation, as measured by distributional beliefs or use

preferences regarding hypothetical water savings. However, our data show that farmers assign ownership of hypothetical water savings predominantly to their WUA and that modernization favours environmental ownership beliefs. Exploratory analyses further demonstrate that these perceptions of environmental ownership are associated with pro-social preferences. We discuss potential reasons for this result and present relevant policy implications for water conservation.

Theoretical background

This study is grounded in the theory of psychological ownership, which serves as the conceptual foundation for our experimental design and hypotheses. Much of common property regime theory, which explains the ability of local users to self-impose rules for the collective management of common pool resources (Cox et al., 2010; Ostrom, 1990; Poteete et al., 2010) rests on the assumption that resource users perceive some form of ownership over the resources they manage (Bromley, 1992; Demsetz, 1974; Sikor et al., 2017). In terms of water rights and ownership, legislations vary across countries and regions. In the Spanish context, water is a public good and legally belongs to the public, though it is governed by the state. WUAs hold water use rights for irrigation, meaning they are entitled to use the water, but may only sell it under specific circumstances (Rey et al., 2014).

In addition to legal ownership, humans can experience perceived ownership over goods or services, which is referred to as psychological ownership (Dawkins et al., 2017; Pierce et al., 2001). Psychological ownership defined as a 'state in which individuals feel as though the target of ownership [...] is theirs' (Pierce et al., 2003, p. 86). Importantly, this sense of ownership can manifest not only at the individual level, but also collectively within groups, shaping shared attitudes and behaviours (Pierce & Jussila, 2011). In the context of nature and natural resources, psychological ownership, just like legal ownership, is an important determinant of behaviour (Matilainen et al., 2017; Wang et al., 2022). In most cases, psychological ownership is positively associated with nature and natural resources. Surveys and vignette experiments have found that psychological ownership can foster support, contribution and protection of natural areas (Preston & Gelman, 2020), enhance intentions to purchase green products and recycle (Felix & Almaguer, 2019), and promote cooperative behaviour towards public goods (Peck et al., 2021). However, psychological ownership can also entail negative or undesired consequences for nature. As theoretical considerations and findings from organizational psychology suggest, feelings of ownership can also give rise to an unwillingness to share or attempts to exclude others from natural resources, potentially hindering cooperation and increasing conflict (Wang et al., 2022). In the context of rebound effects, psychological ownership may also influence water use decisions, as farmers may resist reductions in their water rights following efficiency gains from modernization. In a first study on psychological ownership in the context of irrigation, Hoffmann and Villamayor-Tomas (2025) found that farmers were more likely to have a sense of ownership of water when it was saved through efficiency increases compared to when it was naturally supplied. The collective form of psychological ownership dominated the individual form, likely due to the strong institutional context of collective irrigation in Spain. However, the study remained inconclusive about how these perceptions of ownership emerge.

Organizational theory brings forward three routes through which people develop psychological ownership: investment, knowledge and control (Pierce & Jussila, 2011; Wang et al., 2022). The investment route implies that people develop a feeling of ownership for an object if they invest effort, time, labour or ideas into it. The knowledge route emerges as an individual acquires more information about an object, enabling a more intimate relationship which leads to feelings of ownership. Finally, the control route suggests that the more control a person exerts over the target (e.g., by influencing decisions or practices regarding it), the stronger the feeling of ownership. Hereafter, we refer to these three routes as psychological ownership routes (or short, PO-routes).

The theory of psychological ownership provides a framework for understanding whether and why some actors may feel entitled to water savings after modernization. Such feelings of ownership can influence how water users claim or share water savings, potentially promoting cooperation or conflict, and shedding light on behavioural drivers of rebound effects (Dorner, 2019; Santarius & Soland, 2018). Considering existing theory and previous empirical findings, we expect the three PO-routes to increase the feeling of collective ownership over hypothetical water savings. We expect that if PO-routes increase perceived ownership of hypothetical water savings, this effect will manifest at the community level rather than the individual level (Hoffmann & Villamayor-Tomas, 2025).

Materials and methods

Field context

The context for our study is Spain, a country where irrigation is essential for agriculture and freshwater resources are increasingly scarce and contested. Two major forces drive this water scarcity, namely the extensive development of irrigated agriculture (Albiac et al., 2013), with recent estimates indicating that agricultural water consumption accounts for more than 80% of total water use in Spain (Serrano et al., 2024), and the increasing frequency and severity of droughts (Jiménez-Donaire et al., 2020). This pressure on freshwater leads to reductions in important environmental flows into rivers, lakes and wetlands, causing shifts in species composition and loss of habitat, eventually diminishing ecosystem resilience (Ibáñez & Caiola, 2013).

As a response to the increasing pressure on freshwater resources, Spanish legislation introduced mechanisms for regulating water extraction and ecological flow allocations in river basin plans. The Water Act of 1985 declared all surface and groundwater exploited after 1986 to be public and required River Basin Authorities (in Spanish: *Confederaciones Hidrográficas*) to maintain registers of water resources (Embid, 2002). Furthermore, current legislation sets an order of priority for water use during droughts, granting highest priority to domestic supply, followed by agricultural irrigation (MITECO, 2001). However, monitoring and enforcement of water extractions have been weak, particularly for groundwater, where the effective prevention of illegal wells is difficult to enforce. While caps on abstraction exist in law and have been reinforced by the EU Water Framework Directive, practical implementation remains inconsistent (Closas et al., 2017; Sánchez-Martínez et al., 2012).

Given that regulatory measures alone are unlikely to reduce the pressure on water, technological solutions have become increasingly prominent and, as such, the modernization of irrigation infrastructure dominates the national water management strategy since the beginning of the 21st century (Lopez-Gunn et al., 2012). For example, the Spanish government launched two modernization programmes between 2002 and 2008 that aimed at modernizing 2.3 million hectares with a cost of around EUR 7,600 million (Berbel et al., 2019). Subsidies granted to WUAs for modernizing their infrastructure range from 40% to 100% of the investment costs (Molle & Sanchis-Ibor, 2019) and have covered a variety of infrastructure improvements, ranging from the paving of ditches to the introduction of sprinkler and drip irrigation. Costs of irrigation improvements depend on size, crop and design, but are particularly high when installing sprinkler or drip irrigation systems. Investments typically involve canal lining and pools at the system level, plus sprinkler or drip installations at the farm level. That is why subsidies in Spain have played and continue to play a major role in the modernization process of the Spanish irrigation landscape (García-Mollá et al., 2014). Most recently, the Spanish Ministry for the Ecological Transition and the Demographic Challenge (MITECO) launched a call for subsidies amounting to EUR 100 million, covering up to 100% of the eligible investment costs (MITECO, 2025).

Spain is also a paradigmatic example of collective irrigation management (Garces-Restrepo et al., 2007). WUAs operate under a decentralized governance model, which grants them autonomy in internal decision-making, including allocating water, maintaining infrastructure and enforcing rules (Thuy et al., 2014). WUAs are embedded within a nested system of water governance, in which River Basin Authorities oversee broader hydrological planning and allocate water use-rights at the basin level. These authorities grant concessions to WUAs, not to individual farmers. As such, while WUA members have access to water based on internal allocation rules, they do not hold individual property rights over water. As a result, they generally cannot sell or transfer their share of water to actors outside the association.

Survey and experimental design

We address our research questions by capturing the perceptions of Spanish farmers on hypothetical water savings in different scenarios through a vignette-based experiment embedded within a larger survey (Holbrook & Lavrakas, 2019). The survey comprised three parts: 1) General questions covering agriculturally relevant information about the farmer, their WUA, farming practices and irrigation system characteristics, 2) the survey experiment and 3) socio-demographic control questions. The full survey can be found in Appendix A3 in the online supplemental data.

The experiment consisted of a hypothetical scenario in which farmers were asked to imagine a drought, with modernization enabling them not only to irrigate existing crops but also to generate additional water savings. The inclusion of a drought in the scenario was motivated by the dominant association of droughts and modernization in Spanish agriculture.¹ From this scenario we developed one baseline and three treatment variations. In the baseline, the concrete quantity of water savings was unknown, the modernization was not paid for by the WUA and the WUA was unable to store the generated

savings for the future. We varied each of these three aspects to simulate the three theoretical PO-routes, creating the three treatment scenarios.

