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Abstract

We study how institutional design shapes welfare differences in shared groundwater irrigation schemes where water allocation is governed by sequential access. We conduct framed field experiments with 60 rice-growing farmers in northern Bangladesh, a drought-prone, groundwater-dependent rice-producing region where collective action problems are modeled as repeated water allocation decisions under alternative institutional rules. We find that positional asymmetry has direct economic consequences: farmers who extract later receive less water and earn lower payoffs, generating systematic welfare differences along the extraction sequence. This disadvantage arises primarily from reduced water availability at the time of extraction rather than from behavioral differences. We further show that institutional rules reshape these disparities through distinct channels. Crop-based quotas constrain extraction ex ante and eliminate over-extraction but do not remove downstream shortfalls, while audit-based enforcement affects ex-post compliance and stabilizes outcomes. Although these institutions do not eliminate positional asymmetry, they alter how it translates into extraction behavior and welfare dynamics. Additional analyses indicate that behavior is shaped more by constraints, the amount of water available when farmers extract, and institutional incentives than by learning or adaptation. We find little evidence of within-rule learning; extraction decisions exhibit persistence but limited response to past scarcity or peer behavior. Heterogeneity analysis shows that norm-sensitive farmers, particularly those with higher trust, adjust more strongly to positional disadvantage, highlighting the role of expectations in shaping responses to scarcity. Overall, the results suggest that in shared groundwater irrigation schemes, inequality arises not only from how much water is available, but from when and how access occurs. Effective policy must therefore move beyond regulating extraction to designing irrigation service rules that equalize access and improve recovery following scarcity shocks.

Keywords:Groundwater irrigation, Resource extraction, Positional asymmetry, Institutional design, Economic resilience, South Asia

JEL Codes: O13; Q25; D23; D62, D70; C93

1 Introduction

Over the past few decades, agricultural productivity has grown substantially worldwide, with groundwater playing an increasingly central role in irrigation. Approximately 38% of global irrigated cropland relies primarily on groundwater, which accounts for about 43% of freshwater withdrawals and supports nearly 40% of global food production (Yao *et al.*, 2025). As food demand is projected to increase by nearly 60% by 2050, groundwater pumping is expected to rise by roughly 20% between 2010 and 2050 (Vallury *et al.*, 2020; Yang *et al.*, 2024). At the same time, climate projections indicate declining precipitation and more frequent periods of prolonged dryness in many vulnerable regions. These trends raise concerns about the sustainability of crop production, particularly for water-intensive crops such as rice, and suggest that further declines in groundwater tables may loom large.

Groundwater depletion has been especially pronounced in rice-growing command areas[1], where irrigation demand is high. Rice cultivation is traditionally considered highly sensitive to water shortages, and farmers often apply large volumes of water to suppress weeds and avoid yield losses (Tang, 1989). While this practice can stabilize production, it can also lead to substantial water losses in rice fields, sometimes reaching up to 45% (Tulip *et al.*, 2022). In shared groundwater schemes, such intensive pumping generates congestion externalities (S. M. Smith, 2018). When a farmer extracts water from a shared aquifer, pumping lowers the groundwater level around the well, creating a cone of depression that reduces the water stock available to neighboring farmers within the same command area. In addition, spatial externalities may arise from differences in farmers' locations (Pfeiffer & Lin, 2012). Farmers located closer to the pump or upstream in the distribution network may gain earlier or easier access to irrigation water, while downstream farmers face tighter water constraints. These positional differences can create incentives for opportunistic extraction, potentially reinforcing inequalities in water access and economic outcomes (Jacoby & Mansuri, 2020; Jacoby, Mansuri, & Fatima, 2021).

The collective action literature, primarily based on small-scale irrigation schemes, suggests that self-organized arrangements, such as repeated communication, endogenous rule-making by local communities, and social sanctioning, can help coordinate resources and mitigate common-pool resource problems, including both provisioning and appropriation dilemmas (Amirova, Petrick, & Djanibekov, 2022; Tang, 1991). In such settings, resource users may voluntarily cooperate in irrigation management when they are socially connected and able to monitor one another, leading to more equitable water distribution and improved collective outcomes (Nie, Yang, & Tu, 2020; Turiansky *et al.*, 2021). Information about others' past behavior and access to local networks influence farmers' water-use decisions when scarcity emerges (Haseeb, 2020; Pfaff *et al.*, 2015).

Effective self-governance, however, may be difficult when the underlying resource dynamics are complex and largely unobservable, as is the case with groundwater. Smallholder farmers often lack clear information about the size and evolution of the shared aquifer, making it challenging to coordinate extraction decisions, follow best practices, or internalize the long-run consequences

[1] A command area refers to the geographic boundary of an institutional irrigation scheme, encompassing a group of farmers whose plots are located within that area and who share access to a common pumped irrigation scheme.

of pumping when scarcity becomes evident (Fishman, Giné, & Jacoby, 2023; Meinzen-Dick *et al.*, 2018; R. B. Smith & Tsur, 1997). Moreover, such arrangements may prove fragile or short-lived because they rely on ongoing bargaining and voluntary compliance among resource users (Bentzen, Kaarsen, & Wingender, 2017). When institutional rules are introduced externally, farmers may adjust their behavior in response to these rules even if they were not involved in designing them (Hayo & Vollan, 2012).

In contrast, institutionally managed irrigation schemes[2] are not governed through purely self-organized arrangements but instead operate under externally designed allocation rules and enforcement structures in a nested governance structure. In such settings, allocating water across plots requires an institutional framework capable of coordinating extraction, preventing free-riding, and resolving disputes over scarce resources (Falk, Kumar, & Srigiri, 2019). Formal allocation rules and enforcement mechanisms, such as crop-based quotas, rotational schedules, and monitoring practices, regulate water use, limit excessive extraction, and shape how farmers respond to scarcity (Drysdale & Hendricks, 2018; Meinzen-Dick *et al.*, 2018). Yet relatively little is known about how such institutional arrangements influence farmers' behavioral responses to groundwater scarcity or how they shape the resilience of farmers' economic outcomes over time, particularly in shared groundwater irrigation settings.

We address this gap by investigating two related questions. First, what are the economic welfare and extraction-related behavioral consequences of positional asymmetry, and how do these effects vary across institutional regimes? Second, how does farmers' economic welfare respond over time when scarcity shocks occur, and do welfare trajectories differ across institutional environments? In addition, we explain which mechanisms embedded in irrigation allocation rules mitigate positional disadvantage under groundwater scarcity. Drawing on irrigation collective action games commonly used in collective action research (e.g., Cardenas, Rodriguez, and Johnson, 2011, Janssen *et al.*, 2012, Bernal-Escobar *et al.*, 2025), we design contextually relevant institutional rules governing irrigation schedules (sequential versus rotation), crop choice (water-intensive versus less water-intensive varieties), water balance audits, and penalty enforcement. We then conduct framed field experiments with 60 farmers in northern Bangladesh to study the groundwater irrigation dilemma, exploiting exogenous variation in farmers' assigned position, defined as the physical location of plots within the managed scheme, and in the extraction position, defined as the irrigation turn in the irrigation schedule realized during gameplay. These random assignments, which capture real-world differences between plot location and irrigation turn, are orthogonal to farmers' characteristics, thus generating quasi-random variation in access conditions that we leverage as a design-based source of identification.

Our study is situated in the context of northern Bangladesh, specifically the Rajshahi and Rangpur divisions, which together comprise 16 administrative units and are locally known as the Barind tract-the country's food bowl, contributing 55% to national Boro rice production during the dry season between November/January and April/May (Tulip *et al.*, 2022). Approximately 80% of arable land supports agricultural activity, of which 59% depends on irrigation,

[2]According to Hunt (1988), irrigation schemes differ in both scale and the structure of authority governing water allocation. In large-scale irrigation settings, water delivery infrastructure is designed and managed by external providers, while day-to-day water allocation and pumping decisions are implemented by local operators or organizations.

with groundwater serving as the primary source for 79% of irrigated lands during the dry season (Sadiq, Sarkar, & Raisa, 2023; Tulip *et al.*, 2022). Over the past 20 years, total irrigated agricultural land (≈5.63 million ha) has increased by 66% in 2020 relative to 1990 levels (Maniruzzaman *et al.*, 2025), and ≈48% of the total 33,261 deep tube wells are institutionally installed, providing irrigation services to 36% of farmers (out of 2,979 thousand) who received groundwater in fiscal year 2023–2024.[3] At the same time, rice cultivation in this region exhibits unnecessary water extraction (≈21.3%) and substantial water loss, with only 33% of applied irrigation returning to groundwater as dry-season recharge (Tulip *et al.*, 2022). Extensive groundwater use has contributed to a decline in the regional groundwater table at rates of 1.1–5.3 mm per year (Janardhanan *et al.*, 2023). The Barind tract is also considered a drought hotspot, having experienced 20 meteorological droughts over the past five decades, characterized by prolonged dry spells and limited precipitation. On average, 5% of the area experiences extreme drought, while 12% faces moderate drought conditions (2011–2019) (Sadiq, Sarkar, & Raisa, 2023), and annual precipitation exhibits substantial seasonal variation (1500–3000 mm), with a sharp decline of 86%–115% relative to the national average during the dry season (Bank, 2021). Taken together, this study area presents a compelling case for examining how externally designed allocation rules and enforcement mechanisms shape farmers' behavior in the context of groundwater scarcity.

Our study contributes to a growing body of literature on common-pool resource management and, in particular, to the limited literature on institutionally managed groundwater irrigation service markets in climate-vulnerable contexts, drawing on insights from institutional and behavioral economics. We experiment with rice farmers who have already experienced some form of economic and non-economic institutions (e.g., water pricing and irrigation schedules) in obtaining groundwater irrigation services and who are aware of groundwater depletion in their operating regions. Such a combination in the subject recruitment is limited in the collective action experiments, except in a few studies (e.g., Meinzen-Dick *et al.*, 2018).

First, we provide causal evidence on water extraction behavior and welfare outcomes of access conditions within institutional regimes. Using an instrumental variables strategy that isolates exogenous variation in realized extraction position, we find that extracting later in the sequence significantly reduces farmers' welfare. A one-position shift toward a later extraction order lowers net payoff or economic return by approximately 1.98 tokens on average. This is consistent with the extraction results, which show that downstream farmers appropriate significantly less water: a one-position delay reduces total extraction by roughly 2.1 units, driven primarily by lower rule-compliant water use.

This contrasts with the existing empirical literature, which primarily documents behavioral responses in self-governed schemes (e.g., Anderies *et al.*, 2013; Baggio *et al.*, 2015; Cardenas, Rodriguez, and Johnson, 2011; Janssen *et al.*, 2012; Otto and Wechsung, 2014) without linking extraction to realized economic returns (Pham, Otto, & Zikos, 2019) or isolating the causal effect of access conditions. In these settings, upstream farmers typically extract more while leaving some water for downstream farmers, who, in turn, continue to contribute despite extracting fewer units of water. At the same time, farmers have been found to retaliate by reducing

[3]For further details, please see 'Minor Irrigation Survey 2023-2024' by Ministry of Agriculture, Bangladesh; available at https://mof.portal.gov.bd/

their contributions when others extract disproportionately. Interventions aimed at improving cooperation yield mixed results. In particular, communication treatments are shown to increase cooperation; however, the fixed, short duration of communication (≈ 2–3 minutes) does not necessarily allow participants to resolve the underlying dilemmas. In addition, rotation scheduling is often found to reduce overall performance when players strategically adjust their contribution and extraction decisions based on their assigned turn.

In contrast to this literature, our findings highlight that even when infrastructure and institutional rules are in place, extraction remains a binding constraint, and unequal access translates directly into welfare losses. Moreover, we explicitly link extraction behavior to economic returns, showing that lower extraction does not simply reflect strategic adjustment but leads to economically meaningful reductions in farmer welfare.

Second, we introduce the economic resilience dimension, which determines the extent to which welfare losses persist and how quickly institutional rules reshape the recovery path toward baseline welfare following scarcity shocks. We show that under the baseline sequential rule, scarcity shocks lead to sharp and persistent welfare losses that deepen further over time, suggesting that unregulated sequential extraction amplifies scarcity effects. Under the crop-based quota regime, the initial impact of the shock remains similar, but recovery trajectories improve substantially. Welfare losses are less persistent, and income levels recover more quickly in later rounds. This suggests that crop-based water requirement quotas mitigate the long-run consequences of scarcity, even if they do not prevent the initial shock. The rotation and audit with penalty regime exhibits a similar but more nuanced pattern. While the initial welfare drop may be slightly larger, welfare stabilizes over time, indicating that enforcement mechanisms help prevent the accumulation of losses.

Empirical investigation of resilience as 'recovery after decline', as discussed by Zaharia *et al.* (2021) and Alloush and Carter (2024), is largely absent in the collective action literature, and to our knowledge, our study is one of the very few to incorporate dynamic welfare resilience into experimental analyses of groundwater scarcity and irrigation dilemmas.

Beyond establishing the causal effect of positional asymmetry and documenting its implications for welfare dynamics, our paper provides a detailed characterization of the behavioral mechanisms underlying extraction decisions. While some studies rely on additional experimental treatments or repeated designs to study behavioral responses (e.g., Meinzen-Dick *et al.*, 2018, Otto and Wechsung, 2014, and Bernal-Escobar *et al.*, 2025), we exploit variation within a single experimental design to examine how farmers adjust extraction in response to constraints and institutional incentives. The evidence shows that differences in extraction are driven primarily by limits on water availability at the time of extraction, with little role for intrinsic behavioral differences. We find limited evidence of gradual learning within institutional regimes, while extraction decisions exhibit persistence but little systematic adaptation to past scarcity or peer behavior. Finally, we document heterogeneity in responses: farmers with higher norm sensitivity, particularly those with greater trust, adjust more strongly to positional disadvantage. Taken together, these results provide a comprehensive overview of how behavioral responses operate in sequential allocation environments, complementing the causal and resilience findings of our paper.

The paper is organized as follows. Section 2 describes the study setting in more detail, along with the sampling strategy and the experimental setup for the irrigation collective action games. The theoretical framework and data are presented in Sections 3 and 4, respectively. The estimation strategy and empirical findings are discussed in Sections 5 and 6, respectively, and Section 7 presents robustness exercises. We examine the underlying institutional and behavioral mechanisms in Section 8 and conclude in Section 9.

2 Sampling and Experimental design

2.1 Study setting and sampling strategy

The study is conducted in groundwater-dependent institutional irrigation schemes managed by local irrigation service providers, such as the Barind Multipurpose Development Authority (BMDA) and Solargo Limited. In such institutional settings, groups of local farmers rely on pump-based irrigation schemes, either grid- or solar-powered, organized into command areas. These farmers receive irrigation services from shared pumps within their respective command areas, operated by local operators recruited by the organizations and responsible for day-to-day water allocation and field-level management. This structure makes these irrigation schemes particularly well-suited to studying irrigation dilemmas, particularly in contexts where scarcity, extraction order, and local irrigation institutions shape farmers' behavior.

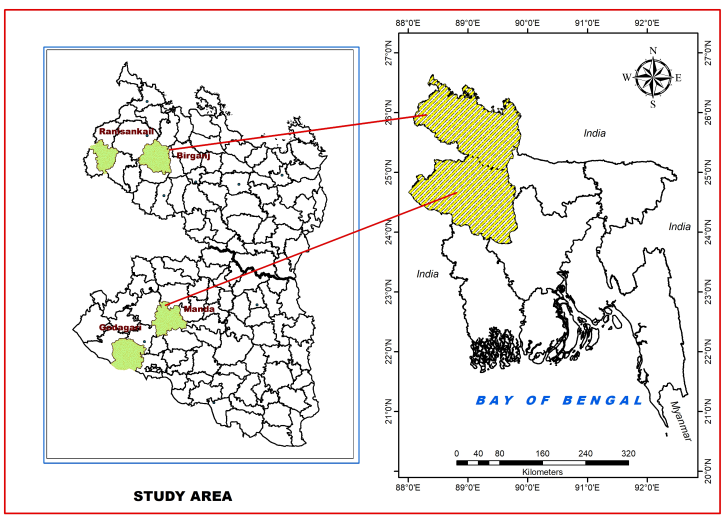


Figure 1: Study areas in the northern Bangladesh

In consultation with these providers, we selected three sites, as shown in the Figure 1, Manda (Naogaon district), Birganj (Dinajpur district), and Ranishankar (Thakurgaon district), while also ensuring the operational feasibility of conducting full-day experimental sessions under close supervision. These areas are located in drought-prone agro-ecological zones where farmers primarily cultivate Boro rice during the dry season, Within each study area, participant farmers are recruited purposively through local irrigation managers and pump operators. To be eligible to participate in the experimental sessions, a farmer must actively cultivate Boro rice using groundwater irrigation, be part of a pump command area, have sufficient literacy to follow the game instructions, and be willing to take part in a long experimental session lasting about six to seven hours.

Each study area contributes 20 farmers, yielding a total sample of 60 participants across the three locations. Farmers within each site are drawn from multiple pump houses or command areas, with recruitment limited to three to five farmers per pump house. The experimental sessions are conducted separately at each site on different days in September 2024, and participating farmers interact only with other farmers from the same site. Before we formally begin our field experiments in these three study areas, we conduct a pilot in a similar setting, Godagari (Rajshahi district), with an additional 20 farmers to assess the viability of the long-day experiment and farmers' overall comprehension of the experimental instructions. We apply those lessons learned from the pilot in the main field experiments. Across experiments, we work with a local survey firm, the MOMODa Foundation, to implement field experiments with four to five trained facilitators.

Our experimental arrangement reflects the operational structure of the irrigation schemes, where cultivated plots and pump command areas are geographically fixed, and farmers typically operate within a single local irrigation network. As a result, there is limited overlap of farming activities across sites. Conducting the sessions separately therefore reduces the possibility of communication or spillovers across locations and allows each site to function as an independent experimental block.

