Ashoka University
Economics Discussion Paper 91

Decentralization and Spatial (Mis-)Allocation of Irrigation Water

January 2023

Sabyasachi Das, Ashoka University
Souvik Dutta, IIIT Delhi

https://ashoka.edu.in/economics-discussionpapers

Plot No. 2, Rajiv Gandhi Education City,
National Capital Region,
P.O.Rai, Sonepat, Haryana 131029

Decentralization and Spatial (Mis-)Allocation of Irrigation Water*

Sabyasachi Das
Ashoka University

Souvik Dutta
IIIT Delhi

January 26, 2023

Abstract

This paper examines the consequence of decentralization in the management of canal irrigation for spatial allocation of water and agricultural performance. Under centralized management, farmers closer to the canal tend to over-extract water, resulting in spatial mis-allocation. We test whether decentralization can improve spatial allocation of water by exploiting the staggered constitution of locally elected canal management bodies ("Pani Panchayats") in the state of Orissa, India, that decentralized its canal management. Using survey data and a heterogeneous treatment effect estimation strategy using farmer level fixed effects, we show that farming plots farther away from the canal received less water under centralized system, but longer exposure to decentralization significantly reduces spatial mis-allocation. Consequently, agricultural revenue and wealth (landholding) improve more for those farmers. We find suggestive evidence that distant farmers' ability to complain to local representatives is an important mechanism explaining our results.

JEL Classification: Q15, Q56, Q58, D78
Keywords: Pani Panchayats, local governance, natural resource management

*Sabyasachi Das: Economics Department, Ashoka University, National Capital Region, India, email: sabyasachi.das@ashoka.edu.in. Souvik Dutta: Social Sciences and Humanities Department, Indraprastha Institute of Information Technology, Delhi, India, email: souvik@iiitd.ac.in. We are grateful to EfD Gothenburg and Monash University for funding the project, CECFEE, Indian Statistical Institute, Delhi for facilitating the EfD grant, Department of Water Resources, Government of Orissa for coordinating the survey, and Regional Center for Development Cooperation (RCDC), Bhuwaneswar, for implementing the survey. Special thanks to Vidyasagar Mishra and Tapan Padhi for their effort and invaluable insights during fieldwork. We thank Hanan Jacoby, Vijayendra Rao, Aaditya Dar, Abhijit Banerji, Mausumi Das, and seminar and conference participants at Delhi School of Economics, Ashoka University, Gokhale Institute of Politics and Economics, INSEE Conference 2021 for their comments. We are responsible for any errors that may remain.

1 Introduction

Food constitutes about two-thirds of the world's water footprint and therefore, efficient management of water in agriculture is key to ensuring long-run food security and avoiding a water crisis. The World Water Council notes, "[...] the crisis is not about having too little water to satisfy our needs. It is a crisis of managing water so badly that billions of people [...] suffer badly." (Cosgrove and Rijsberman, 2014) The two primary sources of irrigation water are groundwater and surface water, and both sources are projected to deplete considerably in the near future if the status quo continues.[1] While there is a substantial empirical literature examining institutional and policy innovations addressing allocation of groundwater, the empirical examination of surface water allocation is relatively scant. Moreover, conceptually, the efficiency concerns for the two systems are quite different, requiring separate analysis.

The volume of surface water is a *flow* variable, while groundwater is *stock*. Hence, the efficiency concerns with inter-temporal allocation while prominent for groundwater, is muted for canal irrigation. Canals, on the other hand, cover large geographic area, heightening concerns for *spatial* misallocation. Specifically, farmers located at the head of the canal have the propensity to extract disproportionate amounts of water, which results in farmers located at the tail receiving too little. Since canal irrigation systems are typically operated by a central authority who allocate water at the source and have limited capacity for monitoring and enforcement across the entire system, extent of spatial misallocation may be large. Several ethnographic field work (Bromley et al., 1980; Chambers, 1988; Wade, 1982) and empirical research (Jacoby and Mansuri, 2020) have highlighted this issue, making it a well-recognized problem in canal irrigation.

This paper examines the consequence of decentralization of the management of canal irrigation for spatial allocation of water and agricultural performance. We exploit an institutional reform in the Indian state of Orissa, that resulted in staggered constitution of locally elected canal management bodies, known as "Pani Panchayats" (or, water councils) throughout the state. The Pani Panchayats are responsible for maintenance of local canal infrastructure and ensuring fair allocation of water across farmers within its jurisdiction. We collect survey data on farmers and elected representatives of the Pani Panchayats to estimate its effect. We show that distant farmers received less water in absence of decentralization and longer exposure to the Pani Panchayat institution significantly reduced this misallocation. Decentralization led to distant farmers getting better price for their output (possibly due to higher quality of grains produced), earning more revenue, and buying more land. Our results

[1] The World Bank projects that availability of surface water in India, for example, will dwindle from 300 km^3 per annum in 2010 to 45 km^3 per annum in 2050. The average depth to groundwater in India has also increased from 6.5 meters in 1996 to 8.5 meters in 2006 (Sekhri et al., 2013).

indicate that the improvement in outcomes for the distant farmers owing to decentralization may have come at the cost of reduced agricultural performance of farmers located near the canal. We find that distant farmers' higher propensity to communicate their issues with the locally elected members is an important mechanism that can explain the observed effect.

The existing models examining water allocation in canal irrigation, such as Chakravorty et al. (1995) and Chakravorty and Roumasset (1991), are concerned with optimizing on the conveyance loss of water in canal (as a function of distance) and the institutional structures that ensure efficiency on that regard. Burness and Quirk (1979), on the other hand, examine implications of different property rights regimes on allocation efficiency of surface water. Our conceptual framework considers the farmers' incentive to over-extract and examines the central planner's optimal monitoring strategy in response. The formal treatment of our framework, which we elaborate in the Appendix, shows that as long as the central authority suffers from capacity constraint, i.e., it is unable to monitor all farmers across the entire irrigation system, farmers closer to the canal will engage in over-extraction. Decentralization improves allocation since local canal management bodies have a greater capacity to monitor farmers in their area. This could be because it is easier for farmers at the tail to complain to the local governments, facilitating greater information flow.

To empirically examine whether decentralization indeed results in improvement in the spatial allocation of water, we utilize the institutional reforms in irrigation management in the Indian state of Orissa. The state government in Orissa initiated the decentralization process by implementing the Orissa Pani Panchayat Act in 2002. Following the enactment, the Water Resources Department of Government of Orissa began constituting locally elected canal management bodies, known as "Pani Panchayats" (PPs) in various parts of the state in a gradual manner.

We collect survey data from farmers and elected members in a sample of Pani Panchayats in Orissa and exploit variation in the introduction of elections across PPs to estimate the effect of decentralization. Moreover, we estimate the heterogeneous treatment effect of decentralization for farmers located at different distances from the canal. This is important to test our hypothesis that decentralization would improve spatial allocation of water. Most parts of the state were "treated" with decentralization at the time of the survey in 2019. However, due to the staggered constitution of PPs, there is variation in the number of terms that PPs had experienced.[2] Hence, we use the variation in the *degree* of treatment or the length of exposure to the decentralized institution as our treatment variable. In the survey, we collect data on outcome variables both for the current period as well as 10 years back

[2]The number of terms that a PP experienced is given by the number of terms completed in the PP in addition to the ongoing term at the time of survey. It takes values 1, 2 and 3 in the sample.

(using recall). Since we also know the history of PP elections in each of the surveyed PPs, it allows us to create a farmer-level panel data across 10 years. We, therefore, can compare the same PP (and individual farmer) over time and estimate the effect of changes in the number of PP terms completed over time using PP (or, even farmer) fixed effect.

The irrigation officials in Orissa do not track flow of water in canals using water meters. Our measure of water allocation to a farmer is therefore self-reported. We use the number of tranches of water a farmer receives in the primary agricultural season as our main variable capturing water allocation. The Water Resources Department of the state government releases water in the canal in tranches, and each tranche of water typically lasts for about 7-10 days. However, depending on the location, a farmer may not receive water in a given tranche. This leads to variation in the number of tranches of water a farmer receives in a season.[3]

In the cross-sectional analysis, where we compare PPs with different number of PP terms, we find that PPs with higher number of terms receive more tranches of water. Moreover, the interaction of PP terms with distance from canal is positive, suggesting that farther off farmers receive more water in PPs with longer exposure to decentralization. The coefficient however is noisily estimated. This could be due to unobservable differences between PPs with different terms, which can result in biased estimates. In the panel analysis, where we compare the same PP over 10 years, we find that in absence of Pani Panchayats, distant farmers receive less tranches of water than those located closer to the canal. However, in PPs that experienced larger number of PP terms, this negative relationship reduces significantly. The interaction between number of PP terms and distance from canal has a positive coefficient, which is statistically significant and economically large in presence of PP fixed effect. Moreover, we get the same result using individual farmer fixed effect as well. This is a significantly stronger specification as it accounts for various farmer specific characteristics that could shape their water allocation, such as their political and social networks, unobservable soil characteristics of their land etc., which could be correlated with their location vis-a-vis the canal.

Consistent with this result, we find that the distant farmers generate lower revenue (conditional on plot size) in absence of PPs. However, with longer exposure to decentralization, revenue improves more for those farmers. Interestingly, the result is driven completely by price and not the quantity produced. This suggests that the constrained supply of water to the distant farmers negatively affect the quality of rice they produce, but it has minimal

[3]Our pilot survey revealed that number of tranches of water is a better measure of water allocation than the number of days of water received in a season. This is because it is much easier for farmers to report it accurately both for the current period as well for 10 years prior.

effect on the quantity of production.[4] We finally examine the wealth accumulation by farmers as our measure of welfare. We find that distant farmers are significantly more likely to buy land with each additional PP term being completed. This suggests that better agricultural performance by them, owing to decentralization of water management, may have led to greater profitability and savings, which allowed those farmers to increase their landholding.

We examine whether the effect of decentralization is heterogeneous across PPs. We test heterogeneity across two dimensions - land inequality among farmers within a PP and correlation between landholding and distance from canal. We find that in PPs with higher land inequality, spatial misallocation was greater under centralization and consequently, decentralization was more effective. Additionally, in PPs where the correlation between farmers' distance from canal and their land-size is small, the spatial misallocation was lower under centralization, and consequently, decentralization in those PPs did not have a significant impact.

A salient mechanism that can explain our results is that elected PP members may have better information about the allocation of water. We show that farmers located farther away from the canal are more likely to interact with their PP representatives frequently. This is consistent with the idea that decentralization makes it easier for farmers receiving less water to complain to local bodies, than to officials in the relevant government department. Moreover, we find that our main result is indeed driven by farmers who interact frequently with elected PP members. We additionally examine whether elected representatives invest more in local canal infrastructure (primarily in the form of constructing field channels) to facilitate better flow of water to distant farmers. We however find weak evidence of this supply side mechanism.

Our work relates to the literature on decentralization of natural resource management. Baland et al. (2010) examined the effect of constituting local forest management bodies in India (known analogously as "Van Panchayats") as opposed to being managed by government bureaucrats, on forest conservation. They find positive results of local management. In their context, the details of the local institution were left in the hands of the local communities, and therefore, differed across regions. Hence, decentralization in that case, though state mandated, was still informal in nature. Somanathan et al. (2009) find that forests in the state of Uttarakhand in India, when managed by village councils are seven times more cost-effective as compared to those managed centrally by the state government. Jacoby et al. (2021) find that decentralization of canal irrigation led to greater corruption in the Punjab province in Pakistan. They find that water theft increased on channels managed by local

[4]Paddy is the primary agricultural output in Orissa and all farmers in our sample produce paddy in their main plots.

farmer organizations compared to those that remained centrally managed. This resulted in the worsening of spatial allocation of water.