For the knowledge route, we specified in the scenario that modernization would generate 10% water savings (*knowledge treatment*). Concrete information helps farmers plan irrigation more effectively and makes the savings more tangible, both of which we expect to strengthen psychological ownership through the knowledge route. For the investment route, the scenario stated that modernization was fully paid for by the WUA (*investment treatment*). When farmers, as members of their WUA, invest financial resources and effort into modernization, they are more likely to expect a return on these investments and to perceive the resulting water savings as partly their own, reflecting economic amortization motives through the investment route. Finally, for the control route, we specified that the WUA could store the generated water savings (*control treatment*). The ability to decide when and how to use these savings enhances perceived control over the resource, thereby reinforcing psychological ownership through the control route proposed by the theory. Table 1 summarizes the main aspects of the four hypothetical scenarios.²

Using a between-subjects design, respondents were presented with only one of the four scenarios. After reading their randomly assigned scenario, respondents first answered three control questions (T01–T03) and proceeded to seven closed questions about ownership, distribution, use and propensity to sell (T04–T10). The latter set of questions (T04–T10) is related to the hypothetical water savings from the respective scenario and constitutes our dependent variables (Table 2). Questions T04 and T05 address perceived and normative ownership, which we differentiate to control for experimenter bias. Questions T06–T08 asked respondents to rank options based on their beliefs about how the water basin authority (T06) or their WUA (T07) would distribute the hypothetical water savings, and their personal preferred distribution (T08). Question T09 addresses the respondents' personal use preference and question T10 their willingness to sell the generated savings.

The provided response options of ownership and distributional preferences (T04 to T08) are based on the four potential recipients of savings: the WUA itself (proprietor), neighbouring WUAs (neighbour), nature or society (Lankford, 2013; Lankford & Scott, 2023). The experiment was preregistered (registration #194533 on aspredicted.org). The survey was programmed using Qualtrics and optimized for completion on mobile devices but was also printed for farmers who preferred to complete it on paper.

Table 1. Overview of experimental scenarios (treatments).

	Information on water savings	Financial investment to generate water savings	Control over water savings
Baseline	No	No	No
Knowledge treatment	Yes	No	No
Investment treatment	No	Yes	No
Control treatment	No	No	Yes

Table 2. Description of main variables of interest based on survey questions.

ID	Question	Variable name	Response options	Variable type
T04	Who do the water savings belong to?	Perceived Ownership	<ul style="list-style-type: none"> • Individual farmer • WUA 	4-factor categorical variable
T05	Who should the water savings belong to?	Normative ownership	<ul style="list-style-type: none"> • Environment • Society 	
T06	In case the water basin authority could decide how to distribute the water savings, how would they do it?	Distributional belief (Authority)	<ul style="list-style-type: none"> • Irrigation use in my WUA • Urban/Industrial use • Environmental flows • Irrigation use in other WUAs 	Rank-ordered variable from 1 (most likely) to 4 (least likely)
T07	In case your WUA could decide how to distribute the water savings, how would they do it?	Distributional belief (WUA)		
T08	In case you personally could decide how to distribute the water savings, how would you do it?	Distributional preference		
T09	Imagine the water savings are distributed within your WUA. What would you do with your share?	Use preference	<ul style="list-style-type: none"> • Increase irrigated area • Leave for other water users in my WUA • Leave for dryland farmers • Save for droughts • Change crops for higher return • Use for double harvest 	Rank-ordered variable from 1 (most preferred) to 6 (least preferred)
T10	In case you could sell the water savings, would you?	Willingness to sell	<ul style="list-style-type: none"> • Absolutely not • Probably not • Unsure • Probably yes • Absolutely yes 	5-scale Likert question

Sampling

After obtaining approval from the Ethical Research Committee of the Autonomous University of Barcelona (CERec, ref: CEEAH7017) and piloting the survey with farmers from the Riegos de Alto Aragón project in July 2024, the actual data collection took place between November 2024 and April 2025. The survey targeted members of Spanish WUAs. Due to low response rates in initial email invitations, we combined phone contact and field visits to increase participation, ultimately concentrating on WUAs in the Ebro River basin for logistical reasons. While acknowledging that this type of convenience sampling might possibly lead to a non-representative sample, previous research has demonstrated that the pitfalls of convenience sampling are often negligible (Ellis et al., 2023). During the data collection, we removed the *control treatment* from the experiment, as pre-analyses indicated it yielded the least promising effects, allowing us to maximize statistical power for the remaining treatments (*baseline*, *knowledge* and *investment*) given the sampling difficulties. Removing less promising experimental treatments throughout the sampling process is a justified approach to guarantee sufficiently high statistical power for the most promising treatments if resources are limited (Jobbjörnsson et al., 2023). In total, 351 surveys were started, but a large fraction was abandoned in the process. We considered surveys for the analysis only if more than 85% of the questions were answered.³ Thus, 149 surveys were discarded due to low completion rates, resulting

Table 3. Descriptive statistics of the main sample.

Demographics	
Male respondents (%)	96.1
Age, mean (SD) [min; max]	55.8 (12.3) [17; 83]
Education (%)	
Primary education	23.0
Secondary education	25.8
University degree	18.5
Agricultural training	32.6
Farm characteristics	
Cultivated area* (ha), mean (SD) [min; max]	73.0 (124.2) [0.5; 950]
Irrigated area* (ha), mean (SD) [min; max]	50.9 (84.7) [0.5; 700]
Land ownership (%)	67.1
Full-time farmer (%)	66.5
Crop: Herbaceous (%)	61.4
Crop: Wooden (%)	31.9
Crop: Vegetable (%)	6.0
Irrigation: Sprinkler (%)	18.4
Irrigation: Drip (%)	18.5
Irrigation: Furrow/Flood (%)	60.4
Modernized** (%)	48.3
Water source: Surface (%)	97.1
N	183

Note: *Excluding two outliers. **A farmer is considered 'modernized' if he indicated having transformed all or parts of his irrigated area from furrow/flood to drip or sprinkler irrigation.

in a full sample of 202 surveys considered. After removing the *control treatment* surveys (19), the sample for the main analysis includes 183 responses, with 64 responses to the baseline scenario, 66 responses to the knowledge scenario and 53 responses to the investment scenario. A descriptive summary of the main sample is presented in Table 3 and the geographical location of all sampled WUAs, colour-coded based on completion mode (digital or paper), is shown in Figure 1. Although we aimed for representativeness, the difficulty of collecting data in the field with farmers introduced some sampling bias. Compared to the Spanish average, our sample includes slightly more male, younger and educated respondents, and the primary water source is surface water. Despite these demographic deviations, the core institutional characteristic of our sample (collective water governance in active WUAs) mirrors those of the wider Spanish irrigation sector, making it relevant and valid for our research objectives. We provide more details on the sampling procedure and comparisons to subsamples and the Spanish farming population in Appendix A1.

