doi:10.20944/preprints202009.0514.v1

Article

The role of common-pool resources' institutional robustness in a collective action dilemma under environmental variations.

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Abstract: Extreme environmental variations (EV), as a phenomenon deriving from climate change (CC), led to an exacerbated uncertainty on water availability and increased the likelihood of conflicts regarding water-dependent activities such as agriculture. In this paper, we investigate the role of conflict resolution mechanisms -one of Ostrom's acclaimed Design Principles (DPs)- when social-ecological systems (SESs) are exposed to physical external disturbances. The theoretical propositions predict that SESs with conflict-resolution-mechanisms will perform better than those without them. We tested this proposition through a framed-field-experiment that mimicked an irrigation system. In this asymmetric setting, farmers were exposed to two (2) dilemmas: (i) how much to invest in the communal irrigation system's (CIS) maintenance and (ii) how much water to extract. The setting added a layer of complexity: water availability did not only depend on the investment but also on the environmental variability. Our findings largely confirmed the theoretical proposition: groups with stronger institutional robustness are able to cope with EV better than those with weaker robustness. However, we also found that some groups, despite lacking conflict-resolution-mechanisms, were also able to address EV. We explored potential explanatory variables to these unexpected results. We found that subjects' and groups' attributes might address uncertainty and avert conflict. Thus, SESs' capacity to respond to external disturbances, such as EV, might not only be a question of DPs. Instead, it might also be strongly related to group members' attributes and group dynamics. Our results pave the way for further research, hinting that some groups might be better equipped for mitigation measures, while others might be better equipped for adaptation measures.

Keywords: Irrigation systems; common-pool resource management; environmental variability; collective action; institutional robustness

1. Introduction

Changing climatic conditions and the liberalization of certain economic sectors that, until recently, had been strictly addressed within the public domain, combined with changes in agriculture, land use, and management strategies -in an increasingly globalized arena- are likely to intensify competition for limited or diminished natural resources. If such global challenges are dealt inappropriately, this may lead to (i) increased disputes over the distribution of vital resources such as water, (ii) additional socioeconomic pressures on already stressed societies, and (iii) further environmental uncertainty. All of these negative forces might not only hamper much needed developmental efforts, but also result in migration flows, degradation of natural resources, epidemics and even pandemics as we witnessed with SARS-CoV-2, fuel inter-regional and inter-sectoral conflicts at all levels, or even civil unrest, violence, and war. In this scenario, water -an ambivalent common pool resource (CPR) containing both conflict and cooperation-inducing qualities (Mirumachi 2015; Mostert 2003; van der Molen and Hildering 2005; Varisco 2010; Wolf 2007) is emerging as an emblematic resource.

Indeed, climate change (CC) makes extreme weather phenomena the *'new normal'*. In this unpreceded setting for humanity, water is one of the most negatively affected natural resources (Parry 2019). Unevenly distributed precipitation patterns cause unpredicted floods and droughts directly impacting, already stressed, water-dependent activities like agriculture (Arunanondchai et al. 2018). The problem of uncertainties regarding water availability becomes particularly acute to small farmers across the globe as they generally lack the resources to cope with them. Contrary to large-scale industrialized agriculture, small farmers cannot rely on costly investments on water storage, drilling, or technological innovation to mitigate the effects of CC (Parry 2019).

Such extreme environmental variability (EV) imposes an additional layer of complexity in the typical CPR's social dilemmas that farmers face. Under the *'new normal'* climatic uncertainty, it is not only a question of how much to extract from the CPR, nor of how much to invest for its maintenance, but it is also that the payoff of these decisions becomes increasingly uncertain. Thus, the final payoff goes beyond decision-making processes alone and it is directly influenced by unpredictable climatic phenomena with unknown effects.

It is well documented that uncertainty increases competition leading to potential conflict scenarios (Humphreys 2005; Ratner et al. 2013). In this article, however, we choose not to discuss the unique role that water holds in the contemporary discourses on property rights and regimes such as *'environmental wars'* and *'environmental peace'*. Instead, and from the perspective previously described, we employ water as the lens through which small-scale farmers cope with CC from an institutionalist perspective. The literature, although lacking the international political attention and a concentrated effort to be studied by different disciplines, acts as a counterpoint placing cooperation and the transition from competition to cooperation at center stage (Fisher, Bavinck, and Amsalu 2018). In this context, our research emphasis is placed on the DPs that are necessary to enable resource users to transform the rules and reach desirable collective outcomes (Ostrom 2005; Meinzen-Dick and Di Gregorio 2004; Ratner et al. 2013). The literature here has some clear-cut propositions to offer. Namely: (i) small farming communities (Ostrom et al. 2002), (ii) with robust institutions (Ostrom 2005) (iii), a certain level of trust (Michaelene Cox 2008), (iv) and social capital (Dietz, Ostrom, and Stern 2003) can cope with uncertainties and resolve external disturbances to their system to a larger extent than communities lacking such qualities (John M. Anderies, Janssen, and Ostrom 2004). By extension, we could intuitively expect that the existence of conflict-resolution-mechanisms -one of the DPs proposed by Elinor Ostrom (2009b)- will enable groups to cope better with the conflicts emerging from uncertainties and act collectively to overcome the social dilemma. However, empirical studies on CPRs focusing on the impact of uncertainty on conflicts over resources in such a frame remain surprisingly unexplored (Safarzynska 2018). It is crucial to highlight that *'conflict'* is viewed here as a crosscutting issue: it is an important contextual factor under which institutional processes take place, as well as a framing condition for the cooperative or non-cooperative strategies adopted by farmers ultimately influencing the success -or failure- of the solutions given to the Social-Ecological Systems' (SESs) social dilemmas. From this perspective, the present work contributes to understanding the associations between contextual and individual attributes, framing conditions (social dilemmas under environmental uncertainty) and outcomes or payoffs of subjects' decisions when exposed to water uncertainty.

The working hypothesis is that organized groups with a higher level of institutional robustness, in particular reporting the existence of conflict-resolution mechanisms, will cope with EV better than non-organized groups. In this frame, we empirically explored the theoretical propositions through a case study in Northwest Argentina with a multimethod approach encompassing a framed-field experiment (FFE), a survey conducted with all the subjects participating in the experiment to assess relevant qualitative characteristics that may not be sufficiently captured by the FFP (socio-demographic variables, physical settings of the communities, and experience with irrigation systems management), and semi-structured interviews with key informants.

This paper's contributions are multifold. First, we measured, on the same subjects, their CPR management performance when exposed to EVs vis-à-vis their *'institutional robustness'*. This combination of inputs offered great insights for further understanding of CPR's management theory and its linkages with *'institutional robustness'*, a highly contested question. Second, our findings might serve as a guideline for policymakers working with small-scale farmers confronted with EV. Finally, we offer empirical evidence to Ostrom's DPs discussion, especially on the importance of conflict resolution mechanisms.