2.2 Experimental setup

Within each study site, the recruited farmers are organized into small irrigation groups for the experimental sessions on the day of the experiment. Each study site has four experimental groups, yielding a total of 12 groups across the three sites. Farmers participate only within their assigned groups and do not interact with participants from other groups during the experimental sessions. In addition, farmers within a group are not allowed to communicate with other co-farmer participants during the experiment. Each five-farmer group represents a simplified command area in which farmers share access to a common pumped irrigation water source and make decisions about investment in maintaining the irrigation infrastructure and how much to extract from the shared source.

The irrigation game is implemented as a repeated, framed field experiment comprising 30 rounds. Let $t = 1, \ldots, 30$ index the rounds of the game, g index irrigation groups, and i index farmers within each group. To examine how different institutional arrangements influence farmers' behavior, the experiment introduces three institutional rules governing water allocation and enforcement. Let $r \in \{1, 2, 3\}$ denote the rule in place in a given round. The thirty rounds are divided into three blocks of ten rounds each. In the first block ($t = 1, \ldots, 10$), farmers play under Rule 1. In the second block ($t = 11, \ldots, 20$), the institutional environment changes to Rule 2. In the final block ($t = 21, \ldots, 30$), the game is played under Rule 3. All groups follow the same sequence of rules, so each group is exposed to all three institutional environments during the experimental session. Before the start of each rule block, the facilitators explain the institutional rule and conduct practice examples to ensure that participants understand the decision environment. Once a rule block starts, the institutional structure remains unchanged for the ten rounds within that block. At the end of experimental sessions, participants are asked to participate in a short debrief survey.

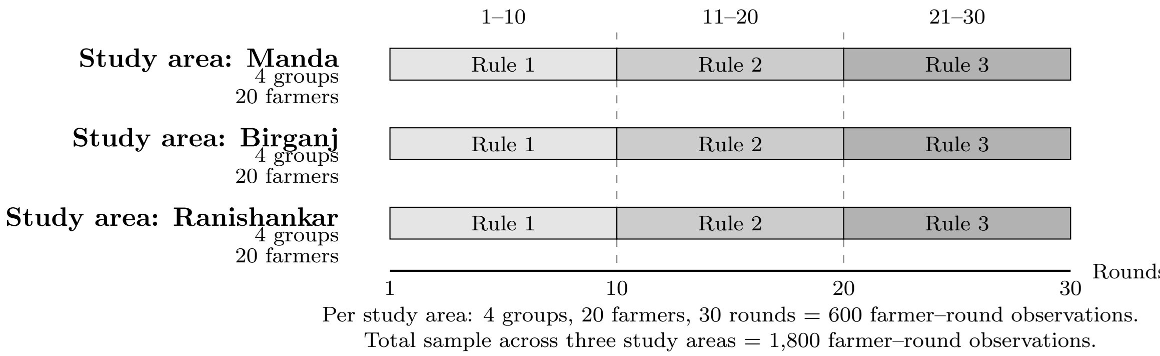


Figure 2: Experimental crossover design across study areas. In each study area, 20 farmers organized into four groups participate in all 30 rounds and are sequentially exposed to Rule 1 (Rounds 1–10), Rule 2 (Rounds 11–20), and Rule 3 (Rounds 21–30).

Each round of the game follows a two-stage structure. In the first stage, each farmer decides how much to contribute to a common irrigation fund. These individual contributions are made privately. Let c_{it} denote the contribution of farmer i in group g in round t. The total group contribution C_{gt} in round t, given by $\sum_i c_{it}$, determines the amount of water available to the group in that round. Let W_{gt} denote the realized water stock available to group g in round t. This stock is a function of the group's contribution decisions in that round. Higher total contributions generate a larger water stock, while lower contributions result in tighter water availability. The contribution stage therefore captures the collective investment problem in irrigation: although the group as a whole benefits from greater investment in the shared schemes, each individual farmer may have an incentive to reduce personal contribution and rely on the efforts of others.

In the second stage, farmers extract water sequentially from the available stock W_{gt}. Let x_{it} denote the amount of water extracted by farmer i in round t. When a farmer's turn arrives, the participant observes the remaining water in the schemes and then chooses how much to extract, subject to the rule in place in that round. Because extraction occurs sequentially, earlier farmers' actions directly affect the opportunities available to later farmers. At the end of each round, farmers are informed of their own payoff. The next round then begins under the same rule until the experiment moves to the next rule block. Repeating this process over 30 rounds allows the study to observe how cooperation, over-extraction, adaptation, and strategic behavior evolve over time.

While the basic contribution and extraction structure remains the same across all rounds, the institutional environment governing water allocation differs across rules. In particular, the three institutional rules differ in how extraction rights are defined, how access order is determined, and whether monitoring and penalties are applied. Under Rule 1, farmers play the baseline sequential irrigation game. Water extraction follows the original assigned order, so the realized extraction position in round t corresponds to the farmer's assigned position in the extraction sequence. Under Rule 2, the game introduces a crop-choice appropriation rule. In each round, after making the contribution decision, each farmer selects one of three crops. This crop choice determines the farmer's water requirement and, therefore, the amount of water the farmer can appropriate. Under Rule 3, the game introduces a rotation rule with an audit and a penalty. In this rule, farmers retain their assigned positions as fixed identity labels, while the extraction order rotates cyclically across rounds. If farmer i has identity $1, 2, 3, 4$, or 5, the order shifts one step each round so that the realized extraction position k_{it} varies systematically over time. Over a five-round cycle, each player occupies every extraction position once, and over the ten rounds of Rule 3 each player becomes first twice. At the same time, each farmer holds an equal extraction right of one-fifth of the total water available in the round. Compliance is monitored probabilistically: in every round, the facilitators roll a die, and when the die shows 6, they check whether any player has taken more than the allowed one-fifth share. If over-extraction is detected, the player has to return the excess amount and pay an additional fine of 6 tokens. Thus, Rule 3 combines equalized rotational access with random audit-based deterrence.

Each farmer is randomly assigned an extraction position $k_i \in \{1, \ldots, 5\}$ at the start of the session. This assigned position determines the baseline order in which farmers access water in the extraction sequence. The realized extraction position of farmer i in round t is denoted by $k_{it} \in \{1, \ldots, 5\}$. While the assigned position k_i remains fixed for each farmer, the realized extraction position k_{it} may vary across rounds depending on the institutional rule governing water allocation. The realized extraction order can be written as $k_{it} = f_r(k_i, t)$, where $r \in \{1, 2, 3\}$ denotes the institutional rule in place in round t, and $f_r(\cdot)$ represents the rule-specific mechanism that determines the extraction sequence. Under Rules 1 and 2, the order remains fixed, with $k_{it} = k_i$, whereas under Rule 3 the rotation mechanism systematically shifts farmers across extraction positions over rounds. This distinction between assigned position and realized extraction order allows the design to generate exogenous variation in farmers' exposure to sequential scarcity: early versus late extraction positions. Formally,

$$k_{it} = \begin{cases} k_i, & \text{under Rules 1 and 2 (sequential order),} \\ f_r(k_i, t), & \text{under Rule 3 (rotational allocation)} \end{cases}$$

3 Theoretical framework

In groundwater irrigation schemes, water is typically pumped from a shared aquifer and distributed through irrigation channels or buried pipelines connected to a common pump, often following irrigation schedules and allocation rules set by the pump operators. When a farmer extracts water, pumping lowers the groundwater level around the well, creating a temporary cone of depression (Pfeiffer & Lin, 2012). As pumping continues, this localized drawdown reduces the flow available to farmers who extract later in the same irrigation network. Consequently, farmers who irrigate earlier benefit from greater water availability, while those who irrigate later face progressively tighter water constraints. This sequential access to a shared resource generates positional asymmetry within the command area.

At the same time, groundwater irrigation schemes are repeatedly exposed to periods of water scarcity due to seasonal hydrological conditions and climatic variability. In the experimental setting, each round corresponds to one Boro irrigation season, so farmers may experience multiple episodes in which water availability becomes unusually tight. Such episodes can generate temporary welfare losses, but the persistence of these losses and the speed of recovery depend on the institutional environment governing irrigation allocation and enforcement. In this context, resilience refers to how farmers' welfare changes and recovers during and after periods of water scarcity within a given institutional regime.

The theoretical framework proceeds in two parts: First, we analyze the welfare and behavioral consequences of positional asymmetry in sequential extraction environments. Second, we examine how welfare responds to scarcity episodes over time and how institutional rules shape resilience to such shocks.

3.1 Positional asymmetry and institutional mediation

The experimental irrigation game reproduces this sequential scarcity environment, providing a controlled setting to examine how extraction position shapes farmers' irrigation behavior and economic outcomes. Farmers who extract earlier experience a larger remaining water stock, while those extracting later face progressively tighter physical water constraints. This positional asymmetry arises mechanically from the sequential appropriation of a shared water resource.

Consider an irrigation group g consisting of $N = 5$ farmers indexed by i. In each round t, farmers first decide how much to contribute to a shared irrigation fund. Each farmer receives an endowment $e = 10$ tokens and chooses a contribution $c_{it} \in [0, e]$. The remaining tokens $(e - c_{it})$ are kept as private income. Total group contributions, $C_t = \sum_{i=1}^{5} c_{it}$, determine the amount of water available for irrigation $W_{gt} = f(C_t)$, where $f(\cdot)$ is a stepwise water production function that converts collective contributions into irrigation water units. Like the real-world setting, irrigation infrastructure requires a minimum level of collective investment to become operational. In the experimental design, water production increases discretely once contributions pass certain thresholds. For example, if total contributions remain below 10 tokens, the irrigation scheme produces no water, whereas contributions above 36 tokens generate the maximum water stock:

$$f(C_t) = \begin{cases} 0, & C_t \in [0, 10], \\ 40, & C_t \in [21, 25], \\ 60, & C_t \in [26, 30], \\ 80, & C_t \in [31, 35], \\ 100, & C_t \geq 36. \end{cases}$$

Thus, low contributions may yield little or no water, whereas sufficiently high collective investment yields a substantial irrigation stock.

Given the realized water stock W_{gt}, farmers extract water sequentially. Let $k_{it} \in \{1, \ldots, 5\}$ denote the realized extraction position of farmer i in round t, where lower values correspond to earlier extraction turns, and x_{jt} denote the amount of water extracted by farmer j. The water available when farmer i arrives to extract is therefore equal to the total water available in the group minus the cumulative extraction of upstream farmers: $W_{it}^{pre} = W_{gt} - \sum_{j:k_{jt}<k_{it}} x_{jt}$. Ex-

traction is limited by the amount of water remaining at the farmer's turn. Consequently, farmer i's extraction must satisfy the water availability constraint: $0 \leq x_{it} \leq W_{it}^{pre}$. This constraint implies that later extraction positions are systematically associated with tighter water availability conditions than earlier positions. Positional disadvantage, therefore, arises mechanically from the sequential structure of extraction, leading to weaker extraction opportunities and lower attainable payoffs for farmers in later positions.

Farmer i's economic return (net payoff or welfare) in each round depends on three components: the tokens retained from the initial endowment, the benefit obtained from irrigation water extraction, and any penalties or institutional constraints imposed by the rule governing the round. Formally, the per-round payoff can be written as $\pi_{it} = (e - c_{it}) + x_{it} - \Phi_{it}(x_{it}; q_{it})$, where $(e - c_{it})$ represents the private payoff from tokens not contributed to the irrigation fund, x_{it} denotes the benefit from irrigation water extraction (with one unit of water yielding one token of payoff), and $\Phi_{it}(\cdot)$ captures penalties or rule-specific constraints associated with the institutional environment.

Because water availability declines as extraction proceeds, farmers who extract later face progressively tighter water availability constraints. For a given level of contributions and institutional rules, the maximized payoff therefore declines with extraction position, $\frac{\partial \pi_{it}}{\partial k_{it}} < 0$. This inequality captures the core implication of sequential scarcity in institutional irrigation schemes: downstream farmers systematically face weaker economic opportunities because they encounter lower water availability when their extraction turn arrives.

Building on the sequential extraction environment described above, farmers' outcomes may depend not only on their extraction position but also on the conditions created by earlier extraction decisions. We therefore control for the prevailing extraction conditions faced by farmer i when their turn begins. These conditions summarize both the physical availability of water and the behavioral signals generated by upstream farmers. we represent these conditions by the vector, $C_{it} = (W_{it}^{pre}, PeerOver_{it}, NoWater_{it})$, where each component captures a different aspect of the extraction environment.

The first component, W_{it}^{pre}, measures the amount of water remaining in the irrigation scheme when farmer i arrives to extract. Lower values of W_{it}^{pre} indicate that upstream farmers have already appropriated a larger share of the available water stock. The second component captures behavioral signals regarding rule compliance among upstream farmers. Let OE_{jt} denote the over-extraction by any farmer j in round t in group g, defined as $OE_{jt} = \max(x_{jt} - q_{jt}, 0)$, where x_{jt} denotes water extracted by farmer j and q_{jt} is the applicable extraction quota. Total group over-extraction in round t is therefore: $OE_{gt}^{tot} = \sum_{j \in g} OE_{jt}$. Farmer i's exposure to peer over-extraction is then constructed as the leave-one-out intensity of quota violations committed by other farmers in the group, $PeerOver_{it} = OE_{gt}^{tot} - OE_{it}$. This variable summarizes the degree to which farmer i observes opportunistic extraction behavior by peers within the group. Finally, we define an indicator for extreme scarcity conditions. Let $NoWater_{it} = \mathbf{1}(W_{it}^{pre} \leq 0)$, which equals one if the irrigation pool has already been exhausted by the time farmer i arrives to extract.

The positional asymmetry described above provides the baseline mechanism through which realized extraction order shapes water access and economic outcomes. Institutional rules may modify this mechanism by altering either the feasibility of extraction or the incentives governing rule compliance. We examine two such institutional channels: Rule 2 introduces crop-based quotas that reshape the feasibility of water extraction through ex-ante crop water requirements, while Rule 3 introduces audit-based enforcement that alters extraction incentives ex-post.

Under Rule 2, farmers select crops prior to the extraction stage, and each crop choice implies a minimum irrigation requirement. Let q_{it} denote the water requirement associated with the crop chosen by farmer i in round t. These requirements are determined before extraction begins, thus representing ex-ante commitments that shape farmers' expectations about water availability. Extraction then proceeds sequentially according to the realized position k_{it}, so the water available to farmer i at the moment of extraction is given by W_{it}^{pre} as defined above.

A binding constraint arises when the remaining water stock is insufficient to satisfy the crop's minimum requirement. Specifically, if $W_{it}^{pre} < q_{it}$, farmer i cannot meet the water requirement of the chosen crop, even though positive water may still remain overall. This constraint reflects the interaction between ex-ante crop commitments and sequential access to water. Consequently, farmers in later extraction positions may face reduced feasibility and lower economic outcomes because they encounter weaker water conditions when their turn arrives. At the same time, the crop-based water quota limits excessive appropriation by early movers, potentially mitigating, but not necessarily eliminating, the positional asymmetry that arises under baseline sequential extraction.

Rule 3 introduces ex-post enforcement through probabilistic audits and penalties for over-extraction. Farmers retain their assigned identity positions, while the realized extraction order k_{it} rotates systematically across rounds. As a result, each farmer experiences different extraction positions over time, redistributing access to the water stock across rounds. Under this rule, each farmer is entitled to an equal share of the available water in a round. Let q_{it} denote the allowed extraction share for farmer i. After extraction decisions are made, compliance is monitored through a randomized audit mechanism. Let A_{gt} denote an indicator for whether an audit is triggered in group g during round t. If an audit occurs and a farmer has extracted more than the permitted share, the excess amount must be returned, and a monetary penalty is imposed.

Define the amount of over-extraction by farmer i as $OE_{it} = \max(x_{it} - q_{it}, 0)$, which captures the extent to which extraction exceeds the (non-binding) quota. Because extraction remains sequential, positional scarcity may interact with enforcement incentives. Farmers in later positions face tighter water availability conditions and may therefore have stronger incentives to exceed the quota in order to secure sufficient water. Conversely, the presence of audits increases the expected cost of such violations. Rule 3, therefore, introduces a deterrence mechanism that may operate differently across extraction positions. Early movers face relatively weak scarcity pressure and may have little incentive to violate quotas, whereas downstream farmers may face stronger trade-offs between respecting the rule and securing water before the stock is depleted.

3.2 Welfare dynamics and resilience to scarcity episodes

The central idea of economic welfare resilience in this setting is to characterize how farmers' welfare responds when water scarcity becomes unusually severe and how institutional rules influence both the magnitude of welfare losses and the speed with which welfare recovers. Consistent with the irrigation game environment described in Section 3.1, each institutional rule defines a distinct decision environment and experimental block, where each block represents the sequence of rounds experienced by farmer i under a particular institutional rule r. Each observation therefore corresponds to farmer i in irrigation group g during round t under institutional rule r. Within each farmer-rule block, welfare trajectories are evaluated over time, and resilience is interpreted as the behavior of welfare within the same institutional environment across successive rounds.

To identify scarcity conditions, we first characterize the hydrological environment that farmers face at the time of decision. Let W_{gt} denote the total water stock available to irrigation group g at the beginning of round t. As farmers extract water sequentially, the remaining stock declines. Let W_{irt}^{pre} denote the amount of water remaining in the round immediately before farmer i makes the extraction decision in round t under rule r. This quantity reflects the water available at the time of decision and accounts for upstream farmers' cumulative withdrawals. Using these quantities, the intensity of scarcity is summarized by the depletion index

$$b_{irt} = 1 - \frac{W_{it}^{pre}}{W_{gt}}.$$

In this expression, the ratio $\frac{W_{it}^{pre}}{W_{gt}}$ measures the share of the original group water endowment that remains available at the time of farmer i's decision. Subtracting this ratio from 1 yields the complementary share, representing the fraction of the original water stock that has already been depleted through prior extraction. The variable b_{irt} provides a continuous measure of scarcity intensity within the irrigation round faced by farmer i. When $b_{irt} = 0$, no water has been withdrawn, and scarcity is absent. As b_{irt} approaches one, the resource becomes increasingly depleted, indicating more severe scarcity conditions.

