SECOND YEAR
POLICY ANALYSIS

Where There's a WUA, There's a Way

Using impact evaluations of an irrigation program in West Bengal to improve support for farmers

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Executive summary

Farmers of West Bengal remain among the poorest citizens of India, with 28% of rural households living below the national poverty line. One of the most fundamental challenges facing farmers in the state is a lack of water, to which the government has responded through widespread provision of minor irrigation structures (each covering less than 2,000 hectares). However, the results of these irrigation interventions are mixed, with some estimating that up to 50% of the traditional irrigation schemes in West Bengal are defunct. Even when the schemes are functioning properly, there is insufficient evidence of downstream increases in farmer income.

We investigate the drivers of low agricultural income in West Bengal through an impact evaluation of the Accelerated Development of Minor Irrigation (ADMI) Project, a publicly provided minor irrigation program unique in its provision of agricultural support and local institution building in addition to infrastructure. The core of ADMI's activities is the formation of a Water User Association (WUA), which acts as a nexus for collective action and the delivery of interventions. Drawing on economic theory, we present a simple conceptual framework that outlines how market and government failures can lead to six types of barriers to increasing farmer income. We then empirically investigate the causal impact of ADMI on these barriers through three quasi-experimental analyses of individual-level survey data and satellite imagery.

We find that the ADMI package has substantial positive impacts on farmer welfare. Among functional schemes, ADMI has more than doubled farmers' revenue from agriculture, providing them with an additional INR 28,275 (USD 382) in revenue per year. These findings are validated by satellite data. Analysis of intermediate outcomes suggests that the agricultural support services provided by ADMI are key to this impact: there is no statistically significant difference in revenue between farmers based on access to irrigation alone. The combination of irrigation availability and agricultural training is most impactful for farmers. The WUA played an important role in promoting the maintenance of the scheme and reducing the likelihood of lapses in irrigation availability: 76% of farmers report that the formation of a WUA led to better upkeep of the scheme.

Based on these findings, we recommend that the Water Resources Department of West Bengal continue the ADMI program, leveraging the opportunity to scale in a structured fashion geared towards learning. Through ongoing piloting and nimble evaluation, the West Bengal government can refine the existing ADMI package and generate further impact by improving farmers' connections to markets and the state's social safety net.

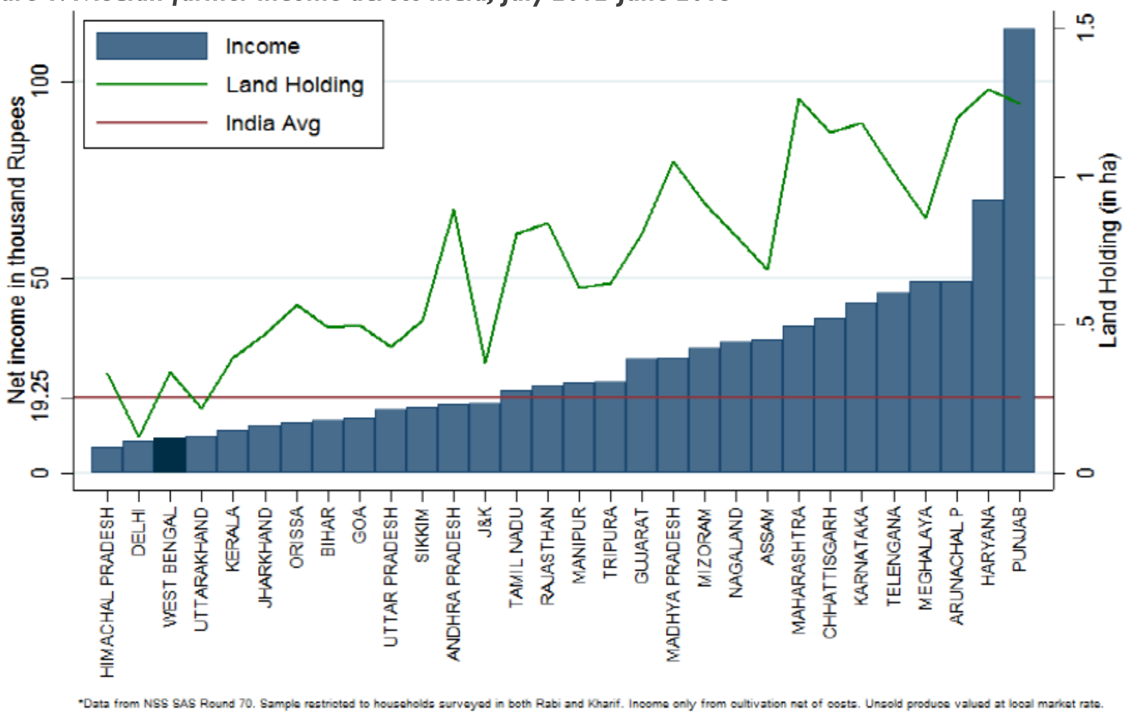
Recommendations

- Use data to target WUAs reporting low likelihood of sustainability with additional support.
- Incorporate structured pilot projects and linked data systems across the Department's activities.
- Scale-up the ADMI package to farmers across West Bengal, incorporating a large-scale randomized evaluation to understand spillover effects and administrative hurdles.
- Explore whether different models of collective sales can increase farmer market power.
- Explore whether the WUA institutional structure can facilitate the adoption of other welfare programs.

1. Introduction

Agriculture represents over half of employment in the state of West Bengal, in eastern India, with more than 90% of these farmers cultivating less than two hectares of land (World Bank 2011). Earning a sustainable livelihood on such a small plot is a tremendous challenge: 28% of rural households live below the national poverty line of USD 168 per year (World Bank 2011, Zhong 2014). Farmers in West Bengal are among the poorest in all India, with the third lowest median income of all states and fourth smallest average land holding (Figure 1). Rural families struggle to meet their basic needs and opportunities are limited. 28% of the rural population is illiterate and 32.5% of children under five in the state are stunted (Census 2011, NFHS-4 2015).

Figure 1. Median farmer income across India, July 2012-June 2013

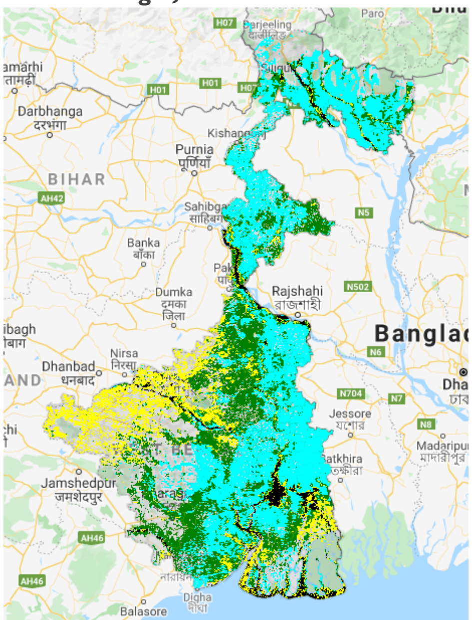


Source: Subramanian (2017).

A large contributing factor to the low productivity of agriculture are the extreme climatic conditions in West Bengal. Farmers are subject to alternating monsoon, or "Kharif," season (July-October) and dry, "Rabi," season (November-April). The "Pre-Kharif" season from April to July has intermittent rainfall. Many farmers cultivate rice paddy during Kharif season as it is resistant to flooding and are unable to cultivate during the dry Rabi season due to a lack of water. Growing for only one season ("mono-cropping") provides less income to farmer than if they were able to grow for two or three of the year's seasons ("double- or triple-cropping") (Smith et al. 2001; Bhatia 1991; Sekhri 2014).

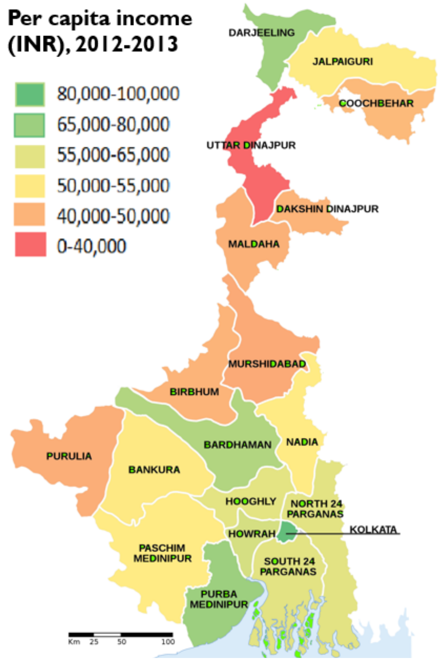
The ability to cultivate in multiple seasons varies with the geology of the state, which ranges from saline coastal floodplains of the Ganges, Brahmaputra, and Meghna Rivers in the southeast, to arid districts in the west and hilly tea-growing region in the north (see Appendix 1). Figure 2 shows the distribution in mono-cropping across the state. The areas with high rates of mono-cropping in the western portion of the state are among its poorest (Figure 3).

Figure 2. Mono- double- and triple-cropping across West Bengal, 2019



Yellow: Kharif only; Green: Kharif & Pre-Kharif; Blue: Kharif & Pre-Kharif & Rabi
Source: ADMI Google Earth Engine.

Figure 3. Income by District, West Bengal



Source: BAES (2014).

Irrigation can increase crop yield, allow farmers to cultivate more area and in more seasons, and reduce the risk of crop loss. Public investment in irrigation infrastructure in India has a long history and remains one of the national government's largest outlays. The national Eleventh Five Year Plan (2007-2012) budgets INR 211700 crore (almost USD 30 billion) for irrigation, representing 5.8% of total government expenditure (Government of India 2011). In the state of West Bengal, early state investment in irrigation in the 1950s and 1960s was primarily dedicated to large-scale dam projects. In the 1970s, the state government expanded its efforts to minor irrigation schemes (less than 2,000 hectares), such as shallow tube wells. Responsibility for irrigation development at the state level is shared among the Ministry of Water Resources, the Planning Commission, and the Ministry of Agriculture. Minor irrigation infrastructure is primarily the responsibility of the Water Resources Investigation and Development Department (WRIDD) (Jana 2012).

Facing chronic inefficient usage of irrigated water and poor scheme maintenance, the Government of India launched a nationwide Participatory Irrigation Management (PIM) initiative in 1987 to improve performance on these metrics. In 1994, the government created a formal legal entity, the Water User Association (WUA), to govern this participatory management, with duties including water distribution and the collection of water use fees (Fatima 2013). These policies in India reflected a global movement toward PIM—first in the Philippines in the 1970s, then Thailand, Indonesia, Sri Lanka, and more than ten countries across sub-Saharan Africa (Aarnoudse et al. 2018). With support from the World Bank, the Government of West Bengal launched a minor irrigation program with a strong emphasis on WUA mobilization, the Accelerated Development of Minor Irrigation (ADMI) Project, in 2012. ADMI also provides ongoing agricultural support services to the WUAs, making it unique within the WRIDD.

The World Bank project concluded at the end of 2019 and the project received funding directly from the state government to fund its operations in 2020. A proposal is presently under development for a future round of World Bank financing, which is an important opportunity to redesign the program to ensure it has the maximum impact on farmer livelihoods. The central motivating question of this study is whether the WUA and other agricultural support provided by ADMI contribute significantly to the program's impact, or if the leaner traditional model is sufficient. Where possible, we also indicate other interventions ADMI could explore to further increase its impact.

The central motivating question of this study is whether the WUA and other agricultural support provided by ADMI contribute significantly to the program's impact, or if the leaner traditional model is sufficient.

This study is the culmination of over a year of conversations with ADMI Project Director Prabhat Mishra, seven weeks spent in the project's headquarters in Kolkata and in focus group discussions with farmers across the state, and ongoing engagement with policy partners in the project office and World Bank.

We leverage data from the first representative household survey of all program participants since its launch in 2012 to evaluate the impact of ADMI on farmers' revenue from agriculture and test potential mechanisms driving the impact. We corroborate these findings with an event study of cultivation using satellite imagery, and compare the ADMI event study to the event study of a traditional government irrigation program. This analysis allows us to disentangle the elements of the ADMI project that have been most impactful for farmers and, in particular, whether ADMI's unique promotion of local governance and agricultural support services amplified the impact of irrigation.

We find that ADMI irrigation structures ("schemes") are less likely to be defunct than traditional schemes (11% of schemes versus 50%). Among functional schemes, ADMI has more than doubled farmers' revenue from agriculture, providing them with an additional INR 28,275 (USD 382) in revenue. This impact is statistically significant.[1] This increase is driven primarily by an increase in the area and yield of rice paddy during the Kharif season and diversification into vegetables in the Pre-Kharif season. These findings are validated by satellite data. The magnitude of the increase in area is much less according to the satellite data, but this could be a result of error in satellite measurement of cultivation, particularly high-value vegetables.

The survey data is suggestive that the agricultural support services provided by ADMI are key to this impact: there is no statistically significant difference in revenue between farmers based on access to irrigation alone. It appears that the combination of irrigation availability and training are what are most important for farmers. The survey data also indicates that the WUA played an important role in promoting the maintenance of the scheme and reducing the likelihood of lapses in irrigation availability: 76% of farmers report that the WUA has led to better upkeep of the scheme.

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[1] Throughout this study we will use 5% as our significance level.

We compare the satellite data on cultivation around traditional irrigation schemes in four western districts of the state with cultivation in area irrigated by ADMI schemes in the same districts. In these districts, ADMI had no statistically significant impact on cultivation, nor did the traditional irrigation schemes. These findings should be interpreted with caution given potential measurement errors of the satellite data. For example, the survey data suggest ADMI farmers had sizable increases in agricultural revenue in these districts. Further ground-truthing of satellite data could make this a valuable tool for evaluation in the future.

We build off these findings and the current policy context to recommend a path for ADMI's second phase, focusing on the use of structured pilots for continued learning. We recommend ADMI continue developing their data systems to build a framework for nimble evaluation. First, we support the scaling-up of the ADMI package to farmers who currently only receive traditional irrigation, and describe how to use a large-scale experimental evaluation to learn about whether ADMI can achieve impact at scale. Second, we recommend that ADMI explore how to help farmers gain greater market power, which remains a barrier in converting agricultural productivity into agricultural income. Here we encourage ADMI to partner with an external agency that can contribute expertise in mobilizing farmers to engage in market transactions. Importantly, we urge that ADMI explore a range of different cooperative structures rather than transition directly to Farmer Producer Organizations as this can be a cumbersome process that requires further learning. Third, we encourage ADMI to further understand how the WUA institutional structure can be used to help farmers gain access to additional policy instruments that can alleviate further constraints without requiring ADMI itself to engage in additional interventions. We propose three interventions of varying administrative burden, motivated by the gaps in the current literature, and showcase how ADMI can use small-scale pilots to choose between different models of promoting convergence without incurring high evaluation costs.