In the following section we briefly review key elements of *institutional robustness*, focusing primarily on its conflict-resolution-mechanisms. The third section, Material and Methods, introduces the methodological approach, including an overview of the sampling strategy and the methodological decisions (for methodological details refer to Dipierri, *forthcoming*). The paper continues with the Results and Findings section where the key findings are presented, to then proceed with the Discussion and Conclusion section. In the latter, we elaborate on the theoretical and practical implications of this research and present future research avenues, based on our findings.

2. Literature Review

Shepsle (1989) defines *'institutional robustness'* as a situation where an institution endurance results from the development of operational rules that are, eventually, modified over time. The modification to the operational rules are introduced according to a set of collective-choice rules which might themselves be modified slowly over time also (Ostrom 2015). For this paper, however, we embrace the contemporary and widely accepted definition by Carlson and Doyle: *"the maintenance of some desired system characteristics despite fluctuations in the behavior of its component parts or its environment"* (2002, 2538) as it puts particular emphasis on complex systems such as SESs and its adaptability to disturbances such as EV.

Elinor Ostrom (1990), following North's (1990) conception of *'institutions'* as mechanisms for reducing uncertainty in complex and uncertain environments, laid out eight (8) key Design Principles (DPs) related to *'institutional robustness'*. They were tailored to sustainably governed CPRs by reducing uncertainty and building trust and reciprocity. Then, collective action becomes possible. From this perspective, the DPs explain the conditions under which trust and reciprocity can emerge and be sustained to overcome social dilemmas embedded in CPRs (Michael Cox, Arnold, and Villamayor Tomás 2010) through collective action.

As these DPs have been extensively discussed in the literature (Gari et al. 2017; Ostrom 1990; 2005; 2015) we briefly mention them in Table 1:

Insert Table 1 about here

Table 1: Design Principles

Caption: Design principles for governing sustainable resources derived from studies of long enduring of institutions

Design principle	Definition
DP1. **Clearly defined boundaries**	"The boundaries of the resource system (e.g., irrigation system or fishery) and the individuals or households with rights to harvest resource units are clearly defined."
DP2. **Proportional equivalence between benefits and costs**	"Rules specifying the amount of resource products that a user is allocated are related to local conditions and to rules requiring labor, materials, and/or money inputs."
DP3. **Collective choice arrangements**	"Most individuals affected by harvesting and protection rules are included in the group that can modify these rules."
DP4. **Monitoring**	"Monitors, who actively audit biophysical conditions and user behavior, are at least partially accountable to the users and/or are the users themselves."
DP5. **Graduated sanctions**	"Users who violate rules in use are likely to receive graduated sanctions (depending on the seriousness and context of the offense) from other users, from officials accountable to these users, or from both."
DP6. **Conflict resolution mechanisms**	"Users and their officials have rapid access to low-cost local arenas to resolve conflict among users or between users and officials."
DP7. **Minimal recognition of rights to organize**	"The rights of users to devise their own institutions are not challenged by external governmental authorities, and users have long-term tenure rights to the resource."
DP8. **Nested enterprises**	"For resources that are parts of larger systems: Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises."

Source: Author's elaboration based on Elinor Ostrom (2009b, 33)

It is worth highlighting that the first five (5) DPs form a single coherent "block" of interconnected and interdependent principles. In Elinor Ostrom's own words:

> *"When the users of a resource design their own rules (design principle 3) that are enforced by local users or accountable to them (design principle 4) using graduated sanctions (design principle 5) that clearly define who has rights to withdraw from a well-defined resource (design principle 1) and that effectively assign costs proportionate to benefits (design principle 2), collective action and monitoring problems tend to be solved in a reinforcing manner*". (Elinor Ostrom 2005, 267)

Gari et al. (2017, 11) find that DP1 and DP2 are the most commonly present DPs, followed by DP3 and DP6, while DP4 and DP5 are less commonly reported. What is of particular interest for this paper is DP6: the importance of low-cost, swift, well-understood, similarly interpreted, and effective conflict-resolution mechanisms within a community. This is seemingly supported by empirical evidence despite some inconsistencies in the findings (Ostrom 2015). However, it is our view that this DP (DP6) incorporates most of the criticism against the eight (8) DPs: their incompleteness, their wider applicability, their fundamental approach (Michael Cox, Arnold, and Villamayor Tomás 2010), and the poor cause-effect relationship between social-ecological institutional robustness and CPR's management (Gari et al. 2017). Numerous studies indeed argue that the DPs are rather descriptive and too case-specific to be employed as tools to understand institutional robustness: *"[…] from our study it has become clear that the real 'glue' that keeps an institution alive over time are the social mechanisms, i.e. trust, legitimacy, and transparency"* (Harkes 2006, 251). External socioeconomic factors that can rapidly disturb and deteriorate a system are also particularly emphasized as totally missing from the DPs (Michael Cox, Arnold, and Villamayor Tomás 2010). Notably Young (2002) and Agrawal (2002) argue that the DPs are formulated as *'laws'* that should hold in every case regardless of other variables, which is not the case. Indeed, it is interesting that Elinor Ostrom (2007; 2009a) slowly distanced herself from the strict nature of the DPs and moved to a rather diagnostic approach.

Thus, our general hypothesis, based on the prevalent literature is that institutionally robust SESs will cope better with external disturbances, such as EVs. In this line, a more specific working hypotheses signals that SESs with conflict-resolution mechanisms will be better equipped to cope with the EVs, without affecting their performance and endurance. Thus, in this paper, we dig deeper into the role of conflict-resolution mechanisms (DP6) and the strategies adopted by the SESs to overcome uncertainty.

The role of institutional robustness in coping with EV is of particular importance for Latin America, where our case study is located. Due to heavy dependence on agriculture for livelihood and poor coping mechanisms to adapt to climatic challenges (Jat et al. 2016) or even mitigate them, the continent is particularly vulnerable to the effect of CC.

3. Materials and Methods

A field version of the irrigation dilemma game with environmental variations (EVs) developed for a lab setting by John M. Anderies et al. (2013), and adapted by (Dipierri, *forthcoming*)[1] for the water variation treatment, was conducted in northern Argentina between 2016 and 2017.

3.1. Case Study

The Argentinian Northwest region had the largest share of the irrigated field in the country in 2011 and this position has increased consistently (FAO 2015). With two well-defined seasons, rainy season (summer and autumn) and dry season (winter and spring), irrigation water management in the region is crucial for guaranteeing water access and use during the dry season. Furthermore, the seasonality of rainfall is expected to intensify in the upcoming decades (Wyatt et al. 2014, 38). This implies that, in the dry season, when the demand for water from small-scale farmers peaks, water uncertainties might surge; while during the rainy season the excessive water might harm the crops and/or destroy their precarious Communal Irrigation Systems (CISs).

Water management in the region is heterogeneous with formal and informal schemes co-existing. In both cases, water is normally distributed through shifts only during the dry season, and the irrigation infrastructure used to distribute the water is rustic[2]. Therefore, the efficiency of the irrigation system in Jujuy, one of Northwest Argentinian states, is low (FAO 2014, 44).