Analytical approach

This section outlines how survey responses were transformed into variables and describes the econometric model we use to test our hypotheses. Single-choice questions measuring perceived and normative ownership (T04, T05) were coded as categorical variables. Rank-order questions on distributional beliefs, distributional

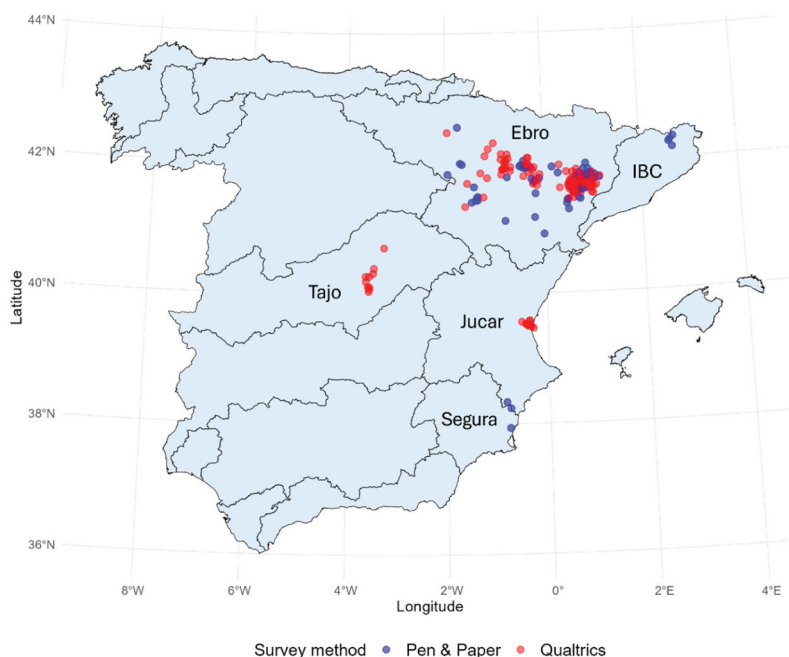


Figure 1. Map of Spain with sampled WUAs and their location within River Basins. IBC = Internal Basins of Catalonia.

preferences and use preferences (T06–T09) required participants to rank options from 1 (highest probability or preference) to 4 (lowest probability or preference). However, many respondents who completed the survey on paper did not follow these instructions, resulting in incomplete or invalid rankings. To minimize data loss and ensure comparability with single-choice questions, we recoded these items by retaining only the option ranked first as the respondent's preferred choice and present them as categorical variables. Finally, responses regarding the willingness to sell (T10), measured on a five-point Likert scale, were treated as ordinal variables. To assess differences across treatments, we applied chi-squared tests and Fisher's exact tests where appropriate.

In addition to descriptive analyses, we estimate a multinomial logistic regression model to examine the relationship between treatments and perceived ownership while controlling for agricultural and socio-demographic variables. The model is formalized as;

$$\ln\left(\frac{P(Y=j)}{P(Y=0)}\right) = \beta_{j0} + \beta_{j1}\text{Knowledge} + \beta_{j2}\text{Investment} + \sum_{k=1}^8 \gamma_{jk}X_k$$

where $Y = j$ denotes the perceived ownership category, β_n are treatment coefficients and X_k represents control variables. As agricultural controls we use area under irrigation (Arealrrigated), proportion of land owned by the farmer (LandOwnership), proportion of woody (CropWood) and vegetable crop (CropVeg) and a dummy variable (Modernized) which takes the value 1 if the farmer indicated to have transformed all or parts of their

irrigated area from furrow to drip or sprinkler irrigation. Socio-demographic controls include age, education (ref = 'Agricultural training') and satisfaction with WUA functioning (Satisfaction, measured on a 10-point Likert scale).⁴ This multinomial logistic regression allows us to understand the factors that lead farmers to assign ownership of hypothetical water savings to certain outcome categories instead of a reference category.

Results

Psychological ownership

Psychological ownership of water savings⁵ is measured by two dependent variables: the perceived ownership (T04) and the normative ownership (T05) of water savings. The distribution of responses across treatments for both T04 and T05 is shown in Figure 2.

To test whether perceived and normative ownership perceptions differ, we conducted a Stuart–Maxwell test of marginal homogeneity (Stuart, 1955). A full comparison shows that the distribution of choices differs significantly between T04 and T05 ($\chi^2(3) = 9.41, p = 0.02$). However, post-hoc McNemar tests (Lachenbruch, 2014) found no single category with a significant change between T04 and T05 (Holm-adjusted p-values: Individual farmer = 0.33, WUA = 0.33, Society = 0.12, Environment = 0.60). This indicates that although the overall distribution of responses across T04 and T05 is different, no single category drives the change. We therefore assume that there is no meaningful difference between perceived and normative ownership in our sample.

Focusing on treatment comparisons, we find no significant differences across treatments for both measures of psychological ownership (Fisher's exact test: $p(T04) = 0.57, p$

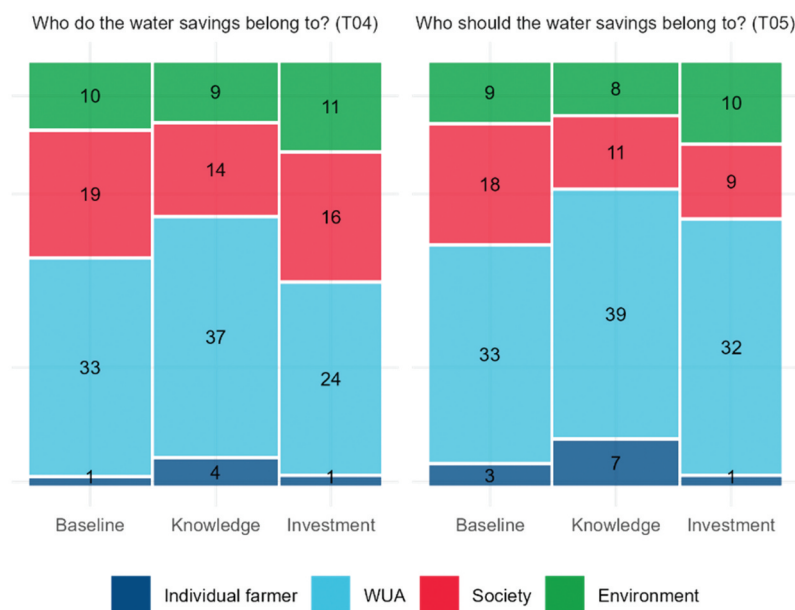


Figure 2. Mosaic plots of responses to perceived (T04) and normative ownership (T05) across treatments. Numbers indicate response counts.

(T05) = 0.28). This holds also for dichotomizing the responses to represent irrigation use (Farmer and WUA) and non-irrigation use (Society and Environment) (Fisher's exact test: p (T04) = 0.21, p (T05) = 0.27).

Figure 2 also shows that the option 'Individual farmer' was rarely selected. In order to improve analytical clarity and statistical robustness, we merged the categories 'Individual farmer' and 'WUA' into the category 'Farmer/WUA' for subsequent analyses. This grouping captures the idea that ownership is attributed to actors directly involved in water use and management at the local level (individually or collectively) and addresses the unreliable sample size of the 'Individual farmer' option.⁶

Regression results are presented in Table 4. The reference category for the dependent variable (perceived ownership, T04) is 'Farmer/WUA'. Thus, we estimate changes in the odds of assigning ownership to 'Environment' or 'Society' relative to 'Farmer/WUA'. Models were estimated sequentially: Model 1 includes treatments only (with 'Baseline' as the reference category), Model 2 adds agricultural controls, and Model 3 further adds socio-demographic controls. For reasons of parsimony, we report only the control variable 'Modernized' separately in Table 4.⁷

All model specifications reveal no significant treatment effect on perceived ownership. The negative intercepts confirm that, in the absence of treatment effects, respondents were generally less likely to select Environment or Society over Farmer/WUA. The significance of the intercept disappears in Model 2 and weakly reappears in Model 3 for assigning ownership to the Environment.

Result 1. Framing water savings via the PO-routes 'Knowledge' and 'Investment' does not lead to an increase in the odds of individuals assigning ownership to Farmer/WUA over Environment or Society.

Table 4. Multinomial logistic regression estimating the perceived ownership (T04).

	Model 1		Model 2		Model 3	
	Environment	Society	Environment	Society	Environment	Society
(Intercept)	-1.224*** (0.360)	-0.582* (0.286)	-1.193 (0.713)	-0.079 (0.529)	-3.657* (1.826)	-1.325 (1.264)
Treatment:	-0.293	-0.493	-0.189	-0.515	-0.202	-0.544
Knowledge	(0.515)	(0.422)	(0.542)	(0.428)	(0.576)	(0.449)
Treatment:	0.403	0.136	0.383	0.084	0.154	0.079
Investment	(0.510)	(0.430)	(0.538)	(0.441)	(0.573)	(0.462)
Modernized			1.071* (0.477)	-0.033 (0.373)	1.303* (0.516)	0.011 (0.393)
Agricultural controls	No		Yes		Yes	
Socio-demographic controls	No		No		Yes	
N	179		176		170	
R ² Adj.	0.004		0.033		0.080	
AIC	359.2		362.0		355.7	
BIC	378.3		412.7		437.2	
RMSE	0.44		0.43		0.42	

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. AIC = Akaike information criterion; BIC = Bayesian information criterion; RMSE = root mean square error.