The paper proceeds as follows. Section 2 outlines our conceptual framework of the potential constraints facing a farmer. Section 3 provides further information on the ADMI intervention. Section 4 provides a literature review on the impacts of irrigation interventions and on PIM in particular. Section 5 describes our data and methodology while Section 6 presents the results from these analyses. Finally, Section 7 concludes with a proposed roadmap for ADMI's second phase.

2. Conceptual framework

There are a number of challenges documented in the literature and described anecdotally by farmers that could potentially contribute to the low income of farmers. We group these into the following six categories: i) barriers to more profitable occupations, ii) barriers to receiving sufficient water, iii) barriers to crop diversification, iv) barriers to investment in production technology, v) barriers to low- or no-cost improvements in practices, and vi) barriers to higher prices for products. We describe each in turn below. In Figure 4, we trace these back to their potential root causes in government or market failures. These failures include:

1. Barriers to migration
2. Coordination failures among farmers
3. Incomplete markets for inputs, training, human capital development, and credit
4. Imperfect information
5. Externalities from experimentation
6. Norms, identity & persistent beliefs
7. Present bias
8. Barriers to entry in middle-man market

1. Farmers cannot work in more profitable occupations. Farmers may desire to move out of agriculture to occupations with higher earnings, but are unable to due to incomplete markets for training, credit constraints, or discrimination (Bryan et al. 2014).

2. Farmers cannot access sufficient water to maximize productivity. Irrigation is often only a worthwhile investment at the village level, and farmers may fail to coordinate or be unable to borrow to make such an investment. Where a structure is constructed, coordination failures may result in poor upkeep and the scheme may fall into disrepair.

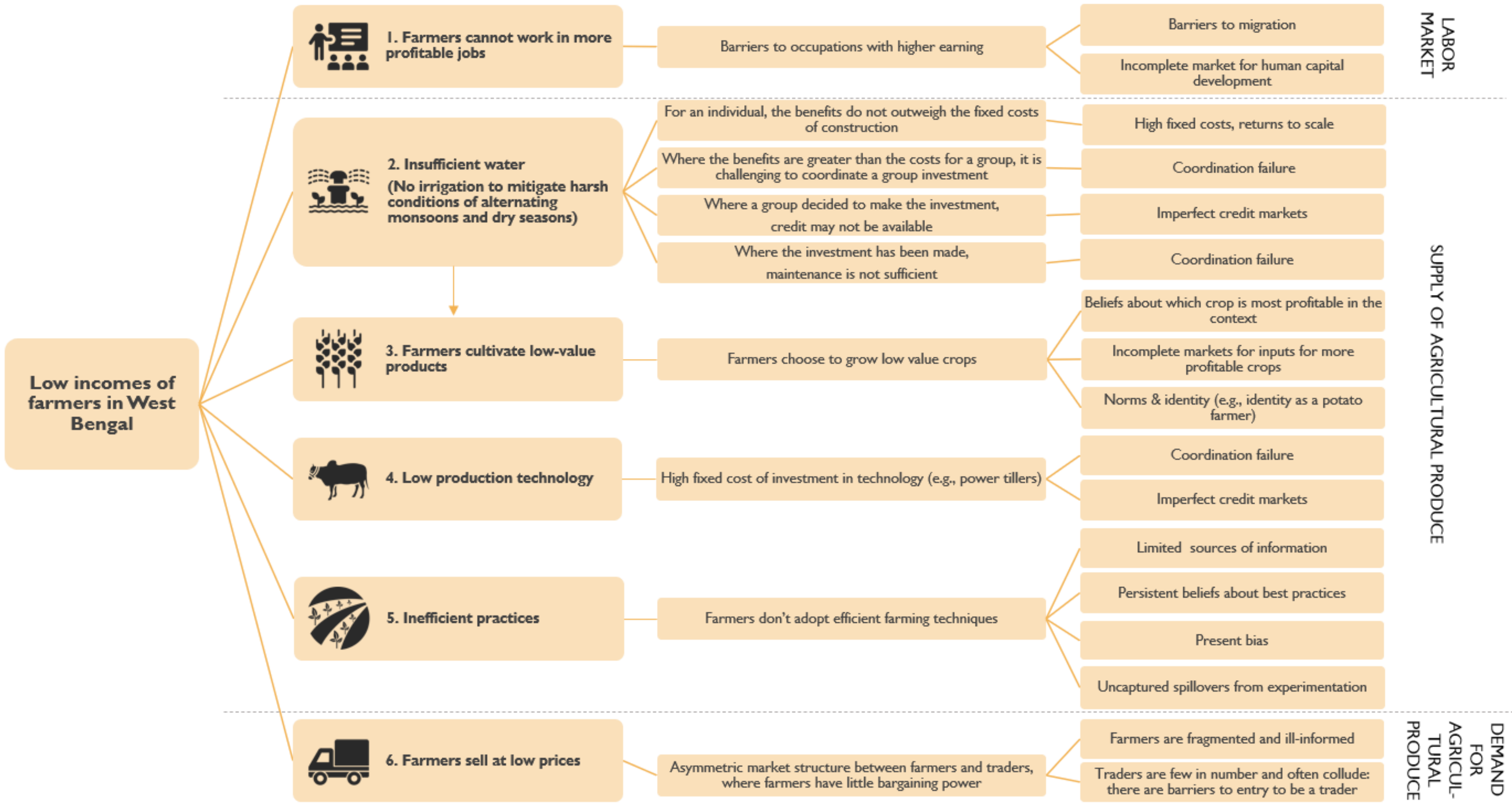
3. Farmers cultivate low-value products. Farmers often cultivate a lower value crop or product than their land might otherwise allow. For example, many farmers choose (or are implicitly forced by rain conditions) to grow rice paddy, despite the low value of this crop. Further, there are other animal husbandry or pisciculture (fish farming) activities that could be more profitable for a farmer to enter, but a lack of information on profitability, incomplete markets for inputs, or norms prevent a farmer from doing so (Narayanamoorthy and Deshpande 2003; Mehta 2009).

4. Farmers have limited production technology. Farmers may operate with suboptimal technology (e.g., fertilizer, power tillers, or other farm machinery) because they cannot access credit or are unable to coordinate with other farmers to make collective investments. Inefficiently harvesting crops can prevent farmers from planting in time for the following season, thus trapping a farmer in mono-cropping.

5. Inefficient practices. Farmers may be able to improve their production through no-cost changes in their practices; for example, by sowing rice paddy in evenly spaced lines rather than at random or utilizing the correct pesticide for a pest. However, limited information on these practices, persistent beliefs even with information, present bias, and uncaptured spillovers from experimentation may prevent farmers from making these changes.

6. Farmers sell at low prices. Asymmetric bargaining power between farmers and the middle-man traders that transport products to central markets could result in farmers selling at lower prices than their products are worth. A recent experimental evaluation in West Bengal indeed found evidence of collusion and rent-seeking among potato traders (Mitra et al. 2017). Farmers also express strong anecdotal support of this hypothesis.

Figure 4. Potential root causes of low farmer incomes in West Bengal



Note: This figure is not comprehensive of farmers challenges. It draws on the World Bank's Project Appraisal Document, Joao Abreu's internship report, and our field experience.

3. The ADMI Project

The ADMI Project is a minor irrigation program launched in 2012 with the support of USD 250 million of credits and loans from the World Bank. ADMI is one of six minor irrigation programs overseen by the West Bengal WRIDD. The project aims to "increase the agricultural productivity of small and marginal farmers" in the state of West Bengal. To achieve its target impact, the ADMI project aims to increase the availability of water for irrigation, improve the sustainability of irrigation infrastructure, and help farmers diversify their production and transition to double- or triple-cropping. The project's headquarters is in the state capital of Kolkata. There are dedicated project staff within the WRIDD in each of the state's district. An NGO is contracted as a Support Organization (SO) in each district to mobilize and support the WUA, with some districts contracting the same NGO.

The ADMI project cycle begins with site selection, based on a hydrological assessment by the project's engineers. Once the site has been chosen, the SO helps to mobilize the farmers that could physically access water from the scheme into a WUA. WUAs range from five to 400 members, with an average of 72 members and a median of 60. The majority of WUA members (82% on average) are men, who are typically the primary agricultural laborers. Once the scheme is constructed, it is "handed over" to the WUA, which then becomes responsible for scheme maintenance. Farmers pay fees to the WUA, primarily for water usage, which is intended to be saved for maintenance. WUAs are also trained to meet regularly to plan water usage and crop plantation. ADMI provides ongoing agricultural training and the SO regularly monitors the activities of the WUA and provides support. The agricultural support services differ according to the needs and potential of each region and WUA. Overall, both in the type of irrigation it provides and its support services, the ADMI project prides itself on being highly contextually sensitive. Occasionally, highly successful WUAs are rewarded with small-scale farm machinery, such as a power tiller.

The project has successfully "handed over" over 1600 irrigation schemes to WUAs, reaching over 100,000 farmers (Figure 16, Appendix 1). In the earlier years of the project, schemes were launched across the state without particular targeting of mono-cropped areas. In 2015, the project began to use satellite imagery to actively target mono-cropped areas and geographically concentrate its efforts. Initially, the project constructed primarily groundwater structures, such as tube wells, which were the most commonly built irrigation structure by the WRIDD. However, groundwater availability was often lower in mono-cropped areas, thus the project began constructing more surface-water schemes (e.g., dams and canals) as it began targeting high-need areas more actively.

To shed light on the marginal impact of the WUA mobilization and agricultural support, we will compare ADMI to the Jalatirtha program, a minor irrigation program within the WRIDD that only constructs irrigation schemes. Figure 5 summarizes how ADMI and traditional irrigation programs (such as Jalatirtha) differ in the constraints they address. Unlike ADMI, Jalatirtha operates only in the arid western districts of Bankura, Birbhum, Purulia, and Paschim Medinipur, thus we only compare Jalatirtha to the ADMI schemes in the same districts.

Figure 5. Constraints Addressed by Traditional Irrigation vs. ADMI

Constraints Addressed by Traditional Government Irrigation Project (Jalatirtha)	Constraints Addressed by ADMI Project
2. Insufficient water (No irrigation to mitigate harsh conditions of alternating monsoons and dry seasons)	**2. Insufficient water** (No irrigation to mitigate harsh conditions of alternating monsoons and dry seasons)
	3. Farmers cultivate low-value products
	4. Low production technology
	5. Inefficient practices

Though Figure 5 makes it appear that a comparison of Jalatirtha and ADMI would isolate the effect of support for Constraint 3 through 5, it is important to note that there are some differences between the two programs in their approach to Constraint 2 of insufficient water. These include:

1. ADMI mobilizes a WUA, thus maintenance and other potential benefits of local governance mobilization may be lower in traditional schemes.
2. ADMI contracts NGOs to mobilize the community, which leads to increased monitoring and interactions with the government department.
3. ADMI has different targeting criteria. The project specifically targets mono-cropped areas (which tend to be lower rainfall or lower groundwater areas) where the marginal impact of water could be higher than in other areas. Their use of GIS for scheme design might also plausibly result in greater impact on the availability of irrigation as the schemes are able to resolve a large need or may result in smaller impact where particularly adverse agroclimatic sites are chosen.
4. ADMI, being a joint venture between the World Bank and the state government, has different hiring practices from typical government departments. Thus, they have been able to hire a mixture of government officials and contractual specialized consultants, which could result in differently qualified staff.

This study will attempt to disentangle the value of these measures ADMI has taken to improve irrigation services, as well as the impact of the additional components ADMI provides. This innovative program can provide great insight into whether this more comprehensive package of services, including the WUA coordinating mechanism, improve the impact of the government's minor irrigation schemes.

4. Literature review

This study contributes to an extensive existing literature on the impact of irrigation and a smaller literature on participatory irrigation management. We summarize the findings and methods used in each to put this study and its findings in context.

The direct effects of irrigation interventions are almost always positive. From the biological foundation, increased water availability has a direct effect on yield of agricultural crops (Chang 1968) and increases the productivity of complementary inputs such as fertilizer (Smith et al. 2001). Irrigation has also been shown to enable farmers to shift to higher-value crops (in India, see Narayanamoorthy and Deshpande 2003; Mehta, 2009). Increased yield and higher-value crops have been documented to reduce poverty among farmers, particularly subsistence farmers (Lipton et al. 2002). In India, access to irrigation was associated with 77% higher income in the states of Bihar and Haryana (Bhatia 1991) and caused a reduction in village-level poverty by 11% in Uttar Pradesh (Sekhri 2014). Similar impacts were identified in sub-Saharan Africa: small-scale irrigation increased farm profits by 70% in Rwanda (Jones et al., forthcoming) and increased household consumption by 27 to 30% in Mali (Dillon 2011). Irrigation may reduce other dimensions of poverty beyond income alone, namely by increasing asset value and reducing volatility of income. In India, Jacoby (2017) finds that an additional borewell is associated with a 46% increase in plot value in Andhra Pradesh while Namara et al. (2007) find irrigation reduces risk of crop failure in Maharashtra and Gujarat. Finally, irrigation may impact empowerment itself—49 out of 50 respondents in an irrigation program in West Bengal stated that their increased self-respect was one of the most important benefits they experienced as a result of participation (Beck 1994).

However, irrigation may have harmful indirect effects. In health, irrigation has been shown to have a positive impact on the nutritional status of farmers in some cases (Pingali 2012), while in other cases it was detrimental to health by increasing the prevalence of water-borne disease vectors (in India, see Singh et al. 1999), arsenic contamination (in India, see Senanayake & Mukherji 2014), or fertilizer and pesticide use (Simmons et al. 2005). In addition to the negative environmental impact of increased fertilizer and pesticide use, if groundwater irrigation is poorly managed, it will deplete precious groundwater stores. This issue is particularly pressing in the Indian context, where low groundwater tables are becoming increasingly problematic (Bhatia 1991; Saith and Tankha 1992). Finally, the effects of irrigation on gender dynamics are ambiguous. In contexts where crops cultivated with irrigation are more female-labor-intensive, irrigation may increase agricultural labor required of women, and vice versa (Hussain 2007; Ringler & Domenech 2013). The implications of this change in labor for women's agency vary by context.

With respect to methodology, the vast majority of studies measure descriptive associations rather than utilizing quasi-experimental or experimental methods to identify the causal impact of irrigation approaches. Notable quasi-experimental studies of small-scale irrigation interventions include Sekhri (2014), Jacoby (2017), Dillion (2011), and Jones et al. (forthcoming), that utilize aquifer characteristics, well failures, propensity score matching, and plot-level spatial regression discontinuity, respectively, to identify causal effects. Among large-scale irrigation interventions, Duflo and Pande (2007)'s quasi-experimental identification of the impact of dams in India leveraging variation in land slope is a notable contribution. There are no experimental evaluations of irrigation interventions to date (Giordano et al. 2019).