For this research, the CISs were the units of analysis and the small-scale farmers were the units of information. Given the need to create trust with the small-scale farmers before the experiments could be conducted, the sampling was finalized in cooperation with the '*Instituto Nacional de Tecnología Agropecuaria*' (INTA). The final decision was to work in the south region of Jujuy Province

[1] The protocol used for this experiment is available in Dipierri (*forthcoming*).

2 The irrigation infrastructure has small doors and dikes built with rocks. The channels are non-laminated.

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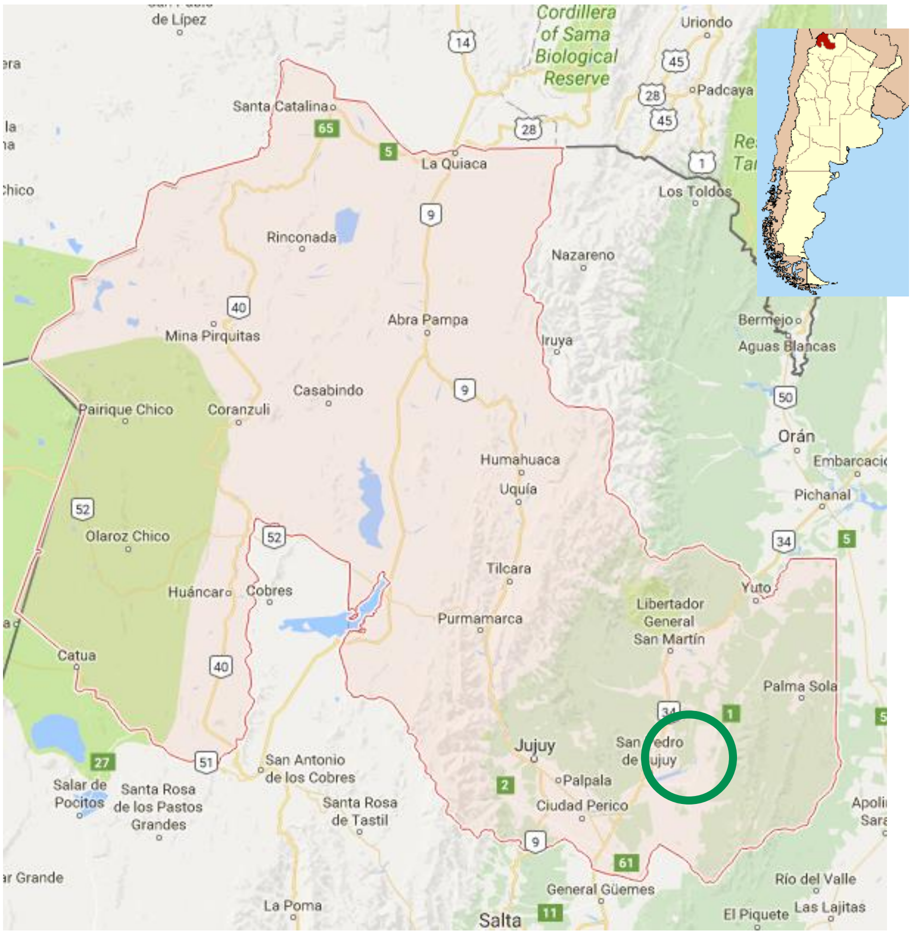
Figure 1: Jujuy's Yungas region, Argentina – Case Study



Source: Author's elaboration based on Google Maps

3.2. Frame-field-experimental setting

In total six (6) framed-field experiments (FFE) were conducted with small scale farmers (from now onwards also referred to as 'subjects') from two (2) small CISs. This consideration was relevant as it has been shown that group size affects CPR management (Gari et al. 2017). Our sampling strategy was to group the subjects in a way that different levels of institutional robustness were represented. More specifically, farmers from four (4) of the six (6) groups belong to an agricultural cooperative or association, while the remainder did not.

In each experiment, farmers were assigned a fixed position in the irrigation system (asymmetric positions ranged from A -upstream position, near the water source- to E-downstream position, away from the water source-). Each experiment lasted 20 rounds divided into two sets: (i) stable or baseline and (ii) unstable. During the first set (from round 1 to 10) irrigation water was constant in all the rounds. Water variations, with the same fluctuation as in the seminal paper (John M. Anderies et al. 2013), were introduced in the second set (from round 11 to 20).

In each of the 20 rounds farmers could collect points through two (2) channels, as explained in detail later in this paper: (i) tokens not invested in the system's maintenance and (ii) crops produced with the water extracted.

Each round had three (3) stages: (i) cheap talk, (ii) investment, and (iii) extraction. *First*, subjects could (i) talk openly for a minute with no restriction of topics, except the typical caveats of no threats and no aftermath payments propositions. In the *second* stage, each subject received 10 tokens at the beginning of each round and (ii) they were asked to individually and privately decide the number of tokens they wanted to invest (INV_t) on the irrigation system maintenance. To simulate the pass of time, the system deteriorated 25 percentage points (1 percentage point equaled 1 token) in every round. If the irrigation system capacity was bellow 45 percentage points, no water would be distributed, because the system would be considered as 'collapsed'. Thus, if in successive rounds the collective investment was not enough to compensate for the deterioration (collective investment < 25 tokens), no water was distributed. Subjects were confronted with the typical 'provision problem' because each non-invested token (10-INV_t) added to their individual payoff (individual payoff from not investing in the CIS). In the *third* stage, each subject could (iii) extract water from the CIS but as water moved from upstream to downstream positions, lower positions only received the water not used by subjects in upper positions. The total amount of water units for distribution in each round depended not only on the irrigation system capacity (collective investment from stage two) but also from the water available in that round (constant between round 1 and 10 and variable between round 11 and 20). The competition exacerbated because the maximum crop production (private earnings) was achieved with 20 water units. Less than 20 water units implied that the crops had not received enough water and more than 20 water units implied that the crops were overwatered (diminishing returns). However, this objective (20 water units) was untenable to all subjects simultaneously, because there was not water enough for everyone. Additionally, while investment was private, water extraction was public, mimicking reality. To make it public each unit of water was represented with a blue card. For example, if 60 units of water were available, 60 blue cards were handed over to the subject in position A, then subject A extracted the number of water units (blue cards) wished and passed the remaining water units (blue cards) to subject B, and so forth. The amount of water extracted by each subject determined the number of crops that this particular subject could produce.

In sum, in each round individual payoff or net gains (NG_t) resulted from the tokens not invested (10-INV_t) in the irrigation system maintenance plus the income from crop production (INC_t). Subjects were paid one (1) peso for each non-invested token and each produced crop. At the end of the experiment, the total amount of points was converted into pesos, and subjects were paid in cash. For example, if a subject had collected 100 points he was paid 100 Argentinian pesos.

This game setting had two (2) potential extreme scenarios, as well as any scenario in between the extremes: Nash Equilibrium (NE) or Social Optimum (SO) also defined as Cooperative-Equilibrium. Table 2 presents an overview of the game setting.