Reference category for the dependent variable is 'Farmer/WUA', for treatment it is 'Baseline'. Standard errors in parentheses.

Models 2 and 3 show that having modernized the farm fully or partially increases the odds of assigning ownership of water savings to the Environment (over Farmer/WUA). The coefficients ($\beta = 1.07$ (1.303), $p < 0.05$) translate into an increase in the odds of assigning ownership to the Environment by 2.9 (3.7). This relationship holds when modernization is modelled as the share of sprinkler and drip irrigation on the farm, although the effect is smaller ($\beta = 0.02$, $p < 0.01$, see Table A4 in the Appendix).

Distributional beliefs and preferences

Distributional beliefs and preferences were elicited using ranking questions T06–T09 (see Table 2). Given that numerous ranking questions were answered wrongly by participants who did the survey on paper, the analysis of ranking questions is based on a reduced sample of 140 responses, eliminating invalid rankings.⁸

Figure 3 visualizes the distributions of the most expected or preferred receiver of water savings, i.e., the option that was ranked first in questions T06–T08. Fisher's exact tests show no significant differences in ranked-first options across treatments ($p(T06) = 0.11$, $p(T07) = 0.12$, $p(T08) = 0.56$).⁹ However, we note visually that farmers tend to favour the same distribution of water savings as they expect of their WUA (T07 and T08) but differ in what they believe an authority would do (T06). Regarding the distributional belief of a water basin authority (T06), 'Environmental flows' is the most frequently first-ranked option in the Baseline, while in treatments Knowledge and Information it is 'Own WUA'. For the distributional belief by the WUA (T07), 'Own WUA' is ranked first by most respondents across treatments. This also holds for the individual distribution preference (T08).

The frequency of responses regarding use preferences (T09) is shown in Figure 4. A Chi-square test yields no difference across treatments for the indicated use preference ($\chi^2 = 16.37$, $p = 0.09$). In the Baseline, the most frequently ranked first options were 'Increase irrigated area' and 'Use for double harvest'. In the Knowledge treatment, 'Increase irrigated area' was also the most frequently selected option, followed by 'Save for droughts'. In the Investment treatment, 'Use for double harvest' was most frequently ranked first, followed by 'Leave for other users of my WUA' and 'Leave for dryland farmers'.

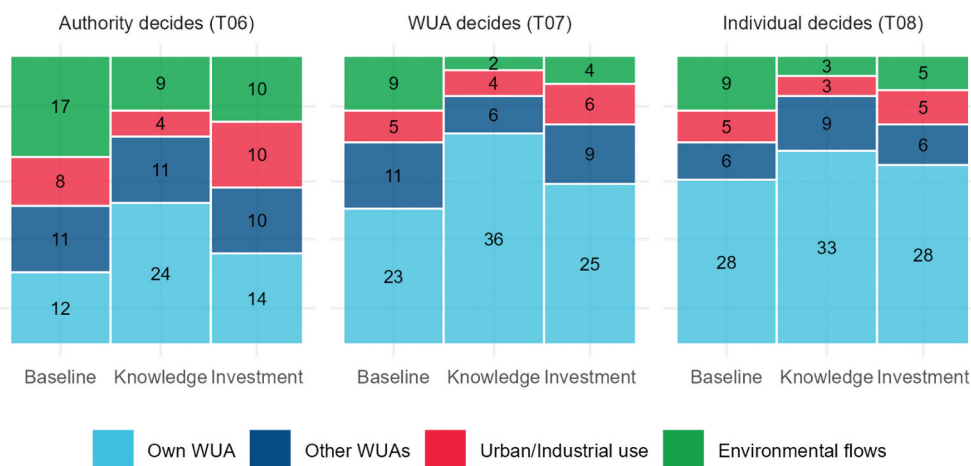


Figure 3. Beliefs (T06–07) and preferences (T08) regarding the distribution of water savings across treatments. Numbers indicate response counts.

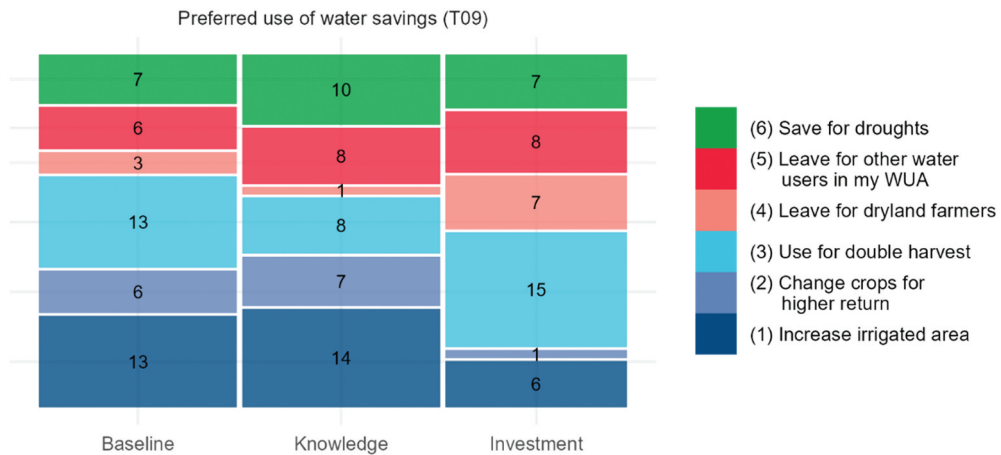


Figure 4. Individual use preferences of water savings (T09) across treatments. Colour coding represents grouping of answers: Options 1–3 (Blue) are characterized by ‘profit-driven’ oriented, Options 4–5 (Red) by ‘redistribution’ oriented, and Option 6 (Green) by ‘adaptation’ oriented.

Result 2. Framing water savings via the PO-routes ‘Knowledge’ and ‘Investment’ does not lead to different distributional or use preferences thereof.

Grouping the six answer options into three thematic categories (profit-driven: increase in irrigated area, change crops for higher return, use for double harvest; redistribution: leave for other water users, leave for dryland farmers; adaptation: save for droughts), we see that profit-driven options dominate in the Baseline and the Knowledge treatment, but are as frequent as the redistribution and adaptation themes taken together in the Investment treatment (colour-coded in Figure 4).

Propensity to sell

Finally, we analyse how respondents perceive the possibility of selling water savings. Figure 5 visualizes responses across treatments. Although participants in the Baseline appear to be more inclined to ‘probably’ sell the water savings, we find no statistical significance for responses across treatments ($X^2 = 8.34$, $p = 0.4$). Overall, while many respondents expressed reluctance to sell water savings (54% on average), indecisiveness (17%) and some willingness to sell (29%) were also common, indicating that attitudes towards selling water do not show a clear direction.

Result 3. Framing water savings via the PO-routes ‘Knowledge’ and ‘Investment’ does not affect the willingness to sell water savings.