In the context of groundwater irrigation, Edwards (2016) finds that introduction of Groundwater Management Districts (GMDs) in counties in Kansas, US, increased land values and corn production, especially in areas with greater movement of aquifer water. Drysdale and Hendricks (2018) show, in the same context of Kansas, that imposition of water quotas through local governance can also help improve allocation. In general, there is a large literature in economics on the effective management of ground water extraction (Smith et al., 2017; Brozović et al., 2010; Koundouri, 2004; Gisser and Sanchez, 1980). Our paper contributes to this discussion by highlighting the differential efficiency concerns with canal irrigation and empirically demonstrating how decentralization may help address them.

The celebrated work of Elinor Ostrom (Ostrom, 1990; Ostrom and Gardner, 1993) has demonstrated that community institutions that locally manage common pool resources can be effective in the sustainable usage of natural resources. Bardhan (2000) has examined community management of irrigation projects in southern India to analyze the determinants of better cooperation in their management. Several studies also highlight the importance of local institutions to deal with the problem of natural resource management (Baland and Platteau, 1996; Bardhan, 1993; Maloney and Raju, 1994; Meinzen-Dick et al., 1994; Tang, 1992). We contribute to this literature by analyzing a context where local management is facilitated through formal decentralization and is implemented at scale, i.e., across a large state (and similarly in other states) in India.

2 Background and Institutional Details

2.1 Study Region – Orissa

We conduct our empirical analysis using survey data from the state of Orissa in India. Orissa is located in the eastern part of India, has a population of 41.9 million (2011 census) and is primarily agriculture dependent. The total cultivated land of the state is 6.2 million hectares. Majority of the farmers are small and marginal and have limited access to resources. Paddy is the major crop grown in Orissa (66.6 percent).

Irrigation plays a significant role in the state of Orissa and during the last six decades irrigation facilities have increased from 0.2 million hectares in 1951 to 4.2 million hectares in 2019. There are primarily two types of irrigation available - canal based and lift. 80 percent of irrigated land in Orissa is under canal irrigation. The canal irrigation projects are classified into three categories based on their command area, i.e., the area covered by one irrigation project. Projects covering land area between 40 and 2,000 hectares are called minor projects, the ones between 2,000 and 6,000 hectares medium, and above 6,000 hectares are called major irrigation projects. The lift irrigation projects are usually small in size and cover up to 40 hectares of land.

2.2 Pani Panchayats in Orissa

The National Water Policy adopted by the government of India in 1987 stressed on adopting participatory irrigation management (PIM), involving farmers in the management of irrigation systems. The state government of Orissa began the process of decentralizing the operation and management of irrigation systems by constituting local bodies known as "Pani Panchayats" (PP) or Water User Associations (WUAs) in 1994. However, the initial efforts were not successful in creating functional WUAs across the state. Consequently to empower the PPs by providing legal standing, the state government enacted the Pani Panchayat Act, 2002 and the rule came into force in 2003. The primary objective of this Act was to create functional PPs across the state and thereby, ensure efficient utilization of water by farmers to improve agricultural production.

PPs are primarily responsible for the operations and maintenance of canal systems at minor, sub-minor and distributary levels. The operations duties can range from removal of silt, grass, shrubs and bushes from canal embankments and field drains to lining, painting and plastering structures. They can also construct field channels within their command area to facilitate better flow of water to all farmers. PPs also communicate with farmers to ensure fair distribution of water. As of 2014, there are approximately 25,000 PPs across 30 districts in Orissa covering all types of irrigation systems.

2.3 Institutional Details of Pani Panchayats

We now provide a brief description about the composition of a PP. Each PP covers 300-600 hectares of command area of an irrigation project. It is divided into a number of jurisdictions which are referred to as outlet command areas or "chaks". Each PP on average have about 15 "chaks".[5] Each chak has a "Chak Committee" composed of three elected members. The members are elected one each from the upper, middle and lower reaches of the chak. A representative, called the chak leader, in each of these chak committees is chosen by rotation to serve as a member in the executive committee of the PP. The size of the executive committee in a PP is therefore given by the number of chaks present in the PP. The executive committee of the PP makes decisions about the operation and maintenance of the relevant part of the irrigation system. We refer to members of the executive committee

[5] This is analogous to a village council or Gram Panchayat in India, which is partitioned into a number of wards.

as the elected members of the PP, since they are the primary decision-makers in a Pani Panchayat. The elected members of PP have six years of tenure.

3 Conceptual Framework

We discuss the conceptual framework surrounding irrigation management to understand the potential implications of decentralization. It helps us form hypotheses and guides our empirical tests in the next section. In Appendix A we build a formal model based on the arguments provided below.

Under a centralized management of the canal irrigation, the primary constraint facing the central planner (the irrigation department) is its ability to monitor the activities of all the farmers covered by the canal system. Specifically, the central planner worries that once it releases water into the canal, farmers who are nearer to the canal and get access to the water earlier, would extract inefficiently high amount of water. This would leave too little water for farmers located towards the tail of the canal, leading to inefficient spatial allocation of water. A capacity constrained planner therefore optimizes it monitoring strategy to minimize over-extraction and consequently, maximize aggregate production. We formally show that, as long as the planner can not audit all farmers – a reasonable assumption in the context of large canal irrigation systems in our context – there will be spatial mis-allocation of water under the centralized management.

A decentralized irrigation management creates locally elected bodies in each village that can monitor the farmers' water extraction decisions in the respective village. The central planner is still responsible for deciding the amount of water to be released in the canal. Decentralization of management improves the capacity to monitor the farmers since the local management bodies will have a greater capacity to audit any given farmer. This could be either because it is easier for the farmers at the tail to complain to the locally elected bodies, facilitating greater information flow, or local monitors already having better information about farmers in their village, making it easier to monitor. Decentralization therefore increases the probability of being audited for any given farmer, reducing over-extraction. Thus, decentralization can increase allocation of water for farmers located farther away from the canal and consequently, ensure more equitable allocation of water.

The effect of decentralization on spatial allocation of water is, therefore, heterogeneous across farmers located at various distances away from the canal. For farmers located near the tail, it increases water allocation, while for those located near the head, it may reduce allocation, negatively affecting their agricultural performance. We test this prediction using survey data from Orissa, India.

4 Data

4.1 Survey Details

To collect data on agricultural outcomes including water allocation, we conducted a survey of farmers and elected members of PPs in the state of Orissa during the months of April-June in 2019. The survey covered 80 Pani Panchayats pertaining to canal irrigation across 8 districts covering 10 irrigation divisions.[6] The eight districts included in our survey are Balasore, Bargarh, Bhadrak, Kalahandi, Khordha, Mayurbhanj, Nayagarh and Naupada. The survey districts are depicted in Figure 1. The districts were chosen to capture the variation in the agro-climatic conditions in the state. The districts of Balasore, Bhadrak, Khordha, Mayurbhanj and Nayagarh are in close proximity to the coastal region while the districts of Bargarh, Kalahandi and Naupada lie in the hinterlands. A comprehensive list of all the PPs in each of these 8 districts were prepared by department of water resources of the state government of Orissa. Then 80 PPs across these districts were randomly sampled from the comprehensive list.

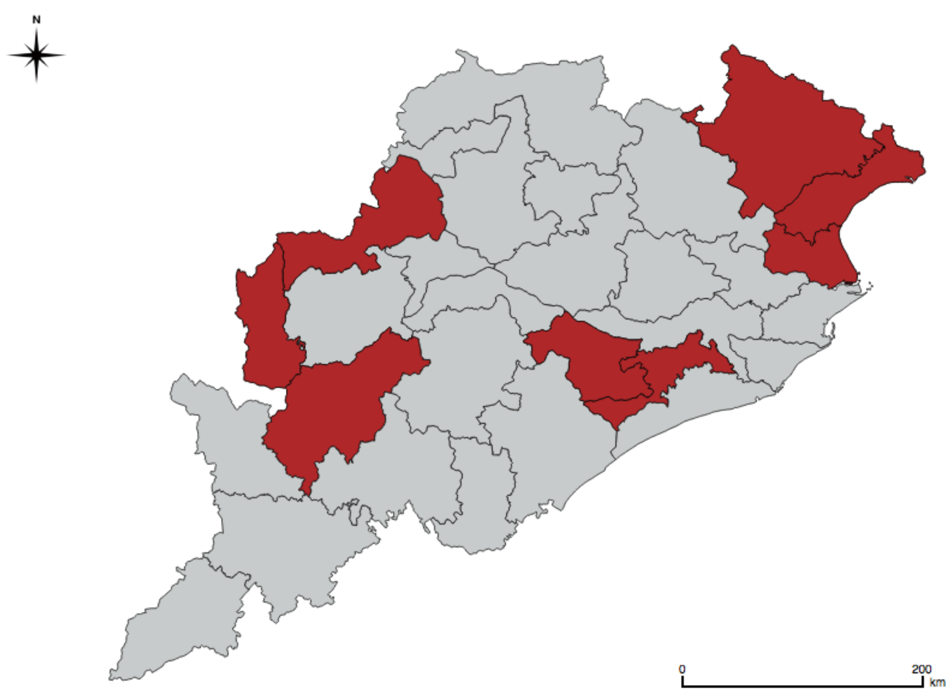


Figure 1. Survey Districts in Orissa

In our survey, we had two sets of questionnaires; one for the elected members of PPs and the other for the beneficiaries or farmers. In each PP, two "chaks" or command areas

[6]We surveyed 100 Pani Panchayats of which 20 belonged to lift irrigation projects, which we do not consider for analysis in this paper.

were randomly selected and 9 randomly selected beneficiaries were interviewed in each of the selected chaks. We interviewed 1423 farmers and 562 elected PP members during the survey.

In the beneficiary survey, we collected information on demographics and household assets, details on agricultural land holdings, output, availability of water, distance to canal and soil quality. We also collected information on the price received for their output and their interaction with PP members. The data on water supply is self-reported by the farmers. This is because the water resources department of the state government does not collect data on water allocation using water meters. The department releases water in the canals in tranches. In a season, the department releases several such tranches of water. Each tranche of water ensures supply for about 7-10 days in the field. However, if there is over-extraction by farmers at the head of the canal, some farmers, especially those located at the tail, may not receive water in a given tranche. The number of tranches of water received by a farmer in a season, therefore, can vary. We use this as our main variable capturing water allocation. We also ask the farmers about water availability, output and price 10 years back. This allows us to create a panel data at the level of farmers.

In the PP member questionnaire, we collected information on demographics, landholding, education, their political experience such as participation in local village council or Gram Panchayat (GP) elections etc. We collected information at the PP level from one of the office bearers in the executive committee of the PP. The PP level data contain number of command areas or "chaks" it serves, its annual revenue and expenditure details, history of Pani Panchayat elections etc.

4.2 Descriptive Statistics

Table 1 provides the descriptive statistics for surveyed farmers and elected PP members in Panels A and B respectively. Panel C reports the descriptive statistics at the PP level. In the final sample that contains information about all the relevant variables, we have data for 1411 beneficiaries and 562 elected PP members across 80 PPs.

4.2.1 Characteristics of Farmers and Elected PP Members

We find that 28 percent of farmers and 22 percent of PP members are from the backward classes comprising of Scheduled Castes (SCs) and Schedule Tribe (STs).[7] The percentage of women farmers is 2 percent while among PP members it is 22 percent.[8] This relatively higher

[7] The SCs and STs are officially designated groups of historically disadvantaged people in India.