This study focuses on the effect of WUAs on the impact of irrigation interventions. A long history of literature has emphasized the game-theoretic case for local management of natural resources (see, for example, Ostrom and Gardner 1993). Evidence of efficient village-level water allocation supports this case (in India, see Banerji et al. 2012). While the importance of institutional structure is often emphasized in the literature on irrigation (Senanayake et al., 2015; Giordano et al., 2017), few studies isolate the effect of the governing institution. Those that do have generally found a positive association of WUAs and irrigation system performance: Reddy & Reddy (2005) find that water shortages declined and land productivity increased following the introduction of WUAs in the Indian state of Andhra Pradesh, Lam (1996) finds farmer-managed irrigation systems in Nepal more effective than government-managed systems, and Acheampong et al. (2014) find that communities around small dams in Ghana that established WUAs outperformed those that did not. However, these studies do not control for potential ongoing trends in cultivation or selection effects into forming WUAs. For example, more advanced farmers may be more likely to start WUAs, and thus the difference between schemes with and without WUAs may simply be a result of this difference in underlying farmer characteristics. No quasi-experimental evaluation of WUAs, which would address these concerns, has been conducted to date. This study begins to fill this gap.

5. Methodology

Our empirical strategy is designed to complement our conceptual framework, combining both descriptive analysis and quasi-experimental causal inference to measure the impact of relaxing the different constraints faced by farmers. We conduct analysis both at the scheme level and individual level, where "scheme" refers to an irrigation structure and, with a few exceptions, corresponds to a WUA. We utilize satellite, survey, and administrative data for our identification strategies. These data sources are described in Table 1. Descriptive statistics on the districts and scheme types included in the representative "ground-truthing" survey are included in Appendix 1.

Table 1. Data sources

	Dataset	Unit (time)	Number of obs.	Description
Primary	**Landsat 7 Normalized Difference Vegetation Index (NDVI)**[2]	Scheme (2008-2019)	216 ADMI schemes with validated polygons, 424 Jalatirtha schemes	Estimate of area cropped (NDVI>0.4) within polygon of potentially irrigated area ("command area") for ADMI schemes and within a half-kilometer buffer from the scheme location for Jalatirtha schemes. NDVI is a calculation of vegetation based on the visible and near-infrared light absorption detected by satellites.
Primary	**World Bank Individual "Ground-truthing" Survey**	Individual (2019 + retrospective questions)	422 ADMI beneficiaries 206 non-ADMI beneficiaries	First of its kind survey of a representative sample of ADMI farmers, collected as part of the World Bank's effort to ground-truth the project's administrative data. A randomly selected individual who is not part of the WUA was also surveyed in each village. Questions include details of agricultural production, practices, and perceptions of ADMI.
Additional	**MIS**	Scheme (Ongoing)	1834 handed over ADMI schemes	ADMI administrative data on handover date, WUA demographics, and other characteristics.
Additional	**Institutional Grading**	WUA (2017-2019)	~750 WUAs	ADMI administrative data from ongoing WUA monitoring, including information on representation, transparency, and fees.

5.1. Institutional effects of the WUA and sustainability of schemes

To understand the role of the WUA in the ADMI project, we begin by calculating descriptive statistics of WUA activities, representation, transparency, and reported institutional effects from the individual ground-truthing survey and ADMI's WUA grading data. We also present descriptive findings from the sampling process for the ground-truthing survey. Of the original sample of 216 villages, 67 were replaced because the scheme was defunct, the WUA was suffering from internal conflict, or other reasons. We present descriptive statistics on all reasons for replacement. As the sampling was random, the descriptive statistics from this sample can be considered representative of all ADMI schemes.

[2] We are very grateful to ADMI Executive Engineer Joydeep Das for preparing this data for us.

5.2. Comparing ADMI and control schemes using satellite data

Using satellite data of vegetation around scheme location and the year of construction of completion, we conduct two difference-in-difference estimations of the effects of ADMI and of non-ADMI (Jalatirtha) schemes on cultivation (see Box 1). This specification is outlined in Equation 1, where *Post* is a dummy for whether the observation occurs after handover of the scheme, and *Scheme* and *Year* are fixed effects to control for location-specific unobserved characteristics and general temporal trends, respectively.

$$Area\ cultivated_{st} = \boldsymbol{\alpha} * Post_{st} + Scheme_s + Year_t + \epsilon_{st} \qquad [1]$$

We first estimate the average change in cultivation after the introduction of the scheme (α) for both ADMI and Jalatirtha. In this specification, we are comparing farmers that had received the scheme to other those that had not yet, to determine whether the former group increased cultivation by more than the latter. The identification assumption required for this estimate to be considered a causal is that farmers exhibit parallel trends in cultivation prior to the introduction of the scheme (see Box 1). We assume that trends in cultivation for both scheme types are independent of the year the farmer received the scheme, controlling for year fixed effects.

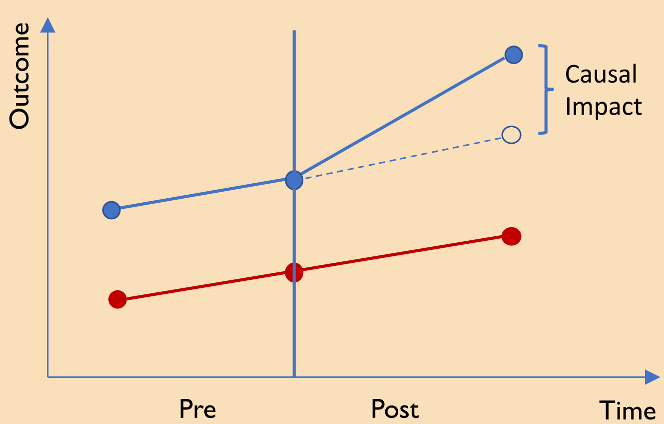
Box 1. Estimating impact through difference-in-difference

Difference-in-difference is a statistical method that can be employed to measure causal impacts even when there isn't a randomized control trial. The method involves comparing the change over time of a treatment group to the change over time of a comparison group. If certain assumptions are met, the differences in the changes can be interpreted as the causal impact of the treatment. There are two main requirements of difference-in-difference:

1. Time Series Data: Data needs to be collected on both groups before and after the intervention.
2. Parallel Trends: The two groups would have followed similar trajectories if not for treatment. However, this is an assumption that can never be fully tested but can be motivated through looking at the time-series data prior to treatment and thus the method should be applied carefully.

For example, it is not required that ADMI and non-ADMI farmers in the ground-truthing survey had the same level of income prior to Handover. Instead, we require the much more plausible assumption that they would have changed in similar ways if not for the introduction of ADMI to one group.

All that is needed for ADMI to continue using this method for regular impact evaluation is to begin collecting regular data on non-ADMI farmers and schemes.



Next, we estimate the impacts of ADMI and Jalatirtha on the percentage increase in cropped area, restricting the ADMI sample to the four districts where Jalatirtha operates. We use the percentage increase as the outcome variable to control for the difference in sampled area across the two programs. This allows us to then test whether the estimated impacts of ADMI and Jalatirtha schemes differ. This is an additional estimation of impact, this time against a counterfactual farmer near a traditional government irrigation scheme. To interpret this triple difference specification as the causal impact of ADMI relative to Jalatirtha, there must be parallel trends in cultivation over time across the two types of schemes. Figure 22 of Appendix 3 indicates that this assumption holds.

To further understand the effects of each program by year since completion of construction, we conduct an event study for both ADMI schemes and Jalatirtha schemes. This specification is given in Equation 2, where $D_{i,t,\tau}$ is a vector of indicators for each of the years before and after a scheme was constructed, with τ constructed to be equal to zero for the year that the scheme was constructed and ranging from -5 (5 years before the scheme) to +3 (3 years after), *Scheme* and *Year* are fixed effects, and *a* is the constant. The dummy indicator for the year prior to scheme handover is omitted, as is typical in event studies, in addition to the dummy indicator for the year five years prior to handover to account for a potential time trend (Borusyak and Jaravel 2017) . Here, γ_τ represents the estimated increase in cultivation as a result of the irrigation scheme τ years after handover, relative to the year prior to handover.

$$Area\ cultivated_{st} = a + \sum (\boldsymbol{\gamma_\tau} * D_{s,t,\tau}) + Scheme_s + Year_t + \epsilon_{st} \qquad [2]$$

As the estimates from Equation 1 may be implicitly weighted based on the number of post-handover years of data available for each scheme, the event study provides a more reliable estimation of the evolution of impact over time.

5.3. Comparing ADMI and non-ADMI famers within village using survey data

The data used for this analysis is a representative household survey of all functional schemes handed over at least one year prior to the survey (the "ground-truthing" data described in Table 1). 30% of schemes in the sample were replaced (see discussion in Section 5.1). Within each sampled village with an ADMI scheme, a randomly selected female WUA member and a randomly selected male WUA member were surveyed, in addition to a randomly selected resident of the village that was not a member of the WUA (most often because their land cannot be reached by water from the scheme). These observations were pooled for analysis. Of 723 original individual observations, 95 were restricted from the analysis because they were incomplete or showed systematic errors in data entry. Outliers were also removed from individual observations. A description of the final 422 ADMI individuals and 206 non-ADMI individuals in the dataset is given in Table 10 in Appendix 1. Sampling weights were used in the analysis to correct for sample stratification by district, scheme type, and gender.

The specification of the difference-in-difference between ADMI beneficiaries and neighboring non-ADMI farmers is given in Equation 3, where the outcome of interest is the change in farmer *i*'s since scheme handover and *ADMI* is a dummy variable indicating a farmer is an ADMI beneficiary, *X* is a vector of controls, *a* is the constant. Our estimate of β is the average increase in income attributed to the ADMI program.

$$Present\ Revenue_i - PreHandover\ Revenue_i = a + \boldsymbol{\beta} * ADMI_i + X_i + \epsilon_i \qquad [3]$$

For us to interpret β as the causal impact of ADMI, the two assumptions described previously must hold. Unfortunately, we have no data on trends in farmer income prior to scheme handover, and thus our estimate is dependent on the assumption that ADMI and non-ADMI farmers' revenue increased at a similar rate prior to the introduction of ADMI. Though Table 10 in Appendix 1 indicates that there are statistically significant differences between the two groups, we believe it is not unreasonable to assume that the trends in their revenue over time are similar.

To provide insight into the mechanisms driving ADMI's impact, we will analyze the relationship between various intermediate outcomes (including proxy measures for the constraints defined in Section 2) and income, as well as the variation in ADMI impact across demographic, scheme, and district characteristics.

5.4. Analyzing constraints facing farmers

One of the primary objectives of our analysis is to inform future policy in the state of West Bengal to better target the challenges that are most pressing for farmers. To the extent possible, we will draw insights from the data gathered on the relative urgency of the constraints presented in Section 2.

Our analysis of the relationship between our proxies for the constraints and income will provide initial insight. To deepen this analysis, we conduct heterogeneity analysis of the impact estimate by presence of underlying market failures—if the impact is greater where the market failure existed, this is an indication that this was a particularly important constraint that ADMI helped farmers to overcome. The specification for this analysis is as in Equation 3, but controls for the baseline constraint are added and the dummy variable for ADMI is replaced by an interaction term of ADMI and each category of the baseline constraint.

Finally, we will leverage descriptive evidence from the survey data to further understand the urgency of the first and sixth constraints.

To better understand whether farmers would prefer to change industries rather than continue to work in agriculture, we will utilize a question on the new individual-level survey of farmers about the occupations they aspire for their children to hold—if many farmers prefer their children to work outside of agriculture, this could indicate that barriers to changing occupations may be an important area to explore further. Importantly, this is a rough measure for our question of interest, and should be interpreted with caution. Farmers may aspire for their children to work in other sectors even when they themselves do not face barriers to work in those sectors.

To better understand whether the market structure is resulting in rents to middleman traders beyond their costs and risk assumption, we will utilize data from the individual-level survey on product sale price and the distance of the market where the product is sold. We conduct a linear regression to analyze variation in prices across buyer types, controlling for distance to market and village. If prices vary greatly for farmers from the same village for reasons other than distance, this would be an indication that rents to middlemen exceed transport costs.

6. Results

6.1. Institutional effects of the WUA and sustainability of schemes

Here we present our findings on the activities WUAs carry out and WUA members' perceptions of the effect of the WUA on their communities. Unless otherwise noted, statistics presented are based on the ADMI project's ongoing effort to "grade" WUAs to monitor their institutional progress. Figures associated with all grading data presented here are included in Appendix 3. A number of questions in the recent individual ground-truthing also shed light on the institutional effects of the WUA. In addition, in the original sampling for this survey, 31% of randomly selected schemes were replaced due to various issues. As this is a random sample, the frequency of these issues can be considered representative of all schemes, providing further insight on the institutional and physical status of ADMI schemes.

6.1.1. Frequency of meetings and degree of inclusion

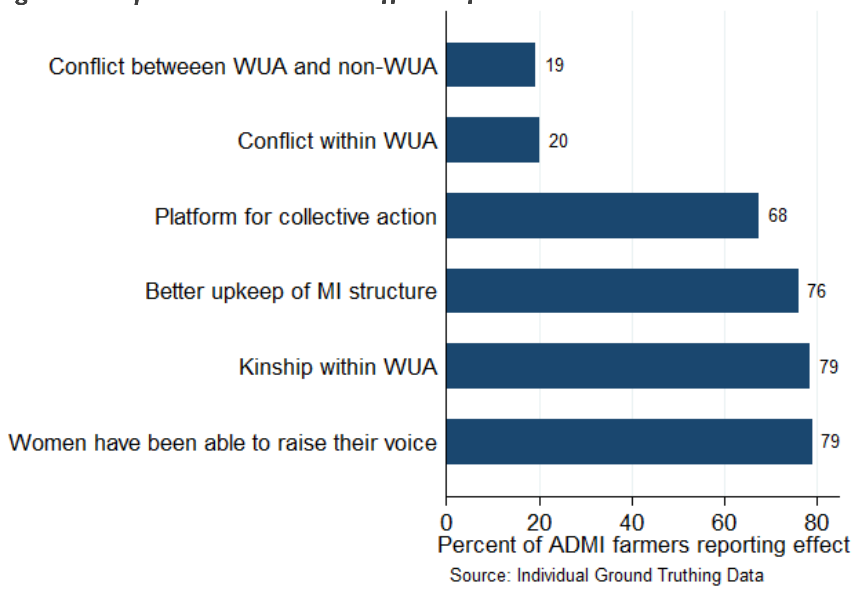
We find that the WUAs meet less frequently than ADMI's target. The leadership of the WUA is a democratically elected WUA Management Committee (MC), which seeks to coordinate the farmers that participate in the WUA. MCs of WUAs differ greatly in the frequency in which they meet and the attendance in these meetings. Only 30% of MCs achieve the objective of at least eight meetings per year with at least 80% attendance. While about 61% have between four and eight meetings, there remain 9% of MCs that meet less than three times per year.