Exploratory analyses

Given that our pre-registered analysis did not show any significant treatment effect, we explore potential relationships between dependent variables by pooling responses from all treatments to increase statistical power.¹⁰ First, we explore whether ownership

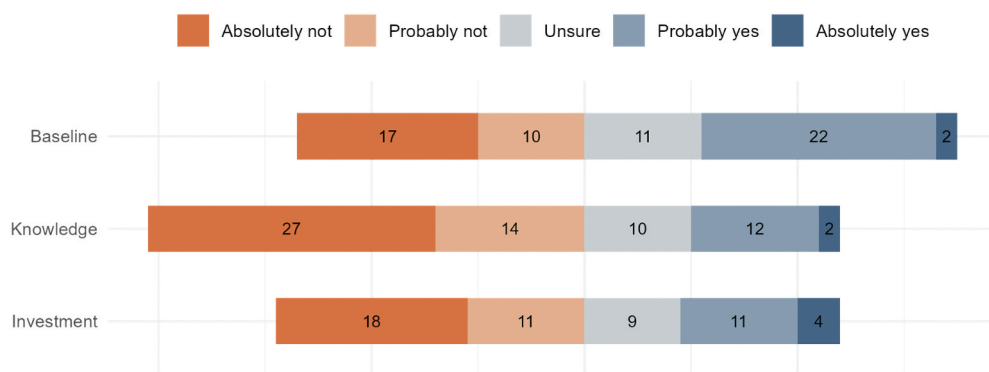


Figure 5. Distribution of willingness to sell the water savings from the hypothetical scenario based on a 5-point Likert scale.

perceptions of water savings influence the distributional preferences thereof. We run the same regression as in the main analysis except that we regress perceived ownership (T04) on the individual distributional preference (T08). Table 5 shows regression results without controls (Model 1) and with controls (Model 2).

Apart from the significant intercepts in Model 1, the regression yields a positive relationship between assigning ownership of savings to the environment (over Farmer/WUA) and distributing those savings to other WUAs (over own WUA). In other words, those farmers who believe that water savings belong to the Environment are more likely to prefer a distribution thereof that benefits other WUAs compared to their own. The coefficient can be translated into an odds ratio increase by a factor of 4.38 in choosing 'Other WUA' when the environment is the perceived owner. Assigning ownership to society, however, does not seem to impact distributional preferences of water savings.

Table 5. Multinomial logistic regression estimating the individual distributional preference (T08).

	Model 1			Model 2		
	Env. flows	Other WUAs	Urban/ industrial use	Env. flows	Other WUAs	Urban/ industrial use
(Intercept)	−1.740*** (0.343)	−1.846*** (0.359)	−2.251*** (0.429)	−2.217 (1.911)	−2.797 (1.817)	−2.110 (2.055)
Ownership: Environment	0.967 (0.601)	1.478** (0.563)	1.073 (0.715)	0.945 (0.700)	1.943** (0.644)	1.371 (0.800)
Ownership: Society	−0.862 (0.809)	0.496 (0.555)	0.565 (0.649)	−1.047 (0.844)	0.743 (0.622)	0.432 (0.695)
Modernized				−0.333 (0.651)	−0.911 (0.558)	−0.344 (0.685)
Agric. and socio-dem. controls	No			Yes		
N	155			153		
R2 Adj.	0.029			0.114		
AIC	336.1			361.0		
BIC	363.5			479.2		
RMSE	0.37			0.35		

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. AIC = Akaike information criterion; BIC = Bayesian information criterion; RMSE = root mean square error.

Reference category for the dependent variable is 'Own WUA', for perceived ownership (T04) it is 'Farmer/WUA'. Standard errors in parentheses.

Model 2 adds agricultural and socio-demographic control variables to the regression. Intercepts remain negative, but are no longer significant, suggesting that the added controls explain more of the baseline variation. The relationship between assigning ownership to the Environment and preferring a distribution that favours other WUAs from Model 1 is still significant ($\beta = 1.94$, $p < 0.01$). None of the controls themselves significantly affect distributional preferences, although they do increase model fit (0.03 to 0.11 of R^2 adj.).

Result 4. Assigning ownership of water savings to the environment increases the odds of distributing these savings to other WUAs compared to the own WUA.

In Table 6, we regress psychological ownership responses on the first ranked option from question T09, using the full model with controls. The regression shows a significant relationship between farmers who assign ownership to the environment and the preference for leaving water savings for dryland farmers ($\beta = 3.4$, $p < 0.01$,

Table 6. Multinomial logistic regression estimating the individual use preference (T09).

	Change crops	Leave for dryland	Leave for others in my WUA	Save for droughts	Double harvest
(Intercept)	-5.364* (2.522)	-7.757* (3.359)	-3.519 (2.120)	-1.372 (1.778)	-2.004 (1.700)
Ownership:	1.148	3.396**	1.408	1.250	1.164
Environment	(1.053)	(1.141)	(0.938)	(0.977)	(0.891)
Ownership:	0.747	0.970	0.196	1.133	0.554
Society	(0.773)	(1.142)	(0.734)	(0.638)	(0.634)
ArealIrrigated	-0.004 (0.005)	0.000 (0.002)	-0.009 (0.007)	-0.007 (0.006)	0.000 (0.001)
LandOwnership	-0.007 (0.010)	-0.001 (0.011)	0.007 (0.009)	-0.003 (0.008)	-0.005 (0.008)
CropWood	-0.010 (0.011)	-0.014 (0.013)	0.005 (0.009)	0.002 (0.008)	-0.022** (0.008)
CropVeg	0.016 (0.023)	-0.002 (0.034)	0.013 (0.023)	0.029 (0.020)	0.018 (0.020)
Modernized	-0.203 (0.775)	0.570 (0.863)	0.365 (0.690)	0.119 (0.617)	1.106* (0.559)
Age	0.061* (0.031)	0.071 (0.040)	0.024 (0.025)	0.011 (0.022)	0.008 (0.021)
Education:	-14.579***	-0.244	-2.002	0.552	0.007
Primary	(0.000)	(1.561)	(1.258)	(0.819)	(0.883)
Education:	0.906	1.270	1.508	0.997	0.754
Secondary	(0.884)	(1.029)	(0.797)	(0.828)	(0.775)
Education:	0.448	-0.078	0.124	0.329	0.587
University	(0.853)	(1.123)	(0.822)	(0.801)	(0.702)
Satisfaction	0.227 (0.196)	0.176 (0.249)	0.120 (0.144)	-0.007 (0.126)	0.179 (0.147)
N	153				
R2 Adj.	0.181				
AIC	557.2				
BIC	754.2				
RMSE	0.34				

Notes: The estimate for Education: Primary in the Change crops option reflects complete separation: our sample includes no respondents with primary education who selected this option. We therefore do not interpret this coefficient. Significance levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. AIC = Akaike information criterion; BIC = Bayesian information criterion; RMSE = root mean square error.

Reference category for the dependent variable is 'Increase irrigated area', for perceived ownership (T04) it is 'Farmer/WUA', for Crop it is 'Herbaceous', for Education it is 'Agricultural Training'. Standard errors in parentheses.

odds ratio increase by factor 29.8). Furthermore, modernized farmers are significantly more likely to prefer using water savings for double harvest ($\beta = 1.1$, $p < 0.05$, odds ratio increase by factor 3). The effect of modernization, however, disappears when modelled as the share of sprinkler and drip irrigation. Among the significant controls, we observe a weak negative relationship between woody crops and double harvest ($\beta = -0.02$, $p < 0.01$) and a weak positive relationship between age and changing crops for higher return ($\beta = 0.06$, $p < 0.05$).

Result 5. Perceived ownership and modernization affect individual use preferences.

Discussion

Building on the theory of psychological ownership, this study examines how Spanish farmers perceive hypothetical water savings from irrigation modernization. The main result of our vignette-experiment shows no significant effect of any of the psychological ownership routes suggested by the literature (Pierce & Jussila, 2011) on stated perceptions of ownership, distributional beliefs and preferences, use preferences or willingness to sell of water savings (Results 1, 2 and 3). Exploratory analyses, however, indicate a relationship between psychological ownership and distributional and use preferences (Results 4 and 5).

Our hypothesis posited that the routes through which farmers engage with irrigation modernization, such as paying for modernization (investment route) or knowing the amount of generated water savings (knowledge route), would reinforce their perception of ownership thereof. However, treatment variations did not significantly affect statements regarding perceived ownership (Results 1, 2 and 3). Independently of the scenario presented, most respondents consistently assigned ownership of water savings to the WUA. This finding aligns with previous evidence that Spanish farmers tend to perceive water as well as water savings as a communal rather than an individual good (Hoffmann & Villamayor-Tomas, 2025). To account for the perceived link between modernization and drought resilience among farmers in Spain, our experimental scenarios included a drought. By actively stating that water savings were produced despite drought-related lower water availability, we intended to make sure that respondents did not think of using savings to cope with droughts, which would be rather expected in the Spanish context (Villamayor-Tomas, 2014; Villamayor-Tomas et al., 2020). The result of collective psychological ownership reflects the deeply ingrained norm of collective water governance in Spain, where WUAs play an imperative role managing not only the distribution of water but also access to modernization subsidies and long-term infrastructure development.