[8] The low share of women among farmers is due to the fact that landholding in rural India is typically in the name of the male members of a household.

Table 1—Summary statistics

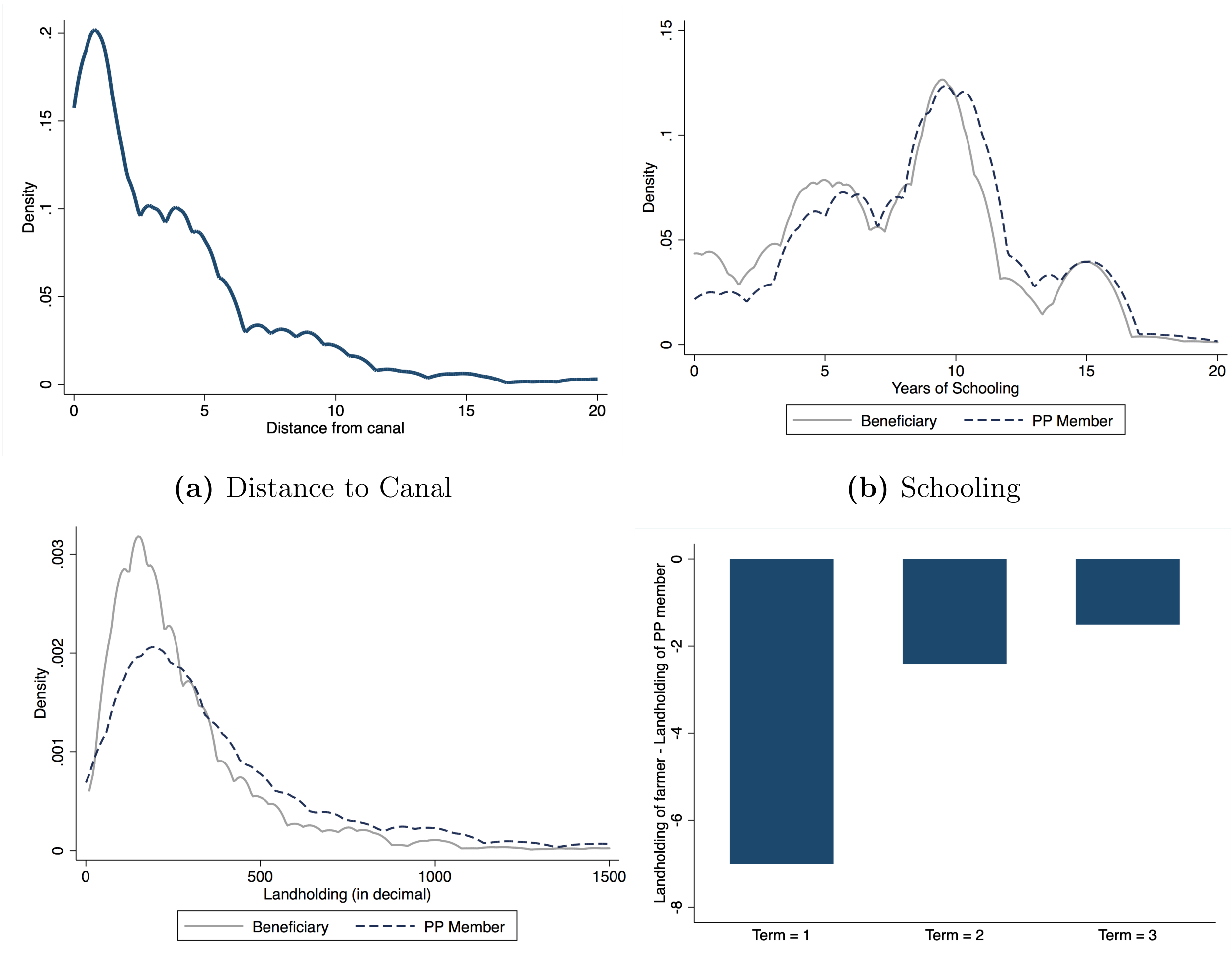
Variable	Obs	Mean	SD
Panel A: Farmers			
SC/ST	1411	0.28	0.45
Female	1411	0.02	0.14
Age	1411	50.98	12.41
Years of schooling	1411	7.71	4.22
Landholding (in decimal)	1411	275.78	247.00
HH size	1411	5.79	2.58
Distance from canal (in '00 meters)	1411	3.55	3.89
Number of tranches of water received	1411	9.32	4.94
Agricultural output (in ton)	1411	2.72	2.64
Interacts with PP members	1411	0.79	0.40
Panel B: Elected PP Members			
SC/ST	562	0.22	0.41
Female	562	0.21	0.41
Age	562	52.18	11.77
Years of schooling	562	9.01	3.9
Landholding (in decimal)	562	493.00	635.28
Upper reach	562	0.43	0.49
Middle reach	562	0.34	0.42
Lower reach	562	0.22	0.41
Contested in GP election	562	0.12	0.33
Held position in GP council	562	0.09	0.28
Anyone in family held position in GP council	562	0.09	0.29
Panel C: Pani Panchayat			
Number of outlet command areas	80	15.15	9.96
Number of PP Terms completed and ongoing	80	2.22	0.59
Annual expenditure on canal construction (in rupees)	80	112787.5	373074.5

Notes: The variables in panel A are for beneficiaries, panel B for PP members and panel C are at the level of PP.

representation of women among PP members is primarily driven by quotas for women in PP elections. The farmers' main farming plot within a PP are located at various distances from the canal. The average distance of the farming plot from the canal is 355 meters.[9] There is substantial heterogeneity in the distance of the farming plot from the canal as shown in Figure 2a. As discussed in our conceptual framework, this is an important source of mis-allocation of water. In our empirical analysis we will examine heterogeneity in treatment effect along this dimension. Farmers receive irrigation water on average 9.32 times in the primary agricultural season and produce 2.72 tonnes of agricultural output on average. About 80 percent of the farmers interact with PP members at least once in a farming season.

The average age of farmers and PP members is 50.98 years and 52.18 years respectively. The average years of schooling for the farmers and PP members are 7.71 years and 9.01 years

[9]This distance is the sum of the distance of the plot from the outlet that serves canal water to the outlet's command area and the distance of the outlet from the main canal.



(a) Distance to Canal

(b) Schooling

(c) Landholding

(d) Landholding Difference across Terms

Figure 2. Farmer and PP Member Characteristics

respectively. The distribution of years of schooling for both the groups, as shown in Figure 2b, depicts that PP members are slightly more educated than farmers. PP members have on average higher landholding as compared to farmers. The average landholding for farmers is 275.78 decimal while that for PP members is 493 decimal. Moreover, the distribution of landholding in figure 2c is more right-skewed for PP members as compared to the farmers indicating that PP members are wealthier than an average farmer. This is similar to a finding by Besley et al. (2004) and others that elected village council or GP members also tend to be more educated and wealthier than the average voter.

4.2.2 Characteristics of Pani Panchayats

By the time of the survey, the Pani Panchayats had already been introduced in all the relevant regions of the state. Hence, all areas were treated at the time of survey. However, due to the staggered constitution of the Pani Panchayats, there is cross-sectional variation in the number of terms that a PP has experienced so far (i.e., number of terms completed in addition to the ongoing term). We therefore use number of PP terms experienced as the treatment variable, measuring the degree of the treatment. On average, our sample of PPs have had 2.22 terms; it varies from 1 to 3 in the sample. Figure 2d plots the average difference in landholding between farmers and elected PP members across PPs with different number of terms experienced. The average values are always negative implying that farmers are less wealthy than the elected representatives. The magnitude of the difference however is significantly lower in PPs that have experienced larger number of terms, i.e., PPs with a longer exposure to the decentralized system. It suggests that the "representativeness" of elected members have increased with greater experience of the new institution.

Table 2 Panel A regresses various PP level characteristics and outcomes on PP Term. We do not find any significant correlation, suggesting that PPs that have had more terms (at the time of survey) are not systematically different based on observable characteristics. Additionally, we use data on the history of PP elections in each PP to compute the change in PP terms between 10 years prior to the survey and the survey year. Panel B of Table 2 regresses the PP characteristics on the change in PP Term and find that most characteristics are not significantly correlated with the change, except share of SC/ST farmers. The coefficient is significant at 10% for that variable, suggesting that areas with fewer SC/ST farmers have experienced a greater change in PP terms.

4.2.3 Activities and Political Experience of PP Members

Among the PP members interviewed, 43 percent belong to the upper reach, 24 percent belong to the middle reach and the rest 22 percent are from the lower reach of an outlet in a command area. The political experience of PP members in formal politics is relatively low with only 12 percent having contested a village council or Gram Panchayat (GP) elections ever.[10] In our sample, only 9 percent of PP members report that they have held some position within a GP council and a similar percentage report that someone in the family have held a position in the GP council. These figures indicate that participation in the newly created institution is not determined by individuals' activities in the other local government institution.

The average number of "chaks" or outlet command areas within a PP is 15 as reported in Panel C of Table 1. The average annual expenditure on canals in a PP is 112,787.5 rupees. The canal expenditure includes both new construction as well as maintenance and cleaning expenses.

[10]GPs are the lowest tier of governance in rural India. The elected members of a GP are responsible for providing a broad array of local public goods such as hand pumps, sanitation facilities, local roads, etc.

Table 2—Differential Characteristics of PPs with Different Terms

	Landholding (1)	Price (2)	Productivity (3)	SC/ST (4)	Female (5)	Inequality (6)
			Panel A			
PP Term	7.666	-6.539	-0.000	-0.004	0.028	8.149
	(8.297)	(6.323)	(0.001)	(0.052)	(0.031)	(8.128)
			Panel B			
Δ PP Term	6.813	-6.377	-0.001	-0.090*	0.020	10.633
	(10.894)	(5.891)	(0.000)	(0.048)	(0.026)	(11.524)
Mean Dep. Var. at baseline	167.05	16.72	0.02	0.28	0.02	101.47
Observations	80	80	80	80	80	80
Irrigation Division FE	YES	YES	YES	YES	YES	YES

Notes: The dataset is at the level of Pani Panchayats. The dependent variables across columns are mean landholding of farmers in a PP (1), mean price of output farmers received (2), mean productivity of plots (3), share of SC/STs (4), share of women farmers (5) and standard deviation of landholding (6). PP Term is the number of terms experienced (i.e., completed and the current ongoing term) by the Pani Panchayat where a farmer's main plot is located. Δ PP Term is the change in PP Term over 10 years. All regressions include number of chaks in a PP and irrigation division fixed effect. Robust standard errors are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

5 Empirical Strategy

Cross-sectional Estimation: We first estimate the effect of Pani Panchayats using cross-sectional data. We use number of PP terms experienced, defined in Section 4.2 above, as our measure of the treatment. It captures how long a PP has been exposed to the decentralized institution. We therefore examine whether greater exposure to the decentralized institution leads to differential outcomes across PPs. We estimate the following specification:

$$Y_{ipd} \;=\; \alpha_d + \gamma PP\_Term_{pd} + X_{ipd}\beta_1 + Z_{pd}\beta_2 + \epsilon_{ipd} \tag{1}$$

where Y_{ipd} is the outcome variable for beneficiary i in Pani Panchayat p under irrigation division d. PP_Term_{pd} is the number of PP terms experienced and takes the values 1, 2 and 3. X_{ipd} is a vector of individual level controls including distance of farmer i's main plot from canal, Z_{pd} is a vector of PP level controls, α_d are the irrigation division fixed effects, and ϵ_{ipd} are unobserved idiosyncratic shocks that affect Y_{ipd}. Our coefficient of interest is γ that estimates the effect of an additional PP term on outcome. Moreover, we examine whether the treatment effect is larger for farmers whose farming plots are farther away from the canal. This will allow us to test the impact of decentralization on spatial allocation of water. We therefore estimate the heterogeneous treatment effect using the following specification:

$$Y_{ipd} \;=\; \alpha_d + \gamma PP\_Term_{pd} + \delta PP\_Term_{pd} * Distance_{ipd} + X_{ipd}\beta_1 + Z_{pd}\beta_2 + \epsilon_{ipd} \qquad (2)$$

where $Distance_{ipd}$ is the distance of farmer i's main plot from the canal. δ estimates the heterogeneous treatment effect; it measures the differential impact of an additional PP term on outcome for every unit increase in distance.