The majority of WUAs are generating inclusive participation. One potential concern with the creation of new infrastructure in a community is that those with power in the community will prevent equitable use. ADMI's SO staff help to prevent this form of "elite capture" by helping the WUA to establish norms of transparency and broad participation in meetings. The WUAs appear to have a good level of inclusion—68% of WUAs have over 60% of members attend crop planning meetings. Further, in 62% of WUAs over 60% of members are aware of nine activities and norms of their WUA. In the recent individual, nearly 80% of WUA members report that the WUA has increased kinship among villagers and has empowered women within the village. However, the effects are not only positive, with one in five members reporting conflict within the WUA and between WUA members and non-WUA members (Figure 6). In 7% of WUAs, conflict was so severe that the WUA was replaced in the ground-truthing sampling. An additional 2% were replaced because the WUA was non-responsive. Box 2 describes our analysis of the determinants of the institutional strength of WUAs. ADMI should use the grading data and ground-truthing data to target the WUAs that report low levels of inclusion and high levels of conflict, understand what is driving these outcomes, and develop remedial strategies.

6.1.2. WUA as a mechanism for maintenance

WUAs have indeed resulted in better upkeep of the scheme; however, reserve funds are still not adequate for maintenance in at least half of WUAs. WUAs are responsible for maintaining a reserve fund to cover any upkeep and maintenance required for the scheme. WUAs collect fees in various ways, most commonly by collecting membership fees or charging for water use. The most common way of charging for water is based on hours of irrigation, but the majority of WUAs (55%) also collect fees through another method. In the recent individual survey, 76% of WUA members reported that mobilization of the WUA had driven better upkeep of the irrigation structure, but only 50% reported that they considered their reserve funds to be adequate for their maintenance needs. In general, there is a mixed picture on the sufficiency of maintenance. 60% of WUA members reported that they expected the WUA to be sustained beyond the next decade. According to the WUA grading data, 33% of WUAs are not able to fund even half of their operational costs using water charges, 38% of structures are operating with less than 75% efficiency and do not receive maintenance, and 80% did not meet their target reserve accumulation amount.

Figure 6. Reported institutional effects of WUAs



Furthermore, WUA members may be overly optimistic about whether their reserve funds will be adequate for maintenance. Data on the actual reserve funds from the WUA grading data provide an even more concerning picture. While some WUAs only require INR 1,000 to 5,000 to repair their pump structures or power tillers (e.g., a WUA visited in Darjeeling), other WUAs have spent INR 26,000 for a new pump (e.g., a WUA visited in Hooghly). The average reserve fund of the WUAs is INR 16,483. Reserve funds vary across districts, from INR 38,321 on average in Hooghly to INR 2,810 on average in Darjeeling. Only 18% of WUAs have corpus funds greater than INR 25,000, suggesting that the other 82% may struggle to finance the necessary maintenance. Some WUAs mentioned that they successfully raised funds when the need for maintenance arose, suggesting that a finance-as-needed option could be viable, but is clearly not optimal. Additional support services should be provided to all WUAs with reserve funds below INR 25,000 and best practices in other methods of revenue generation should be shared across WUAs.

An estimated 11% of ADMI schemes are defunct. Though concerning, this may be an improvement over status quo: a recent study of other government schemes found that 50% of these schemes are defunct.

6.1.3. ADMI scheme sustainability

ADMI schemes are less likely to become defunct than traditional government schemes; however, further targeting of support is needed to reduce the likelihood even further. Of the schemes sampled for the ground-truthing exercise, 11% were defunct and 4% were temporarily defunct.[3] To put this in perspective, a 2015

[3] In addition to those mentioned in this section, 5% of the sample was replaced due to political conflict and 4% due to duplicates or non-compliance with the inclusion criteria.

study by Deloitte of non-ADMI government irrigation schemes handed over since the 1990s found that 42% of schemes were defunct and 7% were partially functioning. Among those handed over within the last five years, which is more comparable to the timeframe used for the survey results we present, 50% were defunct (Deloitte 2015).[4] This is an encouraging indication that ADMI schemes were less likely to become defunct than traditional government irrigation schemes. ADMI schemes could be less likely to be defunct due to better maintenance, as discussed previously, or better site selection and construction, which was suggested in anecdotal evidence from field visits.

Overall, it is encouraging that the WUA may be helping to reduce the likelihood that a scheme becomes defunct; however, it will be important for ADMI to address the potential vulnerability of over 80% of current schemes to ensure their sustainable maintenance.

Box 2. Determinants of WUA quality

We generated an index to measure the institutional quality of WUAs based on responses to four questions in the recent individual-level survey: whether the individual thought i) the WUA leadership was satisfactory, ii) the WUA had generated kinship, iii) the WUA led to better maintenance, and iv) the WUA served as a platform for collective action. The index ranges from one to five, where one indicates no affirmative response and each additional point is associated with each affirmative response. The average score is 3.78.

Using linear regression, we are able to test the association of certain characteristics and the WUA quality index. The results are presented in Table 11 in Appendix 3. These results should not be interpreted as causal effects as we are unable to include all potentially relevant variables.

Notably, there is no statistically significant difference in perception of quality by gender, caste, religion, or level of education. Interestingly, WUAs with a higher percentage of women or marginal farmers are no more likely to report higher institutional quality. A member of a sub-committee is likely to perceive the WUA to be higher quality, but a member of the Managing Committee is not.

The district of the WUA has the strongest association with WUA quality. For example, Malda is a particularly low performer while Hooghly is particularly strong. This could be a result of the variation in institutional support staff across districts, or other district characteristics. ADMI staff should explore the drivers of the district variation to share best practices and address potential areas of weakness.

In conversations with WUAs, WUA members most often attributed their success to the underlying social cohesion of their community. For example, in the WUA pictured to the right, WUA members cited an existing "neighborly" feeling among them that allowed for transparency and trust in the operation of the irrigation structure.

Bhangar Hat Jatileswar Krishi Unyayan WUA, Jalpaiguri District

[4] Note that the Deloitte numbers may be slight overestimates as the report's authors mention that their random sampling method was adjusted for "adequate representation of defunct schemes" across scheme type and agroclimatic zone.

6.2. Comparing ADMI and control schemes using satellite data

6.2.1. Impact of ADMI

Our first identification of the impact of ADMI is an event study comparing ADMI farmers' cultivation after the introduction of ADMI with that before introduction of ADMI. In Table 2 we estimate the change in hectares cultivated by the WUA after the introduction of ADMI and test whether this change is statistically significant. We find that ADMI results in an increase of 1.47 hectares of cultivation in Pre-Kharif, 0.55 hectares in Rabi, and 2.09 hectares in Kharif per scheme. The results for Pre-Kharif and Kharif are statistically significant, while the effect in Rabi is not. For reference, the average area cultivated before ADMI is 17.7 hectares in Kharif, 6.1 hectares in Pre-Kharif, and 4.2 hectares in Rabi.

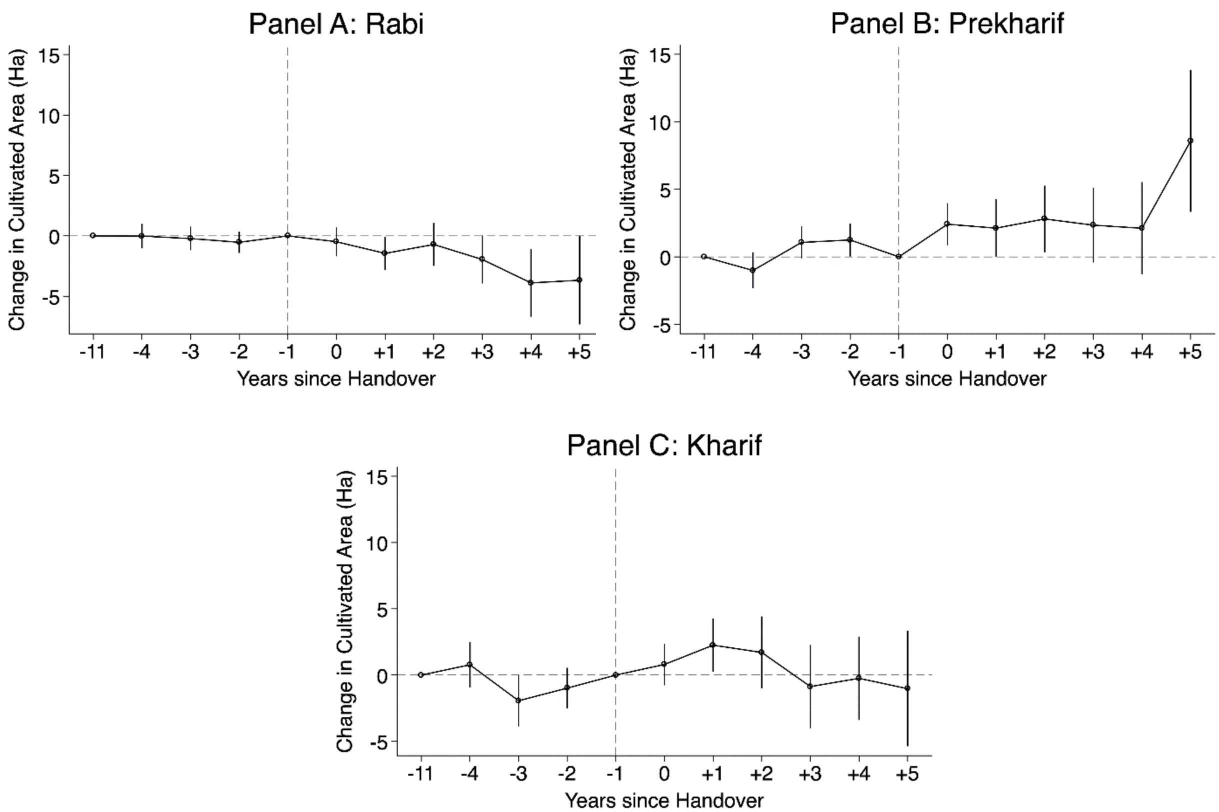
Table 2: Difference-in-differences estimates of ADMI impact on cropped area (in hectares)

	(1) Pre-Kharif	(2) Rabi	(3) Kharif	(4) Ln Pre-Kharif	(5) Ln Rabi	(6) Ln Kharif
Post ADMI	1.473***	0.551	2.089***	0.626***	-0.167	0.000847
	(0.525)	(0.601)	(0.789)	(0.152)	(0.120)	(0.0484)
Constant	6.123***	4.246***	17.74***	1.741***	0.730***	2.523***
	(0.409)	(0.331)	(0.316)	(0.107)	(0.0981)	(0.0241)
Scheme and year FE	X	X	X	X	X	X
Observations	2,292	2,292	2,292	1,364	1,747	1,952
R-squared	0.283	0.163	0.178	0.214	0.143	0.114
Number of schemes	191	191	191	190	189	191

Robust standard errors in parentheses. Standard errors clustered at district level. *** p<0.01, ** p<0.05, * p<0.1
Source: Landsat 7 NDVI.

To understand this effect further, we conduct an event study to determine the effect of ADMI by year after scheme handover. Results of the event study are presented in Figure 7. We find no statistically significant effect of ADMI in Rabi or Kharif seasons, with the exception of a small increase in the first year after handover in Kharif and a small decrease in cultivation in Rabi four years after handover. On the contrary, there is a statistically significant increase in cultivation in Pre-Kharif—increasing from approximately three additional hectares per scheme in the first year to eight additional hectares per scheme five years after handover. Note that there are only 31 schemes in the sample were handed over five years ago, thus the estimate of eight hectares should be interpreted with caution.

Figure 7. Event studies of ADMI impact on area cultivated



Note: The dummy for five years prior to handover was omitted in addition to that of the year prior to control for a time trend.
Source: 216 ADMI schemes from ground-truthing

6.2.2. Impact of Jalatirtha

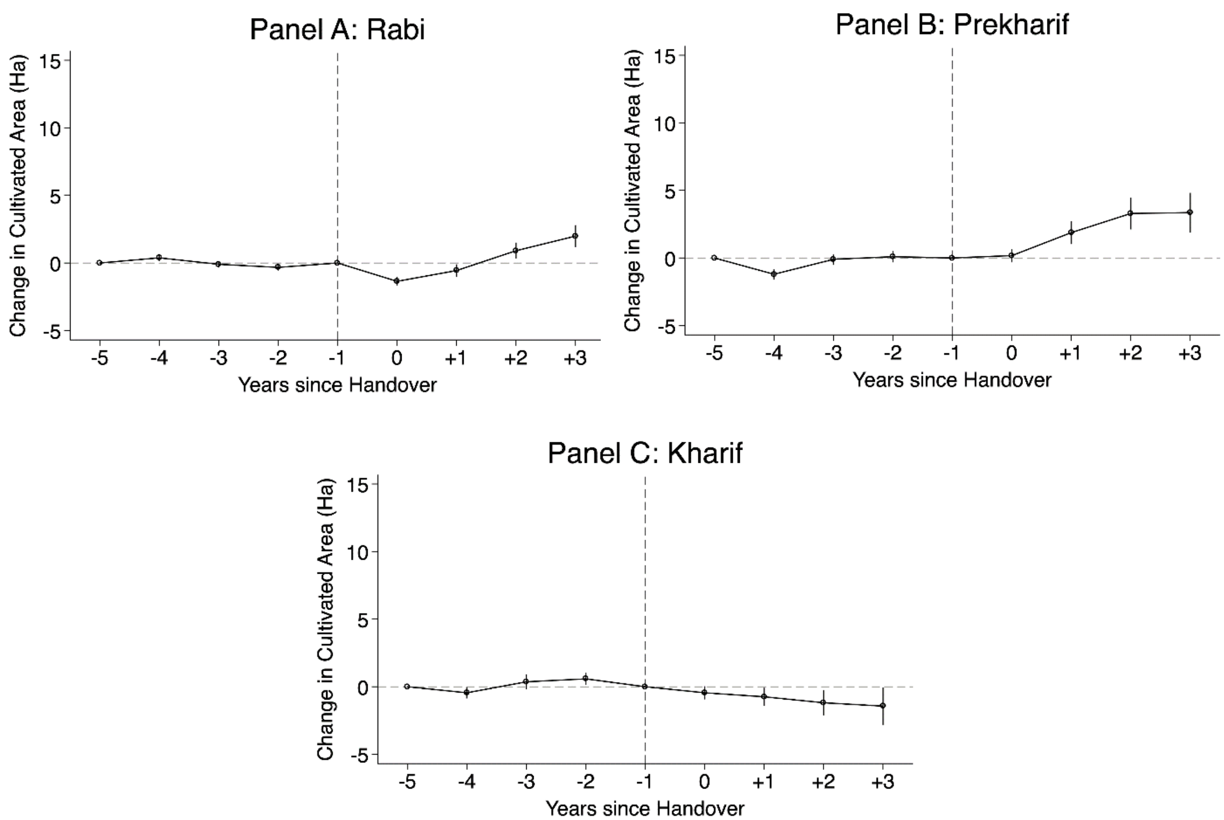
To understand how this impact compares to the status quo traditional irrigation programs, we can conduct the same analysis for Jalatirtha schemes. Although we do not have polygons of the command area for Jalatirtha schemes, we can analyze the trends in cultivation in a half-kilometer radius around the point location of the scheme. As most schemes are groundwater schemes, such as tube wells, this circle is likely to approximate water usage. In the difference-in-difference specification, we find a statistically significant decrease in cultivation on average around Jalatirtha schemes in all seasons (Table 3). However, when this is disaggregated in the event study (Figure 8), there is essentially no impact on cultivation in Rabi or Kharif but a statistically significant increase in cultivation in Pre-Kharif of approximately two hectares per scheme in the first year after handover, increasing to approximately four hectares in the second and third year after handover. The negative estimated impact in Pre-Kharif in the simple difference-in-difference is likely driven by implicit weighting by year based on data availability. These empirical designs, event studies and generalized difference-in-difference for panel data, are actively being explored by econometric researchers (Bacon-Goodman 2019, Borusyak and Jaravel 2017) and thus we urge caution in interpreting these differing results. Current practice points towards favoring the event-study plots as true measures of impact (Bacon-Goodman 2019).