Table 2: Experimental setting summary

Caption: The frame-field-experiment setting conducted is presented in brief.

Participants	5 per experiment
Positions	A (upstream) to E (downstream)
Rounds	20
First set	Rounds 1-10 without EVs (stable water flow)
Second set	Rounds 11-20 with EVs (unstable water flow)
Stages per round	Stage 1: 'cheap-talk' for one minute Stage 2: Private investment decision Stage 3: Public water extraction decision
Action-outcome linkages	The capacity of the CIS depended on the collective investment, the CIS depreciation, and the previous round CIS capacity. The amount of water extracted by upstream subjects affected the amount of water available for downstream subjects. The amount of water available to subjects downstream might affect their contribution in the following rounds.
Outcomes	Nash-Equilibrium: subjects do not invest, the infrastructure deteriorates, and it does not distribute water. Each player earns 10 tokens per round.

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	Social-Equilibrium: collective investment keeps the CIS at the optimal capacity and water is distributed. Each player earns from the non-invested tokens and the crops produced.
Information	All the players had the same information.

Source: Authors' elaboration based on (Ostrom 2005)

3.3. Complementary methods

In addition to the framed field experiments (FFE), a survey was carried out among the entire sample. It included production settings, living conditions, and socio-demographic information. In particular, we asked participants to assess their communal irrigation systems' (CISs) institutional robustness. To develop the statements, we built on Ostrom's Design Principles (DPs). The seventh and eighth DPs were not included in this self-assessment, as they are to be answered by levels of governance above the CISs (J. M. Anderies and Janssen 2016, 77).

Each of the first six (6) DPs were measured with a five (5) points Likert scale ranging from '*totally disagree*' to '*totally agree*' (see Table 3). Following Gari et al. (2017), who propose a scale from '*absence*' (0) to '*present*' (1) of the DPs, we coded the answers ranging from '*total disagreement*' (0) to '*total agreement*' (1). We also considered intermediate answers with 0.25 for '*disagreement*', 0.5 for '*neutral*', and 0.75 for '*agreement*'. Then, the level of '*institutional robustness*' was calculated as a cumulative result of the DPs values. For comparability purposes with Gari et al. (2017), all DPs had the same weight and the total score was rescaled to six (6) DPs with four (4) potential outcomes: '*failed*', '*fragile*', '*weak*', and '*successful*'.

Table 3: Coded values for DPs based on the Likert scale, and potential outcomes.

DPs category	**Value**	**Total Score**	**Outcome**
Totally disagree (TD)	0.00	0.0-2.2	Failed
Disagree (D)	0.25	2.3-2.9	Fragile
Neutral (N)	0.50	3.0-3.7	Weak
Agree (A)	0.75	3.8-6.0	Successful
Totally Agree (TA)	1.00		

Source: Adapted from Gari et al. (2017, 4)

Finally, we conducted 27 in-depth interviews with key informants including technical advisors, government officials, and of course the subjects. In the latter case, we were particularly interested in the participants that reflected an outstanding behavior (over or under investment and over or under extraction).

4. Results and Findings

4.1. Descriptive Statistics

On average, subjects that participated in the framed-field experiment (FFE) had 1.5 (SD=1.2) hectares for their agricultural activities, 43% were female and 7% were illiterate (see Table 4). Some outstanding elements from the survey are that three (3) of the six (6) groups reported to live and work in the same place and two (2) of the six (6) groups (G3 and G6) had used irrigation systems for fewer years (*M*=12.3, *SD*=8.3) and lived in the area fewer years than the sample average (*M*=21.4, *SD*=15.5). These groups also reported a lack of formal institutional arrangements such as cooperatives or associations. Thus, they were classified as '*non-organized*' groups (G3 and G6), in opposition to the remaining groups (G1, G2, G4, and G5) that were classified as '*organized*'.

 doi:10.20944/preprints202009.0514.v1

Individual net gains[3] ranged from 134 to 434 tokens (*M*=333.0); while at a group level they accumulated between 1,469 and 1,889 tokens (*M*=1,665.0, *SD*=68.5). It is worth noticing that two (2) of the six (6) groups (G1 and G5) earned more than average. Per subject, the investment had a greater spectrum with a minimum of 13 and a maximum of 119 tokens (*M*=89.7). At a group level the behavior was more homogenous (*M*=448.0, *SD*=20.6). Finally, the comprehension quiz showed a quite robust understanding of the game. On average 94% of the subjects gave the right answers.

Table 4: Group socio-economic features and overall performance

Variable	G1	G2	G3	G4	G5	G6	Average
Female	20%	40%	40%	0%	60%	**100%**	*43,33%*
Illiterate	20%	20%	0%	0%	0%	0%	*6.66%*
Age	**57.2** **(6.97)**	**58.6** **(15.33)**	**51.0** **(3.76)**	**47.0** **(5.50)**	**34.0** **(6.85)**	**35.0** **(4.07)**	*47.1* *(12.63)*
Hectares	1.8 (1.28)	1.6 (.86)	1.8 (2.14)	0.9 (.20)	1.3 (.60)	1.6 (.86)	*1.5* *(1.20)*
Household members	6.4 (2.95)	5.8 (2.23)	4.39 (0.50)	5.48 (1.69)	5.0 (1.68)	5.2 (.98)	*5.38* *(1.95)*
Live in the area	**40%**	**40%**	**40%**	**100%**	**100%**	**100%**	*70%*
Years in the same place	27.8 (13.34)	31.4 (11.97)	28.0 (17.44)	36.2 (16.66)	22.4 (12.15)	21.4 (14.47)	*27.87* *(15.30)*
Institutional Arrangements	YES	YES	NO	YES	YES	NO	
Trust	**4.8** **(.40)**	4.4 **(.80)**	3.8 **(.98)**	**4.6** **(.49)**	3.6 **(1.75)**	3 **(1.42)**	**4.03** **(1.25)**
Average investment per round and subject	4.68 (1.39)	4,41 (1.98)	4.31 (2.52)	4.66 (2.06	4.55 (1.57)	4.31 (2.07)	*4.49* *(1.96)*
Average extraction per round and subject	11.96 (3.01)	10.08 (4.73)	10.92 (4.35)	9.88 (4.04)	11.75 (2.28)	9.76 (3.99)	*10.72* *(3.91)*
Average earnings per round per subject	**18.6** **(5.54)**	15.54 (6.44)	16.64 (7.43)	14.69 (6.81)	**18.89** **(4.25)**	15.58 (6.56)	*16.65* *(6.43)*
Comprehension Quiz	92% (1.17)	98% (.40)	90% (.90)	92% (.75)	92% (1.17)	98% (.40)	*94%* (.91)

Notes: In parenthesis the Standard Deviation

Source: Authors

4.2. Experimental performance

It is important to highlight that the experiment was used to identify the "*best-performing groups*" to then inform the subsequent qualitative analysis of *institutional robustness*. Therefore, we will limit the presentation of the experimental results to the minimum only to allow the understanding of how *institutional robustness* was approached and how it relates to each of the groups.