One potential explanation for the absence of treatment effects is the fact that, in the Spanish context, water (and potential savings) is managed and redistributed collectively, suggesting that individual experiences of contributing to or knowing about savings may not necessarily lead to a sense of psychological ownership. It is common that a resource surplus from a higher efficiency lacks clear property rights (Lankford & Scott, 2023). In the context of strong water institutions like those embodied by WUAs, it seems plausible that farmers delegate the decision about water savings to the collective level. These collective decisions can in turn lead to reallocation towards uses that maintain or even increase total consumption,

resulting in rebound effects instead of environmental conservation (Hoffmann & Villamayor-Tomas, 2023; Sampedro-Sánchez, 2022). River basin authorities could, in principle, reduce irrigation rights when modernization allows crops to meet water needs with less water, but in reality this practice has been far from mainstream due to administrative inertia, political interests or resistance from farmers (Schütze, 2025). This lack of enforcement strengthens the tendency for surplus water to be absorbed into production rather than conservation. The governance of water savings in the aftermath of modernization investments shall be decided collectively by WUAs, public authorities and other stakeholders before said investments. In the pioneering case of the Acequia Real del Júcar irrigation system, farmers agreed to transfer part of their water rights to the nearby coastal lagoon of 'L'Albufera de València' in exchange for modernization subsidies. The decision was the result of a multi-stakeholder participatory process that involved consensus-building about the hydrological boundaries of the irrigation system, the impact of modernization in the basin and measures to counterbalance them (Sanchis-Ibor et al., 2024).

We further explored the relationship between psychological ownership and stated preferences over distribution and use of water savings. We found that farmers who assigned ownership to the environment were significantly more likely to prefer distributing the generated water savings to other WUAs compared to their own (Result 4). This suggests that farmers who view the environment as owner of water savings may develop a pro-social or community-oriented perspective, prioritizing social benefits over immediate personal gains. The finding also suggests that such pro-social behaviour is not necessarily parochial, i.e., that farmers do not necessarily perceive a trade-off between recognizing the public nature of water and favouring the interests of the farming/irrigation sector. Such a shift in preference aligns with theories of environmental stewardship, which state that individuals may act in ways that benefit the collective and long-term environmental sustainability simultaneously (Bennett et al., 2018). It may also reflect a recognition of interdependences between water users across WUAs, particularly in basins where water scarcity affects multiple communities. By favouring environmental ownership, i.e., good hydrological conditions across the basin, farmers implicitly demonstrate concerns about water supply to other irrigation systems, and willingness to engage in cooperative resource governance beyond their own WUAs. However, this preference can also be interpreted less favourably, namely that farmers may favour keeping water within agriculture rather than outside, limiting broader environmental or societal benefits.

Our second exploratory analysis uncovered that perceived ownership affects agricultural use preferences for water savings (Result 5). In particular, we found that farmers who assigned ownership to the environment were more likely to prefer leaving water savings for dryland farmers. This supports the previous exploratory finding and reinforces the argument that farmers can combine environmental stewardship, pro-social behaviour and in-group preferences. Acknowledging that our result is only exploratory, future research in this direction might contribute to a better understanding of pro-environmental and pro-social behaviour of farmers (Burton, 2014; Maharjan et al., 2022).

Furthermore, controlling for modernization in our analyses yielded two interesting findings. We modelled modernization in two ways: As a dummy variable representing whether a farmer indicated to have modernized parts or all of their farm and as a continuous variable representing the share of sprinkler and/or drip irrigation systems

on the farm. First, modernization is associated with increasing the odds of assigning ownership to the environment rather than to the individual farmer or the WUA. In other words, having modernized one's cultivation increases the odds of seeing water savings as 'owned' by the environment. This result holds for both modernization variables and can be interpreted in two ways. On the one hand, it provides evidence for farmers reproducing the narrative of the 'ecological role' of modernization and suggests that modernization may indeed foster a more ecological perception of water governance (Hoogesteger et al., 2023). On the other hand, modernization leaves farmers with little remaining scope for on-farm savings and potentially increases concern that others' modernization will raise overall use. Thus, modernized farmers have weaker on-farm incentives and thus prefer reallocating savings to the environment.

Second, modernization increases the likelihood of preferring double harvesting as a destination for water savings. This effect is weaker than the previous one and only holds for the dichotomized modernization variable. However, it aligns with the previous result and suggests that farmers who have modernized their farms are more inclined towards intensifying production. One explanation for this preference is the increased costs of water application following modernization (Sanchis-Ibor et al., 2017). Consequently, farmers may seek to dedicate water savings to double harvesting to redeem these costs. Furthermore, this result illustrates a dual effect of irrigation modernization: while it appears to strengthen ecological perceptions of water savings, it simultaneously encourages behaviour that can negate or reverse the intended water savings, precisely what is observed in the irrigation rebound effect (Pérez-Blanco et al., 2020). Although these results should be treated with caution, they point to the importance of farmers' perceptions and water accountability. First, the findings show that farmers are willing to save water for the environment provided that their production preferences (specifically double harvesting) are somewhat satisfied. Second, in the absence of serious accountability of water efficiency gains, it remains unclear whether water use intensification and environmental sustainability are indeed truly compatible and, if so, to what extent. In certain contexts, farmers' perceptions that such a balance is achievable may be justified.

Implications for governance and policy

The consistent ownership assignment of water savings to WUAs implies that WUAs should be seen as legitimate and credible actors and thus be held accountable for efforts to manage or redistribute water savings in ways aligned with sustainability goals. This aligns with previous arguments calling for the empowerment of WUAs in allocation and conservation decisions (Hoffmann & Villamayor-Tomas, 2025; Poblador et al., 2021). Since the hypothesized routes to psychological ownership (knowledge and investment) did not affect responses regarding perceived ownership, policy measures based on such and similar mechanisms may have limited behavioural leverage.

The absence of individual ownership of water savings could help explain why water conservation remains elusive in the wake of irrigation modernization (Pérez-Blanco et al., 2020). From the perspective of the rebound effect, one might expect that if farmers feel ownership over water savings, they would be more likely to reinvest it into production, thereby precluding potential conservation gains. However, if water

savings are collectively owned and perceived as such, the behavioural drivers of the rebound effect may lie in the collective incentive to store and use water savings at the community-level. This indicates that any behavioural water conservation policies or interventions, such as information or feedback nudges (Otaki et al., 2022), which are usually targeted at individuals, need to be thought and designed at the community-level. This is not to say that WUA leaders would have an easy job convincing members to give up on water or that they may be interested at all in conserving water to benefit environmental or other uses downstream. WUAs in Spain have indeed been very keen on expanding irrigated land and demanding governments to fully implement irrigation transformation plans. They have also shown increasing concern about droughts and their severity. However, WUAs have also shown to be key in the articulation of win-win solutions, showing concern for environmental conservation (Sanchis-Ibor et al., 2024).

The findings raise questions about the logic of subsidy conditionality schemes, such as those used in Australia, where farmers surrender part of their water rights in exchange for modernization support (Wheeler et al., 2020). In Spain's collective irrigation context, similar trade-offs may be less meaningful unless institutions allow or encourage WUAs to reallocate savings externally (e.g., to the environment or cities). It is unclear whether River Basin Authorities in Spain have implemented any mechanisms to actually account for the water saved and, for example, store it in the reservoirs under their jurisdiction. Knowing that the water saved can be stored could be an incentive for WUAs to negotiate their water use rights in the aftermath of modernization investments. Without clearer ownership rules or enforcement mechanisms, water savings remain a grey area between increased agricultural flexibility and missed conservation potential.