Table 3. Difference-in-difference estimates of Jalatirtha impact on cropped area (in hectares)

	(1)	(2)	(3)	(4)	(5)	(6)
	Pre-Kharif	Rabi	Kharif	Ln Pre-Kharif	Ln Rabi	Ln Kharif
Post Jalatirtha	-0.781***	-1.633***	-0.950***	-0.170*	-0.133	-0.0379
	(0.186)	(0.193)	(0.194)	(0.0961)	(0.0845)	(0.0256)
Constant	3.711***	2.057***	10.15***	0.823***	0.484***	2.268***
	(0.115)	(0.128)	(0.111)	(0.0527)	(0.0535)	(0.0175)
Scheme and year FE	X	X	X	X	X	X
Observations	5,004	5,004	5,004	3,566	3,383	3,951
R-squared	0.273	0.196	0.558	0.235	0.166	0.243
Number of Schemes	417	417	417	416	408	416

Robust standard errors in parentheses. Standard errors clustered at scheme level. *** p<0.01, ** p<0.05, * p<0.1
Source: Landsat 7 NDVI.

Figure 8. Event studies of Jalatirtha impact on area cultivated



Note: The dummy for five years prior to handover was omitted in addition to that of the year prior to control for a time trend.
Source: 424 Jalatirtha Schemes

6.2.3. Comparing ADMI and Jalatirtha

We cannot compare the size of the effects of the ADMI and Jalatirtha event studies directly because the size of the sampled area differs between the two. However, we can compare trends. In both types of schemes, farmers move increasingly into cultivation in the Pre-Kharif season. Neither irrigation scheme seems to increase cultivation in the driest Rabi season. The primary difference in trends is that ADMI has a positive impact on cultivation in the rainy Kharif season for two years following handover while Jalatirtha has no impact. The ADMI findings are consistent with a model of a risk-averse farmer. The farmer is likely to utilize additional irrigation for crops they know well, such as rice paddy in the Kharif season. The farmer may be willing to expand to the next lowest risk season—Pre-Kharif—where occasional rains provide additional protection against crop loss. Farmers are least likely to begin cultivating in the highest risk Rabi season. ADMI farmers in particular demonstrate a dynamic trend where they increasingly switch from supplementing their Kharif crops to Pre-Kharif crops, which could be explained by the Agricultural support services trainings and resources they receive for crop diversification. Contrastingly, Jalatirtha farmers seem to shift cultivation directly to new seasons which we hypothesize could be a result of them not switching crop types and thus not having to incur the self-insurance in kharif. While we do not have a definitive answer to this, we will provide evidence in the next section that non-ADMI farmers have less crop diversification even if they have access to irrigation. An important area of future study is to collect more data on Jalatirtha farmers to complete the picture their agricultural activities and further validate a model of farmer behavior.

Though we cannot compare the impact on hectares cultivated across scheme type, we can compare the estimated percentage change in cultivated area, as this normalizes the size of command area. We restrict our sample to the 39 ADMI schemes in the four districts where Jalatirtha operates (see Section 3). We estimate that ADMI led to a 39% increase in cultivation in Pre-Kharif, 19% increase in cultivation in Rabi, and a 6% decrease in cultivation in Kharif, though none of these effects is statistically significant. Jalatirtha schemes resulted in essentially no percent change in the area cultivated. The difference in estimated impact between the two types of schemes is not statistically significant for any season (Table 4).

Table 4. Difference in means test for ADMI and Jalatirtha percentage change in cultivation

	ADMI (4 districts)		Jalatirtha		*P-value of difference in means test*
	Estimate	SE	Estimate	SE	
Ln Pre-Kharif	0.389	0.401	-0.17	0.0961	0.175
Ln Rabi	0.191	0.382	-0.133	0.0845	0.408
Ln Kharif	-0.0573	0.0748	-0.0379	0.0256	0.806

*** p<0.01, ** p<0.05, * p<0.1
Source: Landsat 7 NDVI

In sum, we currently have inconclusive evidence on the difference between ADMI and Jalatirtha in the districts that they both operate in, which might be a result of the differing scheme types between ADMI and Jalatirtha or the differential measurement error in using inexact buffers for Jalatirtha and exact polygons for ADMI. We recommend refining this analysis through obtaining command areas for a subset of Jalatirha schemes and additionally collecting data on non-ADMI groundwater schemes, both of which can be done at low cost by the ADMI GIS team.

6.3. Comparing ADMI and non-ADMI farmers within village using survey data

In the previous section, we compared ADMI farmers to farmers using traditional government irrigation structures. In this section, we utilize new data from a representative individual-level survey to contrast ADMI farmers to other members of their village that are not members of the WUA. As described previously, farmers typically join the WUA only if their plot is within the area that an irrigation engineer has determined can be irrigated by the structure. As the only difference between these farmers is a result of near-random geological variation, these non-ADMI farmers in the same village should be a good representation of what would have happened to ADMI farmers in the absence of ADMI. That being said, non-ADMI farmers in the same village may have benefitted from training from ADMI or learned directly from observing ADMI neighbors' practices. These "spillover" effects would lead us to underestimate the impact of ADMI. Therefore, the estimates in this section can be considered a lower bound on the potential impact of ADMI.

As discussed in Section 5.1, 31% of sampled schemes were replaced because the scheme was defunct, the WUA was in conflict, or other similar reasons. The results of this section therefore apply only to ADMI beneficiaries of functional schemes.

6.3.1. Impact on agricultural revenue

According to ADMI farmers, their revenue from agriculture has more than quadrupled from the year before the ADMI scheme was handed over, increasing from INR 18,005 to INR 76,794 (Figure 9). These results should be interpreted with caution, given potential challenges in recalling agricultural sales from years prior and social desirability bias to report an increased income to the enumerator. Despite these limitations, such a large increase in the average is encouraging. Non-ADMI farmers also saw an increase in revenue over the same time period, but only increasing by INR 15,006 (Figure 9). This may be the result of benefitting from ADMI trainings or learning practices from ADMI farmers (spillover effects) or it could be due to other broader improved conditions for farmers.

Comparing the two changes allows us to understand how much ADMI farmers improved relative to how much they might have improved in the absence of the project. It also allows us to minimize the recall bias and some of the social desirability bias, as these are likely to be similar among the two groups. The raw difference-in-difference of averages is INR 43,783, meaning that ADMI farmers' revenue increased by INR 43,783 more than their non-ADMI neighbors' revenue.

We can make the estimate more rigorous by considering only farmers for which we have data on revenue for both before and after ADMI[5] and by controlling for other variables in our dataset. The bare bones difference-in-difference specification results in an estimated impact of ADMI of INR 22,718 per farmer, or USD 317 (Table 5, Column 1). The estimate is statistically significant. In our preferred specification with demographic, scheme type, and district controls, the estimate increases to INR 28,275 (USD 382) and remains statistically significant. This constitutes a 2.6-fold increase over average baseline income; an enormous increase. We can use data from the ground-

We estimate that, on average, ADMI increased farmers' revenue from agriculture by INR 28,275, more than doubling baseline income.

[5] A technical glitch prevented collection of pre-ADMI data for the first 166 observations.

truthing survey to understand how the constraints established in our conceptual framework (Section 2) interrelate with the ADMI program. Box 3 describes the measures we use for these constraints. As the first step in this analysis, we show that our estimate of ADMI's impact is robust in a specification that controls for these proxies for five constraints of our conceptual framework, as well as the quality of the WUA (see Box 2).

Figure 9. Observed difference-in-difference in agricultural revenue

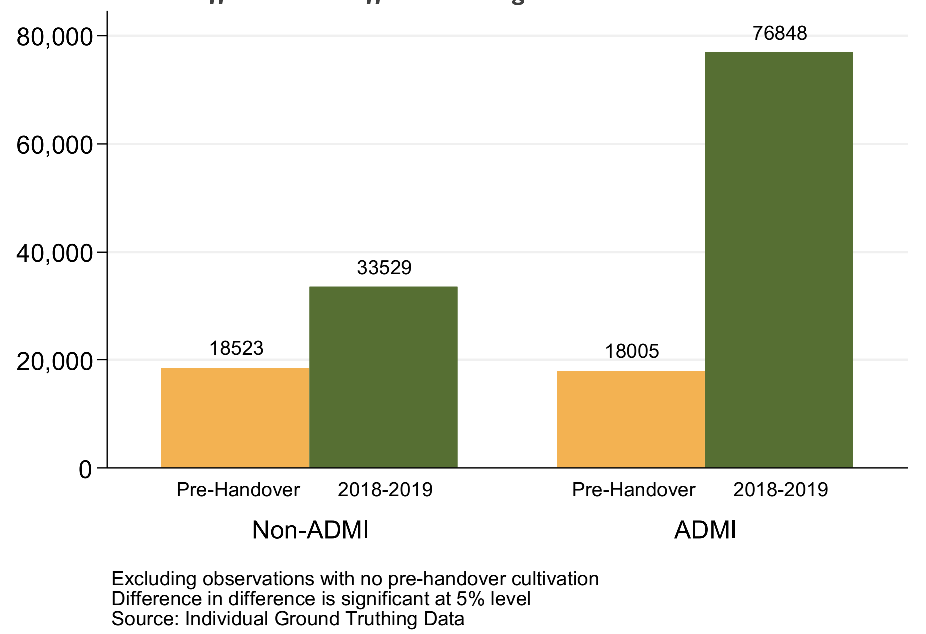


Table 5. Difference-in-difference estimates of ADMI impact on revenue

	(1)	(2)	(3)
		Change in Revenue	
ADMI	22,718***	28,275***	24,881**
	(6,021)	(7,019)	(11,436)
Receives sufficient water			-8,800
			(7,128)
Began growing an additional crop type			25,324*
			(13,007)
Made an investment in agr. equipment			-5,386
			(4,910)
Began a new agr. practice			1,390
			(4,502)
Began selling collectively			20,351*
			(10,173)
WUA institutional quality index			-862.5
			(4,590)
Constant	13,489***	-8,484	-2,248
	(3,747)	(32,322)	(26,363)
Controls		X	X
Observations	402	333	333
R-squared	0.047	0.230	0.306

Robust standard errors in parentheses. Standard errors clustered at district level. Controls include gender, age, caste, religion, education, house type, district, and scheme type. *** p<0.01, ** p<0.05, * p<0.1
Source: Individual ground-truthing survey.

6.3.2. ADMI impact in context

To put the impact of ADMI in context and to understand more about the importance of our five barriers of interest, we examine the associations[6] of our proxies for overcoming these barriers and increased revenue (Table 6). For all the barriers but water, our proxy measures a change in that barrier, thus we can compare the change in the barrier and the change in revenue. For water, we only know whether farmers presently receive sufficient water, and therefore only test whether receiving sufficient water presently is associated with higher present revenue. Receiving sufficient water is associated with INR 21,899 higher revenue; however, the coefficient is not significant, indicating that there is large variation in revenue within the groups with and without sufficient water.

The greatest difference in increase in revenue exists between farmers that did not change the number of crops they cultivated and those that were able to expand into additional crops—on average, farmers that were able to diversify to at least one additional crop increased revenue by INR 29,751 more than those that did not. Farmers that began selling collectively saw their revenue increase by INR 15,742 more than those that did not. This estimate is not statistically distinguishable from zero, but may suffer from the low power of our sample. Notably, a higher WUA institutional quality index (see Box 2) is not associated with a greater increase in revenue for farmers. Finally, whether a farmer presently receives sufficient water is not predictive of that farmers increase in revenue. Unfortunately, we are unable to determine whether an increase in availability of water is associated with an increase in income because we do not have data on the change in water availability.

Table 6. Associations of intermediate outcomes and revenue

	(1)	(2)	(3)	(4)	(5)	(6)
	Revenue, 2018-2019	Change in Revenue, pre-handover to 2018-2019				
Receives sufficient water	21,899 (24,519)					
Started an additional crop type		29,751** (13,205)				
Invested in agr. equipment			-3,245 (7,944)			
Began a new agr. practice				2,773 (4,020)		
Began selling collectively					15,742 (11,871)	
WUA institutional quality index						-5,402 (6,789)
Constant	575,681 (108,179)	3,339 (31,065)	7,270 (35,657)	6,584 (35,250)	7,566 (35,787)	25,422 (53,548)
Includes Non-ADMI farmers	X	X	X	X	X	
Controls	X	X	X	X	X	X
Observations	476	333	333	333	333	257
R-squared	0.146	0.271	0.183	0.183	0.189	0.253

Robust standard errors in parentheses. Standard errors clustered at district level. Controls include gender, age, caste, religion, education, house type, district, and scheme type. *** p<0.01, ** p<0.05, * p<0.1
Source: Individual ground-truthing survey.

[6] Note that these coefficients can no longer be interpreted causally—we do not assume that the farmers that are able to overcome these barriers exhibited parallel trends in revenue prior to ADMI.

Box 3. Measures of constraints facing farmers

Throughout this section, we use the following five variables as proxies for five of the barriers outlined in the conceptual framework in Section 3.

1. **Sufficient irrigation:** Farmers were asked whether they *receive sufficient irrigation*. Unfortunately, we do not have a measure of the change in sufficiency of irrigation since the introduction of the ADMI irrigation scheme (WUA handover).
2. **Crop diversification:** The household survey includes detailed information about crop production. The change in crop diversification measures how many farmers reported *cultivating at least one more crop* at endline than baseline.
3. **Production technology:** Farmers were asked whether they had *invested in equipment for agriculture* since handover of the WUA.
4. **Agricultural practices:** Farmers were asked whether they practice presently and at baseline a series of agricultural practices for which ADMI provides training. We measure the *number of farmers that report adopting at least one new practice*.
5. **Low prices & bargaining power:** Farmers were asked whether they participate in *collective sales* of their products. Such collective sales could improve farmers' bargaining power to earn higher prices.