Figure 2 summarizes the tokens investment and water extraction behavior per group comparing the first set (Round 1 to 10: R1-10), when water was stable, with the second set (Round 11 to 20: R11-20), when water varied from round to round. Our results show that G1 (Group) and G5 increased their investment during environmental variation (R11-20), and where the groups that invested the

[3] Net gains (NGi) resulted from tokens not invested (10-INVit) on the infrastructure and the tokens earned from growing (INCit) crops in all the rounds (Section 3.2 Frame-field-experimental setting).

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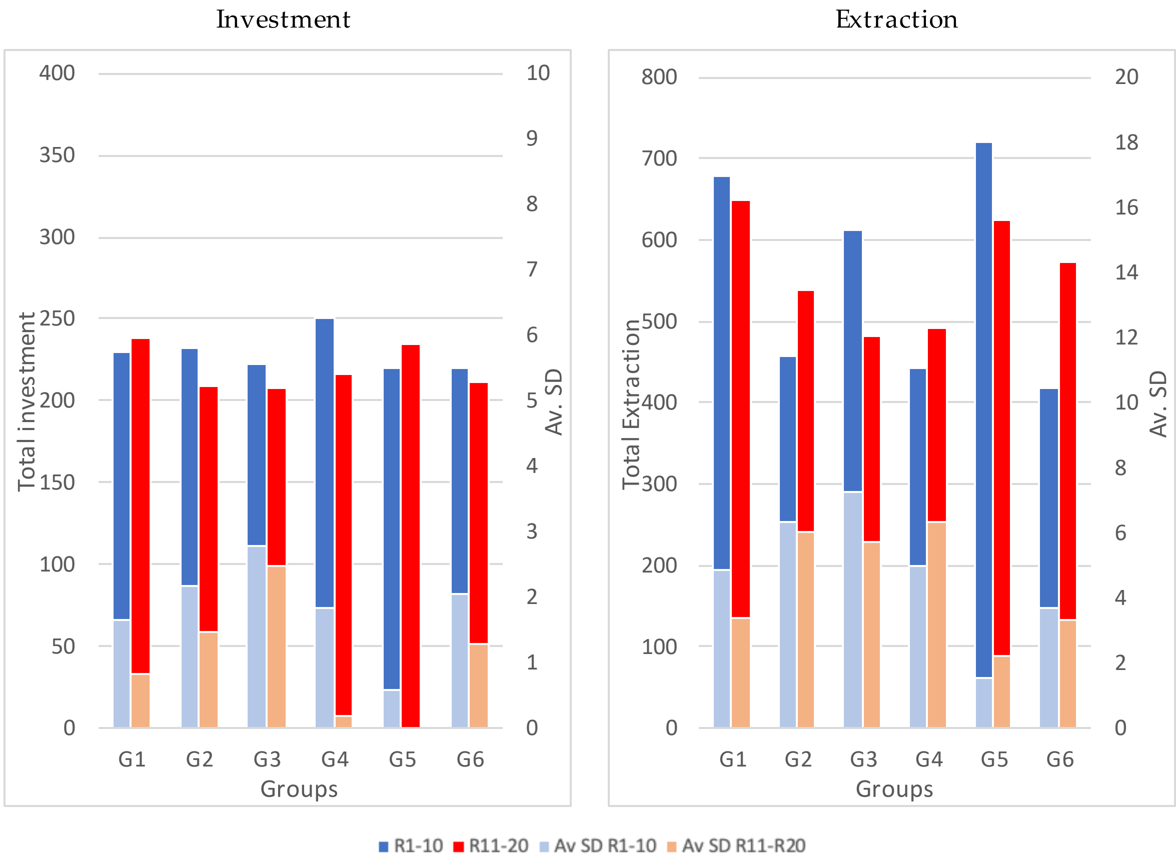
most during this set. We also observed that these groups (G1 and G5) were able to extract more than the other groups during both sets. They also had a smaller average standard deviation than the other groups, for both sets in the investment and extraction process.

Figure 2: Total investment and extraction per set by a group

Caption: The graph shows the total group investment (panel a) and the total water extraction (panel b) of each group and its evolution, comparing R1-10 to R11-20. The average standard deviations among subjects per round investment and extraction are also presented.



(a) (b)

Notes: Round 1 to 10 (R1-10); Round 11 to 20 (R11-20); Average Standard Deviation (Av SD).

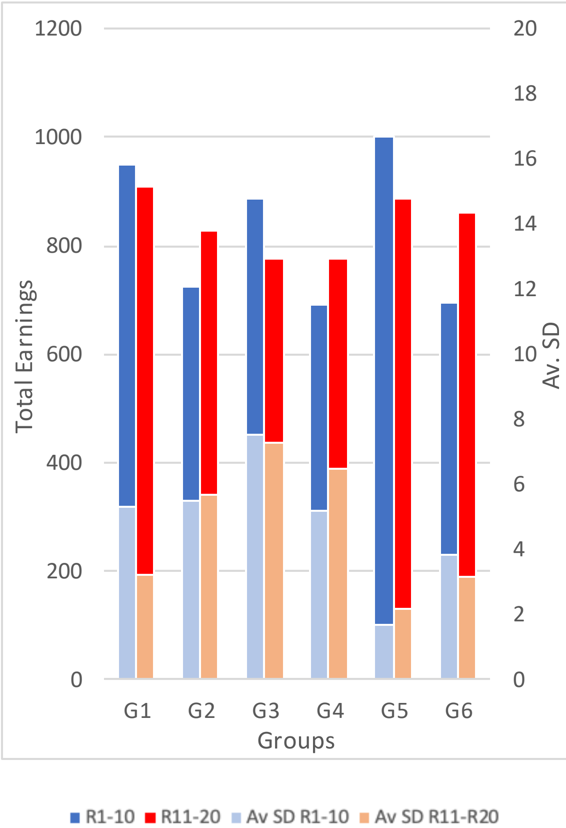
Source: Authors

The investment and extraction behaviors reflected on the groups' Net Gains (NGs) (Figure 3) with G1 and G5 obtaining the higher total NGs. The decline in their NGs between R1-10 and R11-20 can be explained by the higher experimental setting complexity of the second set (R11-20) and the shortage of water during the rounds that mimicked droughts. We also observed that in these two (2) groups the earnings' asymmetry was smaller than in other groups, except G6 that also reported a low average standard deviation.

 doi:10.20944/preprints202009.0514.v1

Figure 3: Total Net Gains per set by group

Caption: The graph shows the total Net Gains per group and their evolution, from R1-10 to R11-20. It also shows the Net Gains average standard deviations.



Notes: Round 1 to 10 (R1-10); Round 11 to 20 (R11-20); Average Standard Deviation (Av SD).