Limitations and future research

Our results must be interpreted considering some key limitations. First, the experimental design relied on a hypothetical scenario, which may not fully capture how farmers would behave in real-world decision contexts. Despite our efforts to simplify and pre-test the hypothetical scenarios, we observed some difficulties among respondents in understanding the situation fully. This suggests a need for more immersive or iterative methods, such as experimental games with incentivized decision-making or deliberative choice experiments, to unpack other behavioural theories in irrigation. In addition, we acknowledge that our relatively small sample size provides only limited power to detect a small effect. Given that farmers generally have a low willingness to participate in surveys (Glas et al., 2019), we still reached a sample that is comparable to those of similar studies (e.g., Block et al., 2024; Villanueva et al., 2015) and believe that it is large enough to provide valuable insights because it encompasses a diverse set of farmers, farm sizes and other contextual conditions.

Second, while the null results suggest that PO-pathways do not drive differences in perception, low statistical power and modest treatment intensity could obscure small effects. Our treatments, though theoretically grounded, might not have been strong enough to activate significant psychological reactions, especially in a context where strong collective thinking is prevalent. Moreover, the way PO-pathways were represented in the experiment may pose limitations. For instance, the Knowledge treatment could also be framed as an awareness of investments in modernization, or the Investment treatment

may depend on the amount contributed. Such aspects were not varied in this study. Third, while we focused primarily on ownership perceptions, there remains an open question about the link between ownership and action. How do feelings of ownership over water savings translate into actual decisions on land use, cropping intensity or participation in water markets? Further behavioural studies could explore this connection using revealed preference data or real-effort experiments. Finally, future studies could aim for a more diverse sample with potentially important differences in perception (e.g., ecologists, urban planners) and move beyond the realm of collective water management in Spain.

Conclusion

This study examines psychological ownership and preferences for the distribution and use of hypothetical water savings from irrigation modernization. It does so through a survey experiment inspired by the theory of psychological ownership. Despite the theoretical relevance of psychological ownership pathways (investment, knowledge and control), we found no significant treatment effects on ownership perceptions, distributional beliefs, use preferences or willingness to sell. Our results highlight the deeply embedded collective governance norms in the Spanish irrigation sector, where water savings, much like water itself, are predominantly viewed as owned by the water user association. While this collective perception may reduce conflicts within water user associations, it does not necessarily translate into conservation-oriented preferences and behaviour. Many farmers still favour productive uses of savings, reinforcing the structural drivers behind the rebound effect. Exploratory analyses show that farmers who perceive the environment as the owner of water savings tend to favour the redistribution of those savings to other WUAs. Additionally, modernization appears to foster ecological perceptions of water governance while simultaneously encouraging intensification through double harvesting, highlighting the dual and sometimes contradictory effects of irrigation modernization. Our findings suggest that behavioural interventions targeting individual perceptions may have limited impact in contexts where water governance is collective. Future policy efforts should therefore be targeted at the collective level and focus on persuading WUAs with clear mandates and incentives to manage water savings in line with broader sustainability goals.

Notes

1. This was confirmed in field visits during previous data collection efforts and the piloting for this study.
2. The exact formulation of the scenario can be revisited in the full survey in Appendix A3.
3. Most of the surveys abandoned in the process were those which were started in our absence on Qualtrics. Since Qualtrics reports the progress of each survey, we chose the 85% threshold because it ensures that the most critical questions in our survey were answered.
4. We do not include the variable 'cultivated area' as control due to causing multicollinearity. The corresponding testing procedure can be found in [Appendix A2](#).
5. Whenever we refer to water savings in the context of our experiment, we imply hypothetical water savings without an explicit mention.
6. The grouping does not substantially alter the results regarding the difference between T04 and T05 (SM-test: $\chi^2(2) = 8.05$, $p = 0.02$; pairwise McNemer-tests: $p(\text{Farmer/WUA}) = 0.03$, $p(\text{Environment}) = 0.60$, $p(\text{Society}) = 0.06$) and the treatment comparison (Fisher's exact test: $p(T04) = 0.49$, $p(T05) = 0.37$). The weakly significant increase in responses assigning ownership

to Farmer/WUA in terms of normative ownership suggests a stronger normative ownership at the Farmer/WUA level. Given the small effect and the modest sample size, we view this as suggestive only and do not interpret it further.

7. The full table with all controls can be found in [Appendix A2](#) (Table A3).
8. Details on this reduced sample are described in [Appendix A1](#) and summarized as Sample B in Table A1.
9. We also tried grouping the responses into irrigation use (Own and Other WUA) and non-irrigation use (Urban/industrial use and Environmental flows). Although a Fisher's exact test appeared significant for T06 ($p = 0.03$), none of the pairwise comparisons between treatments remained significant after Bonferroni adjustment (all $p > 0.06$).
10. This means that we include 16 additional observations that were gathered in the omitted Control-treatment that are not part of the main analysis. However, we still exclude those with invalid ranking questions. Details on the sample are presented in [Appendix A1](#) (Table A1, Sample C).

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Author contribution statement

CRedit: **Patrick Hoffmann:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft;

Sergio Villamayor-Tomas: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

The authors used Microsoft Copilot (GPT-4) solely for language refinement and improving the clarity of text and formulations. No content generation, data analysis, or conceptual development was performed using the tool. All outputs were reviewed and verified by the authors to ensure accuracy and integrity.

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ORCID

Patrick Hoffmann  <http://orcid.org/0000-0002-2001-8588>

Sergio Villamayor-Tomas  <http://orcid.org/0000-0002-5170-1718>

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Appendix A

A1. Sampling

The sampling process unfolded in several stages. In the first step, we sent emails including a brief description of the project and a link to the survey to 15 WUAs across Spain that were recommended by the national federation of WUAs in Spain (FENACORE) (September to December 2024) as non-modernized and potentially interested in participating. Response rates during this attempt were extremely low, as it is usually the case with email-based surveys in this sampling population. Hence, we expanded the sampling to a larger number of WUAs by making direct contact with them via phone calls, explaining the project and asking for their collaboration in distributing the survey among their members (second step, January 2025). Although some WUAs signalled interest in participating, response rates remained low. Acknowledging the high average age of farmers and their low preference for the use of technology, in the third step we decided to expand data collection through field visits to general assemblies of the WUAs, following invitations. Having initially aimed for a sample across the entire country, we had to limit the third step sampling to a smaller geographical area, which was the Ebro River basin. The Ebro River basin was chosen for two reasons: First, we wanted to maximize travel efficiency. Assemblies are not usually attended by more than five to 10 farmers. Thus, we expected a fair number of field visits. The basin is located relatively near the research teams' centre, which allowed day trips to the villages. Second, WUA representatives would usually let us know about the possibility of visiting them one or two days in advance, which prevented sampling WUAs that were relatively far away from our base location (Barcelona area). We approached base WUAs as well as second order WUAs (comprising various local base WUAs).

Given the sampling difficulties and conducting pre-analyses to check for treatment strength, we noticed that one of our three treatment scenarios, the 'Control' treatment, yielded the least promising effects. Thus, we opted to remove this scenario from the experiment and continued the sampling of the three remaining scenarios (baseline, knowledge, investment), maximizing the sample of the remaining treatments. During the field visits, we allowed farmers to fill out the survey with pen and paper if they preferred so. As a consequence, some of the questions, in particular the rank-order questions, were filled out incorrectly. Also, some farmers failed to mark the correct answers to the control questions. This is because in the digital version of the survey, control questions needed to be answered correctly in order to proceed with the survey. This could not be guaranteed for the paper version of the survey. Removing observations from participants who wrongly answered control questions does not affect the results. We pursued both strategies (emails and field visits) simultaneously until we reached our pre-registered sample. Table A1 provides an overview of sample sizes and characteristics for each sample. Table A2 compares our Sample A to the general Spanish irrigation farmer population to assess the level of representativeness. We calculated the average values of seven key indicators from the 2023 Survey on the Structure of Agricultural Holdings conducted by the Spanish Institute of Statistics (INE). Although our sample includes slightly more male, younger and better-educated respondents than the national average, the institutional context (members of active WUAs) is highly comparable to those of the broader Spanish irrigation sector. We explain the slight deviation with the fact that our sample concentrates on the Ebro River Basin (dominated by surface water sources) and believe that a higher level of education correlates with a higher willingness to participate in scientific surveys. However, the Ebro Basin also represents a major share of irrigated agriculture in Spain, making our findings relevant for similar regions.