6.3.3. Mechanisms of ADMI's Impact

To understand what could be driving ADMI's impressive impact, we test the impact of ADMI on various intermediate outcomes. The results for the five barriers from the conceptual framework are presented in Table 7 and additional intermediate outcomes in Table 8. First, ADMI members are 37 percentage points more likely to have sufficient water for irrigation than their neighbors that are not a part of the ADMI WUA (Table 7, Column 1). This increase in water did not reduce their risk of losing crops due to drought, interestingly, but did allow them to cultivate an additional 1.6 bigha[7] of land and increase the likelihood they cultivated in an additional season by 12.4 percentage points.

Interestingly, the change in area cultivated was only statistically significant in Kharif season, where the ADMI farmers on average increased the area they cultivate by 1.2 bigha more than non-ADMI farmers. Pre-Kharif shows a 0.38 bigha increase relative to non-ADMI farmers, though the difference is not statistically significant, while there is no discernable increase in Rabi. This is consistent with the findings based on the satellite data—the largest increase in area cultivated took place in Kharif, followed by Pre-Kharif, with hardly any change in Rabi cultivation. Assuming 60 WUA members per scheme (the median according to the MIS system), this is equivalent to an increase of 72 bigha or 11.5 hectares of cultivation in Kharif. This is much higher than the estimate of 2 hectare increase per scheme in Kharif using the satellite data. This difference could be a because the NDVI threshold to calculate cultivated area using

ADMI farmers on average increased the area they cultivate in Kharif by 1.2 bigha more than non-ADMI farmers and increased rice yield by an additional 20%. There was no statistically significant increase in Pre-Kharif or Rabi cultivation.

[7] Bigha is a commonly used measure of land in India. 1 hectare is approximately equal to 6.23 bigha. The average cultivation of ADMI farmers prior to ADMI is approximately 5 bigha.

satellite data was too low, because the within-village random sampling of WUA members became biased toward farmers present as enumerators were forced to replace farmers they couldn't find, or other reasons.

Table 7. Difference-in-difference estimates of ADMI impact on intermediate outcomes (A)

	(1) Receives sufficient water	(2) Started an additional crop	(3) Invested in agr. equipment	(4) Began a new agr. practice	(5) Began selling collectively
ADMI	0.367***	0.238***	0.164***	0.139***	-0.00379
	(0.0983)	(0.0428)	(0.0414)	(0.0464)	(0.0433)
Constant	0.602***	-0.169*	-0.0782	-0.0665	-0.0188
	(0.188)	(0.0912)	(0.172)	(0.121)	(0.0940)
Controls	X	X	X	X	X
Observations	476	476	476	476	476
R-squared	0.236	0.224	0.130	0.257	0.091

Table 8. Difference-in-difference estimates of ADMI impact on intermediate outcomes (B)

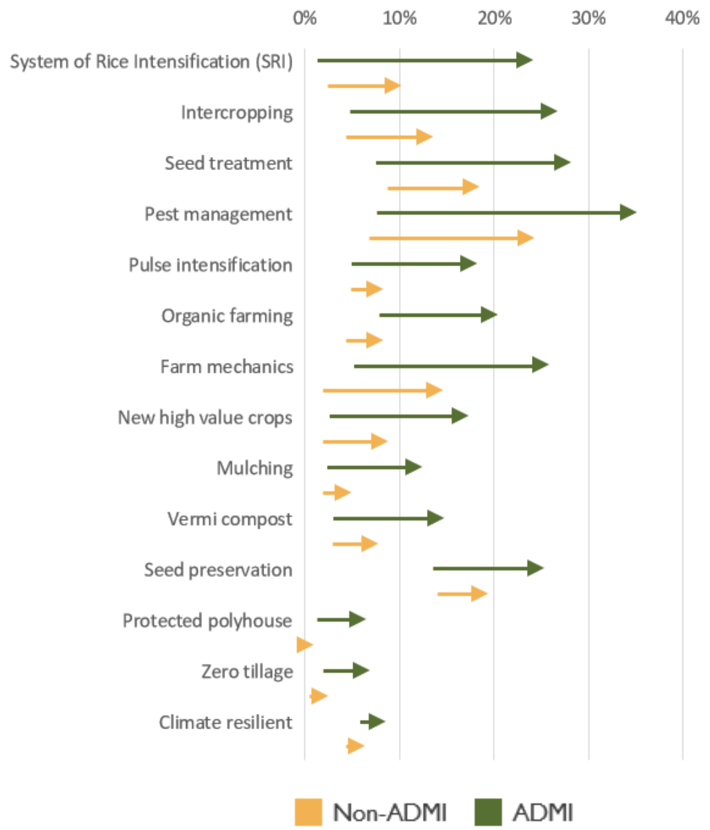
	(1) Lost crops this season due to drought	(2) Increase in area cultivated (bigha)	(3) Increase in double cropping	(4) Increase in paddy yield (kg/bigha)
ADMI	-0.0562	1.603*	0.124*	109.2**
	(0.0525)	(0.787)	(0.0686)	(37.22)
Constant	-0.120	-1.400	-0.415	-102.9
	(0.119)	(2.883)	(0.305)	(98.56)
Controls	X	X	X	X
Observations	476	333	333	290
R-squared	0.293	0.090	0.267	0.263

Robust standard errors in parentheses. Standard errors clustered at district level. Controls include gender, age, caste, religion, education, house type, district, and scheme type. Unless other unit is indicated, results represent likelihood of event or practice. *** p<0.01, ** p<0.05, * p<0.1. 1 hectare=6.23 bigha.
Source: Individual ground-truthing survey

With respect to productivity, ADMI farmers saw a statistically significant increase in rice paddy yield of 109 kilograms (kg)/bigha more than their non-ADMI neighbors since the introduction of ADMI. This is the primary crop of most marginal farmers, and tremendous increase over a baseline yield of 436 kg/bigha. Apart from the first order effect of receiving more water, this could be a result of improved practices introduced by the ADMI agricultural support services—ADMI farmers had a 13.9 percentage point higher likelihood of taking up a new agricultural practice. Figure 10 indicates the change in the percentage of farmers undertaking a number of improved agricultural practices, and indeed ADMI farmers have experienced much higher uptake of practices; particularly rice intensification, intercropping, and pest management. Non-ADMI farmers also increased their use of these improved practices, indicating potential spillover effects. Increased productivity may also be a result of ADMI farmers' increased likelihood to have invested in agricultural equipment (16.4 percentage points higher likelihood).

In marketing, ADMI farmers did not increase their propensity to sell collectively by more than non-ADMI farmers. Interestingly, this is likely due to the fact that ADMI farmers were far more likely to sell collectively prior to the introduction of ADMI—26% of ADMI farmers reported selling collectively prior to ADMI relative to 6% among non-ADMI members (Figure 23, Appendix 3).

Figure 10. Changes in % of farmers using improved agricultural practices, pre-ADMI to present



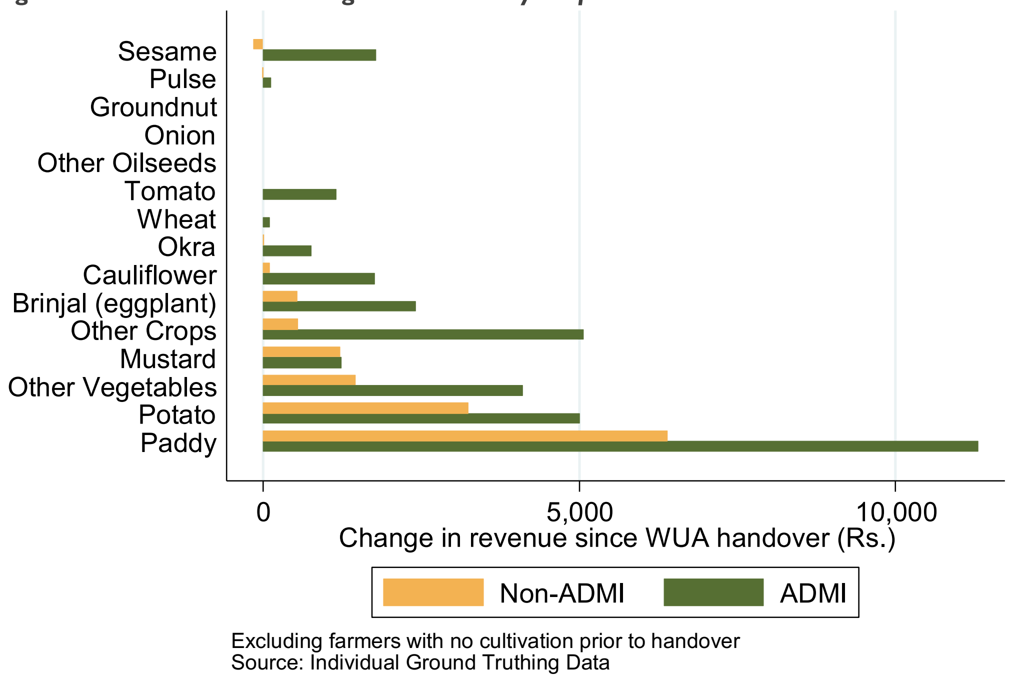
See Table 12 in Appendix 3 for underlying data. Start of line represents % of farmers practicing pre-ADMI, arrowhead represents % of farmers practicing at present.
Source: Individual ground-truthing survey

In line with the finding that ADMI farmers saw the largest increase in area under cultivation during the monsoon (Kharif) season and saw large increases in yield of rice paddy, we see the greatest increase in revenue relative to non-ADMI farmers in rice paddy, a monsoon crop. Crop diversification also seems to be driving the difference in revenue between ADMI and non-ADMI farmers, with higher increases in revenue from vegetables and seeds (Figure 11).

6.3.4. Variation in ADMI impact

To further understand the story of how ADMI was able to affect farmers' lives, we can conduct heterogeneity analysis of the impact of ADMI on agricultural revenue for various sub-groups of interest. The full specifications are presented in Table 13 in Appendix 3. First, we find that ADMI had a statistically significant larger impact for males (INR 26,694) than for females (INR 10,180). This should be interpreted with caution, because ADMI females were oversampled in the individual survey. As a result, there are only 19 non-ADMI females in the sample to compare ADMI females to. Furthermore, females in ADMI are have much higher revenues from agriculture, on average, than their non-ADMI counterparts. Having higher revenue prior to ADMI may generate ceiling effects preventing these women from improving by as much relative to the non-ADMI women. However, it is important to explore further whether there is any reason for men to benefit less than women from ADMI interventions. Second, there is variation in impact of ADMI by caste status—members of Scheduled Tribes, on average, benefit less from ADMI than members of other castes. However, this difference is not statistically significant. The same is true of religion. Third, those with primary education benefit more from ADMI than those with incomplete primary or complete secondary. Again, the difference between these coefficients is not statistically significant. Finally, we observe no differences by farmer age or whether the farmer has a brick or mud house, a proxy for income.

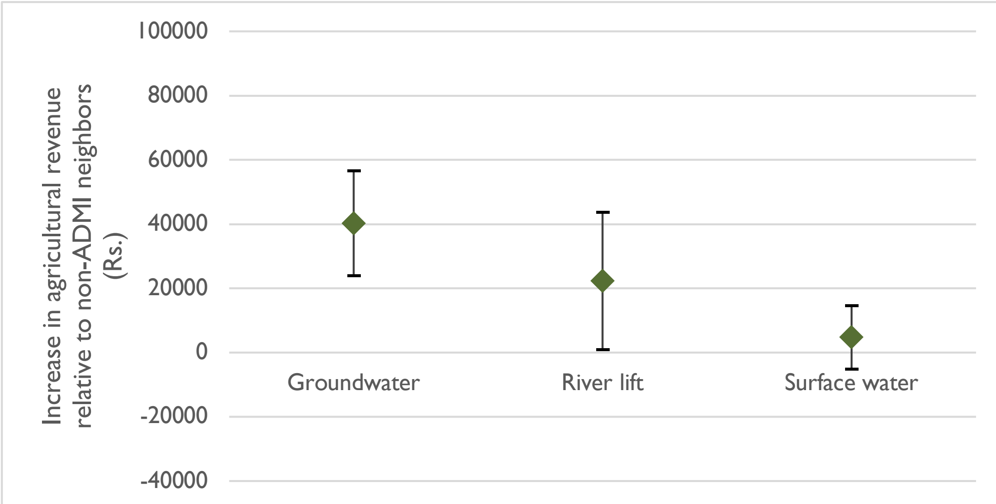
Figure 11. Breakdown in change in revenue by crop



We conduct additional assessment of the heterogeneity of ADMI impact by scheme level variables, including scheme type, district, and year of handover. We find that ADMI impact varies greatly by scheme type (Figure 12) and district (Figure 13), controlling for demographic characteristics. Across scheme types, ADMI impact is only statistically significant for groundwater schemes, not for river lift or surface water schemes. For groundwater schemes, ADMI farmers are estimated to have increased their revenue from agriculture by INR 40,264 more than their non-ADMI neighbors. Given ADMI's interest in pursuing surface water schemes, it would be worthwhile to conduct further investigation into the muted impact in these schemes.