Source: Authors

Finally, we assessed the movement from Non-cooperation (Nash-Equilibrium=0) to Cooperation (Social-Optimal=100), by measuring to what extent the Net-Gain (NG) exceeded the Nash-Equilibrium (NE), related to the difference between the Social-Optimal (SO) and the NE following John M. Anderies et al. (2013). This is:

$$\%increase=(NG-NE)/(SO-NE) \quad (1)$$

The NE was calculated considering selfish subjects that did not invest in the irrigation system maintenance. Thus, the CIS deteriorated rapidly, and the subjects only earned 10 tokens per round (the 10 tokens that were given to them in each round). The SO was calculated considering that the subjects invested in a collaborative manner, keeping the irrigation system at the SO level and were able to distribute all the water available in each round.

Table 5: Cooperation per set by group

Caption: The table shows the distance between the Nash Equilibrium (NE) and the Net Gain (NG). The higher the percentage, the higher the level of cooperation.

	R 1-10				R 11-20				R 01-20			
	NG	N.E.	S.O.	% increase	NG	N.E.	S.O.	% increase	NG	N.E.	S.O.	% increase
G1	949	570	1034	**82%**	911	568	945	**91%**	1860	1138	1979	**86%**
G2	725	570	1034	33%	829	568	945	69%	1554	1138	1979	49%
G3	889	570	1034	69%	775	568	945	55%	1664	1138	1979	63%
G4	693	570	1034	27%	776	568	945	55%	1469	1138	1979	39%
G5	1000	570	1034	**93%**	889	568	945	**85%**	1889	1138	1979	**89%**
G6	697	570	1034	27%	861	568	945	78%	1558	1138	1979	50%

Notes: Nash-Equilibrium=(NE); Social-Optimal=SO

Source: Authors

As shown in Table 5, we found that the groups with a better collective action performance, in both sets, were G1 and G5. Both groups reported to be closer to the SO outcome than other groups, even when exposed to water variability (second set – R11-20).

4.3. Institutional Robustness

According to Anderies, Janssen, and Ostrom 2004, greater robustness of SESs ensures better performance when confronted with disturbances. This is also in line with Gari et al.'s (2017) findings that indicate that successful SESs are those that accomplish not only long-lasting survival, but that also accomplish their objectives, when confronted with external disturbances, such as the EVs we introduced in the second set of the FFE. Consequently, it was expected that better-performing groups (G1 and G5) would report higher *'institutional robustness'*.

To explore this premise we asked the subjects to self-assess 'institutional robustness' using a Likert Scale as part of the survey (for methodological precisions see Dipierri, forthcoming). Although all results presented in this section reflect the subjects' opinion, the results were in line with information collected through the in-depth interviews to the subjects and the technical advisors and field observations. Additionally, Ketokivi and Schroeder (2004) indicate that perceptual measures, such as the robustness self-assessment we implemented, offer not only a satisfactory validity but also reliability.

As shown in Figure 4 and Table 6, three (3) of the six (6) groups (G1, G2, and G4) reported a *'successful'* institutional robustness. These groups also reported higher levels of trust, confirming the link between robustness and trust argued by Anderies, Janssen, and Ostrom (2004, 12).

Now, looking particularly at the best performing groups (G1 and G5) we find contrasting results. While subjects from G1, reported a *'successful'* institutional robustness, in line with Anderies, Janssen, and Ostrom's (2004) results; subjects from G5 reported a *'fragile' institutional robustness.* To search for potential explanations, we continue with an analysis at a principle level in the following sections. However, before continuing it is worth noticing that in general and as expected, organized groups (G1, G2, G4, and G5) agreed more with the DP's statements than non-organized groups (G3 and G6).

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Table 6: Group socio-economic features and overall performance

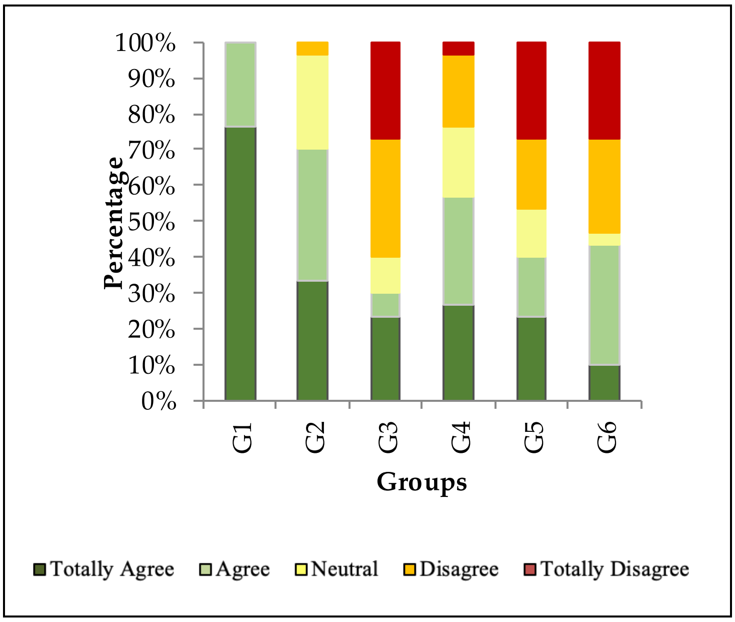
Variable	G1	G2	G3	G4	G5	G6	Sample Average
DP 1	**0.95**	**0.80**	0.60	0.70	**0.85**	0.65	*0.76*
DP 2	**0.95**	**0.85**	0.45	0.75	0.75	**0.85**	*0.77*
DP 3	**0.90**	**0.80**	0.20	**0.75**	0.45	0.35	*0.58*
DP 4	**1.00**	**0.80**	0.45	0.50	0.25	0.40	*0.57*
DP 5	0.85	0.45	0.45	**0.60**	0.20	0.25	*0.47*
DP 6	**1.00**	**0.80**	0.50	**0.55**	0.40	0.50	*0.55*
Robustness	*5.65 Successful*	*4.50 Successful*	*2.65 Fragile*	*3.85 Successful*	*2.85 Fragile*	*2.60 Fragile*	

Source: Authors

[Insert Figure 4 about here](#)

Figure 4: Self-assessed institutional robustness per group

Caption: The overall level of robustness is presented as a summary of the Design Principles reported by the participants.



Source: Authors

Overall, the boundaries (DP1) seem to be better defined in G1 and G5 (Figure 5). Indeed, these two (2) groups performed better throughout the experiment with high levels of investment and low average standard deviations in their investment, extraction, and earnings (see the Results' section). Furthermore, and in line with Elinor Ostrom's (2009b, 32) argumentation, the poor boundaries reported by non-organized groups (G3 and G6) could partially explain the free-riding cases observed during the FFE.