Panel Estimation: The PP elections were introduced in a staggered manner primarily due to administrative reasons. However, if the administrative difficulty of conducting PP elections is correlated with local characteristics of the PPs, such as the ability of farmers in the area to coordinate among themselves or other unobservable features of farmers and local geography, then the cross-sectional estimation may yield biased estimates. More generally, cross-sectional estimation may not be ideal given that the timing of the PP elections is likely to be affected by PP level unobservable factors. Hence, we exploit the panel nature of the data. For each PP, we compute $PP\_Term_{pd,-10}$, i.e, the number of PP terms experienced 10 years ago. We do this using the data on years of all the past PP elections in each PP. Moreover, we ask each farmer to report the number of tranches of water they received 10 years ago, as well as farm output, price and revenue at that time. This allows us to estimate the effect of the change in PP terms over 10 years *for the same PP* on the change in the outcome variables for the farmers living in the PP. By comparing outcomes for the same PP, we eliminate time invariant unobservable factors that could have affected the timing of the PP elections. Specifically, we estimate the following regression equation:

$$Y_{ipd,t} \;=\; \alpha_p + \psi_t + \gamma PP\_Term_{pd,t} + X_{ipd}\beta_1 + \epsilon_{ipd,t} \qquad (3)$$

where α_p are PP fixed effects and ψ_t is the time period fixed effect with $t \in \{0, -10\}$ being the time period; $t = 0$ implies the survey year while $t = -10$ implies 10 years back. We estimate the heterogeneous treatment effect using the following equation:

$$Y_{ipd,t} \;=\; \alpha_p + \psi_t + \gamma PP\_Term_{pd,t} + \delta PP\_Term_{pd,t} * Distance_{ipd} + X_{ipd}\beta_1 + \epsilon_{ipd,t} \qquad (4)$$

Our coefficient of interest, δ, now estimates the differential impact of changes in PP terms over a 10 year period for a given PP on farmers located in that PP at various distances away from the canal. γ measures the effect of PP term for the farmers located right next to the canal. In equation 4, however, estimate of δ could be biased if the location of farmers' plots is correlated with unobservable characteristics of farmers or the plots that shape the treatment effect of PP terms. For example, if farmers with weaker political connections are more likely to be located farther away from the canal, then the effect of decentralization may be underestimated for them, as they may not be able to communicate their grievance effectively with the elected members of the Pani Panchayat. To test if our results are robust to this selection issue, we estimate equation 4 with *individual farmer fixed effects* as well. In this specification, we control for all observable and unobservable differences across farmers and therefore, compare the same farmer over the ten year period to estimate δ.

6 Results

Cross-sectional Estimation: We first examine the effect of PP terms on the allocation of water using cross-sectional estimation given in equation 1 and 2. The outcome variable is the number of times or tranches water was released in the relevant season in the year of the survey.

Table 3—Impact of Pani Panchayat on Allocation of Water: Cross-sectional Analysis

	Number of Tranches			
	(1)	(2)	(3)	(4)
PP Term	1.003**	0.768*	0.531**	0.478*
	(0.470)	(0.437)	(0.264)	(0.262)
Distance from canal	-0.002	-0.190	-0.010	-0.057
	(0.029)	(0.145)	(0.016)	(0.075)
PP Term * Distance from canal		0.078		0.019
		(0.057)		(0.033)
Mean Dep. Var. at baseline	7.18	7.18	7.18	7.18
Observations	1,411	1,411	1,411	1,411
R-squared	0.43	0.43	0.86	0.86
Irrigation Division FE	No	No	Yes	Yes

Notes: The dataset is at the individual farmer level. The dependent variable is the number of tranches in which a farmer received canal water in their main farming plot in the last primary agricultural season. PP Term is the number of terms experienced (i.e., completed and the current ongoing term) by the Pani Panchayat where a farmer's main plot is located. Distance from canal (in 100s of meters) measures the distance of a farmer's main plot from the canal. All regressions include individual and PP level controls. Standard errors are clustered at the Pani Panchayat level and reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 3 reports the results. Column (1) reports the overall treatment effect without any fixed effect. We observe that estimate of γ is positive and statistically significant at 5% level. The estimate is about 1, which implies that farmers in the PPs exposed to one additional PP term receive on average one more tranche of water (on a baseline average of 7.18). This corresponds to a treatment effect of about 14%. In column (3), after adding irrigation division fixed effect, the estimate of γ falls to 0.53 (or 7.4%), but remains statistically significant. The coefficient on the variable 'distance from canal' in both columns is small and statistically insignificant. In columns (2) and (4) we estimate equation 2. Consistent with the model prediction, we find that the coefficient on distance to canal is negative, and its interaction with PP term is positive. However, the coefficients are noisily estimated. The magnitudes of the coefficients are not small. In column (4), for example, the coefficient on distance is about -0.06, which implies that farmers with plot about a kilometer away from the canal receive 0.6 times less number of tranche of water than those located right next to the canal. Moreover, the estimate of δ in column (4) is 0.02, implying that the gap between those same farmers in a PP with one additional PP term will be less by 0.02.

An important reason for a statistically insignificant estimate of δ could be that cross-sectional variation in PP terms is likely to be correlated with unobservable characteristics of PPs, as explained in the previous section. This may result in attenuation bias in the estimate. The panel analysis presented below takes into account of this issue, and therefore, is our preferred method.

Panel Estimation: We now estimate the effect of PP terms using regression equations 3 and 4. Table 4 reports the results for the number of tranches of water allocated. The estimate of γ in column (1) is 3.6 and it is statistically significant at 5% level. The treatment effect estimated using the panel regression therefore is significantly larger than the cross-sectional estimate (Table 3 column (1)). Column (2) estimates the heterogeneous treatment effect. The results verify the model predictions. The coefficient on distance to canal is -0.16 and is statistically significant at 1% level. Therefore, in PPs without any exposure to decentralization, the plot which is one kilometer away from the canal receives 1.6 tranches less water in a season than the plot right next to the canal. The estimate of the interaction term is 0.09 and is statistically significant also at 1% level. Therefore, for every additional term that a PP is exposed to, the aforementioned gap closes down by 0.09 tranches on average. Since the data is an individual level panel, we can estimate γ and δ using individual fixed effects as well. This will compare the responses of the same respondent and therefore, will remove individual level unobservables affecting their survey responses. Columns (3) and (4) report the results. We find that the results are robust to this specification. The coefficient

Table 4—Impact of Pani Panchayat on Allocation of Water: Panel Analysis

	Number of Tranches			
	(1)	(2)	(3)	(4)
PP Term	3.603**	3.175*	3.603**	3.040*
	(1.682)	(1.620)	(1.675)	(1.606)
Distance from canal	-0.004	-0.163***		
	(0.010)	(0.057)		
PP Term * Distance from canal		0.089***		0.117***
		(0.032)		(0.041)
Mean Dep. Var. at baseline	7.18	7.18	7.18	7.18
Observations	2,822	2,822	2,822	2,822
Year FE	Yes	Yes	Yes	Yes
Fixed Effect	PP	PP	Individual	Individual

Notes: The dataset is individual farmer level panel. There are two time periods - current year and 10 years back. The dependent variable is the number of tranches in which a farmer received canal water in their main farming plot in the last primary agricultural season. PP Term is the number of terms experienced (i.e., completed and the current ongoing term) by the Pani Panchayat where a farmer's main plot is located. Distance from canal (in 100s of meters) measures the distance of a farmer's main plot from the canal. All regressions include individual level controls and year or period fixed effect. Columns (1) and (2) have Pani Panchayat fixed effects while (3) and (4) have individual fixed effects. Standard errors are clustered at the Pani Panchayat level and reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

of δ in column (4) is 0.12, marginally larger in magnitude than column (2), and is still statistically significant at 1% level.

Farming Outcomes: We now examine the effect of PP terms on the agricultural performance of the farmers, specifically, the total output produced, the price received and the total revenue generated from the main plot of the farmer. All the farmers in the sample produce paddy in their main plot. Paddy is also the primary agricultural output of the state. The availability of water can affect both the quantity and the quality of rice produced. Specifically, the constrained supply of water can negatively affect the quality of rice grains (Pandey et al., 2014; Cheng et al., 2003), which in turn is reflected through the price.[11] We therefore estimate equation 4 on output, price and revenue as the outcome variables.

Table 5 columns (1) and (2) report the results for paddy output, columns (3) and (4)

[11]The quality of rice is, at least partly, determined by the shape and nature of the kernel, its color etc. (Singh et al., 2000), all of which gets affected by water availability during various stages of the production process.

Table 5—Impact of Pani Panchayat on Farming Outcomes: Panel Analysis

	Output		Price		Revenue	
	(1)	(2)	(3)	(4)	(5)	(6)
PP Term	0.0929	0.0305	-3.265	-3.573	-11,420	-13,893
	(0.130)	(0.144)	(6.682)	(6.786)	(23,374)	(23,760)
Distance from canal	0.00590		-0.812		-3,828**	
	(0.0343)		(0.627)		(1,895)	
PP Term * Distance from canal	-0.0190	-0.00605	0.466*	0.530**	1,757**	2,271***
	(0.0248)	(0.0306)	(0.266)	(0.247)	(705.8)	(706.8)
Mean Dep. Var. at baseline	1.88	1.88	14.23	14.23	21,737	21,737
Observations	2,822	2,822	2,822	2,822	2,822	2,822
R-squared	0.875	0.933	0.032	0.500	0.059	0.513
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cross-sectional FE	PP	Individual	PP	Individual	PP	Individual

Notes: The dataset is individual farmer level panel. There are two time periods - current year and 10 years back. The dependent variable in columns (1) and (2) is total output produced (in unit of 1000 kilogram), in columns (3) and (4) the price received (in rupees per kilogram) on the output, and in columns (5) and (6) total revenue (in rupees) generated in the main farming plot of a farmer. PP Term is the number of terms experienced (i.e., completed and the current ongoing term) by the Pani Panchayat where a farmer's main plot is located. Distance from canal (in 100s of meters) measures the distance of a farmer's main plot from the canal. All regressions include individual level controls and year or period fixed effect. Odd numbered columns have Pani Panchayat fixed effects while even numbered ones have individual fixed effects. Standard errors are clustered at the Pani Panchayat level and reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

for price, and (5) and (6) for revenue. The odd numbered columns have PP fixed effects, while the even numbered columns have individual farmer fixed effects. We find that both coefficients γ and δ are small and statistically insignificant in columns (1) and (2), implying that quantity of output did not respond to PP terms. Columns (3) and (4) show, using price as the proxy of quality, that the distance primarily affects the quality of output, and PP terms significantly reduces the distance penalty. In column (3), the coefficient of distance to canal is negative, but is noisily estimated. Its magnitude, however, is large. For every 100 meter distance, price received by a farmer falls by 0.8 rupees per kilogram. Since an average farmer's plot is 355 meters away from the canal, such a farmer therefore receives 2.8 rupees (or 20% of mean) lower price per kilogram. The interaction of distance with PP term is 0.46 in column (2) and 0.53 in column (3), and they are statistically significant at 10% and 5% respectively. This implies that for every PP term, the price gap closes by more than half, suggesting that distant farmers benefit from decentralization through superior quality paddy.[12] The coefficient on PP term is -3.27, but it is statistically insignificant. It indicates that there might be some reduction in the quality of paddy for the farmers close to the canal. This can happen as with decentralization they may now not be able to get as much water as before. Result 2 in our model predicts this as well. We find in column (5) that distant farmers make significantly lower revenue under centralized system.[13] The coefficient on distance to canal is -3,828 and is statistically significant at 5%. However, every additional PP term reduces the gap by 46%. Hence, the result is consistent with the effect on price. The coefficient of the interaction term is larger and more precisely estimated in column (6), i.e., in the presence of individual fixed effects. The coefficient on PP Term is negative and large in magnitude, but is estimated noisily, in both columns (5) and (6). This is also consistent with the result on prices.