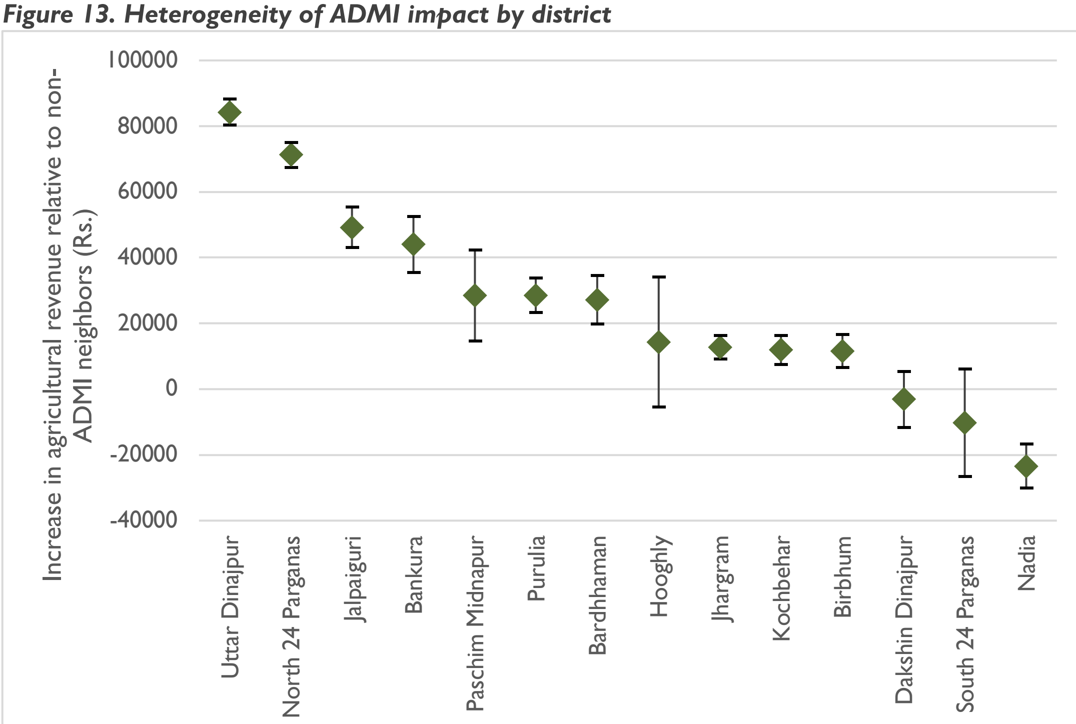
Across districts, farmers saw the highest impacts from ADMI in Uttar Dinajpur, North 24 Parganas, and Jalpaiguri districts. These districts are located across agroclimatic zones and vary greatly in average district income. Nadia, South 24 Parganas, and Dakshin Dinajpur all had near zero impact of ADMI relative to non-ADMI farmers. These states border the best performers. ADMI should explore further what might be driving these differences in impact across districts to share best practices and support underperforming WUAs. Finally, there were no strong trends in ADMI impact by year of handover (Figure 25 in Appendix 3). Farmers in schemes handed over in 2019 underperformed those handed over in other years, but this is very likely due to the fact that they have not yet had a season to benefit from the additional irrigation.

Figure 12. Heterogeneity of ADMI impact by scheme type



Point represents coefficient estimate, controlling for district, gender, age, caste, religion, education, and house type. Bars represent 95% confidence interval. Complete regression results are available in Table 14 in Appendix 3.
Source: Individual ground-truthing survey.

Figure 13. Heterogeneity of ADMI impact by district



No data for Howrah and Malda. Point represents coefficient estimate, controlling for scheme type, gender, age, caste, religion, education, and house type. Bars represent 95% confidence interval. Complete regression results are available in Table 14 in Appendix 3.
Source: Individual ground-truthing survey.

Story of a WUA: Food security in the face of climate vulnerability

Narasinghapur Baro Bandh Sidhu Kanhu WUA, Bankura District

ADMI completed construction of a Water Detention Structure (WDS) in this community of Scheduled Tribe members in 2018. The village had been experiencing increasing crop loss as a result of climate change. The WUA members expressed deep gratitude for the new WDS, which has helped save their rice paddy crops and provide solace that they will be able to feed their families. WUA members have now begun growing tomato, eggplant, onion, and cabbage, and have planted fruit orchards with ADMI's support. An elderly community member stressed his appreciation for the new vegetables and the vitamins they provided him and his family. In addition, women in the village emphasized that the WDS provided a clean place for them to bathe, one of the benefits they were most grateful for.

Only one person in this community sells produce commercially; all other farmers cultivate for subsistence alone. As such, these impacts will not be picked up in our measure of revenue from agriculture. It is important to keep in mind that the program's impact may be much deeper than our analysis can reveal.

Though ADMI schemes provide farmers with some additional resiliency, farmers continue to become more vulnerable. The water in the WDS was 20 feet deep when it was first constructed, but the severe drought in 2019 had depleted it to 10 feet. Almost all WUAs we met with described new challenges resulting from climate change. Sweeping global action is required to mitigate the effects of the climate crisis on these and the millions of other farmers worldwide who will bear the greatest burden. In the meantime, these farmers will require increasing support to adapt and build resilience.

6.3.5. Externalities

Irrigation could have a number of additional impacts for beneficiaries as well as spillover effects on farmers in the same village. For example, ADMI farmers have a 10 percentage point higher likelihood of reporting that their children's consumption of fish increased and an 11 percentage point higher likelihood of reporting that their spending on their children's education increased, controlling for our preferred demographic and scheme controls used throughout. Both effects are not statistically significant, but important areas for further research. ADMI farmers had an 18 percentage point higher likelihood of reporting an increase in land value (again with the same controls). This effect is statistically significant.

Impacts on non-ADMI farmers in the same village are an important area for further research. We encourage other researchers to compare the increase in agricultural income we observe in non-ADMI farmers in this data with that of other farmers outside ADMI villages. As Figure 10 indicates, we see increased uptake of improved agricultural practices among non-ADMI farmers indicating that they are likely benefiting from ADMI trainings as well.

6.4. Analyzing constraints facing farmers

6.4.1. Heterogeneity analysis by presence of baseline constraints

The same heterogeneity analysis method was used to shed light on our understanding of the constraints presented in our conceptual framework. If a farmer experiencing this constraint prior to the introduction of ADMI benefitted more, it would indicate that the constraint was an important binding constraint for ADMI to address. For example, we find that ADMI farmers that did not practice collective sales prior to the introduction of ADMI benefitted more from ADMI than those that did, indicating that the ability of ADMI to mobilize additional farmers into collective sales could be an important driver of its impact (Table 15, Appendix 3). Farmers who sold in markets benefited more than farmers that sold to aggregators at their farm. This could indicate that ADMI has not been able to resolve the binding constraint of market access. Finally, farmers with pre-handover bank accounts benefitted more. Again, this could indicate credit access is required for farmers to fully take advantage of the ADMI package. Importantly, the difference in coefficients for each of these was not statistically significant, so they should be interpreted with caution.

We find that farmers that practiced double-cropping prior to the introduction of ADMI were able to improve by more than farmers that did not, though this difference is not statistically significant. Further, there was no statistically significant difference in the impact of ADMI among farmers that owned less land or earned lower revenue prior to the introduction of ADMI.

In sum, the heterogeneity analysis does not provide strong insights on constraints facing farmers as there are no statistically significant differences in impact based on these baseline characteristics.

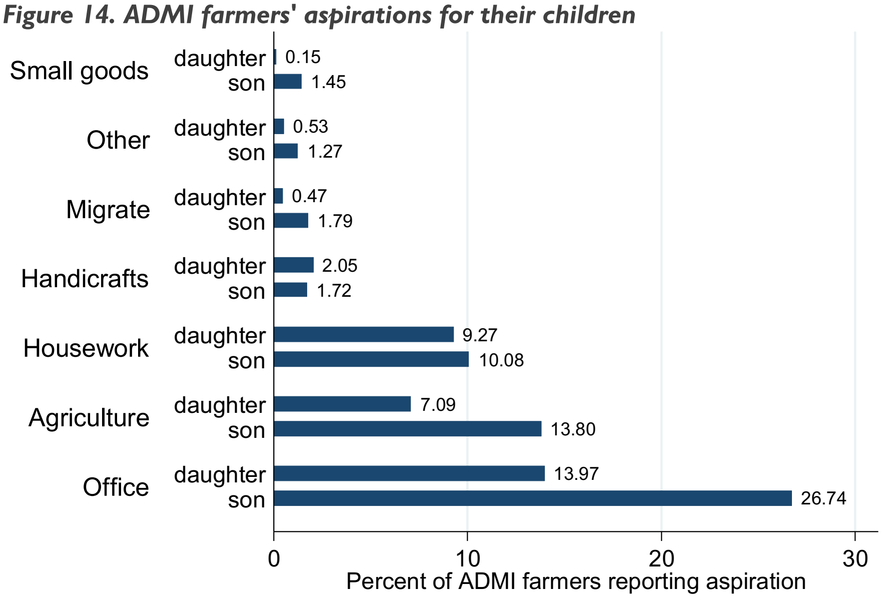
6.4.2. Barriers to higher prices

We can add to our analysis of farmers' bargaining power through collective sales by analyzing data collected on prices and market attributes. First, we find that participating in collective sales does not affect the prices farmers receive, indicating that the increase in revenue associated with entering into collective sales is likely driven by volume rather than price. Second, we find that price is not correlated with the distance the farmer travels to a market (Figure 26) and there is no statistically significant difference in price across market location, controlling for distance and village. These findings are challenging to interpret given potential selection effects—for example, farmers that are more likely to travel to further markets may have lower quality products and unable to sell to the local aggregator, and thus do not benefit from selling at a more centralized market. As such, we rely most on our third finding to understand the relevance of market access and bargaining power: 45% of ADMI farmers express interest in selling at a further market than they presently do. This high demand for further market connection indicates the potential for government support in this area; however, further research is needed into prices across various markets to ensure that there is actually potential gain from selling further away. The most commonly cited barrier to selling further is access to a vehicle (Figure 27), an indication that this could be a good entry point for such support.

6.4.3. Barriers to more profitable employment

Finally, we analyze the constraint facing farmers that we have not yet addressed—the barriers preventing farmers for entering other, potentially more profitable, occupations. Even if farmers' revenue from agriculture increases, it is important to consider whether they would have preferred an alternative outside of the sector. In Figure 14 we present the aspirations farmers report for their children, disaggregated by gender. The most common aspiration for both genders is office work (27% of ADMI farmers aspire for their sons to work in an office and 14% for their daughters). From a broad public policy perspective, programs to address this latent demand for support to enter office jobs must complement programs such as ADMI that improve agricultural revenue.

Figure 14. ADMI farmers' aspirations for their children



Note: Respondents were allowed to tick all that apply.
Source: Individual ground-truthing survey.

6.5. Implications for our understanding of constraints facing farmers

The results of the previous sections lead us to conclude that irrigation helps resolve an important barrier for farmers, but only when properly maintained and supplemented with support that allows farmers to diversify into new crops.

Irrigation alone does not appear to be sufficient to increase farmers' incomes. First, we find that traditional irrigation schemes do not result in any statistically significant increase in cultivation in the surrounding area (Table 3). Second, there is no statistically significant difference in revenue between farmers that do and do not receive sufficient irrigation (Table 6).

However, when irrigation is maintained and combined with agricultural support services for crop diversification, the package can have a very large impact for farmers. We estimate that, on average, the ADMI package of services more than doubled farmers' revenue from agriculture (an INR 28,275, or USD 382, increase). ADMI schemes were less likely to be defunct than traditional irrigation schemes (11% failure rate versus 50%). The WUA appears to be an important driver of improved maintenance, with 76% of farmers reporting this effect, though improved site selection may also have contributed. The improved access to irrigation combined with training in agricultural practices allowed ADMI farmers to increase the area they cultivated in rice paddy in the monsoon Kharif season, increase the yield of the rice paddy, and diversify into new crops in the Pre-Kharif season. Crop diversification was associated with the highest increase in revenue, with farmers that started an additional crop increasing revenue by INR 29,751 more than those that did not (Table 6). With the caveat that some of this may be driven by selection, this finding indicates that access to irrigation and access to support to diversify into new crops are particularly important constraints for farmers.

Irrigation helps resolve an important barrier for farmers, but only when properly maintained and supplemented with support that allows farmers to diversify into new crops.

Our results indicate that bargaining power may also be a relevant barrier for farmers, but less so than irrigation and support for crop diversification. ADMI farmers indicated demand for access to further markets, but the price data does not indicate that prices were higher at further markets. Farmers that entered into collective sales did experience an increase in revenue of INR 15,742, though this difference was not statistically significant (Table 6). Those that participated in collective sales did not receive higher prices, but may have been able to sell larger quantities.

Low production technology and inefficient practices alone are less likely to be as important for farmers. Farmers that invested in agricultural equipment or began a new agricultural practice did not see larger increases in revenue than those that did not (Table 6).

Finally, our analysis of farmers' aspirations for their children indicates that barriers to employment in other sectors are likely to be strong and policymakers should not lose sight of farmers' long-term aspirations to move away from agriculture.

Our analysis also indicates that there are likely barriers we have not explored in this analysis. The impact of ADMI was highest in Uttar Dinajpur, North 24 Parganas, Jalpaiguri, and Bankura (Figure 13), which do not share common geographical or economic characteristics. An important area for future research is to explore whether this variation is driven by best practices in implementation in these districts or barriers ADMI was able to alleviate that we do not cover in this study.

Story of a WUA: Crop diversification and female empowerment

Uttar Matiali Jiban Jyoti WUA, Jalpaiguri District

ADMI constructed a solar-powered tube well in this tightly knit community 25 kilometers from the city of Jalpaiguri in northern West Bengal. The WUA members have been able to diversify into cultivation of many types of vegetables and have started fish cultivation, all with ADMI's support. The new crops resulted in such large increases in revenue that the WUA was able to pool their funds to buy a car to transport their goods (and save on costs for other local travel needs).

As vegetable and fish cultivation are typically led by women, women have taken on increasing responsibility within the WUA, with the two women standing in this photo now serving as the WUA's President and Secretary. These women, who were described by another WUA member as soft-spoken prior to the ADMI project, now confidently presented their objectives for the WUA. Not only has crop diversification been one of the largest drivers of increased revenues for ADMI farmers, but cases such as this highlight the potential additional impact on village gender dynamics. Increasing productive opportunities for women increases the productive potential for the household as a whole, as well as potentially increasing female's relative bargaining power within the household.

7. Policy proposals

The WRIDD finds itself at a critical juncture as the ADMI project shifts to state funding this year, with a mandate to improve the current design of irrigation provision and continue to improve the income of marginal farmers. The opportunity for action is made even more concrete by the appointment of Mr. Prabhat Mishra, Project Director of ADMI, to the role of Principal Secretary of WRIDD and the potential for a second round of World Bank funding. In light of the results of our impact evaluations, we present three potential policy options for WRIDD:

1. **Scale ADMI to additional farmers:** Extend the ADMI package to traditional irrigation schemes, while continuing to support existing WUAs.
2. **Facilitating collective sales:** Add additional services to help WUAs increase their market power by coordinating their economic activities.
3. **Converge with other government programs:** Use the WUA's institutional structure as a platform to increase the uptake of other government policies targeting farmers.

We recommend against continuing the current status quo of irrigation construction without agricultural support or WUA mobilization. This is based both on technical considerations, namely the positive impact revealed through our empirical analysis, and political pragmatism – WRIDD is already in the process of considering a Phase II of ADMI. Their current plans include creating approximately 2,500 new schemes and extending coverage of ADMI services to approximately 4,000 traditional irrigation schemes. Our policy proposals are designed to operate within these plans.

We also recommend the use of randomized pilots and design thinking principles for rapid learning as a framework of implementation across all policy options. We consider this methodological recommendation as important as the policy proposals themselves, as it can become bedrock for all future actions. After discussing this approach, we elaborate on a possible implementation plan for each of the three policy options and discuss their administrative feasibility and political supportability.

7.1. General principles for learning through implementation

In this section we present key considerations for successful implementation of our policy recommendations through the use of pilots and effective data systems.