To evaluate scarcity conditions relative to institutional environments, we define a rule-specific benchmark that accounts for systematic differences in depletion patterns across institutional regimes. Let the average depletion intensity observed under institutional rule r be defined as

$$\bar{b}_r = E[b_{irt} \mid r],$$

where the expectation operator $E[\cdot \mid r]$ denotes the average value of the depletion index among all observations governed by rule r. This quantity represents the typical level of water depletion associated with institutional rule r. Using this benchmark, we define an adverse scarcity state as

$$B_{irt} = \mathbf{1}(b_{irt} \geq \bar{b}_r).$$

The variable B_{irt} is a binary indicator that equals one when the depletion intensity faced by farmer i in round t under rule r is at least as large as the average depletion observed under that same rule, and zero otherwise. The condition $b_{irt} \geq \bar{b}_r$ therefore identifies rounds in which farmers face scarcity that is unusually severe relative to the institutional norm. This indicator is later used to identify welfare episodes and to trace dynamic recovery paths.

To evaluate welfare losses relative to typical conditions, the framework next establishes a baseline level of welfare against which deviations can be measured. In the irrigation game, farmers may systematically receive different payoff levels due to persistent behavioral differences, favorable or unfavorable extraction positions, or other characteristics that do not change over time. At the same time, some rounds may yield higher or lower payoffs for all farmers due to common environmental conditions. Let y_{irt} denote the realized payoff of farmer i in round t under institutional rule r. This payoff represents the farmer's economic welfare in that decision period. The observed payoff is decomposed into several components reflecting persistent farmer characteristics, round-level conditions, and temporary shocks, expressed as

$$y_{irt} = \alpha_i + \lambda_t + \gamma B_{irt} + \varepsilon_{irt}.$$

where, α_i denotes a farmer fixed effect that captures all time-invariant characteristics of farmer i, including persistent behavioral tendencies, risk preferences, or systematic extraction patterns. λ_t denotes a round fixed effect capturing factors common to all farmers in round t, such as aggregate hydrological conditions or learning effects that affect behavior as the game progresses. The variable B_{irt} represents the adverse scarcity indicator defined above, and the coefficient γ measures the average welfare impact of experiencing such scarcity conditions. Finally, ε_{irt} captures the remaining unexplained component of welfare after accounting for these systematic factors.

Using this decomposition, the baseline welfare level for farmer i in round t is defined as

$$\mu_{irt} = \alpha_i + \lambda_t.$$

where, μ_{irt} represents the payoff that farmer i would be expected to receive in round t under typical hydrological conditions, after abstracting from unusually severe scarcity states. Because resilience is evaluated within institutional regimes, this baseline is summarized separately for each farmer-rule block. Let T_{ir} denote the number of rounds that farmer i experiences under institutional rule r. The rule-specific baseline welfare is then defined as

$$\mu_{ir} = \frac{1}{T_{ir}} \sum_{t=1}^{T_{ir}} \mu_{irt}.$$

where, μ_{ir} therefore represents the typical welfare level experienced by farmer i when operating under rule r, and it serves as the benchmark against which welfare losses are measured. Once this benchmark has been established, welfare deviations are defined relative to it. Let the normalized welfare deviation be

$$\tilde{y}_{irt} = y_{irt} - \mu_{ir},$$

where, $\tilde{y}_{irt}$ measures how far realized welfare deviates from the farmer-rule baseline. Negative values of $\tilde{y}_{irt}$ indicate that welfare in round t is below the typical level experienced by farmer i under rule r, while positive values indicate that welfare exceeds typical conditions.

After normalizing welfare relative to the farmer-rule baseline, we identify the point at which a sufficiently large welfare decline occurs. To distinguish routine welfare variation from meaningful shocks, we scale welfare declines using the within-block dispersion of welfare. Let σ_{ir} denote the standard deviation of payoffs for farmer i under rule r. We then define the episode threshold as, $\kappa_{ir} = 0.5\sigma_{ir}$, which implies that a welfare decline must exceed half of the typical welfare variation experienced by the farmer under that institutional rule in order to qualify as an episode.

A welfare episode begins when normalized welfare falls below this threshold. We define the onset condition as $\tilde{y}_{irt} \leq -\kappa_{ir}$, meaning that the realized payoff falls sufficiently below the farmer-rule baseline to represent a substantial welfare loss. The onset round is defined as the first round in which this threshold is crossed, $t_{0,ir} = \min\{t : \tilde{y}_{irt} \leq -\kappa_{ir}\}$, which identifies the beginning of the welfare decline for farmer i under rule r. Once the onset round has been identified, welfare dynamics are analyzed relative to this reference point using event time, $\tau_{it} = t - t_{0,ir}$, which measures the number of rounds before or after the onset of the welfare shock.

Recovery occurs when welfare returns sufficiently close to its baseline level. We set a recovery band that allows small deviations around the benchmark, $\tilde{y}_{irt} \geq -0.1\sigma_{ir}$, meaning that welfare has returned close to its typical level within the farmer-rule block. The recovery round is therefore defined as $t_{1,ir} = \min\{t \geq t_{0,ir} : \tilde{y}_{irt} \geq -0.1\sigma_{ir}\}$, which identifies the first round in which welfare returns to this recovery band. Finally, the episode window is defined as the set of rounds between onset and recovery, $E_{ir} = \{t : t_{0,ir} \leq t \leq t_{1,ir}\}$, representing the full period over which welfare declines and subsequently recovers.

Within an episode window, we summarize welfare resilience using three scalar measures. Loss severity captures the depth of the welfare decline, $S_{ir} = -\min_{t \in E_{ir}} \tilde{y}_{irt}$, which represents the largest welfare shortfall experienced during the episode. Recovery time is measured by the duration of the episode, $R_{ir} = t_{1,ir} - t_{0,ir}$, which corresponds to the number of rounds required for welfare to return to the recovery band; $t_{0,ir}$ is the first round in which welfare crosses the episode threshold, and $t_{1,ir}$ is the first subsequent round in which welfare returns to the recovery band. Cumulative adversity captures the total welfare loss accumulated during the episode, $CAL_{ir} = \sum_{t \in E_{ir}} (-\tilde{y}_{irt})$, which aggregates the welfare shortfalls across all rounds within the episode window. Since $\tilde{y}_{irt}$ is negative within the loss portion of the episode, the term $-\tilde{y}_{irt}$ converts each shortfall into a positive contribution to cumulative adversity Together, these quantities summarize three distinct dimensions of welfare resilience: the depth of the welfare decline, the time required for recovery, and the total welfare burden experienced during the scarcity episode.

4 Data

Table 1 describes the socioeconomic characteristics, farm structure, irrigation practices, and behavioral attributes of the 60 farmers who participated in the framed irrigation game experiments. The table shows that the participant group reflects a diverse yet realistic cross-section of actors within groundwater irrigation systems in northern Bangladesh. About 71.7% of participants identify as farmers only, meaning they rely on irrigation services but do not operate pumps, and their average age is 37 years. Only 3.4% report no schooling or literacy training, while 45.8% completed primary or secondary education, and 50.8% report post-secondary education. Although the sample includes farmers with limited formal education, the majority have moderate to relatively high levels of schooling, which may facilitate their comprehension of the experimental tasks and institutional rules presented in the irrigation game. Farmers also exhibit strong community embeddedness: Approximately 63.6% have resided in the community between 21 and 40 years, while another 29.1% report more than 40 years of residence.

Table 1: Sample characteristics (N = 60)

	N / %	Mean	SD	Median
Panel A: Farmer characteristics				
Farmer type: Farmer only	43 (71.7)			
Farmer type: Operator / other irrigation actors	17 (28.3)			
Education: No schooling / literacy	2 (3.4)			
Education: Primary–secondary	27 (45.8)			
Education: Post-secondary	30 (50.8)			
Age (years)	60	37.083	10.583	35.000
Community tenure: ≤20 years	4 (7.3)			
Community tenure: 21–40 years	35 (63.6)			
Community tenure: >40 years	16 (29.1)			
Farming as main activity (Yes)	54 (94.7)			
Panel B: Farm characteristics				
Land rights: Own land only	28 (46.7)			
Land rights: Leased / tenant	31 (51.7)			
Land rights: Other / mixed	1 (1.7)			
Farming experience: ≤10 years	17 (32.1)			
Farming experience: 11–20 years	21 (39.6)			
Farming experience: >20 years	15 (28.3)			
Weekly farming hours (hours/week)	56	35.036	17.183	35.000
Farm size: Small (≤4 acres)	51 (85.0)			
Farm size: Medium (4–10 acres)	5 (8.3)			
Farm size: Large (>10 acres)	4 (6.7)			
Panel C: Irrigation characteristics				
Irrigation cost: Low (≤10,000 BDT)	32 (53.3)			
Irrigation cost: Medium (10,000–30,000 BDT)	20 (33.3)			
Irrigation cost: High (>30,000 BDT)	8 (13.3)			
Panel D: Infrastructure and investment				
Maintenance cost: None	42 (70.0)			
Maintenance cost: Low (1–3,000 BDT)	11 (18.3)			
Maintenance cost: High (>3,000 BDT)	7 (11.7)			
Panel E: Behavioral traits				
Trust: Low	30 (50.0)			
Trust: Moderate	10 (16.7)			
Trust: High	20 (33.3)			
Collective norms: Weak	29 (48.3)			
Collective norms: Moderate	17 (28.3)			
Collective norms: Strong	14 (23.3)			

Notes: Descriptive statistics on farmers' socio-demographic characteristics are presented. BDT denotes Bangladeshi Taka, and one BDT is equivalent to 121 USD.

Approximately 46.7% cultivate only their own land, while 51.7% cultivate leased or tenant land. Farmers also possess substantial agricultural experience. About 39.6% have 11 to 20 years of farming experience, and 28.3% have more than 20 years. Approximately 85% operate small farms of four acres or less, while 8.3% cultivate medium farms between four and ten acres, and 6.7% operate larger farms exceeding ten acres. Farmers also display heterogeneous irrigation expenditure patterns and investment in irrigation infrastructure: About 53.3% report relatively low irrigation costs (≤10,000 BDT per year) and 70% report no maintenance expenditure. The distribution of behavioral traits related to cooperation and risk provides additional insight into the social context in which irrigation decisions take place. About 33.3% of farmers exhibit high trust, while 48.3% of participants fall into the group with weak collective norms. On average, farmers select 1.12 risky choices, indicating a risk-averse attitude of participating farmers in general.

Table 2: Descriptive statistics of behavioral outcomes by institutional rule

	Institutional rule											
	Rule 1: Sequential (no quota)				Rule 2: Sequential (crop quota)				Rule 3: Rotational (equal quota, audit & penalty)			
Variable	N	Mean	SD	Median	N	Mean	SD	Median	N	Mean	SD	Median
Contribution (in tokens)	600	6.3	2.4	6.0	600	6.2	2.3	6.0	600	.9	2.5	6.0
Extraction (in units)	600	12.9	8.8	11.5	600	11.5	5.8	12.0	600	12.2	8.9	12.0
Within-quota extraction (in units)	600	9.9	5.2	10.0	600	11.5	5.8	12.0	600	9.6	5.5	12.0
Over-extraction (in units)	600	3.0	5.8	0	600	0.0	0.2	0.0	600	2.5	5.9	0.0
Gross payoff	600	16.6	8.6	15.0	600	15.3	5.8	16.0	600	16.2	8.4	16.0
Net payoff (penalty-adjusted)	600	16.6	8.6	15.0	600	15.3	5.8	16.0	600	14.8	7.7	15.0
Water available before move (lag)	600	40.2	22.6	40.0	600	42.3	22.1	42.0	600	36.1	23.5	34.0
Peer over-extraction (lag)	600	41.7	21.7	40.6	600	4.7	15.3	0.0	600	30.7	19.2	30.0
No-water event (lag)	600	0.0	0.1	0.0	600	0.0	0.1	0.0	600	0.1	0.3	0.0

Notes: We report farmers' provision and appropriation behavior, together with their economic outcomes (income proxy), using key round-level mean variables across institutional rules. Contribution denotes tokens invested in the shared water fund, while extraction measures the amount of water appropriated during a farmer's extraction turn. Extraction is further decomposed into within-quota extraction, which captures rule-compliant appropriation, and over-extraction, which captures appropriation beyond the quota imposed by the institutional rule. Net payoff measures the farmer's economic return in a round after accounting for private savings, extraction benefits, and penalties for over-extraction under Rule 3. Lagged variables describe the inherited hydraulic and strategic environment, including the amount of water available before extraction, whether previous farmers over-extracted, and whether water had already been depleted or fallen below a usable level. We measure contribution, payoff, and penalty in terms of tokens and extraction and penalty in water units, where each unit of water yields one token of payoff (1 water unit = 1 token).

Table 2 reports round-level summary statistics for key variables, including farmers' provision decisions (contribution), appropriation behavior (extraction), rule compliance (within-quota and over-extraction), and economic outcomes (gross and net payoff), together with lagged hydraulic and strategic state variables inherited from the previous round of play. Overall, the descriptive statistics indicate that institutional rules significantly shape both appropriation behavior and economic outcomes.

Under Rule 1 (Sequential - no quota), farmers contribute on average about 6.3 tokens, while the average extraction is 12.9 units with a large standard deviation (8.8). In the absence of a compliance mechanism, the extraction remained unconstrained, resulting in an average over-extraction of about 3 units. Mean gross and net payoffs are both about 16.6 units. Among the hydraulic variables, moderate water availability is evident (≈40 units on average), and over-extraction by peers (earlier farmers in the group) occurs in 42% of instances, indicating opportunistic appropriation.

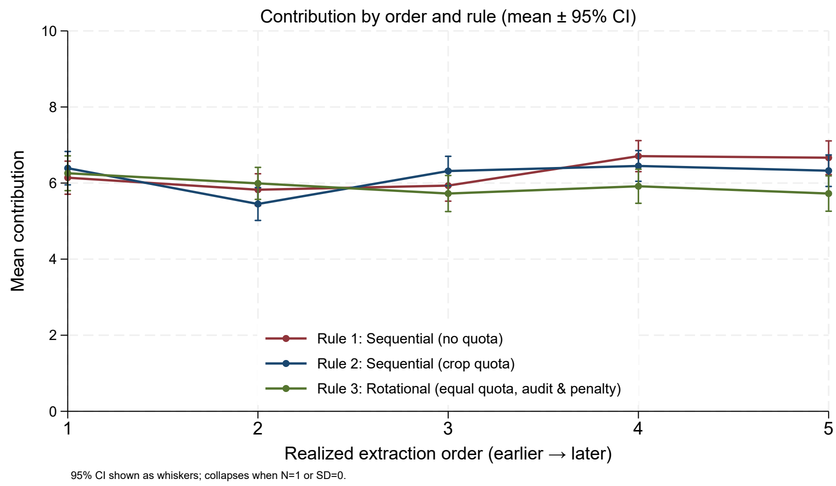
Under Rule 2 (Sequential - crop quota), average contributions remain similar (≈6.2 tokens); however, extraction declines to an average of 11.5 units following the imposition of the crop-based water quota, thereby constraining the tendency of over-extraction. This follows a slight reduction in the average payoffs (≈15.3 units) compared to Rule 1. In addition, we observe that the amount of remaining water at the farmer's extraction turn in the previous round improves slightly to ≈42 units, while reducing over-extraction by 5%.

Under Rule 3 (Rotational - equal quota with audit and penalty), we observe that extraction jumps to 12.2 units, despite a decline in the contribution of 5.9 tokens. While farmers appear less compliant with the extraction quota than under Rule 2, over-extraction persists despite audit enforcement, though the amount of excessive extraction is relatively lower (≈2.5 units on average) than under Rule 1. As a result, net payoff falls to 14.8 tokens. As a result, net payoff declines to about 14.8 tokens under the rotational rule. At the same time, the average water available before a farmer's turn falls to approximately 36 units, indicating stronger scarcity pressure within the round. Peer over-extraction occurs in approximately 31 % of observations, suggesting heterogeneous strategic responses to the enforcement of audit-induced penalties. Across all rules, however, complete water depletion events remain relatively infrequent.

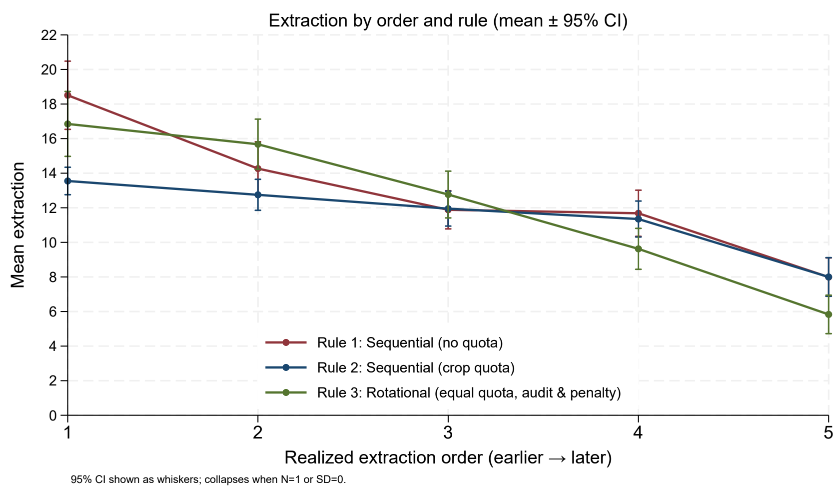
Figures presented in 3 illustrate how farmers' cooperative investment, water appropriation, and economic outcomes vary across the realized extraction order under the three institutional rules. The horizontal axis represents the extraction sequence within a round, moving from earlier (upstream) to later (downstream) farmers, while the vertical axis shows the round-level mean of each behavioral outcome. Overall, the patterns reflect institutional groundwater service arrangements in which farmers typically make limited investments in infrastructure maintenance and instead focus on short-run water extraction decisions. Institutional rules then shape these decisions either by constraining water appropriation or by redistributing water access across extraction positions.