Farmer Welfare: We finally examine whether decentralization led to improvement of farmers' material welfare. For this, we focus on their wealth or landholding; specifically, we examine their land purchasing behavior. Land markets in rural India is thin, and individuals typically buy land when they plan to expand their agricultural activities. Therefore, purchase of land can be a good proxy of the overall material welfare of farmers. We collected data on the history of land buying and selling for each farmer for the past 10 years. The data gives us information about the year in which the land transaction took place, and the amount of land bought or sold. We restrict our attention to land buying only, and create a farmer-year level panel data. Let $L_{ip,y}$ denote a dummy variable that takes value one if farmer i in Pani Panchayat p purchased land in year y, and is zero otherwise. We then run the following regression:

$$L_{ip,y} \;=\; \alpha_i + \psi_y + \gamma PP\_Term_{p,y-1} + \delta PP\_Term_{p,y-1} * D_{ip} + \epsilon_{ip,y}$$

where $PP\_Term_{p,y-1}$ is the value of PP term for p in year $y-1$ and α_i is individual fixed effect, and D_{ip} is a dummy that takes value one if the distance of farmer i's plot from canal is larger than median, and is zero otherwise. We use this indicator variable in place of the continuous distance variable because the mean of land purchase dummy is very small (0.005). Hence, we may not get sufficient power to estimate heterogeneous treatment effect with the continuous distance measure. Table 6 columns (1) and (2) report the results with and without the interaction term, respectively. We find that consistent with the result in Table 5, in column (2), the estimate of γ is negative and significant at 10% and the estimate

[12]The effect in part could be driven by farmers planting lower quality of paddy before decentralization that do not require as much water. This may explain why output does not get affected by distance.

[13]Both the output and revenue regressions control for plot size.

Table 6—Impact of Pani Panchayat on Land Transactions

	Land Purchased (1)	Land Purchased (2)	Area of Land Purchased (3)	Area of Land Purchased (4)
PP Term$_{t-1}$	-0.003	-0.008*	0.698	0.062
	(0.004)	(0.004)	(0.619)	(0.499)
PP Term$_{t-1}$ * Large distance from canal		0.007**		1.050**
		(0.003)		(0.514)
Mean Dep. Var.	0.005	0.005	0.827	0.827
Observations	12,699	12,699	12,699	12,699
R-squared	0.109	0.109	0.118	0.118
Year FE	Yes	Yes	Yes	Yes
Cross-sectional FE	Individual	Individual	Individual	Individual

Notes: The dataset is individual farmer level yearly panel. The time period is 2010-2019. The dependent variable in columns (1) and (2) is a dummy that takes value one if a farmer purchased any land in that year and is zero otherwise. The dependent variable in the last two columns is the area (in decimal) of land purchased by a farmer in a year. PP Term$_{t-1}$ is the number of terms experienced (i.e., completed and the current ongoing term) by the Pani Panchayat where a farmer's main plot is located in the previous year. Large distance from canal is a dummy that takes value one if the distance of a farmer's main plot from the canal is larger than the median of the sample, and is zero otherwise. All regressions include individual and year fixed effects. Standard errors are clustered at the Pani Panchayat level and reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

of δ is positive and significant at 5%. Moreover, the magnitudes of the coefficients is larger than the mean of the dependent variable. Therefore, the effects are sizable. In columns (3) and (4) we use area of land purchased as our dependent variable. We find that the estimate of γ is positive, but small in magnitude (relative to the mean) and statistically insignificant. The estimate of δ is 1.05 and is significant at 5% level. The estimate implies that with every additional PP term, the farmers located farther away from the canal doubled their land purchase relative to the mean.

7 Heterogeneous Experience with Decentralization

In this section we examine whether the experience with decentralization analyzed above is heterogeneous across Pani Panchayats with different pre-existing characteristics. The primary motivation behind this exercise is to ascertain whether pre-existing economic environment can impinge on how decentralization shapes spatial allocation of water. Understanding the sources of such heterogeneity can help us examine the generalizability of our results. We focus on two salient features of agriculture and irrigation systems – namely, land inequality and correlation between land size and distance from canal.

Land Inequality: Ability of farmers to over-extract water under centralized management of irrigation may depend on land inequality among them. For example, it could be that in PPs with more equal landholding, it is easier to ensure cooperation among farmers leading to less over-extraction under centralized management. In villages with high land inequality, ensuring cooperation is likely harder. Therefore, decentralized management could potentially have a larger impact in those areas.

To test this, we measure the standard deviation of land holdings of farmers in each PP, and refer to the PPs with higher than median standard deviation as "High Land Inequality" PPs. We estimate heterogeneous effect of decentralization experience across PPs with "High" vs "Low" land inequality using the following specification:

$$\begin{aligned}
Y_{ipd,t} &= \alpha_p + \psi_t + \gamma_1 PP_Term_{pd,t} + \delta_1 PP_Term_{pd,t} * Distance_{ipd} \\
&+ \gamma_2 PP_Term_{pd,t} * High_Ineq_{pd} + \delta_2 PP_Term_{pd,t} * Distance_{ipd} * High_Ineq_{pd} \\
&+ \lambda_2 Distance_{ipd} * High_Ineq_{pd} + X_{ipd}\beta_1 + \epsilon_{ipd,t}
\end{aligned}$$

where $High\_Ineq_{pd}$ is a dummy that identifies whether PP p is "High Land Inequality" or not. Our coefficients of interest are γ_2 and δ_2. γ_2 estimates whether the effect of an additional PP term for a farmer located next to the canal is different in high inequality PPs. δ_2 estimates whether the differential impact of PP term on distant farmers is different in high inequality PPs.

Table 7, column (2) report the results. Column (1) reproduces the main result from Table 4 column (2) for comparison. We see that the main result is primarily concentrated in PPs with high land inequality. The estimates of coefficients γ_2, δ_2 and λ_2 are all statistically significant at 5%, while the coefficients without the interactions with "High Land Inequality" are small in magnitude and statistically insignificant. Therefore, in PPs with low land inequality, the extent of spatial mis-allocation under the centralized management was negligible. Hence, the impact of decentralization was also minimal. In high land inequality PPs, on the other hand, spatial mis-allocation was large, denoted by a negative and statistically significant estimate for λ_2. Moreover, the effect of decentralization was also more pronounced there.

Correlation between Distance and Landholding: The correlation between distance from the canal and land size captures whether distant farmers have comparable landholding

Table 7—Heterogeneous Impact of Pani Panchayat on Water Allocation

	Number of Tranches		
	(1)	(2)	(3)
PP Term	3.175*	1.010	2.989*
	(1.620)	(1.342)	(1.769)
Distance from canal	-0.163***	0.016	-0.311***
	(0.057)	(0.036)	(0.077)
PP Term * Distance from canal	0.089***	-0.020	0.165***
	(0.032)	(0.019)	(0.048)
PP Term * High Land Inequality		2.570**	
		(0.981)	
Distance from canal * High Land Inequality		-0.212**	
		(0.088)	
PP Term * Distance from canal * High Land Inequality		0.126**	
		(0.048)	
PP Term * Low Correlation PP			0.232
			(1.199)
Distance from canal * Low Correlation PP			0.256**
			(0.111)
PP Term * Distance from canal * Low Correlation PP			-0.134**
			(0.065)
Mean Dep. Var. at baseline	7.18	7.18	7.18
Observations	2,822	2,822	2,822
R-squared	0.622	0.653	0.624
Year FE	Yes	Yes	Yes
Cross-sectional FE	PP	PP	PP

Notes: The dataset is individual farmer level panel. There are two time periods - current year and 10 years back. The dependent variable is the number of tranches in which a farmer received canal water in their main farming plot in the last primary agricultural season. PP Term is the number of terms experienced (i.e., completed and the current ongoing term) by the Pani Panchayat where a farmer's main plot is located. Distance from canal (in 100s of meters) measures the distance of a farmer's main plot from the canal. High Land Inequality is a dummy that takes value one if the standard deviation of land size of farmers in a PP is larger than the median. Low Correlation PP is a dummy that takes value one if the absolute value of the correlation between Distance from canal and land size of the plot within a PP is lower than 0.2. All regressions include individual level controls, year or period fixed effect and PP fixed effect. Standard errors are clustered at the Pani Panchayat level and reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

relative to the nearby farmers. If the correlation is very small, then farmers' land sizes are comparable across distance. If, on the other hand, the correlation is high, then farmers' average landholding across various distances are unequal. In low correlation areas, farmers across distance may have better understanding and cooperation among them, potentially limiting the over-extraction problem (under centralization). In high correlation areas, achieving cooperation across farmers may be more difficult, resulting in greater over-extraction. Decentralization may be more effective in those areas.

We compute the correlation between farmers' land sizes and distance from canal for every PP. We identify "low correlation PP" as those having absolute value of the correlation lower than the median. We then estimate a specification similar to (4) with the variable $High\_Ineq$ being replaced by *Low Correlation PP*. The results are reported in column (3) of Table 7. We find that in PPs that are not low correlation, the coefficients on distance and its interaction with PP Term are both statistically significant at 1% and have the expected sign. The interactions of the two variables with Low Correlation PP, however, have opposite signs and similar magnitudes (both are statistically significant at 5%). Therefore, in PPs exhibiting low correlation, distance did not significantly affect water allocation under centralization and consequently, decentralization did not significantly change that relationship. Hence, decentralization is more effective in high correlation PPs, where over-extraction was also more pronounced under centralization.

8 Mechanism

In this section, we examine the possible mechanisms that might be driving the results. Theories of political economy tell us that the source of local government's greater efficacy maybe twofold – firstly, it is easier for dissatisfied farmers to complain about misallocation of water, since the PP members are locally elected and hence, are likely to be more approachable than government officials. Therefore, it is easier for PP members to collect information about "cheating" farmers and audit them. Several papers examining local political institutions do find that citizens approach local political representatives to redress their issues and that it is effective (Chaturvedi et al., 2021; Besley et al., 2005; Ghatak and Ghatak, 2002). We refer to it as the *demand* mechanism, since it operates via farmers' interaction with local representatives facilitated by decentralization. Additionally, the PP members, being farmers themselves, could be in a better position (relative to the officials in the Irrigation Department) to understand the issues related to spatial misallocation of water. Hence, they may take local policy decisions – such as investment in canal expansion and repairing projects – that help reduce the extent of misallocation. We refer to this as the *supply* mechanism. In the subsequent analysis, we investigate both these mechanisms separately.