Table A1. Sample descriptions and characteristics.

	Sample A (Main)	Sample B	Sample C
Description	Excluding Control-treatment	Excluding Control-treatment and invalid ranking questions	Including Control-treatment and excluding invalid ranking questions
Demographics			
Male respondents (%)	96.1	94.9	96.1
Age, mean (standard deviation (SD)) [min; max]	55.8 (12.3) [17; 83]	53.9 (12.4) [17; 82]	55.8 (12.3) [17; 83]
Education (%)			
Primary education	23.0	18.0	23.0
Secondary education	25.8	27.3	25.8
University degree	18.5	20.9	18.5
Agricultural training	32.6	33.8	32.6
Farm characteristics			
Cultivated area* (ha), mean (SD) [min; max]	73.0 (124.2) [0.5; 950]	73.0 (129.0) [0.5; 950]	73.0 (124.0) [0.5; 950]
Irrigated area* (ha), mean (SD) [min; max]	50.9 (84.7) [0.5; 700]	52.4 (92.5) [0.5; 700]	50.9 (84.7) [0.5; 700]
Land ownership (%)	67.1	64.5	67.1
Full-time farmer (%)	66.5	64.0	66.5
Crop: Herbaceous (%)	61.4	61.3	61.4
Crop: Wooden (%)	31.9	30.9	31.9
Crop: Vegetable (%)	6.0	7.8	6.0
Irrigation: Sprinkler (%)	18.4	17.4	18.4
Irrigation: Drip (%)	18.5	19.3	18.5
Irrigation: Furrow/Flood (%)	60.4	59.9	60.4
Modernized** (%)	48.3	48.9	51.6
Water source: Surface (%)	97.1	96.6	97.1
N	183	140	156
Baseline	64	48	48
Knowledge treatment	66	48	48
Investment treatment	53	44	44
Control treatment	0	0	16

Note: *Excluding two outliers. **A farmer is considered 'modernized' if he indicated having transformed all or parts of his irrigated area from furrow to drip or sprinkler irrigation.

Table A2. Population characteristics of Spanish irrigated farms used to assess the representativeness of the study sample.

Indicator	Representative Value	Corresponding Sample A value
% male farm heads	74.1	96
Mean age of farm head (years)	62.7	55.8
% with primary or lower education	93.1	48.8
% with formal agricultural training	3.24	32.6
% with university education	3.66	18.5
Mean cultivated area (ha)	33.6	73.0
% of farms using surface water for irrigation	35.8	97.1

Data for the representative value gathered from the Spanish survey on the structure of agricultural holdings (Encuesta sobre la Estructura de las Explotaciones Agrícolas) 2023 (INE, 2023).

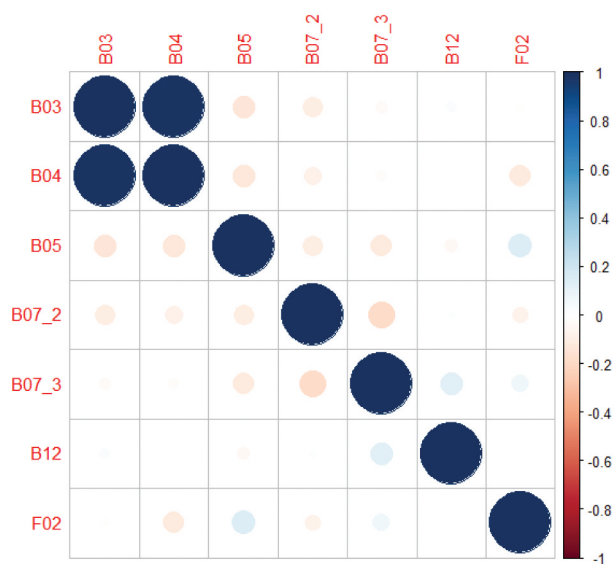


Figure A1. Correlation plot of numerical control variables.

A2. Additional statistical results

To assess potential multicollinearity among predictors, we conducted two complementary checks. First, we inspected pairwise correlations between numeric variables. Based on the high correlation between the controls *area cultivated* (B03) and *area under irrigation* (B04; Figure A1), we removed B03 from the set of predictors.

Second, we computed generalized variance inflation factors (GVIFs) for all remaining predictors to assess linear dependencies, including in the presence of multi-level factors (Treatment, F03, Modernized).

The adjusted GVIFs were moderately high for B12 (Satisfaction, adj. GVIF = 5.97) and F02 (Age adj. GVIF = 5.12). However, regressions of these variables on all other predictors yielded very low R^2 values, and pairwise correlations with other numeric variables were negligible. This indicates that the elevated GVIFs are driven by the presence of factor variables in the design matrix rather than by substantive multicollinearity. Consequently, all predictors (except B03) were retained in the models.

Table A3. Replication of Table 4 with full list of controls.

	Model 1		Model 2		Model 3	
	Environment	Society	Environment	Society	Environment	Society
(Intercept)	−1.224*** (0.360)	−0.582* (0.286)	−1.193 (0.713)	−0.079 (0.529)	−3.657* (1.826)	−1.325 (1.264)
Treatment:	−0.293	−0.493	−0.189	−0.515	−0.202	−0.544
Knowledge	(0.515)	(0.422)	(0.542)	(0.428)	(0.576)	(0.449)
Treatment:	0.403	0.136	0.383	0.084	0.154	0.079
Investment	(0.510)	(0.430)	(0.538)	(0.441)	(0.573)	(0.462)
AreaIrrigated			−0.003 (0.003)	−0.000 (0.001)	−0.004 (0.003)	−0.000 (0.001)

(Continued)

Table A3. (Continued).

	Model 1		Model 2		Model 3	
	Environment	Society	Environment	Society	Environment	Society
LandOwnership			−0.002 (0.006)	−0.003 (0.005)	−0.001 (0.007)	−0.004 (0.006)
CropWood			−0.010 (0.006)	−0.006 (0.005)	−0.008 (0.007)	−0.004 (0.005)
CropVeg			−0.002 (0.011)	−0.012 (0.011)	0.002 (0.012)	−0.012 (0.012)
Modernized			1.071* (0.477)	−0.033 (0.373)	1.303* (0.516)	0.011 (0.393)
Age					0.008 (0.020)	0.032 (0.017)
Education: Primary					−1.436 (0.893)	−0.337 (0.554)
Education: Secondary					0.593 (0.583)	0.463 (0.488)
Education: University					0.607 (0.610)	−0.043 (0.550)
Satisfaction					0.209 (0.152)	−0.071 (0.090)
N	179		176		170	
R2 Adj.	0.004		0.033		0.080	
AIC	359.2		362.0		355.7	
BIC	378.3		412.7		437.2	
RMSE	0.44		0.43		0.42	

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Standard errors in parentheses.

Table A4. Replication of Table 4 with continuous modernization variable (= sum of sprinkler and drip irrigation share on farm).

	Model 2		Model 3	
	Environment	Society	Environment	Society
(Intercept)	−1.119 (0.685)	−0.320 (0.524)	−4.531* (1.993)	−2.117 (1.370)
Treatment:	−0.312 (0.552)	−0.638 (0.438)	−0.509 (0.595)	−0.750 (0.467)
Knowledge				
Treatment:	0.449 (0.554)	0.065 (0.451)	0.106 (0.594)	−0.045 (0.474)
Investment				
Modernized_cont	0.017** (0.006)	0.007 (0.005)	0.022*** (0.006)	0.009 (0.005)
Agricultural controls	Yes		Yes	
Socio-demographic controls	No		Yes	
N	172		166	
R2 Adj.	0.045		0.103	
AIC	348.1		339.2	
BIC	398.5		420.2	
RMSE	0.43		0.42	

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Standard errors in parentheses.