In panel (a), the contribution graph shows that cooperative investment remains relatively stable across extraction positions and institutional rules. On average, farmers contribute about 6 tokens to the shared water fund regardless of whether they extract earlier or later in the sequence. The relatively small overlap in confidence intervals across positions suggests that positional asymmetry has only a limited effect on cooperative investment. This pattern is consistent with the descriptive statistics on farmer characteristics (Table 1), which show that farmers rarely invest in irrigation infrastructure or maintenance under groundwater service arrangements managed by providers such as BMDA or Solargao. Because irrigation infrastructure is typically managed by service providers rather than collectively by farmers, individual incentives to invest directly in maintenance remain limited. Consequently, willingness to contribute to the shared water fund does not vary strongly with the farmer's position in the extraction sequence.

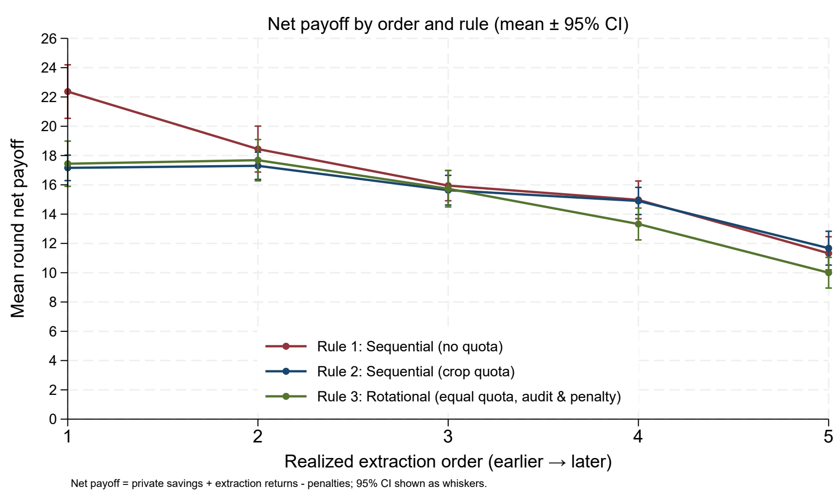
In contrast, the extraction graph in panel (b) reveals that extraction declines sharply from early to late players under the baseline sequential rule (Rule 1), indicating that upstream farmers



(a) Contribution by order and rule (mean ± 95% CI)



(b) Extraction by order and rule (mean ± 95% CI)



(c) Net payoff by order and rule (mean ± 95% CI)

Figure 3: Provision, appropriation, and economic outcomes by extraction order and institutional rule.

appropriate substantially more water than downstream users. This pattern reflects the physical dynamics of groundwater irrigation: pumping by earlier players lowers the water table and reduces the flow available to later users. The crop-based water quota rule (Rule 2) reduces extraction levels, particularly for early players, thereby weakening the positional differences, while the rotational rule (Rule 3) redistributes access across positions but still exhibits declining extraction for later players as scarcity accumulates within the round.

The net payoff graph, in panel (c), closely mirrors the extraction pattern. Farmers who extract early obtain higher payoffs under the sequential rule because they face fewer hydraulic constraints and can extract more water. As the extraction order moves downstream, net payoffs decline steadily. Institutional rules modify these outcomes differently. The crop-based water quota rule (Rule 2) mitigates positional asymmetry by limiting extraction to crop-specific water requirements, thereby constraining early players from appropriating disproportionately large amounts of water. In contrast, the rotational rule redistributes access across rounds by allowing farmers to cycle through extraction positions. However, because the quota is partly voluntary and not always binding, some players opportunistically extract more water than the suggested level, reducing the water available to subsequent farmers and lowering average payoffs for later positions.

Building on these descriptive patterns, Table 3 reports the mapping between the assigned extraction position and the realized extraction order under each institutional rule. Under Rules 1 and 2, extraction proceeds in a strict sequential order, so the assigned position uniquely determines the realized extraction turn. In contrast, Rule 3 introduces a rotational allocation mechanism that systematically shifts farmers across extraction positions. As a result, each assigned position is observed across multiple realized turns under Rule 3, with shares ranging between approximately 18% and 23%. This institutional shift weakens the deterministic relationship between assigned and realized orders, generating exogenous variation in extraction positions, which allows us to identify the causal effect of positional advantage on extraction behavior and economic outcomes.

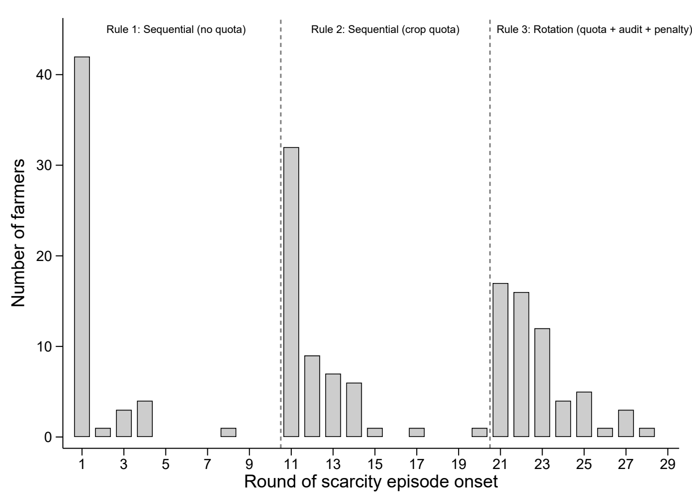


Figure 4: Distribution of scarcity episode

Table 3: Assigned position and realized extraction order by institutional rule

	Realized extraction order (player turn)				
Assigned position	1	2	3	4	5
Panel A: Rule 1 - Sequential (no quota)					
1	100.0	0.0	0.0	0.0	0.0
2	0.0	100.0	0.0	0.0	0.0
3	0.0	0.0	100.0	0.0	0.0
4	0.0	0.0	0.0	100.0	0.0
5	0.0	0.0	0.0	0.0	100.0
Panel B: Rule 2 - Sequential (crop quota)					
1	100.0	0.0	0.0	0.0	0.0
2	0.0	100.0	0.0	0.0	0.0
3	0.0	0.0	100.0	0.0	0.0
4	0.0	0.0	0.0	100.0	0.0
5	0.0	0.0	0.0	0.0	100.0
Panel C: Rule 3 - Rotational (equal quota, audit & penalty)					
1	23.3	18.3	20.0	20.0	18.3
2	18.3	20.0	20.0	18.3	23.3
3	20.0	20.0	18.3	23.3	18.3
4	20.0	18.3	23.3	18.3	20.0
5	18.3	23.3	18.3	20.0	20.0

Notes: We present the design-based variation used as an instrument, summarized by the percentage share of realized extraction turns conditional on the assigned extraction position across institutional rules. Under Rules 1 (Sequential - no quota) and 2 (Sequential - crop quota), resource appropriation follows a fixed sequential order, implying a deterministic mapping between assigned position and the realized extraction turn. Under Rule 3 (Rotational - equal quota with audit and penalty), the rotational allocation modifies this deterministic relationship so that each assigned position appears across multiple realized extraction turns.

Figure 4 shows the distribution of episode onset rounds across farmers. The distribution exhibits three distinct clusters corresponding to the institutional regimes of the irrigation game. A total of 42 farmers experience the onset of their first scarcity episode in round 1 under the baseline sequential rule. A second cluster appears at the transition to the crop quota regime, with 32 farmers experiencing onset in round 11. A third cluster emerges at the beginning of the rotation and audit regime, where 17, 16, and 12 farmers experience onset in rounds 21, 22, and 23, respectively. The presence of episodes across all institutional regimes and their clustering around regime transitions support the use of an event study framework to examine welfare dynamics in response to scarcity shocks.

Table 4: Scarcity episode timing and event time distribution

	Value
Panel A: Episode timing	
First episodes beginning in Rule 1 (count)	51.000
First episodes beginning in Rule 2 (count)	57.000
First episodes beginning in Rule 3 (count)	59.000
Panel B: Event time distribution	
Pre-onset observations (%)	10.615
Onset observations (%)	10.072
Recovery observations (%)	79.313
Number of event study observations	1658.000
Mean onset round	12.605
Median onset round	12.000

Notes: Panel A reports the timing of first scarcity episodes, where the onset round is defined as the first round in which the scarcity condition switches from zero to one. Rule 1 corresponds to rounds 1–10, Rule 2 to rounds 11–20, and Rule 3 to rounds 21–30. Counts refer to the number of farmers whose first observed scarcity episode begins under each institutional regime. Panel B reports the distribution of observations across event time. Pre-onset includes early, late, and immediate pre-onset periods; recovery includes early, mid, and late recovery periods following the onset of scarcity.

Table 4 reports the distribution of event time observations used in the event study analysis. In panel A, the distribution of onset across institutional regimes shows that 51 farmers experience their first episode under Rule 1 (rounds 1-10), 57 under Rule 2 (rounds 11-20), and 59 under Rule 3 (rounds 21-30). This relatively balanced distribution indicates that scarcity episodes arise under all institutional arrangements rather than being concentrated in a single regime. In panel B, the event study sample comprises 1,658 observations: approximately, 10.6% ($\equiv$ 176) of observations occur before the episode, 10.1% at the onset ($\equiv$ 167), and 79.3% ($\equiv$ 1,315) in the recovery phase. The presence of pre-onset observations allows us to assess the pre-trend dynamics, and the large number of post-onset observations provides sufficient variation to examine recovery patterns following scarcity shocks.

We also observe that the average payoff in the immediate pre-onset period is approximately 20 tokens, compared with an overall sample mean of 14.7 tokens. This difference reflects the welfare losses associated with scarcity episodes and subsequent recovery dynamics. Baseline welfare levels are broadly comparable across institutional regimes, with mean payoffs of approximately

21, 20, and 20 units under the sequential extraction, crop-quota, and rotation and audit with penalty rules, respectively.

5 Estimation strategy

This section describes our estimation strategy in two steps: First, we outline an instrumental variable strategy in Subsection 5.1 to causally identify the positional power effects and design an event study framework to assess the welfare dynamics around groundwater scarcity episodes in Subsction 5.2.

5.1 Identification of positional asymmetry

The central empirical question we investigate is whether extraction position causally affects farmers' welfare and behavioral outcomes. To identify this relationship, we estimate an instrumental variables strategy that exploits two sources of exogenous variation: the random assignment of extraction order and the institutional rule mediating whether that assignment confers effective positional power.

Let the outcome variable Y_{it} represent either an economic welfare outcome or a behavioral outcome of farmer i in t rounds. Welfare is measured by the farmer's penalty-adjusted payoff π_{it}, which includes the private residual from contributions $(e - c_{it})$ and the realized return from water extraction x_{it} net of any rule-specific penalties. Behavioral outcomes capture farmers' extraction decisions, x_{it}.

Each farmer is assigned a baseline extraction position k_i at the start of the experiment, which remains fixed throughout the session. The endogenous regressor is the farmer's realized extraction position, denoted k_{it}, which determines when the farmer accesses the shared water stock in round t. Earlier positions correspond to lower values of k_{it}, thus providing greater access to available water, whereas later positions correspond to tighter water availability conditions. Institutional rules determine whether and how this assigned order maps into the realized extraction position. In particular, while Rules 1 and 2 largely preserve the sequential mapping between assigned and realized positions, Rule 3 rotates extraction order across rounds, causing farmers to experience different positions over time.

We specify the first-stage equation 1 to capture this institution-specific translation of assignment into positional power,

$$k_{it} = \pi_0 + \pi_1 k_i + \pi_2(k_i \times R2_t) + \pi_3(k_i \times R3_t) + \theta' C_{i,t-1} + \alpha_i + \lambda_t + v_{it}, \tag{1}$$

where $R2_t$ and $R3_t$ indicate institutional Rules 2 and 3 (Rule 1 is the baseline). The vector $C_{i,t-1}$ contains lagged prevailing extraction conditions from the previous round: water availability at arrival, $W^{pre}_{i,t-1}$, peer over-extraction, $PeerOver_{i,t-1}$, and complete exhaustion of the water stock, $NoWater_{i,t-1}$. We include lagged controls so that they remain predetermined with respect to the current round's extraction position and payoff.

The coefficient π_1 captures the mapping between assigned position and realized extraction position under the baseline institutional rule (Rule 1). Because the baseline regime preserves sequential access, we expect $\pi_1 > 0$ and to be close to one. The coefficient π_2 measures how this mapping changes under Rule 2; since the crop-based quota rule preserves sequential extraction order, we expect π_2 to be small. The coefficient π_3 captures the change under Rule 3; the rotation rule weakens the assignment–position mapping, we expect π_3 to offset most or all of the baseline effect, implying that assignment has little remaining predictive power under the rotational regime.

The second-stage equation relates realized extraction position to outcomes:

$$Y_{it} = \beta k_{it} + \gamma' C_{i,t-1} + \alpha_i + \lambda_t + \varepsilon_{it}. \tag{2}$$

The endogenous variable k_{it} is instrumented using the excluded instrument set $\{k_i,\ k_i \times R2_t,\ k_i \times R3_t\}$. The coefficient β measures the causal effect of realized extraction position on outcomes. As higher values of k_{it} correspond to later extraction positions, we expect $\beta < 0$ for welfare outcomes: farmers who extract later earn lower payoffs because they face limited access to the water stock and a higher probability of experiencing scarcity. For behavioral outcomes, the coefficient captures how extraction decisions respond to positional scarcity. If the outcome is total extraction x_{it}, the sign of β may be negative if later positions simply face tighter water availability and therefore extract less. If the outcome is within-quota extraction $\min(x_{it}, q_{it})$, we also expect a negative sign if later movers are less able to secure water within the rule-based limit. If the outcome is over-extraction OE_{it}, the sign is theoretically ambiguous in the general specification: downstream farmers may over-extract less because little water remains, or they may over-extract more if scarcity increases incentives to violate rules.

The coefficient on lagged water availability at arrival, $W^{pre}_{i,t-1}$, is expected to be weakly positive in payoff regressions because having recently experienced greater water availability may improve expectations, reduce stress, and indicate persistence in favorable extraction conditions. In behavioral regressions, higher lagged water availability may also be associated with less defensive or opportunistic extraction. The coefficient on lagged peer over-extraction, $PeerOver_{i,t-1}$, is expected to be weakly negative in payoff regressions and weakly positive in opportunistic behavioral regressions, since observing greater peer rule-breaking may signal a less cooperative environment and encourage strategic competition. The coefficient on lagged exhaustion, $NoWater_{i,t-1}$, is expected to be negative in payoff regressions because having recently encountered complete depletion reflects persistent scarcity and may lower current expected returns. For behavioral outcomes, it may either suppress extraction because farmers anticipate scarcity or encourage opportunistic extraction as a protective response.

Farmer fixed effects α_i absorb time-invariant individual characteristics such as aggressiveness, extraction skill, competitiveness, or rule-following tendencies. Round fixed effects λ_t absorb common round-specific influences, including learning, fatigue, and other shocks shared by all farmers in a given round. The identification variation, thus, comes from within-farmer variation in realized extraction position across rounds.

Standard errors are clustered at the irrigation-group level; farmers within the same irrigation group share a common water stock and face interdependent extraction opportunities, and shocks to outcomes are correlated within groups. Given the relatively small number of clusters, inference is complemented by weak-instrument-robust procedures and wild-cluster bootstrap methods.

The IV strategy identifies a local average treatment effect for farmers whose realized extraction position responds to the assigned order under institutional regimes in which positional power remains operative Under the following assumptions:

The relevance condition requires that the excluded instruments predict realized extraction position after conditioning on fixed effects and lagged controls. In this setting, relevance is guaranteed by the experimental design under institutional regimes that preserve positional power. When the extraction order is sequential (Rules 1 and 2), the assigned position strongly predicts the realized extraction position. Under the rotational regime (Rule 3), this mapping is weakened. Interacting the assigned position with rule indicators, therefore, captures institution-specific variation in the strength of this relationship.

The exclusion restriction requires that the assigned extraction position affect outcomes only through the realized extraction position. The assigned order has no direct economic meaning in the game: it does not affect water production, crop requirements, monitoring, or penalties. Its only consequence is to determine when a farmer accesses the shared water stock. Conditional on farmer fixed effects, round fixed effects, and lagged prevailing extraction conditions, the instrument therefore affects outcomes only through realized extraction position.

Monotonicity requires that being assigned later does not systematically cause a farmer to extract earlier. In the current setting, this assumption is natural. Institutional rules may preserve, weaken, or sever the mapping between assigned and realized positions, but they do not systematically reverse it. In particular, Rule 3 reduces the relevance of assignment through rotation, but it does not create systematic defiers who extract earlier when assigned later.

Taken together, the random assignment of extraction order, the institutional variation that governs how assignment maps into realized extraction position, and the inclusion of farmer and round fixed effects provide a credible source of exogenous variation in positional power. The instrumental-variables specification identifies the causal effect of realized extraction position k_{it} on farmers' economic welfare and behavioral outcomes. In other words, the randomly assigned extraction order is orthogonal to unobserved determinants of payoff, conditional on farmer fixed effects, round fixed effects, and lagged prevailing extraction conditions, and the estimates isolate how outcomes change when the same farmer extracts earlier or later in the sequence, solely due to the institutional translation of assigned order into realized positional power.