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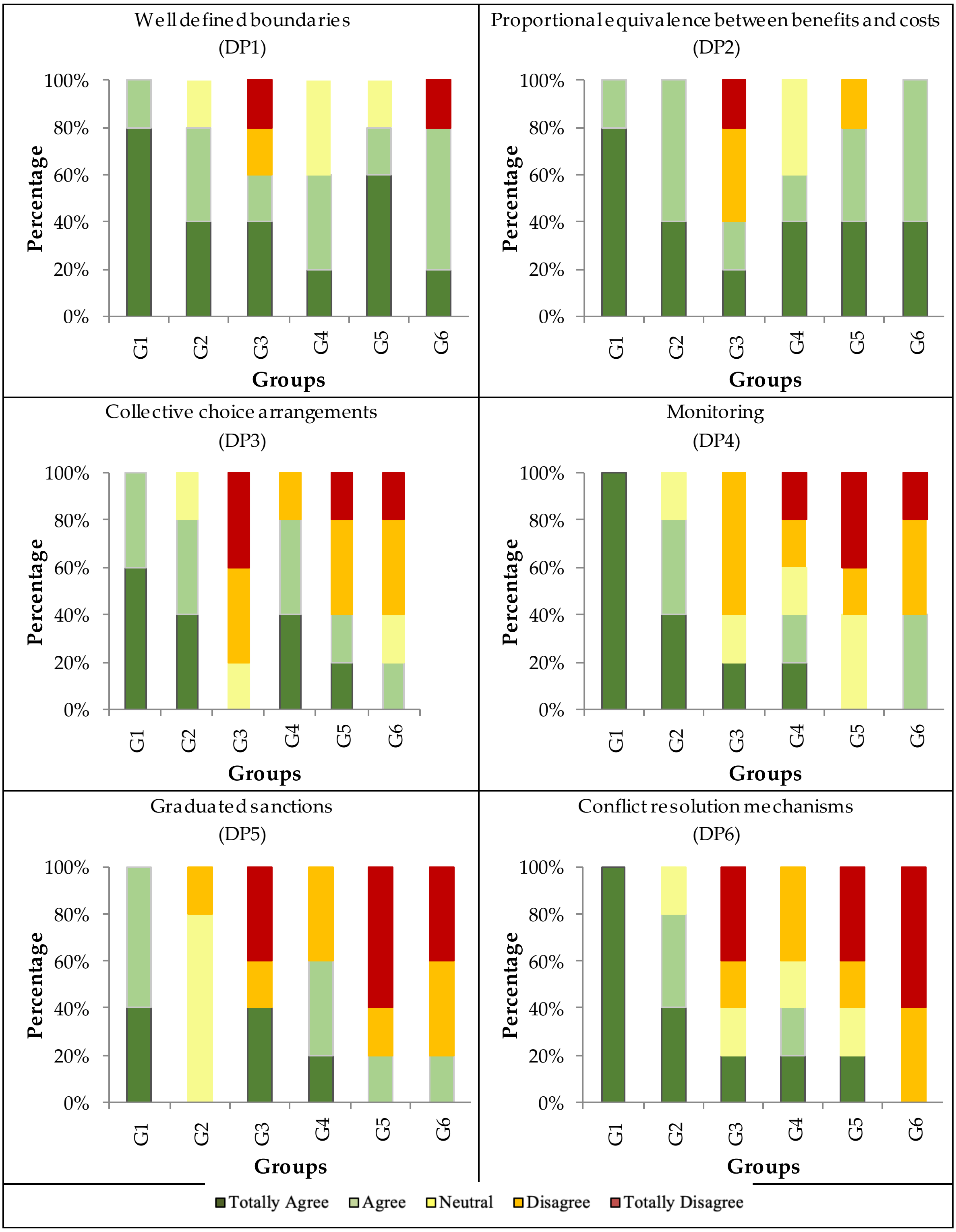
Figure 5: Self-assessed institutional robustness by Design Principle (DP) per group

Caption: The proportional group self-assessment of each design principle is presented per group of subjects.



Source: Authors

Theoretically, with clear boundaries (DP1), the equivalence between the costs and benefits (DP2) obtained from being part of the social-ecological systems (SESs) could be better assessed by users, hence their willingness to comply with the rules would be enhanced (Ostrom 2009b, 34). Unexpectedly, a non-organized group (G6) assessed their 'costs and benefits' DP as high. A potential explanation for this contradiction is that subjects in G6 did not expect great benefits in their actual situation, while organized groups (G1, G2, G4, and G5) expectations were higher. The role and direction of expectations are an important element to consider explicitly in future institutional robustness assessments. If the expected benefits are very low and the costs are low, then the equivalence is reached. However, this might be a misleading assertion, as perceived benefits are not being offered by the system, despite the expectations of the users (Lonsdorf, Koh and Ricketts 2020; Rakatama, Iftekhar and Pandit 2019).

The relevance of collective choice arrangements (DP3) is that their absence seems to lead to SESs' failure (Cox, Arnold, and Villamayor Tomás 2010, 9). In this case, the empirical evidence showed two (2) clear scenarios: (i) the organized groups (G1, G2, G4, and G5) agreed more with the statement than (ii) the non-organized groups (G3 and G6). An obvious explanation might be that organized groups have developed several collective action rules while non-organized groups lack this feature. However, interesting discrepancies emerged among organized groups (G1, G2, G4, and G5). Subjects in G1 and G2 reported that they self-crafted their institutional arrangements, that their decisions are based on a '50 plus one' rule and that actual community decisions are voted during their monthly meetings (informants I21, I26, and I6). The latter strategy allowed them to bypass the lack of efficiency that Huntjens et al. (2012, 73) argued might emerge when participation is required. Conversely, plots from subjects in G4 and G5 are located within the boundaries of a larger farm and their institutional arrangements are mediated by the farm administration (informants I6, I27, F40, and F25).

The differences between the groups are more evident in the last three (3) Design Principles (DPs). G1 and G2 almost fully agreed with the monitoring system (DP4) statement, while G3, G4, G5, and G6 disagreed with it. Similarly, the graduated sanctions (DP5) statement registered the most diverse assessments. Intriguingly, one of the groups that reported the highest disagreement was the group with the best performance during the experiment (G5). Subjects explained that they have not developed a 'sanctions system' and problems are solved on a one-to-one basis. Furthermore, several cases of violence have been registered (informant F25), probably due to the lack of conflict resolution mechanisms (DP6). For instance, G1 and G2 agreed with the conflict resolution mechanisms' (DP6) statement, while all the remaining groups disagreed. During the interviews subjects from G1 and G2 explained that before the establishment of the 'Water Association'[4], conflicts often emerged and sometimes escalated to violence (informants I27, I6, and I22), like in the other groups. However, as they developed their institutional arrangements conflicts decreased, and currently, if they emerge, they are solved using their endogenously developed sanctioning system. Nevertheless, this robustness might come at the cost of much-needed flexibility to adapt their strategies to changing environmental conditions. Whether these adaptations have created fragilities in the SESs or not requires further analysis.

Contrariwise, the externally imposed rules in G4, G5, and G6 might be negatively affecting the SESs development, as suggested by several authors (Cárdenas, Rodríguez, and Johnson 2015; Ibele, Sandri, and Zikos 2016; Otto and Wechsung 2014; Roßner and Zikos 2018), due to incomplete information and a lack of understanding of local needs by the farm administration. Hence, the groups' good performance during the experiment could be explained by the fact that (i) they live and work in the same space sharing a high level of trust, (ii) they are all younger farmers, (iii) they rely on direct and efficient communication, and (iv) they have long experience of collective action (sharing among others: machinery, working-tools, and social benefits).