Demand Mechanism: To test if the demand mechanism is at work, we collect data on the frequency with which beneficiaries interact with their local PP representatives. We create a dummy variable called "Interaction" that takes value one if a respondent interacts with

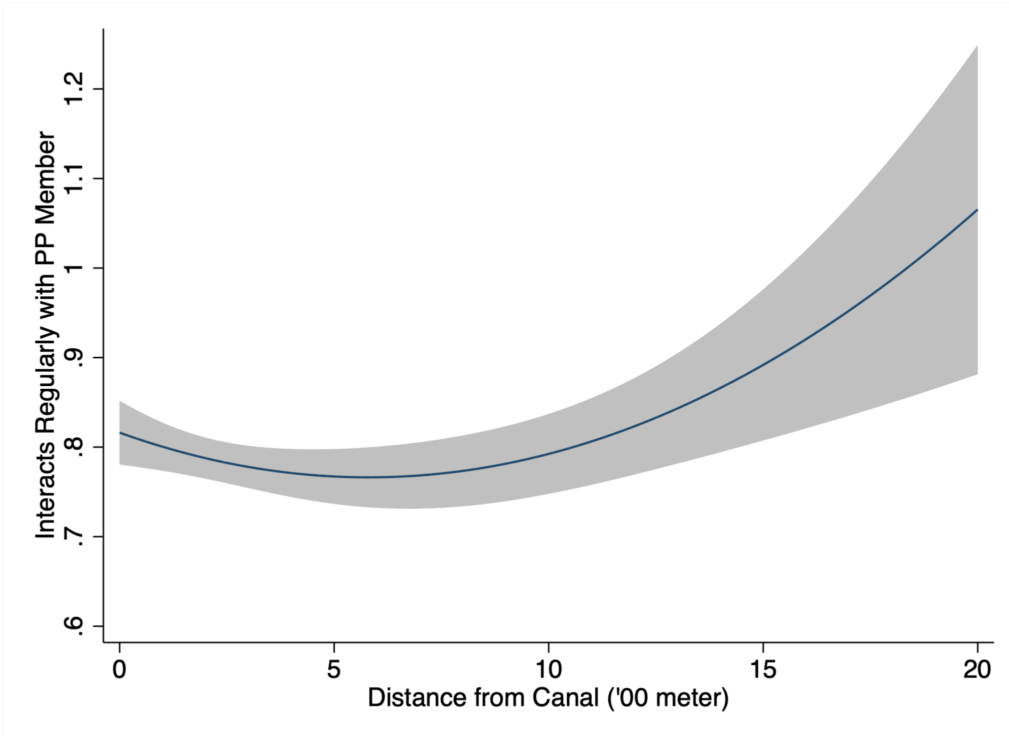


Figure 3. Farmers with Distant Plots Interacts More Frequently with PP Members

PP members at least once every season.[14] Table 1 reports that the mean of the variable is 0.8. This suggests that the PP members are generally in constant communication with the farmers. If the demand mechanism is at work, then the farmers who are farther away from the canal would have higher incentive to interact with the PP members, to communicate about receiving less water than desired. In Figure 3, we plot the dummy variable against the distance from canal. We find that the relationship is initially flat; however, after about 700 meters, the probability of interaction increases with distance. The probability of interaction is one for distance more than 1500 meters. The pattern is therefore consistent with demand mechanism being an important channel.

We test the importance of this mechanism more directly by examining whether the treatment effect and its heterogeneity are concentrated for farmers who interacts regularly with the PP members. We estimate the following regression equation:

$$Y_{ipt} \quad = \quad \alpha_p + \psi_t + \gamma_1 PP\_Term_{pt} + \delta_1 PP\_Term_{pt} * Distance_{ipd}$$

[14]The respondents give one of four responses to our question about whether they interact with PP members – no interaction, interacts once a year, once every six months, and once every season. All results remain robust if we consider the last three categories (i.e., at least some interaction) as our indicator of interaction.

$$
\begin{aligned}
&+ \quad \gamma_2 PP\_Term_{pt} * Interaction_{ip} + \gamma_3 Interaction_{ip} * Distance_{ipd} \\
&+ \quad \delta_2 PP\_Term_{pt} * Distance_{ipd} * Interaction_{ip} + X_{ip}\beta + \epsilon_{ipd}
\end{aligned}
$$

The vector of controls X_{ip} includes the variables Distance and Interaction. Our coefficients of interest are γ_2 and δ_2. γ_2 estimates the differential treatment effect for the farmer who interact regularly with PP members, and δ_2 estimates how the heterogeneous treatment effect across plots with varying distance differ for regularly interacting farmers.

Table 8—Demand Mechanism Explaining the Impact of Pani Panchayat

	Number of Tranches			
	(1)	(2)	(3)	(4)
PP Term	2.353*	2.127	1.657	1.656
	(1.385)	(1.360)	(1.198)	(1.185)
Distance from canal	-0.00345	-0.145**		
	(0.00983)	(0.0555)		
Interacted with PP member	-2.905***	-2.813***		
	(0.899)	(0.882)		
PP Term * Interacted with PP member	1.746***	1.554***	2.719***	2.123***
	(0.540)	(0.540)	(0.779)	(0.797)
PP Term * Distance from canal		0.0410		-0.0267
		(0.0299)		(0.0195)
PP Term * Distance from Canal * Interacted with PP member		0.0443**		0.148***
		(0.0169)		(0.0470)
Mean Dep. Var. at baseline	7.18	7.18	7.18	7.18
Observations	2,822	2,822	2,822	2,822
Year FE	Yes	Yes	Yes	Yes
Fixed Effect	PP	PP	Individual	Individual

Notes: The dataset is individual farmer level panel. There are two time periods - current year and 10 years back. The dependent variable is number of tranches in which a farmer received canal water in their main farming plot in the primary agricultural season. PP Term is the number of terms experienced (i.e., completed and the current ongoing term) by the Pani Panchayat where a farmer's main plot is located. Distance from canal (in 100s of meters) measures the distance of a farmer's main plot from the canal. Interacted with PP member is a dummy that takes value one if a farmer interacts with elected PP members at least once every season and is zero otherwise. All regressions include individual level controls and year or period fixed effect. Columns (1) and (2) have Pani Panchayat fixed effects while (3) and (4) have individual fixed effects. Standard errors are clustered at the Pani Panchayat level and reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 8 reports the results. Column (2) estimates the equation specified above. Column (1) reports the results without the heterogeneous treatment effect w.r.t. distance. In both columns, the estimate of γ_2 is positive and is statistically significant at 1% level. Therefore, the treatment effect is higher for the farmers who interact regularly with PP members. The estimate of γ_1 in both columns is smaller in magnitude and is noisily estimated, suggesting that for the farmers who do not interact frequently, the treatment effect is weaker. In column

(2), the estimate of δ_2 is also positive and is statistically significant at 5%. Therefore, the heterogeneous treatment effect is also concentrated among regularly interacting farmers. The coefficient on interaction is negative and statistically significant. Therefore, at the baseline (i.e., in PPs without any decentralization) these farmers received *less* tranches of water (even after controlling for their distance to canal). Therefore, our result is likely not driven by the unobservable characteristics of the farmers who interact more. In columns (3) and (4) we estimate the same specifications with individual fixed effect. This controls for individual level unobservable factors that could be correlated with both interaction and water allocation. We find that the results in fact get strengthened with this specification. Estimates of both γ_2 and δ_2 are positive, larger in magnitude than columns (1) and (2), and statistically significant at 1%. The results therefore suggest that demand mechanism is an important channel explaining the results.

Table 9—Impact of Pani Panchayat on Local Canal Expenditure

	Canal Expenditure per Chak	
	(1)	(2)
PP Term	4,234	6,730
	(6,903)	(8,374)
Mean Dep. Var.	12544.98	12544.98
Observations	80	80
Fixed Effect		Irrig. Division

Notes: The dataset is at the level of Pani Panchayats. The dependent variable is the total canal related expenditure (in rupees) made by a Pani Panchayat per "chak" or command area in the previous financial year. PP Term is the number of terms experienced (i.e., completed and the current ongoing term) by the Pani Panchayat where a farmer's main plot is located. Both regressions include Pani Panchayat level controls. Column (2) has irrigation division fixed effects. Robust standard errors are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Supply Mechanism: In addition to the demand mechanism, it may be possible that supply side factors, such as investment in local canal expenditure, drive part of the results as well. To examine this, we test whether PPs with higher number of terms invest more in canal construction or maintenance per chak. Since the Pani Panchayat representatives lacked information about expenditure details in previous terms, we could not collect panel data on expenditure across terms. We therefore estimate a PP level cross-sectional regression by regressing canal expenditure per chak on PP terms and other PP level controls.

Table 9 reports the results. Columns (1) and (2) report the coefficient on PP term without and with irrigation division fixed effects. In both cases, we find that the coefficient is positive but is statistically insignificant. The magnitude of the coefficient is however large, relative to the mean of the dependent variable. It suggests that there might be some supply side effect, but the evidence in favor of the mechanism is not strong.

9 Conclusion

Canal irrigation has been known to suffer from spatial misallocation of water, due to incentive of farmers located at the head of the canal to over-extract water. Farmers located farther away from the canal, consequently, get too little water, leading to lower agricultural performance. Decentralization can increase the monitoring capacity since it maybe easier for local canal management bodies to be informed about over-extracting farmers in their own area. Hence, decentralization can lead to improvement in the spatial allocation, leading to efficiency gains.

We empirically examine the effect of decentralization of irrigation management using survey data from the state of Orissa, India, that decentralized the management of its canal irrigation system by constituting elected local bodies known as "Pani Panchayats". We exploit variation in the degree of exposure to the decentralized institution, due to the staggered constitution of these local bodies, to estimate its effect on water allocation and other outcomes. We find that while farmers located farther away from the canal received less water and generated lower revenue under the centralized system, these relationships get significantly reduced in PPs exposed to the local institution for a longer time. Consequently, the distant farmers also accumulate more land in those PPs. We find that distant farmers' greater ability to communicate with local representatives can explain our result.

Our results highlight that institutional reforms are an important way to address inefficient distribution of water in agriculture. Given that canal irrigation covers a significant share of irrigated land in India, the potential efficiency gains from such reforms are presumably large.

References

Baland, J.-M., P. Bardhan, S. Das, and D. Mookherjee (2010): "Forests to the people: Decentralization and forest degradation in the Indian Himalayas," *World Devel-*

opment, 38, 1642–1656.

Baland, J.-M. and J.-P. Platteau (1996): *Halting degradation of natural resources: is there a role for rural communities?*, Food & Agriculture Org.

Bardhan, P. (1993): "Analytics of the institutions of informal cooperation in rural development," *World Development*, 21, 633–639.

——— (2000): "Irrigation and cooperation: An empirical analysis of 48 irrigation communities in South India," *Economic Development and cultural change*, 48, 847–865.

Besley, T., R. Pande, L. Rahman, and V. Rao (2004): "The politics of public good provision: Evidence from Indian local governments," *Journal of the European Economic Association*, 2, 416–426.

Besley, T., R. Pande, and V. Rao (2005): "Participatory democracy in action: Survey evidence from South India," *Journal of the European Economic Association*, 3, 648–657.

Bromley, D. W., D. C. Taylor, and D. E. Parker (1980): "Water reform and economic development: institutional aspects of water management in the developing countries," *Economic Development and Cultural Change*, 28, 365–387.

Brozović, N., D. L. Sunding, and D. Zilberman (2010): "On the spatial nature of the groundwater pumping externality," *Resource and Energy Economics*, 32, 154–164.