5.2 Event study design for welfare resilience

To evaluate how institutional rules shape the resilience of economic welfare to scarcity shocks, we estimate a fixed-effects event study specification that traces farmers' welfare dynamics around the onset of scarcity episodes. The key empirical question is whether, for the same farmer, welfare evolves differently before and after a scarcity shock depending on the institutional rule governing irrigation decisions.

Scarcity episodes are first identified within farmer-rule blocks as described in Section 3.2. In particular, for each farmer i operating under institutional rule r, the onset round $t_{0,ir}$ is defined as the first round in which normalized welfare falls below the episode threshold. Once the onset round has been determined, we construct an event time index relative to this onset round and retain round-level observations surrounding the episode window. This transformation aligns episodes that begin in different experimental rounds across farmers and institutional regimes onto a common timeline centered on the onset of the scarcity shock, thereby allowing welfare trajectories to be compared at the same episode stage.

Event time is defined as $\tau_{it} = t - t_{0,ir}$, which measures the number of rounds before or after the onset of the welfare shock. We group event time into economically meaningful phases, capturing distinct stages of shock dynamics. Specifically, we define the following bins: early pre-onset (-5 to -3), late pre-onset (-2), immediate pre-onset (-1), onset (0), early recovery (1â€"2), mid recovery (3-5), and late recovery (6-9). Let $1(\tau_{it} = k)$ denote an indicator for event time bin ℓ. The immediate pre-onset period ($\tau = -1$) is omitted and serves as the reference category.

The estimating equation is

$$\tilde{y}_{it} = \sum_{\ell \neq -1} \beta_\ell \, 1(\tau_{it} = \ell) + \sum_{\ell \neq -1} \gamma_\ell \, 1(\tau_{it} = \ell) \times Rule_{it} + \alpha_i + \lambda_t + \theta' C_{i,t-1} + \varepsilon_{it}, \tag{3}$$

where, $\tilde{y}_{it}$ denotes the deviation of realized welfare from the farmer-specific baseline level defined prior to the episode.

The coefficients β_ℓ trace the baseline welfare trajectory around scarcity shocks under the omitted institutional regime (Rule 1). Each β_ℓ measures the average change in welfare in event time phase ℓ relative to the immediate pre-onset period. In particular, the coefficient associated with the onset bin reflects the immediate welfare loss when the scarcity shock occurs, while coefficients corresponding to recovery phases describe how welfare evolves in subsequent rounds.

Institutional differences in these dynamics are captured by the interaction coefficients γ_ℓ. The variable $Rule_{it}$ indicates the institutional regime governing irrigation decisions in round t. Because the experimental design follows a cross-over structure in which each farmer experiences all institutional regimes sequentially, this rule indicator varies within a farmer over time. The interaction coefficients γ_ℓ, therefore, measure how the welfare trajectory under each institutional rule differs from the baseline sequential regime at event time phase ℓ. Positive values of γ_ℓ in recovery phases indicate that the institutional rule mitigates persistent welfare losses, whereas negative values at onset indicate larger immediate welfare declines relative to the baseline regime.

The specification includes farmer fixed effects α_i and round fixed effects λ_t. Farmer fixed effects absorb all time-invariant farmer characteristics, including extraction ability, risk preferences, cooperative norms, and baseline productivity. Because each farmer experiences multiple institutional regimes, treatment effects are identified from within-farmer variation over time. Round fixed effects capture shocks common to all farmers in a given round, including aggregate scarcity conditions, learning effects, or fatigue during the experiment.

The vector $C_{i,t-1}$ summarizes lagged prevailing extraction conditions inherited from the previous round. These include the amount of water remaining before the farmer's extraction, peer over-extraction in the previous round, and an indicator for complete water exhaustion in the previous round. These lagged variables capture the inherited scarcity and behavioral environment at the start of the current round and help isolate institutional effects from resource conditions that might otherwise confound the interpretation of welfare dynamics. The coefficient vector θ measures the marginal association between these inherited conditions and current welfare deviations.

The residual term ε_{it} captures unexplained idiosyncratic variation in welfare outcomes. Standard errors are clustered at the irrigation-group level; farmers operate within irrigation groups, and decisions within groups may be correlated. We use wild cluster bootstrap procedures for inference, given the relatively small number of clusters.

Identification of institutional effects relies on a parallel pre-trend assumption. The underlying assumption is that in the absence of institutional differences, farmers' welfare trajectories around scarcity episodes would evolve similarly across institutional rules in the periods preceding the shock. In other words, conditional on farmer fixed effects, round fixed effects, and lagged extraction conditions, the timing of welfare deviations relative to the episode onset should not systematically differ across institutional regimes before the scarcity shock occurs.

Formally, the event study specification assumes that for pre-onset event time phases $\ell < 0$, the interaction coefficients satisfy $\gamma_\ell = 0$. This condition implies that welfare trajectories across institutional rules follow the same path prior to the onset of the scarcity episode. Under this assumption, differences in welfare dynamics observed after the onset can be interpreted as causal effects of institutional rules on farmers' resilience to scarcity shocks. The identifying variation, therefore, arises from within-farmer comparisons of welfare trajectories across institutional regimes. The experimental design follows a cross-over structure in which each farmer is sequentially exposed to all institutional rules. As a result, the estimation exploits changes in the institutional regime experienced by the same farmer over time.

We assess the plausibility of the parallel pre-trend assumption by testing whether the interaction coefficients associated with the pre-onset bins are jointly equal to zero. We fail to reject this hypothesis, indicating that welfare trajectories across rules do not differ systematically prior to the shock and supporting the validity of the identification strategy. By contrast, significant coefficients in post-onset bins indicate that institutional rules alter the magnitude or persistence of welfare losses following scarcity episodes. Together, these tests allow the event study specification to distinguish institutional effects on welfare dynamics from pre-existing differences in farmer behavior or resource conditions.

6 Results and discussion

6.1 Instrumental variable estimates

The results of the instrumental variable estimation, which investigates the causal effect of positional power on welfare and behavioral outcomes specified in equations 1 and 2, are presented in Table 5. In columns (1) and (3), we provide evidence on how positional power operates in the irrigation game. The first-stage results confirm that the experimental assignment strongly predicts realized extraction position. Under the baseline sequential regime (Rule 1), the coefficient on assigned position is close to one and statistically significant. This indicates that the assigned extraction order almost perfectly determines the realized extraction position. To illustrate, consider a farmer who is assigned position $k_i = 2$ in the extraction sequence. Under Rule 1, the estimated coefficient implies that the farmer's realized extraction order is also approximately two. In other words, the institutional rule preserves the original assignment: farmers extract water in the order in which they were initially placed.

Table 5: Instrumental variables estimates: the effect of positional power

	Welfare (net payoff)				Extraction behavioral			
	First stage (1)		Second stage (2)		First stage outcome (3)		Second stage (4)	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Assigned position	1.021***	(0.008)			1.021***	(0.008)		
Assigned position × Rule 2	-0.000	(0.002)			-0.000	(0.002)		
Assigned position × Rule 3	-1.011***	(0.007)			-1.011***	(0.007)		
Realized extraction position			-1.938***	(0.459)			-2.108**	(0.546)
Lagged prevailing extraction conditions								
Water at arrival (lag)	0.002***	(0.001)	-0.014	(0.013)	0.002**	(0.001)	-0.026	(0.013)
Peer over-extraction (lag)	0.001	(0.001)	-0.037*	(0.018)	0.001	(0.001)	-0.044*	(0.020)
No water exposure (lag)	0.027	(0.204)	-2.543	(1.546)	0.027	(0.204)	-4.474*	(1.605)
Estimation statistics								
Observations	1740		1740		1740		1740	
Farmer FE	Yes		Yes		Yes		Yes	
Round FE	Yes		Yes		Yes		Yes	
SE clustered at irrigation group	Yes		Yes		Yes		Yes	
Kleibergen–Paap rk Wald F			13312.371				13312.371	
Underidentification test (p)			0.011				0.011	
Anderson–Rubin test (p)			0.003				0.004	
Wild cluster bootstrap p (Position)			0.004				0.007	

Notes: Columns (1) and (3) report the first-stage regression where realized extraction position is regressed on assigned extraction position and its interactions with institutional rules. Columns (2) and (4) report the second-stage instrumental variables estimate of the effect of realized extraction position on farmers' welfare (net payoff) and extraction behavior. Water at arrival (lag) corresponds to $W^{pre}_{i,t-1}$, measuring the water remaining when the farmer arrived to extract in the previous round. Peer over-extraction (lag) corresponds to $PeerOver_{i,t-1}$, capturing over-extraction by other farmers in the previous round. No water exposure (lag), $NoWater_{i,t-1}$, equals one when the irrigation pool was already exhausted when the farmer arrived to extract in the previous round. Standard errors are clustered at the irrigation-group level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Wild cluster bootstrap p-values use Webb weights with 9,999 replications.

The interaction terms show how institutional rules modify this relationship. The coefficient on the interaction between assigned position and Rule 2 is essentially zero, indicating that the crop-based water quota rule does not materially alter the mapping between assigned and realized positions. In other words, even though farmers choose crops with different water requirements, such as high-yielding rice varieties or hybrid rice varieties, the irrigation sequence still follows the original order. For example, a farmer assigned to position three will still extract water roughly third in the sequence.

In contrast, the interaction with Rule 3 is large and negative, nearly offsetting the baseline effect. Because the baseline coefficient is approximately one, the interaction coefficient of about

-1 implies that the relationship between assigned and realized position essentially disappears under the rotation rule. To illustrate, a farmer assigned position two may extract first in one round, third in another, and fifth in another, depending on the rotation schedule. The institutional rule, therefore, breaks the deterministic link between assigned position and realized extraction order by systematically rotating farmers across positions over rounds.

Taken together, these results confirm that the experimental design generates exogenous variation in realized extraction position. While assignment determines extraction order under Rules 1 and 2, the rotational mechanism under Rule 3 disrupts this relationship, allowing the analysis to isolate how positional power affects welfare outcomes.

The second-stage estimates on the welfare outcome, expressed as net payoff (penalty adjusted), are presented in column (2). We observe that a substantial welfare cost is associated with extracting later in the sequence. The coefficient on realized extraction position is negative and statistically significant at the 1% level, indicating that farmers who extract later receive lower payoffs. That is, moving one position later in the extraction sequence reduces net payoff by approximately 1.94 tokens on average. This result provides direct evidence that positional asymmetry in sequential irrigation schemes generates economically meaningful welfare losses.

This lower economic return is presumably consistent with the fact that positional power also affects how much water farmers can extract, as presented in column (4). The coefficient on realized extraction position is negative and statistically significant at the 5% significance level, indicating that farmers who extract later in the sequence appropriate less water on average. In other words, moving one position later in the extraction order reduces total extraction by approximately 2.1 water units, reflecting the tighter water constraints faced by downstream farmers once upstream farmers have already appropriated part of the shared stock.

To illustrate, consider two farmers located at different positions in the extraction sequence. A farmer extracting in the first position faces the full water stock available to the group, whereas a farmer extracting in the fourth or fifth position arrives after several upstream withdrawals have already occurred. Even if both farmers behave similarly, the downstream farmer experiences a smaller remaining water stock and therefore extracts less on average, resulting in fewer feasible extraction opportunities.

In addition, decomposing total extraction into within-quota and excess extraction in the Appendix Table A1, we observe that most of the reduction occurs through lower within-quota water extraction. This indicates that farmers primarily respond to positional scarcity by adjusting extraction within the institutional limits, either the crop-based water requirements under Rule 2 or the (non-binding) equal quota under Rule 3, rather than by increasing excess extraction.

The lagged control variables capture the resource environment experienced from the previous round. Higher peer over-extraction in the previous round is associated with slightly lower extraction in the current round, indicating that exposure to opportunistic behavior may induce more cautious appropriation in subsequent rounds. The indicator for a no-water event in the previous round is associated with substantially lower extraction in the current round, consistent with persistent scarcity conditions following extreme depletion.

Instrument diagnostics confirm the validity of the identification strategy. The Kleibergen-Paap rk Wald F statistic is extremely large, indicating that the instrument is strong. The underidentification test rejects the null that the model is unidentified, and the Anderson-Rubin test confirms the statistical significance of the positional effect even under weak-instrument robust inference. In addition, wild cluster bootstrap inference, given the small number of irrigation groups, yields p-values of 0.004 and 0.007 for the positional coefficients, reinforcing the robustness of the results.

Taken together, these findings demonstrate that positional power plays a central role in determining economic and behavioral outcomes in sequential irrigation regimes. Institutional rules that modify the relationship between assigned and realized extraction order therefore have the potential to reshape the distribution of welfare across farmers by altering the extent to which positional advantages persist. The evident behavioral patterns also indicate that positional asymmetry generates welfare inequality mainly through differential access to water rather than through systematic differences in compliance behavior.

To illustrate this mechanism in a real-world groundwater irrigation context, the assigned extraction position in the experiment can be interpreted as analogous to the physical location of a farmer's field relative to the pump outlet or main distribution pipe. This location is largely predetermined and exogenous from the farmer's perspective, as we have assigned farmers to positions randomly in the experiment. The realized extraction order, in contrast, corresponds to the actual irrigation sequence through which farmers receive water during a given irrigation cycle.

In practice, this sequence is often determined by water allocation rules or schedules administered by pump operators, irrigation committees, or informal agreements among farmers. Although a farmer's physical location may influence when water arrives, institutional arrangements, such as rotational irrigation schedules, crop-based water quotas, or monitoring and enforcement mechanisms, can modify the order in which farmers access water. In this sense, the realized extraction order captures the effective positional power that farmers hold over water access within shared irrigation schemes. Therefore, institutions that introduce rotational irrigation schedules, enforce equitable water quotas, or strengthen monitoring and compliance mechanisms may reduce the welfare disadvantages faced by downstream farmers in shared groundwater irrigation schemes. At the same time, these findings highlight how irrigation governance, rather than physical geography alone, can determine which farmers benefit from shared groundwater resources.

6.2 Event study estimates

We now examine how farmers' welfare evolves before and after scarcity episodes and whether these dynamics differ across institutional regimes. The event study specification traces welfare deviations relative to the immediate pre-onset period ($\tau = -1$), which serves as the reference phase in the regression. In the estimation sample, the average payoff in this baseline period is approximately 20 tokens per round. All coefficients, therefore, measure changes in welfare relative to this benchmark.

Results are presented in Table 6. We first examine the trajectory of welfare in the periods preceding the onset of scarcity. Under the baseline sequential regime (Rule 1), the coefficients for early and late pre-onset phases are positive but statistically insignificant (Early pre-onset: 4.21, $p = 0.15$; Late pre-onset: 1.41, $p = 0.61$). These estimates indicate that welfare in the periods leading up to the shock does not differ significantly from the immediate pre-onset round. In economic terms, payoff levels remain statistically stable prior to the scarcity episode.

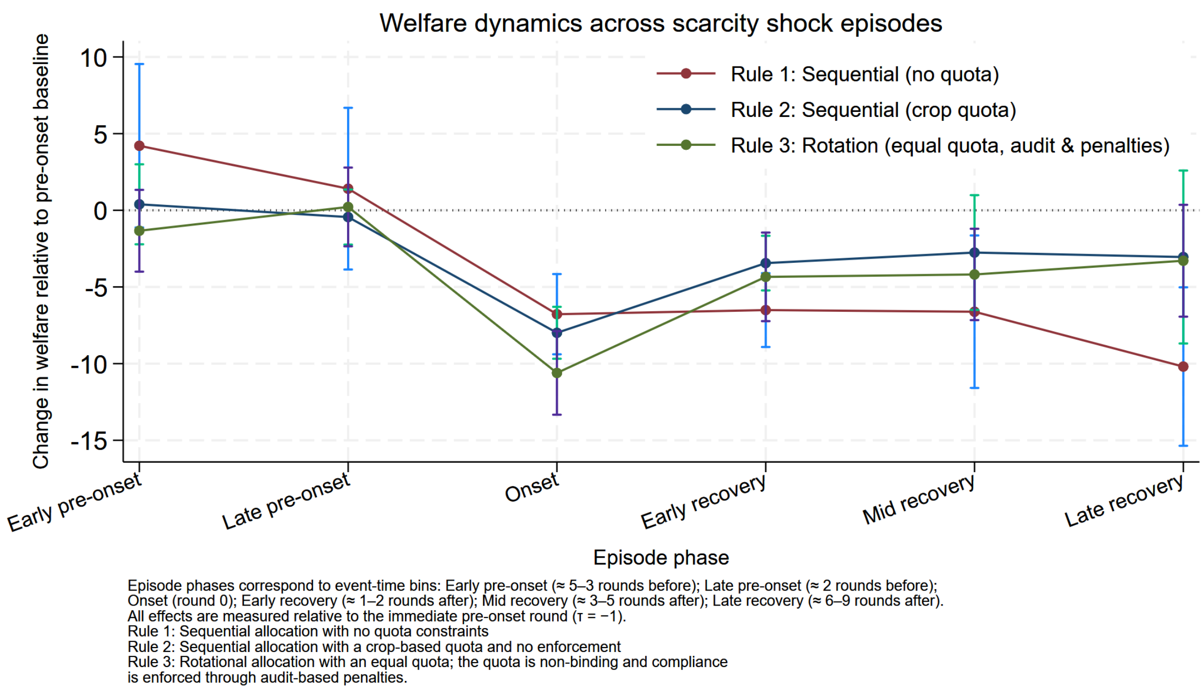


Figure 5: Welfare dynamics around scarcity episodes by institutional rule

Notes: The figure plots changes in welfare relative to the immediate pre-onset period ($\tau = -1$) across event time bins. Episode phases correspond to early and late pre-onset, onset ($\tau = 0$), and early, mid, and late recovery periods. Error bars represent 95% confidence intervals. Rule 1 denotes sequential allocation without quotas, Rule 2 introduces a crop-based quota, and Rule 3 implements rotation with audit-based penalty enforcement.