[4] Understood as a non-profit organization were members coordinate the irrigation water management.

5. Discussion and Conclusion

We deployed a multimethod approach that included a framed-field experiment (FFE), surveys, interviews, and non-participant observation, in Northwest Argentina. Through this methodological design, we were able to assess our guiding hypothesis: social-ecological systems (SESs) with conflict resolution mechanism (Ostrom's design principle six - DP6)) manage their common-pool resources (CPR) better when exposed to environmental variations (EVs).

Our results support this guiding hypothesis, stating that institutionally robust groups perform well under environmental variability (EV), while groups lacking appropriate institutional arrangements -in line with Ostrom's design principles (DPs)- are more exposed to the effect of external disturbances, as shown in other studies (Kolinjivadi et al. 2019, 496). However, we also find that groups lacking conflict-resolution mechanisms are still able to successfully cooperate and avoid conflicts even under conditions of increased uncertainties. This might be explained by a higher level of pre-existing trust (Kolinjivadi et al. 2019) in combination with certain sociodemographic variables, like age, living settings, and working conditions that allow them to quickly deliberate and effectively communicate adapting to new challenges, as well as previous experiences with CPR management.

The importance of these variables found in our study further contributes to the "incompleteness" of the DPs discussed in the critical literature and most notably articulated in Agrawal (2002) and Cox et al. (2010). The observed diverging characteristics of groups, despite converging performances (especially between G1 and G5) further illustrate the importance of social relationships and the integrated power relationships as enacting elements of successful CPR management and institutional robustness (Singleton 2017).

It is possible to assume here that G1 relies much more on successful and long-surviving water management practices (for example over investing to have a highly developed communal irrigation system (CIS) – a "better safe than sorry" strategy) allowing them to mitigate the effect of uncertainties. This is achieved by the group's willingness to share the additional economic burden of such a strategy for the sake of increased security. Mitigation in this case is costly, as resources are wrongly allocated (over-invested) in the CISs' maintenance. We also observe in this case the power relations that serve as an incentive to invest (Kolinjivadi et al. 2019). Overall, G1 seems to have strong institutional arrangements but on the other hand, its flexibility to adapt to changing environments seems to be underdeveloped, as the group maintains the observed strategy regardless of the changing conditions.

On the contrary, G5, despite the lack of conflict resolution mechanisms is also able to cope with the effect of uncertainties by capitalizing on their higher adaptive capacity. Potential explanations for this adaptive capacity are found on the group members' socio-demographic characteristics. A key element seems to be their age. People in Northwestern Argentina traditionally have great respect for elders; hence the absence of elder subjects in this group might have fostered younger subjects' participation and the possibility to voice their proposals. However, age seems to be very specific to the kind of adaptation strategies developed by the communities, as shown in Mugi-Ngenga et al. (2016). Furthermore, as the subjects from G5 live and work in the same space, a higher level of trust has probably developed over-time, which had a positive effect on investments, as suggested by Janssen et al. (2012, 74). Previous experience with CPRs might have also played a role. Indeed, members of G5 belong to a communitarian cooperative. This potential explanation finds grounds on Pfaff et al.'s (2015) results where a subsample of subjects that belonged to a cooperative reported lower levels of extraction from the upstream position during resource scarcity, compared to the rest of the sample.

This does not imply that the existence (or lack thereof) of conflict-resolution mechanisms can be compensated by other group attributes. However, our study strongly hints that despite the limitations and the lack of generalization of our results, the specific characteristics exhibited in G1 illustrate a higher potential to follow mitigation strategies. In a similar line, the different characteristics of G5 might indicate a community more suited for adaptation strategies, regardless of the failure of the group in terms of the formal requirements of DP6.

Our FFE setting does not allow a further investigation on this topic, namely what would happen if G1 was facing a strict adaptation problem and G5 a mitigation one. Thus, we urge future studies to explore these potential pathways in the behavior of resource users as uncertainties related to climate change will escalate. Such direction of future research may have important policy implications as our findings, once again, strongly hint that transplanting institutions that have been successful elsewhere (even in nearby local communities) without understanding why they have succeeded, might disturb a system rather than fortify it. Instead, identifying the particular characteristics of rural communities and building upon their strengths might enhance their resilience and institutional robustness.

Furthermore, our findings are in line with Gari et al. (2017), suggesting that forecasting SES endurance based on the DPs assessment might lead to wrong conclusions. We have shown that groups lacking conflict resolution mechanisms (amongst others) are also capable of overcoming external disturbances over time, challenging the theoretical predictions.

Finally, in a reflection of the criticism against the DPs and especially DP6, our study rather justifies Ostrom's distancing from the rigid deterministic nature of DPs as "blueprints" and instead highlights their value as diagnostic tools. We have shown that by utilizing the DPs to investigate issues related to the problem at hand, we were able to go beyond a simple checking of variables but instead identify factors that further highlight the complexity of SES and human behavior. In this frame –and as a concluding sentence- we would like to refer to Ostrom's words calling for "*attention to perverse and extensive uses of policy panaceas in misguided efforts to make social-ecological systems (SESs), also called human-environment systems, sustainable over time*" (Ostrom 2007, 15181).

Author Contributions: Conceptualization, Ana Alicia Dipierri and Dimitrios Zikos; Formal analysis, Ana Alicia Dipierri and Dimitrios Zikos; Funding acquisition, Ana Alicia Dipierri and Dimitrios Zikos; Investigation, Ana Alicia Dipierri and Dimitrios Zikos; Methodology, Ana Alicia Dipierri; Resources, Ana Alicia Dipierri and Dimitrios Zikos; Visualization, Ana Alicia Dipierri; Writing – original draft, Ana Alicia Dipierri; Writing – review & editing, Ana Alicia Dipierri and Dimitrios Zikos.

Funding: This research fieldwork in Argentina was possible thanks to the external funding of the Fiat Panis Foundation. This research communication actions were possible thanks to the support of Fonds de la Recherche Scientifique – FNRS, Université libre de Bruxelles and HTW Berlin - Hochschule für Technik und Wirtschaft Berlin.

Acknowledgments: We would like to thank the Instituto Nacional de Tecnología Agropecuaria (INTA) for their support as gatekeepers during the fieldwork and all the farmers and key informants that actively participated during the fieldwork. The authors would also like to thank the accurate and valuable feedback from Prof. Wurzel, Prof. Hudon, and Prof. Dedeurwaerdere, as well as Prof. Janssen for their generosity during the project design phase.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Abbreviations

CC	Climate Change
CPR	Common Pool Resource
DP	Design Principle
EV	Environmental Variability
CIS	Communal Irrigation System
FFE	Framed-Field Experiment
NE	Social Optimal
SO	Nash Equilibrium
G	Group
INTA	Instituto Nacional de Tecnología Agropecuaria - National Institute of Agricultural Technology
R	Round
INV	Investment
EXT	Extraction
NG	Net Gain
INC	Income
I	Informant
F	Farmer

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