Burness, H. S. and J. P. Quirk (1979): "Appropriative water rights and the efficient allocation of resources," *The American Economic Review*, 69, 25–37.

Chakravorty, U., E. Hochman, and D. Zilberman (1995): "A spatial model of optimal water conveyance," *Journal of Environmental Economics and Management*, 29, 25–41.

Chakravorty, U. and J. Roumasset (1991): "Efficient spatial allocation of irrigation water," *American Journal of Agricultural Economics*, 73, 165–173.

Chambers, R. (1988): *Managing canal irrigation: Practical analysis from South Asia*, Cambridge University Press.

Chaturvedi, S., S. Das, and K. Mahajan (2021): "The Importance of Being Earnest: What Drives the Gender Quota Effect in Politics?" *ISI Discussion Paper*.

Cheng, W., G. Zhang, G. Zhao, H. Yao, and H. Xu (2003): "Variation in rice quality of different cultivars and grain positions as affected by water management," *Field Crops Research*, 80, 245–252.

Cosgrove, W. J. and F. R. Rijsberman (2014): *World water vision: making water everybodyâs business*, Routledge.

Das, S. (2023): "Inequality in Hierarchies," *Working Paper*.

Drysdale, K. M. and N. P. Hendricks (2018): "Adaptation to an irrigation water restriction imposed through local governance," *Journal of Environmental Economics and Management*, 91, 150–165.

Edwards, E. C. (2016): "What lies beneath? Aquifer heterogeneity and the economics of groundwater management," *Journal of the Association of Environmental and Resource Economists*, 3, 453–491.

Ghatak, M. and M. Ghatak (2002): "Recent reforms in the Panchayat system in West Bengal: Toward greater participatory governance?" *Economic and political weekly*, 45–58.

Gisser, M. and D. A. Sanchez (1980): "Competition versus optimal control in groundwater pumping," *Water resources research*, 16, 638–642.

Jacoby, H. G. and G. Mansuri (2020): "Enforcement for sale: Lobbying for water in Pakistan's Indus Basin," *Journal of Public Economics*, 190, 104255.

Jacoby, H. G., G. Mansuri, and F. Fatima (2021): "Decentralizing corruption: Irrigation reform in Pakistan," *Journal of Public Economics*, 202, 104499.

Koundouri, P. (2004): "Potential for groundwater management: Gisser-Sanchez effect reconsidered," *Water resources research*, 40.

Maloney, C. and K. Raju (1994): *Managing irrigation together*, Sage Publications.

Meinzen-Dick, R., M. Mendoza, L. Sadoulet, G. Abiad-Shields, A. Subramanian, et al. (1994): "Sustainable water user associations. lessons from a literature review," .

Ostrom, E. (1990): *Governing the commons: The evolution of institutions for collective action*, Cambridge university press.

Ostrom, E. and R. Gardner (1993): "Coping with asymmetries in the commons: self-governing irrigation systems can work," *Journal of economic perspectives*, 7, 93–112.

Pandey, A., A. Kumar, D. Pandey, and P. Thongbam (2014): "Rice quality under water stress," *Indian J. Adv. Plant Res*, 1, 23–26.

SEKHRI, S. ET AL. (2013): "Missing water: agricultural stress and adaptation strategies in response to groundwater depletion in India," *Department of Economics, University of Virginia, Charlottesville, VA, Processed.*

SINGH, V., U. SINGH, AND G. KHUSH (2000): "Basmati rice of India," *Aromatic rices*, 135.

SMITH, S. M., K. ANDERSSON, K. C. CODY, M. COX, AND D. FICKLIN (2017): "Responding to a groundwater crisis: The effects of self-imposed economic incentives," *Journal of the Association of Environmental and Resource Economists*, 4, 985–1023.

SOMANATHAN, E., R. PRABHAKAR, AND B. S. MEHTA (2009): "Decentralization for cost-effective conservation," *Proceedings of the National Academy of Sciences*, 106, 4143–4147.

TANG, S. Y. (1992): *Institutions and collective action: Self-governance in irrigation*, ICS press.

WADE, R. (1982): "The system of administrative and political corruption: Canal irrigation in South India," *The Journal of Development Studies*, 18, 287–328.

Appendix

A Model

A.1 Production and Water Allocation

Suppose there is a unit mass of farmers in a village who are uniformly distributed on a straight line in the interval $[0, 1]$. A farmer located at point i in the interval $[0, 1]$ is i distance away from the canal. Hence, farmer at point 0 is closest to the canal and farmer at point 1 is furthest from the canal. Each farmer has an identical, strictly increasing and strictly concave production function given by:

$$q = f(w), \quad f(0) = 0, \quad f' > 0, \quad f'' < 0$$

where q is the quality adjusted amount of output produced and w is the amount of water used by a farmer.[15]

The central planner (irrigation department) decides on the aggregate amount of water to be supplied to the village, denoted by W. Hence, W also captures the average amount of water allocated to each farmer in the village. Once the planner releases water in the canal, farmers who are nearer to the canal get access to the water earlier. Therefore, a farmer i is able to extract positive amount of water provided that the first i proportion of farmers have not appropriated the entire W amount of water allocated. The central planner's objective is to maximize aggregate quality adjusted output of the village net of cost of providing water. The central planner faces strictly increasing and strictly convex cost of providing W, given by $C(W)$.

A.2 Auditing by the Central Planner

In absence of any disciplining device, the farmer 0 would extract all the water allocated. The central planner is aware of this issue and therefore, randomly audits some of the farmers and imposes penalty on those found to be extracting water in excess of the average allocation. The planner, however, has a capacity constraint on auditing; it can audit only $\phi < 1$ mass of the farmers in a given village. Formally, it chooses an auditing scheme $\gamma(i)$ which is a function that specifies the probability with which farmer i will be audited and respects the

[15] In our context, farmers primarily produce rice, and water availability can affect both the quality and quantity of rice. Hence, q denotes the composite index of production after accounting for quality.

aggregate capacity constraint. Hence $\gamma(i) \in [0,1]$ for all i and

$$\int_0^1 \gamma(i)di \;\leq\; \phi \tag{A.1}$$

Let κ denote the exogenously fixed penalty per unit of excess extraction that the planner can impose on farmers, conditional on auditing them. Ideally, the planner would like to impose as high a penalty as possible to minimize over-extraction. However, social and political norms often restricts the planner from imposing very high penalty. κ therefore denotes the maximum penalty that the planner can credibly commit to implement. We assume that κ is common knowledge among farmers and the planner.

A.3 Timeline and Payoffs

The game proceeds as follows: first the central planner decides W and announces the auditing scheme $\gamma(i)$. Next, farmers sequentially decide the optimal level of water to be extracted from the canal, subject to availability. Naturally, the sequence is given by farmers' locations. The central planner then implements its auditing scheme, and finally, the payoffs are realized. The payoff of farmer i is given by:

$$\Pi = \begin{cases} f(w(i)) - \gamma(i)\kappa[w(i) - W] & \text{if } w(i) \geq W, \\ f(w(i)) & \text{if } w(i) < W. \end{cases}$$

where $w(i)$ is the water extracted by farmer i. The optimality condition, subject to availability of water, is then given by:

$$f'(w(i)) = \gamma(i)\kappa$$

Hence, farmer i's optimal choice is

$$w^*(i) = \begin{cases} {f'}^{-1}(\gamma(i)\kappa) & \text{if } \int_0^i {f'}^{-1}(\gamma(j)\kappa)dj < W, \\ 0 & \text{otherwise.} \end{cases} \tag{A.2}$$

The inequality in the equation above says that the aggregate water extracted by all the farmers located ahead of i is smaller than the water released by the planner. $w^*(i)$ is then positive and optimal. If for a farmer, the inequality becomes an equality, then the farmer would not get any water, i.e., $w^*(i) = 0$ in that case. The central planner's optimization problem is given by:

$$\max_{W,\gamma(i)} S \;=\; \int_0^1 f(w^*(i))di - C(W) \quad \text{sub. to} \int_0^1 \gamma(i)di \;\le\; \phi$$

A.4 Equilibrium

We first characterize the nature of equilibrium auditing scheme for any W chosen by the planner. It turns out that the optimal auditing scheme is quite simple; it is characterized by two parameters, $\gamma \in (0,1]$ and $\alpha \in [0,1]$ such that

$$\gamma(i) = \begin{cases} \gamma & \text{if } i \in [0,\alpha] \\ 0 & \text{if } i \in (\alpha,1] \end{cases}$$

We derive the optimal auditing scheme (for a given W) in three steps. First, it is easy to see that in equilibrium, we can not have $\gamma(i) > 0$ and $w^*(i) = 0$. Otherwise, the planner can always reduce its auditing probability on the farmers not getting water and increase it among over-extracting farmers, and this will increase aggregate output. Hence $\gamma(i) = 0$ if $w^*(i) = 0$.

Additionally, for the set of farmers extracting positive amount of water, we must have a constant auditing probability for all of them, i.e., $\gamma(i) = \gamma$, for some positive constant γ. To see this, notice that $\gamma(i) > \gamma(j)$ would imply that $w^*(i) < w^*(j)$. Hence, $\gamma(i)$ falling (or, rising) with i can not be an equilibrium, as reducing the slope of the $\gamma(i)$ function (keeping the aggregate mass of audited farmers constant) would increase aggregate output due to strict concavity of f.

Finally, equation (A.2) implies that if $w^*(i) = 0$ for some i then, $w^*(j) = 0$ for all $j \ge i$, and if $w^*(l) > 0$ for some l then $w^*(j) > 0$ for all $j \le l$. We therefore get that the equilibrium auditing scheme is characterized by a share $\gamma \in (0,1]$ and $\alpha \in [0,1]$ such that

$$\gamma(i) = \begin{cases} \gamma & \text{if } i \in [0,\alpha] \\ 0 & \text{if } i \in (\alpha,1] \end{cases}$$

Under the optimal auditing scheme, therefore, each of the first α share of farmers get audited with probability $\gamma > 0$ and the rest are not audited. For any choice of $\gamma \in (0,1]$, capacity constraint implies

$$\alpha \;=\; \min\left\{\frac{\phi}{\gamma}, 1\right\} \tag{A.3}$$

Since all farmers are identical in terms of production function, allocation of water across farmers is also characterized by α where farmers $[0, \alpha]$ extract positive and identical amount of water, given by $w^* = f'^{-1}(\gamma\kappa)$ and farmers $(\alpha, 1]$ do not receive any water. Higher is the value of γ, lower is the amount of water extracted by a farmer (i.e., w^*), and hence, higher is α. For any given aggregate supply of water W and any $\gamma \in (0, 1]$, the fraction of farmers who receive water is given by

$$\alpha = \min\left\{\frac{W}{w^*}, 1\right\} \tag{A.4}$$

The central planner's optimization problem now becomes

$$\max_{W,\gamma} S \;=\; \alpha f(w^*) - C(W) \quad \text{sub. to equation (A.3)}$$

where α is given by equation (A.4). We solve the problem in two steps. First, we solve the unconstrained optimization, ignoring equation (A.3). We then impose the constraint in the second step to compute equilibrium. The FOC w.r.t. W of the central planner's unconstrained optimization problem is given by:

$$\begin{aligned} C'(W) &= \frac{f(w^*)}{w^*} \\ \Rightarrow \quad W^* &= C'^{-1}\Big(\frac{f(w^*)}{w^*}\Big) = \frac{C'^{-1}\Big(\frac{f(f'^{-1}(\gamma\kappa))}{f'^{-1}(\gamma\kappa)}\Big)}{f'^{-1}(\gamma\kappa)} \end{aligned}$$

The second equality comes from substituting $w^* = f'^{-1}(\gamma\kappa)$. This unconstrained optimal W^* depends on γ. Given this W^*, the fraction of farmers in the village who receive water is given by (from equation (A.4)):

$$\alpha \;=\; \frac{C'^{-1}\Big(\frac{f(f'^{-1}(\gamma\kappa))}{f'^{-1}(\gamma\kappa)}\Big)}{f'^{-1}(\gamma\kappa)} \tag{A.5}$$

Equation A.5 describes how the share of farmers extracting positive amount of water changes with the audit probability γ. However, the share of farmers that the planner can audit for any γ is given by equation A.3. The share of farmers who are extracting surplus water and the share of farmers who are audited must be the same in equilibrium. The equilibrium, therefore, is given by (α^*, γ^*) such that both equations A.3 and A.5 are satisfied. We now make the following assumption on the parameter ϕ:

Assumption 1:

$$1 \geq \bar{\alpha} = \frac{C'^{-1}\Big(\frac{f(f'^{-1}(\kappa))}{f'^{-1}(\kappa)}\Big)}{f'^{-1}(\kappa)} > \phi$$

Intuitively, the assumption implies that even when farmers believe that they will be audited with probability one (i.e., $\gamma = 1$), the share of farmers extracting excess water (i.e., $\bar{\alpha}$ in the equation above) is still larger than the audit capacity of the planner, but is smaller than one. As the result below states, Assumption 1 ensures an interior solution (i.e., both $\alpha^*, \gamma^* \in (0, 1)$) to the problem.