The interaction coefficients for Rule 2 and Rule 3 in these pre-onset phases are also statistically insignificant. Early and late pre-onset interactions with Rule 2 are small and imprecisely estimated, and the corresponding interactions with Rule 3 likewise show no systematic difference. Wild cluster bootstrap joint tests reinforce this fact; for Rule 2, the joint null that pre-onset interaction coefficients equal zero cannot be rejected ($F(2, 11) = 1.33$, $p = 0.56$), and the same is true for Rule 3 ($F(2, 11) = 1.75$, $p = 0.44$). In other words, welfare trajectories across institutional regimes evolve similarly before scarcity shocks occur. The absence of differential pre-trends supports the validity of the event study design and the interpretation of post-onset differences as causal institutional effects.

We next consider the baseline welfare trajectory under the sequential extraction regime (Rule 1). The event time coefficients reveal a sharp and persistent decline in welfare once scarcity begins. At the onset of the episode, payoff falls by approximately 6.78 tokens relative to the immediate pre-onset period ($p < 0.001$). Given the baseline payoff of roughly 20 tokens, this corresponds to a decline of about 34% of typical welfare. Welfare remains significantly below the pre-shock level in early recovery (-6.51, $p < 0.001$) and mid recovery (-6.61, $p = 0.024$). Even

Table 6: Event study estimates of welfare dynamics around scarcity episodes

	Welfare deviation					
	Rule 1: Sequential (no quota) (1)		Rule 2: Sequential (crop quota) (2)		Rule 3: Rotational (equal quota, audit, penalty) (3)	
	Coef.	SE	Coef.	SE	Coef.	SE
Pre-onset phases						
Early pre-onset	4.210	(2.719)				
Late pre-onset	1.412	(2.690)				
Onset and recovery phases (Rule 1 baseline)						
Onset	-6.775***	(1.335)				
Early recovery	-6.507***	(1.228)				
Mid recovery	-6.614**	(2.537)				
Late recovery	-10.190***	(2.636)				
Institutional differences: Rule 2 vs Rule 1						
Early pre-onset × Rule 2			-3.820	(2.778)		
Late pre-onset × Rule 2			-1.852	(2.847)		
Onset × Rule 2			-1.213	(1.460)		
Early recovery × Rule 2			3.063**	(1.156)		
Mid recovery × Rule 2			3.859	(2.754)		
Late recovery × Rule 2			7.144**	(2.902)		
Institutional differences: Rule 3 vs Rule 1						
Early pre-onset × Rule 3					-5.544*	(3.039)
Late pre-onset × Rule 3					-1.193	(3.031)
Onset × Rule 3					-3.830	(2.439)
Early recovery × Rule 3					2.167	(1.934)
Mid recovery × Rule 3					2.431	(3.613)
Late recovery × Rule 3					6.901*	(3.650)
Lagged prevailing extraction conditions						
Lagged water remaining					-0.007	(0.011)
Lagged peer over-extraction					-0.043**	(0.015)
Lagged no-water					-1.762	(1.433)
Estimation statistics						
Observations				1658		
Clusters				12		
Farmer FE				Yes		
Round FE				Yes		

Notes: The dependent variable is the deviation of welfare from the farmer-rule baseline. Event time is measured relative to the onset of a scarcity episode. The omitted category is the immediate pre-onset phase ($\tau = -1$). In the event study estimation, we include farmer and round fixed effects. We present coefficients, representing deviations relative to this baseline period, in separate columns across rules for better readability. Standard errors clustered at the irrigation-group level are reported in parentheses. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

several rounds after the shock begins, payoff remains roughly 6–7 tokens below the baseline, indicating that farmers do not recover quickly from the scarcity episode. The pattern becomes even more pronounced in late recovery. The coefficient for the late recovery phase is -10.19 ($p = 0.003$), implying that welfare declines to roughly 10 tokens below the pre-shock level. Relative to the baseline welfare of approximately 20 tokens, this represents a loss of roughly half of the typical payoff. Taken together, these results indicate that under the unregulated sequential extraction rule, scarcity shocks generate persistent welfare losses that deepen rather than dissipate over time.

The interaction terms reveal how alternative institutional rules reshape this welfare trajectory. Under the crop quota regime (Rule 2), the onset effect is not statistically different from the baseline rule, indicating that the initial scarcity shock remains substantial. However, the recovery phases diverge significantly from the baseline path. In early recovery, the interaction coefficient is positive and statistically significant ($+3.06$, $p = 0.023$), indicating that welfare is roughly three tokens higher than under the baseline rule. The improvement becomes even larger in late recovery ($+7.14$, $p = 0.032$).

This magnitude is economically meaningful. Under the baseline rule, late recovery welfare is approximately 10 tokens below the pre-shock level. The Rule 2 interaction offsets roughly seven tokens of this loss, implying that welfare in late recovery under the quota regime is only about three tokens below baseline. The joint bootstrap test across all post-onset bins strongly rejects the null of no difference relative to the baseline regime ($F(4, 11) = 21.39$, $p = 0.003$). These results indicate that the quota rule significantly reduces the persistence of welfare losses.

The rotation and audit with penalty regime (Rule 3) exhibits a similar but somewhat weaker pattern. The onset interaction is negative but statistically insignificant (-3.83, $p = 0.145$), suggesting that the immediate adjustment may be somewhat sharper under stricter extraction constraints. However, welfare improves relative to the baseline in later phases. In the late recovery period, the interaction coefficient is positive ($+6.90$) and marginally significant ($p = 0.085$). This implies that the rotation regime offsets nearly seven tokens of the baseline welfare loss, producing a late-recovery welfare level that is roughly three tokens below baseline rather than ten tokens below. The joint bootstrap test across post-onset bins rejects the null of no institutional difference ($F(4, 11) = 9.61$, $p = 0.017$), confirming that the rotation rule significantly alters post-shock welfare dynamics.

The lagged control variables capture the resource and behavioral environment inherited from the previous round. Among these controls, lagged peer over-extraction is negative and statistically significant (-0.043, $p = 0.015$). This result indicates that opportunistic extraction by peers in the previous round reduces subsequent welfare outcomes. In economic terms, strategic over-extraction by other farmers amplifies scarcity conditions and worsens income outcomes for the group.

7 Robustness exercise

In our experiment, all groups are exposed to the three institutional regimes in the same sequence. As a result, the estimated rule effects may, in principle, reflect not only institutional differences but also common period effects such as learning, fatigue, adaptation, or behavioral carryover across blocks. To assess the extent to which the main findings are sensitive to this fixed sequencing, we implement two complementary robustness exercises. First, we re-estimate the baseline specifications after excluding the first two rounds following each institutional transition (rounds 11–12 and 21–22), where short-run adjustment to new rules is most likely to occur. Second, we augment the specifications by allowing for rule-specific within-block trends, thereby capturing smooth behavioral evolution within each institutional regime.

We begin by assessing whether the estimated effects of realized extraction position are driven by short-run adjustment or gradual behavioral change within institutional blocks. In the first robustness check, we re-estimate the baseline IV specification in equation 5 on a restricted sample that excludes the immediate post-transition rounds. This ensures that the estimated positional effects are not driven by transitional dynamics following rule changes.

In the second robustness check, we allow for flexible within-block behavioral evolution by replacing round fixed effects with rule-specific within-block trends. Let $b(t) \in \{1, \ldots, 10\}$ denote the round index within each rule block, such that $b(t) = 1$ corresponds to the first round and $b(t) = 10$ to the last round within a block. The first-stage specification becomes

$$k_{it} = \pi_0 + \pi_1 Z_{1i} + \pi_2 Z_{2it} + \pi_3 Z_{3it} + \theta' C_{i,t-1} + \alpha_i + \sum_{r=1}^{3} \rho_r \, \mathbf{1}(R_{it} = r) + \sum_{r=1}^{3} \delta_r \, \mathbf{1}(R_{it} = r) \, b(t) + v_{it}, \quad (4)$$

where k_{it} denotes realized extraction position, Z_{1i} is assigned position, and Z_{2it} and Z_{3it} are rule-specific instrument interactions. The vector $C_{i,t-1}$ captures lagged prevailing extraction conditions, α_i denotes farmer fixed effects, and $\mathbf{1}(R_{it} = r)$ indicates the institutional regime. The coefficients ρ_r capture rule-specific intercepts, while δ_r allow behavior to evolve smoothly within each rule block.

The corresponding second-stage specification is

$$Y_{it} = \beta \widehat{k}_{it} + \gamma' C_{i,t-1} + \alpha_i + \sum_{r=1}^{3} \rho_r \, \mathbf{1}(R_{it} = r) + \sum_{r=1}^{3} \delta_r \, \mathbf{1}(R_{it} = r) \, b(t) + \varepsilon_{it}, \quad (5)$$

where Y_{it} denotes the outcome of interest, including payoff and extraction outcomes. This specification allows each institutional regime to have its own within-block time profile, thereby absorbing smooth learning or adaptation effects.

We apply the same logic to the event study analysis of welfare dynamics. First, we re-estimate the event study specification after excluding the immediate post-transition rounds to ensure that the estimated welfare trajectories are not driven by short-run adjustment. Second, we augment the specification with rule-specific within-block trends, allowing welfare to evolve smoothly within each institutional regime.

Formally, the robustness specification is given by

$$\tilde{y}_{it} = \sum_{\ell \neq -1} \beta_\ell \mathbf{1}(\tau_{it} = \ell) + \sum_{\ell \neq -1} \gamma_\ell \mathbf{1}(\tau_{it} = \ell) \times \mathbf{1}(R_{it} = r) + \theta' C_{i,t-1} + \alpha_i + \sum_{r=1}^{3} \rho_r \mathbf{1}(R_{it} = r) + \sum_{r=1}^{3} \delta_r \mathbf{1}(R_{it} = r)\, b(t) + \varepsilon_{it} \tag{6}$$

where $\tilde{y}_{it}$ denotes normalized welfare and τ_{it} is event time. The coefficients β_ℓ trace the baseline welfare trajectory, while γ_ℓ capture how institutional rules modify this trajectory.

Table 7: Robustness checks: the effect of positional power (second stage)

	Welfare (net payoff)				Extraction behavioral			
	Excluding transition rounds (1)		Within-block trend (2)		Excluding transition rounds (3)		Within-block trend (4)	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Realized extraction position	-1.897***	(0.482)	-1.963***	(0.459)	-2.087***	(0.547)	-2.118**	(0.552)
Lagged prevailing extraction conditions								
Water at arrival (lag)	-0.014	(0.014)	-0.014	(0.016)	-0.027*	(0.013)	-0.026**	(0.012)
Peer over-extraction (lag)	-0.042*	(0.021)	-0.030**	(0.013)	-0.046*	(0.021)	-0.037**	(0.013)
No water exposure (lag)	-2.523	(1.517)	-2.651	(1.575)	-4.471**	(1.592)	-4.648**	(1.575)
Estimation statistics								
Observations	1740		1740		1740		1740	
Farmer FE	Yes		Yes		Yes		Yes	
Round FE	Yes		Yes		Yes		Yes	
Transition rounds excluded	Yes				Yes			
Within-block trend			Yes				Yes	
SE clustered at irrigation group	Yes		Yes		Yes		Yes	
Kleibergen–Paap rk Wald F	2733.126		14176.694		2733.126		14176.694	
Underidentification test (p)	0.010		0.011		0.010		0.011	
Anderson–Rubin test (p)	0.005		0.003		0.004		0.004	
Wild cluster bootstrap p (Position)	0.007		0.004		0.007		0.007	

Notes: Columns (1) and (3) report instrumental variable estimates based on samples that exclude the immediate post-transition rounds (rounds 11–12 and 21–22), thereby removing short-run adjustment to institutional changes. Columns (2) and (4) report estimates from specifications that incorporate rule-specific within-block trends, allowing outcomes to evolve smoothly within each institutional regime. Water at arrival (lag) corresponds to $W^{pre}_{i,t-1}$, measuring the water remaining when the farmer arrived to extract in the previous round. Peer over-extraction (lag) corresponds to $PeerOver_{i,t-1}$, capturing over-extraction by other farmers in the previous round. The no water exposure (lag), $NoWater_{i,t-1}$, equals one when the irrigation pool was already exhausted upon arrival in the previous round. All specifications include farmer fixed effects. Standard errors are clustered at the irrigation-group level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Wild cluster bootstrap p-values use Webb weights with 9,999 replications.

In Table 7, the results remain qualitatively similar to the baseline findings, presented in Table 5. Excluding transition rounds does not materially alter the estimated positional effects, indicating that the results are not driven by immediate adjustment to rule changes. Similarly, allowing for rule-specific within-block trends does not eliminate the estimated effects, suggesting that they are not explained solely by smooth learning or fatigue over time. These robustness checks indicate that the main findings are not driven solely by order effects associated with the fixed sequence of institutional regimes.

In parallel, the robustness checks indicate that the main event study findings in Table 6 are not driven solely by the fixed sequencing of institutional regimes. When the immediate post-transition rounds are excluded, the baseline welfare decline under Rule 1 remains nearly unchanged, and the recovery improvements under Rule 2 and Rule 3 remain qualitatively similar. Likewise, when rule-specific within-block trends are introduced to absorb smooth learning or adaptation within each institutional block, the core pattern persists: welfare falls sharply at onset under the baseline rule and remains depressed, while the alternative institutional regimes continue to mitigate the persistence of post-shock losses.[4]

Note, these robustness exercises do not fully eliminate the fundamental limitation imposed by fixed sequencing, since treatment order is not randomized across groups. However, they do allow us to distinguish sharp institutional effects from smooth progression through the session. As the main results remain similar after excluding immediate transition rounds and allowing for rule-specific within-block trends, then the evidence is less consistent with a purely learning- or fatigue-based explanation.

8 Mechanism channels

This section examines the mechanisms through which positional disadvantage translates into differences in extraction outcomes. We distinguish between two complementary channels: First, we analyze institutional mechanisms embedded in the experimental design, focusing on how rule-based incentives, such as planning constraints and enforcement, shape outcomes in subsection 8.1. Second, we examine behavioral mechanisms, investigating how farmers adjust their decisions under these institutional and resource constraints in subsection 8.2.

8.1 Institutional mechanism

This subsection provides descriptive evidence on how institutional incentives explain positional disadvantage. In particular, we examine how the planning constraints introduced under Rule 2 and the enforcement mechanisms under Rule 3 shape extraction behavior. These analyses highlight the extent to which differences across positions arise from rule-specific features of the allocation environment.

To evaluate whether positional disadvantage persists under Rule 2, we examine three farmer-level outcomes that capture whether crop requirements are satisfied during the sequential extraction stage. The first outcome measures whether a farmer faces a binding crop constraint. Specifically, we define $Blocked_{it} = \mathbf{1}(W_{it}^{pre} < q_{it})$, which equals one when the remaining water stock at the time t farmer i arrives to extract is insufficient to satisfy the crop's minimum water requirement. This variable captures the extensive margin of crop infeasibility. The second outcome measures the intensity of the constraint through the shortfall between the crop requirement and the realized extraction level, $Shortfall_{it} = \max(q_{it} - x_{it}, 0)$, which records how far the realized extraction level falls below the crop's required water amount. Finally, we define an

[4] We estimated but did not report robustness exercise results for the event study specification. To note, the robustness checks do not show perfect invariance of coefficients, with some interaction estimates moving in magnitude and significance, especially for Rule 3.

indicator for successful fulfillment of the crop requirement, $MeetQuota_{it} = \mathbf{1}(x_{it} \geq q_{it})$, which equals one when the farmer obtains enough water to satisfy the crop requirement. Taken together, these three outcomes characterize whether the crop requirement as the ex-ante planning mechanism binds, how severely it binds, and whether the irrigation need is ultimately satisfied. We estimate the baseline specification in equation 7 for each outcome

$$Y_{it} = \alpha + \beta^{(2)}\, Down_i + \gamma_t + \varepsilon_{it}, \tag{7}$$

where Y_{it} denotes the feasibility outcome, $Y_{it} \in \{Blocked_{it}, Shortfall_{it}, MeetQuota_{it}\}$, for farmer i in round t. Positional disadvantage is captured using a downstream indicator, $Down_i = \mathbf{1}(k_i \geq 4)$, where k_i denotes the farmer's assigned extraction position and values 4 and 5 represent downstream positions. The coefficient of interest, β, measures the positional penalty associated with downstream extraction positions. The term γ_t represents round fixed effects that capture common learning, fatigue, and other round-specific influences in the experiment. Standard errors are clustered at the irrigation-group level to account for within-group correlation in extraction decisions and inference relies on wild cluster bootstrap procedures with Webb weights.

The interpretation of β depends on the outcome considered. For the blocked and shortfall regressions, a positive value of β indicates that downstream farmers are more likely to face binding crop constraints and larger irrigation deficits. For the meet-quota regression, a negative value of β indicates that downstream farmers are less likely to satisfy their crop water requirements.

Table 8: Crop-based quota effects by position

	Blocked (Constraint binds) (1)		Shortfall (Intensity) (2)		Meet quota (Success) (3)	
	Coef.	SE	Coef.	SE	Coef.	SE
Downstream (realized position ≥ 4)	0.076**	(0.027)	1.933***	(0.421)	-0.167***	(0.032)
Estimation statistics						
Observations	600		600		600	
R-squared	0.062		0.090		0.107	
Round FE	Yes		Yes		Yes	
SE clustered at irrigation group	Yes		Yes		Yes	
Wild cluster bootstrap p (Downstream)	0.003		0.000		0.000	

Notes: Estimation sample is restricted to Rule 2 (crop-based quota). Blocked equals one if water remains available but is insufficient to meet the crop requirement. Shortfall measures the gap between the required and actual extraction. Meet quota equals one if the extraction satisfies the crop requirement. Downstream is an indicator for farmers extracting in positions 4 or 5. Standard errors are clustered at the irrigation-group level. Wild bootstrap p-values (Webb weights, 9,999 replications) reported for the downstream coefficient. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The estimates in Table 8 provide descriptive evidence on how positional disadvantage operates under the crop-based quota rule. The results show that farmers located in downstream positions are significantly more likely to face binding water constraints. In other words, the probability of being blocked, defined as having insufficient water to meet the crop requirement at the time of extraction, increases by approximately 7.6 percentage points for farmers extracting in later positions. This indicates that even when water remains available, it is often insufficient to satisfy the minimum requirement imposed by crop choice. Consistent with this pattern, the intensity of constraint is also higher for downstream farmers. The shortfall measure shows that moving to a downstream position increases the gap between required and realized water extraction by nearly 1.93 units, on average. This reflects the cumulative effect of upstream extraction, which reduces the available water stock and leaves downstream farmers with insufficient resources to meet their needs. Finally, the likelihood of successfully meeting the crop requirement declines sharply for downstream farmers. The probability of meeting the quota decreases by approximately 16.7 percentage points for those in later positions, reinforcing the fact that positional disadvantage translates directly into economically meaningful outcomes.

Taken together, these results show that under Rule 2, positional asymmetry persists through a feasibility channel: downstream farmers are more likely to face binding constraints, experience larger shortfalls, and fail to meet crop water requirements, even though the quota rule limits excessive extraction by upstream farmers.

Under Rule 3, we assess whether audit-based enforcement deters over-extraction and whether this deterrence effect varies by extraction position. We focus on two primary outcomes that capture rule violations. The first is the extensive margin of non-compliance, measured by $AnyOver_{it} = \mathbf{1}(OE_{it} > 0)$, which records whether the farmer violates the quota at all. The second is the intensive margin of non-compliance, measured by $OE_{it} = \max(x_{it} - q_{it}, 0)$, which records the magnitude of over-extraction whenever a violation occurs. Together, these outcomes distinguish whether audits reduce the probability of violating the rule and whether they also reduce the amount of excess extraction conditional on violation.

$$Y_{it} = \alpha + \beta_1^{(3)} A_{gt} + \beta_2^{(3)} (A_{gt} \times Down_{it}) + \delta\, Down_{it} + \gamma_t + \mu_i + \varepsilon_{it}, \tag{8}$$

where Y_{it} denotes either the extensive-margin or intensive-margin violation outcome, $Y_{it} \in \{AnyOver_{it}, OE_{it}\}$, for farmer i in round t. The indicator A_{gt} captures whether the audit mechanism is triggered in group g in round t. The interaction term $A_{gt} \times Down_{it}$ allows the deterrence effect of audits to differ between upstream and downstream positions. The coefficient δ captures the baseline positional difference in violations in the absence of an audit. Round fixed effects γ_t absorb common within-Rule-3 dynamics, such as adaptation to the rotation mechanism or general learning over rounds. Farmer fixed effects μ_i absorb persistent individual propensities to violate rules, including stable differences in competitiveness, risk tolerance, or compliance preferences.

The coefficient $\beta_1^{(3)}$ measures the deterrence effect of audits for the omitted category, namely upstream or early movers, and we expect $\beta_1^{(3)} \approx 0$. The interaction coefficient $\beta_2^{(3)}$ captures the differential deterrence effect for downstream farmers, and we expect $\beta_1^{(3)} \approx 0$. The total audit effect for downstream players is therefore $\beta_1^{(3)} + \beta_2^{(3)}$, and $\beta_1^{(3)} + \beta_2^{(3)} < 0$. Standard errors are clustered at the irrigation-group level to account for within-group dependence in extraction decisions and audit exposure and inference relies on wild cluster bootstrap procedures with Webb weights.

The results in Table 9 show that positional status remains a strong determinant of behavior at the 1% significance level: farmers in higher access positions are significantly less likely to over-extract water and extract substantially lower units of water, indicating that favorable access

Table 9: Deterrence effects by position

	Any over-extraction (extensive margin) (1)		Over-extraction (intensive margin) (2)	
	Coef.	SE	Coef.	SE
Audit draw $audit_t = 1$ if the dice roll is 6	0.066	(0.069)	1.166*	(0.617)
Downstream (realized position ≥ 4)	-0.278***	(0.076)	-2.992***	(0.724)
Audit $\times$ Downstream	-0.152	(0.088)	-1.366*	(0.730)
Estimation statistics				
Observations	600		600	
R-squared	0.124		0.096	
Round FE	Yes		Yes	
SE clustered at irrigation group	Yes		Yes	
Wild cluster bootstrap p (Audit $\times$ Downstream)	0.108		0.111	

Notes: Estimation sample is restricted to Rule 3 (rotation with audit and penalty). The variable *Any over-extraction* equals one if the farmer extracts above the allowed quota. *Over-extraction amount* measures the quantity extracted above quota. *Audit draw* is an indicator equal to one when the audit is triggered in the round. *Downstream* is an indicator for farmers extracting in positions 4 or 5. The interaction term *Audit* $\times$ *Downstream* captures whether audit-induced deterrence differs for downstream farmers. We include round fixed effects. Standard errors are clustered at the irrigation-group level. Wild bootstrap p-values (Webb weights, 9,999 replications) are reported for the interaction term. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

conditions reduce both the incidence and intensity of over-extraction. The audit treatment itself has a positive but only marginally significant effect on over-extraction intensity at the 10% level, suggesting that enforcement may increase extraction in some cases, potentially reflecting anticipatory or strategic responses to monitoring.

The interaction between audit enforcement and positional status is negative across both extensive and intensive margins, indicating that audits tend to reduce over-extraction more strongly among farmers with higher access positions. However, these interaction effects are imprecisely estimated and not statistically significant under wild bootstrap inference (p-values ≈ 0.11), implying that the differential impact of audits across positions is suggestive but not conclusive. Taken together, the findings indicate that while baseline access conditions strongly shape extraction behavior, the effectiveness of audit-based enforcement in mitigating positional disparities remains limited, with only weak evidence of heterogeneous deterrence effects across positions.

8.2 Behavioral mechanism

This subsection examines how farmers adjust their behavior within the institutional environment. Specifically, we ask whether differences in extraction arise solely from mechanical constraints, captured by water availability at arrival, or reflect systematic behavioral responses to institutional rules, past experiences, and social context. To address this, we examine four dimensions of behavior: the role of constraints versus active decision-making, adaptation to institutional incentives, persistence over time, and heterogeneity across farmers.

In a sequential extraction setting, farmers do not face the same opportunity set: those who extract later typically encounter a reduced water stock due to upstream appropriation. This creates a natural distinction between what is feasible and what is chosen. A farmer's extraction decision can therefore be understood in two stages. First, water available at arrival determines the feasible set of actions. Second, conditional on this feasible set, the farmer chooses how much to extract. This distinction allows us to assess whether downstream farmers extract less because they cannot extract more, or because they choose not to.

To identify the constraint channel, we estimate the causal effect of realized extraction position on water availability at arrival in equation 9 using the instrumental variable strategy described in equation 2, where realized position is instrumented by assigned position and its interactions with rule regimes. To examine behavioral responses, we estimate equation 10 that conditions on water availability at arrival. In this specification, extraction is expressed as a function of realized position, water at arrival, and their interaction, allowing us to assess whether behavioral responses vary with the severity of the constraint. Because water at arrival is itself determined by upstream extraction decisions, equation 10 is interpreted as descriptive evidence on behavioral responses.

$$W_{it}^{pre} = \beta k_{it} + \gamma' C_{i,t-1} + \alpha_i + \lambda_t + \varepsilon_{it} \tag{9}$$

$$X_{it} = \delta_1 k_{it} + \delta_2 W_{it}^{pre} + \delta_3 (k_{it} \times W_{it}^{pre}) + \gamma' C_{i,t-1} + \alpha_i + \lambda_t + \varepsilon_{it} \tag{10}$$

In Table 10 column (1), the IV estimates show that position has a strong negative effect on water availability at arrival. Moving one position later substantially reduces the residual water stock available to a farmer by 9.3 units, on average. This implies that downstream farmers face tight water constraints due to upstream extraction. The conditional regression results in column (2) indicate that the effect of position on extraction depends on water availability. That is, the coefficient on realized extraction position is negative, while the interaction between position and water available at arrival is positive and statistically significant at the 1% level. The slope δ_3 on position becomes less negative when water availability rises. This implies that moving later in the extraction sequence reduces extraction most strongly when little water remains, but that this positional penalty attenuates as water availability rises. For example, when only 10 units of water are available at arrival, moving one position later reduces extraction by roughly 2.3 units, whereas when 30 units are available, the implied reduction is closer to 1 unit. We find the threshold effect at 44 units, as shown in the Appendix Figure B1; that is, the effect of the positional penalty disappears when water at arrival is at 44 units. This means that when the water stock is sufficiently abundant, farmers' realized extraction order in the sequence no longer strongly constrains extraction. In essence, this pattern suggests that downstream farmers extract less not because they behave differently, but because they face a reduced feasible set determined by upstream appropriation. Thus, behavioral differences across positions are relatively small once feasibility constraints are relaxed.

Table 10: Constraints and behavioral channel of positional power

	Water at arrival (1)		Extraction (2)	
	Coef.	SE	Coef.	SE
Realized extraction position	-9.398***	(0.677)	-3.030***	(0.456)
Water at arrival			-0.008	(0.027)
Realized extraction position × Water at arrival			0.069***	(0.011)
Peer over-extraction (lag)	-0.050	(0.068)	-0.032	(0.023)
No water exposure (lag)	-10.573***	(2.838)	-1.419	(1.324)
Estimation statistics				
Observations	1740		1740	
Farmer FE	Yes		Yes	
Round FE	Yes		Yes	
SE clustered at Irrigation group	Yes		Yes	
Kleibergen–Paap rk Wald F	13312.371			
Underidentification test (p)	0.011			
Anderson–Rubin test (p)	0.000			
Wild cluster bootstrap p (Position)	0.000			
Wild cluster bootstrap p (joint test: position and interaction)			0.001	

Notes: The table provides evidence on downstream farmers' extraction decisions by distinguishing between constraint-driven outcomes and behavioral responses. Column (1) reports IV estimates of the causal effect of realized position on water availability at arrival, W_{it}^{pre}, where realized position is instrumented using assigned position and its interactions with rule regimes. Column (2) reports a conditional specification of extraction on realized position and water at arrival, including their interaction, which allows the marginal effect of position to vary with water availability. This specification is interpreted as descriptive evidence because water at arrival is itself determined by upstream extraction. All specifications include farmer and round fixed effects, as well as lagged controls. Standard errors are clustered at the irrigation-group level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Wild cluster bootstrap p-values use Webb weights with 9,999 replications.

Next, we examine whether farmers' behavior evolves gradually through repeated play, or instead responds primarily to changes in institutional rules. The descriptive evidence presented in Appendix Figure B2 reveals that farmers do not primarily learn to adjust extraction behavior within a given institutional environment; behavior tends to differ across institutional regimes, indicating that incentives embedded in the rules play a more central role than incremental learning does. We estimate within-block learning dynamics using the round index within each rule block. Let $round\_block_{it} \in \{1, \ldots, 10\}$ denote the round index within each institutional regime for farmer i in round t and consider the following specification in equation 11:

$$X_{it} = \beta_1 round\_block_{it} + \beta_2(round\_block_{it} \times Rule_r) + \alpha_i + \varepsilon_{it}, \qquad (11)$$

where β_1 captures the within-block learning effect under the baseline regime, while the interaction terms β_2 allow the slope to differ across Rules 2 and 3. We exclude round fixed effects in this specification because each institutional regime is deterministically assigned across rounds; thus, rule indicators and within-block time variation are perfectly collinear with round fixed effects.

Results are presented in Table 11. We find limited evidence of gradual within-block learning. The estimated coefficient on the round index within each rule block is positive but not statistically different from zero, indicating that farmers do not systematically adjust extraction behavior over repeated rounds within a given institutional environment. This finding is consistent with the descriptive evidence shown in Appendix Figure B2, which shows no clear monotonic trend within blocks and instead reveals fluctuating patterns over time. In contrast, we observe that behavior differs across institutional regimes. The interaction between the within-block round index and Rule 3 is negative and statistically significant at the 5% level, indicating that extraction declines over rounds under the audit regime relative to the baseline. Combining the baseline slope with the interaction term implies that the within-block trend under Rule 3 is approximately -0.124 units per round (0.164-0.288), suggesting a modest downward adjustment over time in response to enforcement. A similar declining pattern is observed under the quota regime (Rule 2), but it is not statistically significant. Taken together, these results indicate that behavior in the irrigation game is shaped more by institutional incentives than by incremental learning. Farmers do not gradually converge toward different extraction levels within a given rule. Instead, differences in behavior arise across institutional environments, with only limited evidence of dynamic adjustment within rules. In this sense, institutional design determines the baseline level of behavior, while learning plays a secondary role.

Table 11: Learning and adaptation across institutional blocks

	Extraction	
	Coef.	SE
Round within rule block	0.164	(0.135)
Rule 2: Crop-based quota	-0.507	(0.889)
Rule 3: Rotation with audit	0.869	(0.991)
Rule 2 × round within block	-0.153	(0.167)
Rule 3 × round within block	-0.288**	(0.120)
Estimation statistics		
Observations	1800	
R-squared	0.161	
Farmer FE	Yes	
SE cluster at irrigation group	Yes	
Wild cluster bootstrap p (baseline slope)	0.252	
Wild cluster bootstrap p (interaction slopes jointly)	0.093	
Wild cluster bootstrap p (all slopes jointly)	0.210	

Notes: We estimate within-block learning by regressing extraction on the round index within each institutional block, rule indicators, and their interactions, including farmer fixed effects. The coefficient on round within rule block captures the slope under Rule 1, while the interaction terms show whether the within-block trend differs under Rule 2 or Rule 3. Standard errors are clustered at the irrigation-group level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Wild-bootstrap values use Webb weights with 9,999 replications.

We next examine whether farmers' behavior depends on past experiences. In repeated interaction settings, farmers may repeat past actions ('persistence') or adjust in response to prior shocks such as water scarcity or peer behavior ('path dependence'). Path dependence could arise if farmers who experienced water shortages become more cautious, or if exposure to peer over-extraction influences subsequent decisions. Alternatively, behavior may remain largely stable over time, reflecting persistent individual tendencies rather than adaptive responses. The descriptive evidence, presented in the Appendix Figure B3, suggests a persistent extraction pattern among farmers, who tend to repeat past actions: those who extract more in one round also extract more in the next. To assess persistence and path dependence more formally, we estimate the following dynamic specification:

$$X_{it} = \rho X_{i,t-1} + \theta_1 NoWater_{i,t-1} + \theta_2 PeerOver_{i,t-1} + \gamma' C_{i,t-1} + \alpha_i + \lambda_t + \varepsilon_{it}, \qquad (12)$$

where X_{it} denotes extraction, $X_{i,t-1}$ captures persistence, and lagged indicators of water scarcity $NoWater_{i,t-1}$ and peer behavior $PeerOver_{i,t-1}$ capture path dependence. Farmer and round fixed effects are included to control for time-invariant heterogeneity and common temporal shocks.

Table 12: Dynamic persistence and path dependence in extraction

	Extraction	
	Coef.	SE
Extraction (lag)	0.235***	(0.050)
No water exposure (lag)	-1.181	(1.684)
Peer over-extraction (lag)	-0.023	(0.015)
Estimation statistics		
Observations	1800	
R-squared	0.215	
Farmer FE	Yes	
SE cluster at irrigation group	Yes	
Wild cluster bootstrap p (Extraction (lag))	0.002	
Wild cluster bootstrap p (No water exposure (lag))	0.552	
Wild cluster bootstrap p (Peer over-extraction (lag))	0.138	

Notes: The table reports estimates from a dynamic specification of extraction decisions. The coefficient on lagged extraction captures behavioral persistence, while lagged no water exposure and lagged peer over-extraction capture path dependence from past scarcity and peer behavior. All specifications include farmer and round fixed effects. Standard errors are clustered at the irrigation-group level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Wild cluster bootstrap p-values use Webb weights with 9,999 replications.

The regression results in Table 12 provide clear evidence of behavioral persistence. The coefficient on lagged extraction is positive and statistically significant, with an estimated magnitude of 0.235. This implies that farmers tend to repeat their past extraction decisions: those who extract more in one round are more likely to extract more again in the subsequent round. In contrast, we find no evidence of strong path dependence with respect to past experiences. The coefficient on the lagged no water exposure is negative but statistically insignificant, and the coefficient on the lagged peer over-extraction is small and not statistically distinguishable from zero. These results indicate that farmers do not systematically adjust their behavior in response to prior scarcity or peer actions. These findings suggest that behavior in the irrigation game exhibits persistence but limited adaptive learning from past conditions. Farmers appear to follow relatively stable behavioral patterns over time, repeating prior actions rather than updating their decisions in response to past shocks.