Result 1 *Under Assumption 1, an interior equilibrium exists and is unique.*

Proof:

Let us denote

$$g(w) = \frac{f(w)}{w}$$

Since, f is strictly concave and $f(0) = 0$, then for any w, we have $f'(w) < \frac{f(w)}{w}$. Hence, $\frac{f(w)}{w}$ is decreasing in w as $f'(w)$ is a decreasing function of w. Thus, $g'(w) < 0$. We can rewrite equation A.5 in terms of $g(w)$ as follows:

$$\alpha = \frac{C'^{-1}(g(w))}{w} \tag{A.6}$$

Differentiating equation A.6 with respect to w we obtain:

$$\frac{dh}{dw} = \frac{\frac{1}{C''(C'^{-1}(g(w))}g'(w) - C'^{-1}(g(w))}{w^2}$$

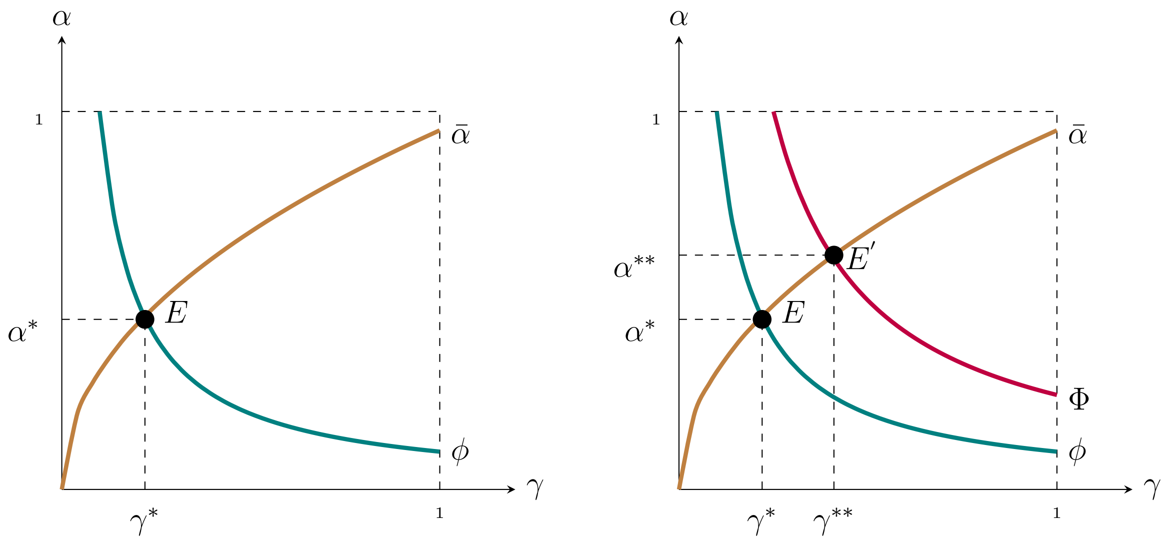
Since $C' > 0$ and $C'' > 0$, we have $C'^{-1} > 0$ and given that $g'(w) < 0$, we have $\frac{dh}{dw} < 0$. From equation A.2, we know that $w = f'^{-1}(\gamma\kappa)$ and hence $\frac{dw}{d\gamma} < 0$. We can thus establish a relationship between α and γ using equation A.5 which can be written as

$$\alpha = h(w(\gamma))$$
$$\frac{d\alpha}{d\gamma} = \frac{dh}{dw}\frac{dw}{d\gamma}$$

Given that $\frac{dh}{dw} < 0$ and $\frac{dw}{d\gamma} < 0$, we obtain that $\frac{d\alpha}{d\gamma} > 0$. Hence from equation A.5, we obtain that there is a monotonically increasing relationship between α and γ. Moreover, when $\gamma = 0$, i.e., the probability of catching a violator is zero then all water will be extracted by the first farmer and hence $\alpha = 0$. Similarly, when $\gamma = 1$, we know that the value of α which is given by $\bar{\alpha}$ in assumption 1.

From equation A.3 it is easy to infer that there is a strict negative relationship between α and γ. Also, when the value of $\gamma = 0$, then the value of α is infinite and when the value of $\gamma = 1$ then the value of $\alpha = \phi$ which under assumption 1 is lower than $\bar{\alpha}$.

This ensures that there exists an intersection between these two curves given by equation A.5 and equation A.3 which determines the value of α^* and γ^* in equilibrium. Moreover, the monotonicity of these two curves ensure that these values are unique. Given the value of γ^*, we can then uniquely determine $w^* = f^{'^{-1}}(\gamma^*\kappa)$ and W^* from equation A.4 respectively. ■



(a) Equilibrium α and γ

(b) Equilibrium with Decentralization

Figure A.1. Equilibrium Analysis

We also explain the computation of the equilibrium graphically using Figure A.1a. The downward sloping green curve in Figure A.1a depicts equation (A.3). We interpret it as the audit supply curve, since it shows for any given value of γ the maximum share of farmers that the planner can audit. Equation A.5 is shown using the upward sloping brown curve. We refer to this as the audit demand curve. This is because it shows the share of farmers who are extracting surplus water (i.e., the share of farmers that needs to be audited) for any given γ. When $\gamma = 0$, the farmers located at zero extract all water, and hence $\alpha = 0$. Moreover, as the audit probability γ increases, it reduces extraction by the farmers located closer to the canal, leading to an increase in the share of farmers receiving water, i.e., α increases. Hence, the audit demand curve begins at the origin and is upward sloping. The equilibrium is therefore given by the point E depicting the intersection of the demand and supply curves for auditing. Such an equilibrium would always exist as long as the demand at $\gamma = 1$, given by $\bar{\alpha}$, is lower than supply at that point, given by ϕ. Assumption 1 ensures that it is indeed true. In equilibrium, $(1 - \alpha^*)$ share of farmers located at the tail of the canal do not receive water. The equilibrium therefore exhibits spatial misallocation of water.

In our model, farmers either receive a given amount of water or do not receive any water at all. This nature of allocation is driven by the simplified version of our model, that assumed a continuum of identical farmers. In reality, as we show in our empirical analysis in the paper, all farmers receive some water, with the allocation falling monotonically with distance. A discrete version of the model with N farmers would have generated such an allocation in equilibrium, but at the cost of significantly increasing the complexity of analysis, without any additional insight.[16] We therefore prefer the simplified version of the model that exhibits spatial misallocation in a more tractable framework.

A.5 Decentralization of Irrigation Management

Now we consider a decentralized irrigation management system. The central planner is still responsible for deciding the aggregate amount of water to be supplied in each village, but now there are local authorities in the village (Pani Panchayats) who can audit the farmers. In our framework, the aspect of decentralization can be captured by an increase in the audit capacity in a village, now denoted by Φ. We assume that $1 > \Phi > \phi$. The central planner is typically responsible for supplying water to multiple villages and hence has limited *per village* audit capacity, which we denoted as ϕ. With decentralization, local authorities audit farmers in their respective villages. The presence of local authorities incentivizes local farmers who are not receiving water to complain to them, which facilitates easier monitoring. This motivates our assumption that the audit capacity in a village under decentralization is larger than the central planner's per village audit capacity. We now make the following assumption on the parameter Φ:

Assumption 2: $1 \geq \bar{\alpha} > \Phi$

Assumption 2 has the same interpretation as Assumption 1 with the capacity being Φ. We now determine the new equilibrium characterized by the tuple $\left\langle W^{**}, \alpha^{**}, w^{**}, \gamma^{**} \right\rangle$ under enhanced audit capacity. Assumption 2 and Result 1 imply that such an equilibrium exists and is unique. Moreover, the following result allows us to compare the equilibria under centralized and decentralized monitoring systems:

Result 2 *If Assumption 2 holds and $1 > \Phi > \phi$, the following are true:*

i. $\alpha^{**} > \alpha^{*}$
ii. $\gamma^{**} > \gamma^{*}$
iii. $w^{**} < w^{*}$
iv. $W^{**} > W^{*}$

Proof:

The existence of the new equilibrium is guaranteed by Result 1. An increase in the auditing capacity from ϕ to Φ leads to a rightward shift of equation A.3. Equation A.5

[16] Das (2023) models such an allocation problem with discrete number of agents and shows that all agents extract positive amounts of resource and agents ahead in the queue extract more resources.

remains unchanged since it is independent of Φ . Hence, now for every γ, a higher value of α would then satisfy equation A.3. Hence, the new equilibrium characterized by α^{**} and γ^{**} would result in $\alpha^{**} > \alpha^{*}$ and $\gamma^{**} > \gamma^{*}$. w^{**} is given by $f^{'-1}(\gamma^{**}\kappa)$. Given the concavity of the production function and $\gamma^{**} > \gamma^{*}$, we have $w^{**} > w^{*}$. From equation A.4, we determine W^{**}. Since f is concave and C is convex, we get that $W^{**} > W^{*}$. ■

Figure A.1b graphically depicts the new equilibrium. With higher audit capacity, the planner can now audit a higher share of farmers for any given γ. Hence, the audit supply curve shifts out. The new equilibrium, $(\gamma^{**}, \alpha^{**})$, therefore lies to the north-east of the equilibrium under the central planner. Therefore, decentralization leads to greater monitoring of farmers (i.e., higher γ) and a greater share of farmers receiving water (i.e., higher α). Hence the farmers located in the range $[\alpha^{*}, \alpha^{**}]$ were not getting any water under the centralized scheme, but are now receiving water under decentralization. Therefore, the extent of spatial mis-allocation of water falls.

Since decentralization ensures more equitable allocation, it increases the marginal return of allocation for the planner. Hence, the planner allocates higher volume of water to the village. Consequently, the average allocation to the village increases (i.e., W is higher). However, the water allocated to the farmers located closer to the canal falls from w^{*} (under centralization) to w^{**} (under decentralization). Consequently, we expect the quality adjusted output to fall for the farmer located closer to the canal, and increase for the farmer located near the tail.