We next examine whether behavioral responses to positional disadvantage differ among farmers according to their sensitivity to the social environment. To capture heterogeneity in farmers' responsiveness to social interactions, we construct a composite index of norm sensitivity, denoted by η_i.[5] In particular, we ask whether farmers whose decisions are more responsive to norm sensitivity adjust extraction differently when they are downstream. Norm-sensitive farmers can be characterized as individuals whose decisions are more responsive to the social environment, including communication, peer behavior, and others' expectations. We examine heterogeneity by splitting the sample at the median of the η index and estimating the positional model separately for low- and high-η farmers. For each subgroup $g \in \{\text{Low } \eta, \text{ High } \eta\}$, we estimate equation 13

$$x_{it} = \beta_g \, k_{it} + \gamma_g' \, C_{i,t-1} + \alpha_i + \lambda_t + \varepsilon_{it}, \quad i \in g, \tag{13}$$

where x_{it} denotes extraction, k_{it} is the realized extraction position, and $C_{i,t-1}$ is the vector of lagged controls. The terms α_i and λ_t denote farmer and round fixed effects, respectively. The coefficient β_g captures the positional effect within subgroup g. Comparing $\beta_{\text{Low } \eta}$ and $\beta_{\text{High } \eta}$ allows us to assess whether farmers with different levels of norm sensitivity respond differently to positional disadvantage. Taken together, the evidence indicates that positional asymmetry affects all farmers, but its behavioral consequences are larger among those who are more socially responsive. Norm-sensitive farmers reduce extraction more sharply when they move downstream, implying that social responsiveness conditions how farmers react to scarcity within the same institutional environment.

The results presented in Table 13 reveal the presence of heterogeneity in behavioral responses. While extraction declines with position for both groups, the effect is substantially stronger among high-norm farmers. In other words, moving one position later reduces extraction by approximately 3.1 units for high-norm farmers, compared to about 2.0 units for low-norm farmers. Figure B4 illustrates this pattern descriptively: although extraction declines with position for both groups, the slope is visibly steeper among high-norm farmers, particularly at later positions.

To understand what drives this effect, we examine individual components of the index and find that the heterogeneity is primarily driven by trust, and the effect is significantly stronger among high-trust farmers.[6] In other words, moving one position later reduces extraction by approximately 3.3 units for high-trust farmers, compared to about 1.8 units for low-trust farmers. This may reflect differences in expectations when high-trust farmers may anticipate that others will also restrain extraction or view the allocation process as credible, making them more willing

[5] How we construct norm sensitivity index, We provide details in the see appendix

[6] Other components of the norm sensitivity index do not exhibit meaningful moderating effects.

to reduce their own extraction. In contrast, low-trust farmers may behave more defensively, limiting how much they adjust.

Taken together, positional asymmetry affects all farmers, but its behavioral consequences are larger among those who are more socially responsive. Norm-sensitive farmers reduce extraction more sharply when they move downstream, implying that social responsiveness conditions, particularly trust, strongly condition how farmers react to scarcity within the same institutional environment.

Table 13: Heterogeneity in behavioral response by norm sensitivity

	Extraction							
	Low norm (1)		High norm (2)		Low trust (3)		High trust (4)	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Realized extraction position	-1.971***	(0.566)	-3.117***	(0.632)	-1.764***	(0.387)	-3.320***	(0.729)
Water at arrival (lag)	-0.036*	(0.017)	-0.025	(0.020)	-0.042**	(0.017)	-0.021*	(0.011)
Peer over-extraction (lag)	-0.013	(0.068)	-0.070***	(0.019)	0.002	(0.014)	-0.093***	(0.031)
No water exposure (lag)	-4.907*	(2.838)	-3.936*	(1.894)	-3.661**	(1.263)	-3.808**	(1.671)
Estimation statistics								
Observations	870		870		870		870	
R-squared	0.305		0.322		0.264		0.374	
Farmer FE	Yes		Yes		Yes		Yes	
Round FE	Yes		Yes		Yes		Yes	
SE clustered at Irrigation group	Yes		Yes		Yes		Yes	
Wild cluster bootstrap p (Position)	0.004		0.004		0.000		0.001	

Notes: The table reports heterogeneity in extraction behavior by norm sensitivity (η) and trust, using median splits of each index. Columns (1) and (2) correspond to low- and high-η farmers, while columns (3) and (4) correspond to low- and high-trust farmers. Each column reports estimates from the same baseline specification estimated separately for each subgroup. The coefficient on position captures the marginal effect of moving one position later in the extraction sequence within each group, and differences across columns reflect heterogeneity in behavioral responses to positional disadvantage. All specifications include farmer and round fixed effects, as well as lagged controls. Standard errors are clustered at the irrigation-group level. Significance levels: $p < 0.10$, $p < 0.05$, $p < 0.01$. Wild cluster bootstrap p-values use Webb weights with 9,999 replications.

9 Concluding remarks

Increasing groundwater depletion and inefficient water use in rice cultivation reflect two dimensions of the same irrigation problem. This paper investigates the irrigation dilemma in institutionally managed groundwater schemes in a climate-vulnerable region of northern Bangladesh, using experimental games with rice farmers. The design introduces variation in water allocation rules and enforcement mechanisms to examine the causal effects of positional asymmetry on welfare and extraction behavior, as well as the dynamics of welfare following groundwater scarcity shocks.

The results show that positional asymmetry has clear economic consequences. Under sequential extraction without strong coordination, farmers who extract later systematically receive less water and earn lower payoffs. This pattern closely mirrors real-world irrigation schemes, in which farmers farther along the delivery network face lower and more uncertain access to water. These findings indicate that institutional arrangements governing extraction order play a central role in shaping the distribution of welfare within shared irrigation schemes.

We further provide evidence that this inequality is driven primarily by feasibility constraints rather than behavioral differences. Downstream farmers extract less, not because they behave differently, but because less water is available when it's their turn. This distinction has critical policy implications. While conventional approaches often focus on regulating behavior through monitoring, pricing, or enforcement (Bruno, Jessoe, & Hanemann, 2024; Hagerty & Zucker, 2025; Shreedhar, Tavoni, & Marchiori, 2020; S. M. Smith *et al.*, 2017), our results suggest that such policies are insufficient when inequality arises from the structure of water delivery itself.

The analysis also highlights that institutions matter for how farmers adjust to scarcity over time. Under the baseline sequential regime, welfare declines sharply at the onset of scarcity and remains persistently low. In contrast, alternative institutional arrangements reshape these dynamics through different channels. Crop-based quotas effectively discipline behavior by eliminating over-extraction, but do not remove positional disadvantage, as downstream farmers may still face binding water constraints. Rotational allocation reduces persistent disadvantage by redistributing access across rounds, but does not eliminate within-round scarcity. These findings show that institutional rules do not eliminate inequality, but alter how it emerges and evolves over time.

Taken together, these results point to a broader shift in how groundwater policy should be framed. In shared irrigation schemes, the key policy margin is not only how much water is allocated, but how irrigation service is delivered over time. Farmers may face equal prices and formal access, yet experience unequal outcomes because of the timing and sequencing of extraction. Effective policy, therefore, requires moving beyond quantity-based allocation toward service-based design that equalizes access to water at the point of use. We recommend three implications to follow. First, irrigation institutions should address positional asymmetry directly by redesigning delivery order, for example, through rotational scheduling that prevents persistent upstream advantage. Second, behavioral regulation, such as quotas, should be complemented by mechanisms that ensure a minimum level of access to services, so that downstream farmers are not excluded when scarcity binds. Third, institutional design should explicitly account for resilience by stabilizing outcomes and supporting recovery following scarcity shocks.

More broadly, the findings suggest that efficient and equitable groundwater management depends less on assigning rights or controlling aggregate extraction, and more on governing how irrigation service is sequenced, timed, and delivered across interconnected farmers. In this sense, the central policy challenge is not only how much water is extracted, but how access to groundwater is organized in practice. An important direction for future research is to examine how these mechanisms operate in real-world irrigation schemes where governance quality and service reliability vary. While experimental evidence isolates institutional design, actual outcomes depend on enforcement credibility, rule transparency, and trust among farmers. In addition, the continuity and timing of water access across irrigation cycles may shape both inequality and farmers' ability to cope with recurring scarcity. Understanding how governance quality interacts with delivery structures to sustain reliable water access over time is, therefore, critical for extending these insights beyond experimental settings.

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Appendix

Table A1: The effects of positional power on additional extraction behaviors

	Extraction		Within-quota extraction		Excess extraction	
	Coef.	SE	Coef.	SE	Coef.	SE
Realized extraction position	-2.108**	0.546	-1.293***	0.276	-0.815*	0.327
Lagged prevailing extraction conditions						
Water at arrival (lag)	-0.026	0.013	-0.016	0.013	-0.009	0.007
Peer over-extraction (lag)	-0.044*	0.020	-0.031	0.014	-0.013	0.016
No water exposure (lag)	-4.474*	1.605	-3.305**	1.014	-1.169	0.810
Estimation statistics						
Observations	1740		1740		1740	
Farmer FE	Yes		Yes		Yes	
Round FE	Yes		Yes		Yes	
SE clustered at	Irrigation group		Irrigation group		Irrigation group	
Kleibergen–Paap rk Wald F	13312.371		13312.371		13312.371	
Underidentification test (p)	0.011		0.011		0.011	
Anderson–Rubin test (p)	0.004		0.000		0.105	
Wild cluster bootstrap p (Position)	0.007		0.001		0.034	

Notes: The table reports second-stage instrumental variables estimates of the effect of realized extraction position on three behavioral outcomes: total extraction, within-quota extraction, and excess extraction. Water at arrival (lag) corresponds to $W^{pre}_{i,t-1}$, measuring the water remaining when the farmer arrived to extract in the previous round. Peer over-extraction (lag) corresponds to $PeerOver_{i,t-1}$, capturing over-extraction by other farmers in the previous round. No water exposure (lag), $NoWater_{i,t-1}$, equals one when the irrigation pool was already exhausted when the farmer arrived to extract in the previous round. All specifications include farmer fixed effects and round fixed effects. Standard errors are clustered at the irrigation-group level. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

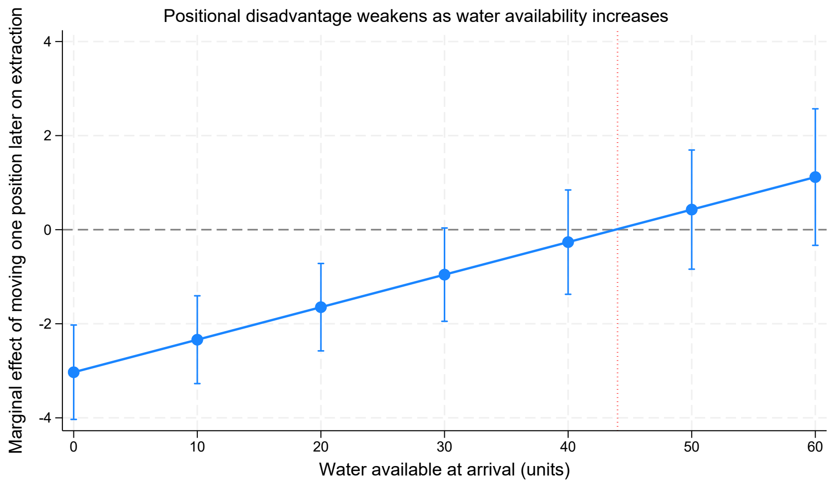

Figure B1: Marginal effect of position on extraction across water availability
Notes: The figure plots the marginal effect of position on extraction, which is decreasing in water availability. When water at arrival is low, downstream farmers experience large reductions in extraction, reflecting binding resource constraints. As water availability increases, the positional effect weakens and eventually disappears (e.g., at 44 units), indicating that positional asymmetry operates primarily through scarcity-induced constraints rather than persistent behavioral differences.

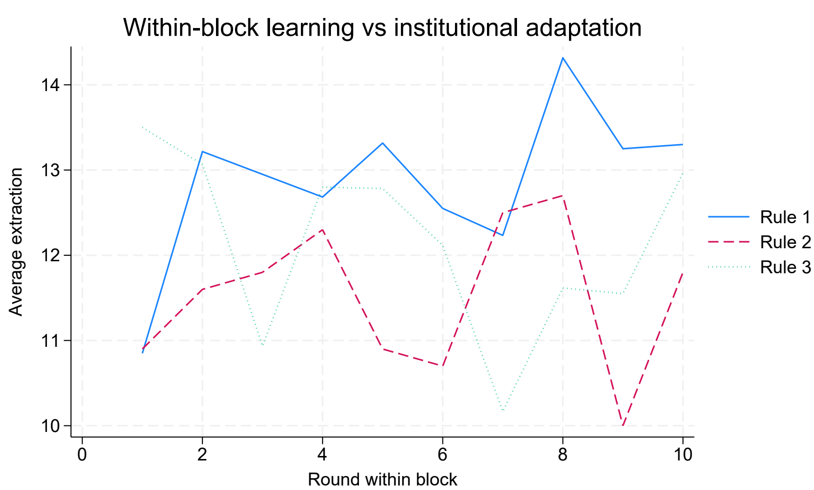

Figure B2: Within-block learning and cross-rule differences in extraction
Notes: The figure plots average extraction across rounds within each rule block, separately for the three institutional regimes. Within each rule, extraction does not exhibit a clear monotonic trend over rounds, indicating limited evidence of gradual learning. In contrast, clear level differences persist across rule blocks: extraction is consistently highest under the baseline regime (Rule 1) and lower under both the quota-based (Rule 2) and audit-based (Rule 3) regimes. This pattern suggests that behavior varies across institutional environments rather than evolving gradually within them.

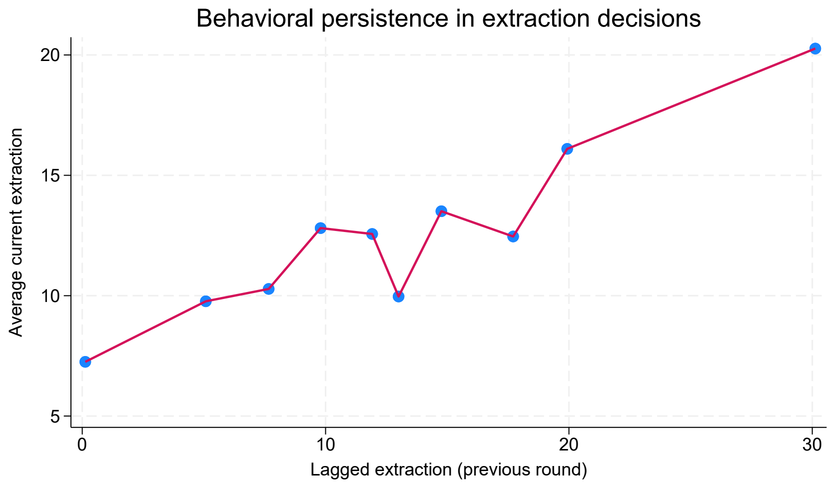

Figure B3: Past behavior and extraction decisions

Notes: The figure plots average current extraction against lagged extraction using binned means. The upward-sloping relationship indicates behavioral persistence, whereby farmers who extract more in one round tend to extract more in the subsequent round. At the same time, the relationship is not perfectly linear and displays noticeable dispersion, suggesting that extraction behavior is also influenced by other factors such as water availability and institutional conditions.

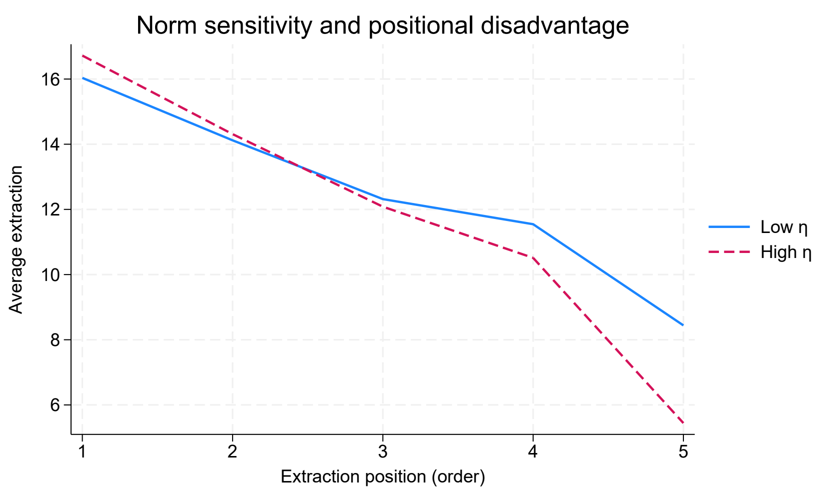

Figure B4: Norm sensitivity and responses to positional disadvantage

Notes: The figure plots average extraction by position separately for low- and high-η farmers. High-η farmers are those whose decisions are more responsive to the social environment, capturing greater sensitivity to communication, peer influence, trust, and collective considerations, while low-η farmers exhibit weaker responsiveness to these factors.Extraction declines with position for both groups, but the decline is steeper for high-η farmers, indicating stronger behavioral responses to downstream scarcity

Construction of norm sensitivity index

The norm sensitivity index, denoted by η_i, is constructed from five components derived from the post-experimental debriefing survey, each capturing a distinct behavioral channel. These include whether a farmer reports being influenced by others' decisions, how communication affected their behavior, the perceived quality of communication, a measure of trust in others, and an indicator of collective action orientation. They capture the different mechanisms by which norms operate in practice: influence, communication, expectations, and coordination. To combine these measures into a single index, each component is first standardized to have mean zero and unit variance. Formally, for each component $s \in \{1, \ldots, 5\}$, we define

$$z_{s,i} = \frac{X_{s,i} - \mu_s}{\sigma_s}, \tag{A.1}$$

where $X_{s,i}$ denotes the value of component s for farmer i, and μ_s and σ_s are the corresponding sample mean and standard deviation. Standardization ensures that components measured on different scales contribute comparably to the index. The norm sensitivity index is then constructed as the unweighted average of these standardized components:

$$\eta_i = \frac{1}{S} \sum_{m=1}^{S} z_{s,i}, \tag{A.2}$$

where $S = 5$. The resulting index captures the extent to which a farmer's decision-making is responsive to the social context. Higher values of η_i indicate that behavior is more strongly shaped by communication, peer influence, trust, and collective considerations. Importantly, the index does not measure cooperation directly, nor does it imply that higher values correspond to more pro-social behavior in a normative sense. Instead, it reflects the degree of social responsiveness, which may manifest differently depending on the institutional environment and resource constraints.

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