The motivation for this methodology comes from understanding ADMI's place within the Ambiguity-Conflict framework (Matland 1995). If we consider a 2x2 matrix along the dimensions of conflict and ambiguity, ADMI currently falls into the High Ambiguity, Low Conflict category. There is high ambiguity as this is a new policy area, and it is unclear what the underlying problems and corresponding solutions might be. At the same time there is low conflict as ADMI has been given the go-ahead to expand from the state. The goal of increasing farmer's income is shared across departments. This calls for an approach of experimental implementation, where the central driving factor will be contextual conditions. The first overarching recommendation for WRIDD is to become increasingly problem-driven and outcome-focused, as opposed to solution-driven and output-focused. The Department has made several important steps in this direction, for example in their recent refocusing on income rather than agricultural productivity.

Rapid impact evaluations using randomized control trials will be a crucial tool in this approach. Randomized control trials are considered the "gold standard" of causal evidence and are being increasingly used to evaluate public policy in India. They consist of randomly allocating beneficiaries to two groups, one that receives the policy and one that remains a control. As randomization ensures that the groups are similar prior to the intervention, the difference in outcomes between the groups at endline can be attributed to the causal impact of the policy. We recommend that WRIDD explore this tool, but urge that they focus on evaluations that are tailored to help them nimbly make policy decisions.

Another important principle is to continue to allow opportunities for positive deviance in both ADMI staff and the WUAs. Instead of adopting a strict adherence to protocol, WRIDD should continuously look for agents who are achieving positive outcomes through activities not strictly planned. ADMI staff should continue experimenting with new advances. A large portion of the GIS analysis in this report is due to the independent work of the GIS team, who have compiled shapefiles and measures of cropping intensity through satellite data. Similarly, many WUAs have found innovative methods that might have not been conceived by ADMI; for example, some WUAs have invested in vehicles to be able to sell at further markets.

7.1.1. Building data systems

Data are a crucial component of making evidence-informed policy decisions, particularly as government organizations enter new areas of exploration. While establishing effective data systems can involve significant financial and staff costs, incurring these prior to implementation can have positive downstream effects and pay for themselves by reducing the need for expensive post-program evaluations. ADMI has already made significant strides in becoming a data-driven organization with its use of GIS analysis and monitoring and evaluation activities. However, there remain some weaknesses that should be addressed as the project enters Phase II.

We offer three simple recommendations for ADMI's to improve its data systems:

1. **Focus on final outcomes.** ADMI should align measurement with their new objective of farmer income and develop streamlined survey instruments to understand farmer costs and revenue. These surveys should be run every year on a small random sample of farmers, both ADMI and non-ADMI, to provide input for continuous monitoring and evaluations. The ground-truthing individual survey can be used as a base for this new instrument.
2. **Understand who is collecting the data**. Different data are collected by different agents, including district staff and NGO workers. ADMI should map out the potential principal-agent problems within each stream of data collection to understand whether incentives could shape data quality. It is also important to ensure that data collection activities do not place undue burden upon frontline workers. To address this, ADMI should continue incorporating the use of satellite data for low-cost monitoring and explore collecting information through phone surveys, perhaps through its new partnership with Precision Agriculture for Development.
3. **Ensure all data are interconnected.** ADMI should ensure that each datapoint is labelled with the Scheme ID and develop a unique WUA ID to standardize WUA names. This will allow all datasets to link to the central MIS, providing a centralized source for all information related to program activities. In particular, linking the WUA grading data with the MIS system will allow for more rapid monitoring of potential institutional weak points.

7.2. Policy Option 1: Scaling ADMI to additional farmers

WRIDD is already in the process of formulating a strategy for scaling the ADMI package to farmers using existing traditional irrigation schemes across West Bengal. This is supported by rigorous evidence – our impact evaluation highlights the positive role of ADMI in promoting farmer welfare through a large causal increase in agricultural revenue and other valuable intermediate outcomes. Together with the robust administrative framework developed over the past five years, WRIDD is well placed for this scale-up.

However, scale-up involves technical and administrative concerns. From a technical perspective, expanding interventions to large-scale has been shown to cause spillovers that change the impact from the initial findings (often called general equilibrium effects). Regarding administrative constraints, the department should be careful about overburdening their current systems as the ADMI package is more intensive than irrigation infrastructure alone. It is critical that ADMI leverages the scale-up for learning, ideally through a large-scale randomized evaluation that is designed to understand mechanisms, capture potential general equilibrium effects, and help refine the administrative systems of the department (Muralidharan et al 2017).

7.2.1. Intervention design

The intervention here is the standard ADMI package, which consists of irrigation construction, local institutional support, agricultural support services, and training in horticulture and pisciculture.

7.2.2. Monitoring and evaluation

We propose evaluating the scale-up through a large-scale randomized trial with the following features:

- **Learning objective:** How can the ADMI package maintain impact at a larger scale?
- **Study sample:** Randomly sample 250 scheme-locations from the set of eligible locations that have not yet been constructed. This would encompass roughly 15,000 farmers.
- **Treatment assignment:** Randomly assign 125 WUAs to the Treatment group and proceed with the standard ADMI package. The other 125 WUAs will act as the Control group, where the only contact with ADMI will be for data collection.
- **Data collection:** Data should be collected on three sets of farmers: farmers eligible for ADMI, farmers not eligible for ADMI within the same village, and farmers not eligible for ADMI in neighboring villages. This will allow us to understand spillovers and general equilibrium effects both within-villages and across-villages in addition to the causal impact of ADMI.
- **Impact metrics:** The key outcomes should capture the effect of the treatment along ADMI's theory of change and thus include indicators for receiving irrigation, adoption of farming practices, agricultural productivity, and agricultural revenue.

Alternative option: If a randomized evaluation is not feasible, we recommend that WRIDD conduct a quasi-experimental methodology using either difference-in-difference (as explained in this report) or matching. For this option, ADMI should ensure it collects data on a sample of beneficiaries and non-beneficiaries prior to expansion.

7.2.3. Political support

There is currently a high level of political support for the scaling-up of ADMI. The Project Director of ADMI has assumed the senior-most position in the state's Water Resources Department and ADMI has gained good acceptance at the community level. At the highest authorization level, the Minister in Charge of the WRIDD has continuously affirmed desire for the project's expansion to new geographical areas. Motivation is also high within the department given the string of recent successes. However, WRIDD should be aware that scaling can produce strains on frontline workers and administrative staff, which might cause internal tensions. Thus, ADMI should continue re-examining their contract design with support staff.

7.3. Policy Option II: Facilitating collective sales

The limited market power of farmers continues to be a concern for farmers and policymakers and WRIDD intends to explore whether they can help alleviate this constraint. Our results indicate that ADMI farmers show demand for selling at further markers. Given that the driver of increased revenue appears to be increases in the quantities sold by farmers rather than prices, it is possible that encouraging collective sales can improve incomes from channels outside of greater bargaining power. Farmer Producer Organizations (FPOs), one common cooperative structure in India, typically involve over 1,500 farmers and are federated collectives. There would be considerable hurdles and mobilization costs to transitioning WUAs directly into FPOs, particularly since there is little rigorous evidence on how best to transition smallholder farmers into these organizations. Given this, we recommend that ADMI use rapid pilots to initially explore different methods of increasing market connections and market power, for example through smaller producer groups, rather than transition directly to FPOs.

7.3.1. Intervention design

The department should identify an external partner who has expertise in both community mobilization and market activities. There are a number of NGOs and private companies with experience in forming farmer collectives, including Pradhan, BAIF, and Access Livelihoods. ADMI should contract with one of these entities to i) conduct a study of existing efforts to improve farmers' market access in the state and across India, ii) carry out an assessment of ADMI farmer needs with respect to market access, and iii) develop a series of proposals to meet the differing needs and contexts of ADMI farmers. We expect this analysis to take approximately six months. This partner can lead the launch of various small-scale pilots of these proposals to test the impact on farmers' incomes and potential for future scale. These could include partnerships with private sector actors.

7.3.2. Monitoring and evaluation

If the studies suggest potential for market access interventions, we recommend that the partner conduct A-B testing of at least two potential context-specific intervention alternatives for each segment of ADMI farmers to learn what works best.

- **Learning objective:** What form of collective sale mechanism results in the greatest increase in net revenue for farmers?
- **Study sample:** For each group of farmers with similar needs, randomly select ten to twenty WUAs.
- **Treatment assignment:** Within each sample, randomly assign WUAs to one of two bespoke interventions.
- **Data collection:** Data should be collected at a minimum i) prior to the intervention and ii) after the interventions are likely to demonstrate initial impact (typically at least a full cycle of growing seasons later).
- **Impact metrics:**. The outcome of interest is farmer income. Intermediate outcomes include the sale price and quantity of the products, the distance to market, the costs incurred by the farmer in making the sale, and indirect effects on women and marginalized WUA members.

7.3.3. Political support

There currently seems to be medium political support for WRIDD to explore activities related to market access. However, it is important to recognize that this currently falls outside the ambit of the Department and there are other departments dedicated to improving market power of farmers; for example, the Agricultural Marketing Board. WRIDD should conduct a stakeholder mapping exercise with the selected external partner, including a broad array of additional potential partners within the public and private sectors. WRIDD should hold meetings with other public departments to understand potential areas for collaboration and to glean lessons from other experiences. There are potential risks associated with mandate overlap, which WRIDD should assess and make plans to mitigate.

7.4. Policy Option III: Convergence with other government programs

In West Bengal, take-up of public services is particularly low, with only an estimated 17% of adult citizens applying for the public goods and services they need, far lower than the national average of 40% (Demirguc-Kunt et al. 2017). The literature on welfare adoption points to several possible causes, including information constraints, costs of the application, difficulty in filling out the form, and politically motivated intermediaries (Gupta 2017). During our fieldwork, numerous ADMI farmers expressed a need for additional services, such as credit and crop insurance, that were available from the state but difficult to access. The WRIDD is in a unique position to help fill this gap as the WUA structure has eased two critical constraints on both sides of effective public service delivery. First, they have created a consistent touchpoint for interaction between the state and farmers, increasing the legibility of farmers and granting WRIDD increased access and information. Second, the organizational capital created through the WUA can potentially be leveraged by farmers for increased claims-making through either better dissemination of information, increase in bargaining power, or pooling together of transaction costs. By taking advantage of these factors, the WRIDD can increase beneficiary farmer welfare without bearing the administrative burden of implementing additional interventions.

However, convergence can itself have significant administrative costs. Much of the evidence points towards the need for a relatively high-touch intervention, including and up to customized assistance with filing applications, to have meaningful impact on adoption with limited success of purely informational interventions (Gupta 2017). As such, ADMI should explore whether it can efficiently achieve convergence through a series of rapid pilots.

7.4.1. Intervention design

The first step of this proposal is to conduct a matching process between the needs of ADMI farmers and available policy instruments. This can be operationalized through a needs assessment survey of a representative sample of current WUA members, comprised of quantitative questions and qualitative focus group discussions, on the remaining challenges they face not currently met by the ADMI package. An important component of the needs assessment should be uncovering possible reasons for low uptake. The WRIDD should then develop a database of welfare programs offered by the West Bengal and Indian government and coordinate. We provide an illustrative set of possible options below. We estimate that this step should not be too burdensome as many officials in the WRIDD have worked across different departments and ADMI is currently fielding a new set of regular data collection exercises through their NGO workers.

Constraint/Market Failure	Existing Policy Solution	Nodal Agency
Lack of credit	Kisan Credit Card (*short term loans*)	National Bank for Agriculture and Rural Development
Incomplete insurance	Bangla Shashya Bima (*free crop insurance*)	Department of Agriculture, West Bengal
Low market power	Sufal Bangla *(fair price purchasing)*	West Bengal State Agricultural Marketing Board

We offer three possible intervention options ranging from low-touch to high-touch.

1. **Information campaign delivered through phones to farmers.** This intervention is light-touch, particularly as ADMI has invested heavily in developing a system for delivering agricultural training through mobile phones. However, it would only be able to reach farmers who have mobile phones, raising equity concerns, and only relieves the informational constraint. On the other hand, it might be that the WUA structure allows the information to disseminate to less-connected farmers through meetings and helps create collective movement to overcome non-informational constraints.
2. **Information campaign delivered by NGO workers to WUA meetings.** The NGO workers are in regular contact with WUAs and have a high degree of social capital with farmers. Thus, they are well suited to deliver in-person sessions on available support. This would require hosting a training for NGO workers to ensure they are properly informed. However, the WRIDD needs to be careful that this does not overburden the NGO workers or cause a decay in trust between them and the farmers, which might occur if failures in delivery of other programs is then attributed to ADMI staff.
3. **Customized assistance in completing applications by NGO workers.** If the NGO workers can be adequately trained and non-informational constraints are binding, this relatively high-touch intervention might be what is needed to increase adoption. However, it places the highest administrative burden on ADMI staff. We recommend including this in the pilot to get some understanding of the upper bound of ADMI's potential for convergence, with the caveat that in scale-up this could become diluted. Additionally, we recommend using the evaluation to understand whether ADMI can taper off the customized assistance and have the WUA members locally empowered to file applications for each other (i.e., can this be an investment in organizational capital rather than an ongoing cost).

7.4.2. Monitoring and evaluation

We propose evaluating the three convergence interventions through a series of rapid small-scale pilots that explore iterations of different interventions.

- **Learning objective:** Can the WUA serve as a platform for the uptake of programs that address relevant constraints for farmers?
- **Design pilot:** Spend two months following the needs assessment refining the form of the three interventions through pilots of five WUAs. The purpose of this pilot is to understand how to make the information campaigns actionable and determine what training is required for the NGO workers in assisting with filing applications.
- **Study sample:** Randomly sample 100 scheme-locations from schemes that have already been handed over and have active WUAs.

- **Treatment assignment:** Randomly assign WUAs to four groups of 50 WUAs each, where groups one through three will receive versions of low-, medium- and high-touch interventions. The fourth group will act as a control group to understand the result of no intervention focused on convergence.
- **Data collection:** Data should be collected on a subset of the farmers who belong to each of the 100 WUAs in the pilot at frequent intervals.
- **Impact metrics:** The intermediate outcomes are knowledge of the welfare policies, awareness of how to access them, and filed applications. The final outcomes for this study are successful adoption of other welfare programs. The eventual impact of adopting these policies on farmer welfare will need to be studied at a later stage, as the desired outcomes will be tailored to the specific policies that are being adopted.

7.4.3. Political support

This option has a high level of political support from the WRIDD and other government departments. The low uptake of welfare schemes is cause for concern for departments and they are normally on the lookout for community-based organizations to help them increase adoption. The WRIDD has already begun forming connections with other departments, including delivering a sprinkler intervention from the Agriculture Department through an ADMI WUA.

We look forward to continuing to collaborate with the ADMI team as they enter this experimental next phase. We are optimistic that their unwavering commitment to the farmers of West Bengal will result in meaningful impacts for families across the state.

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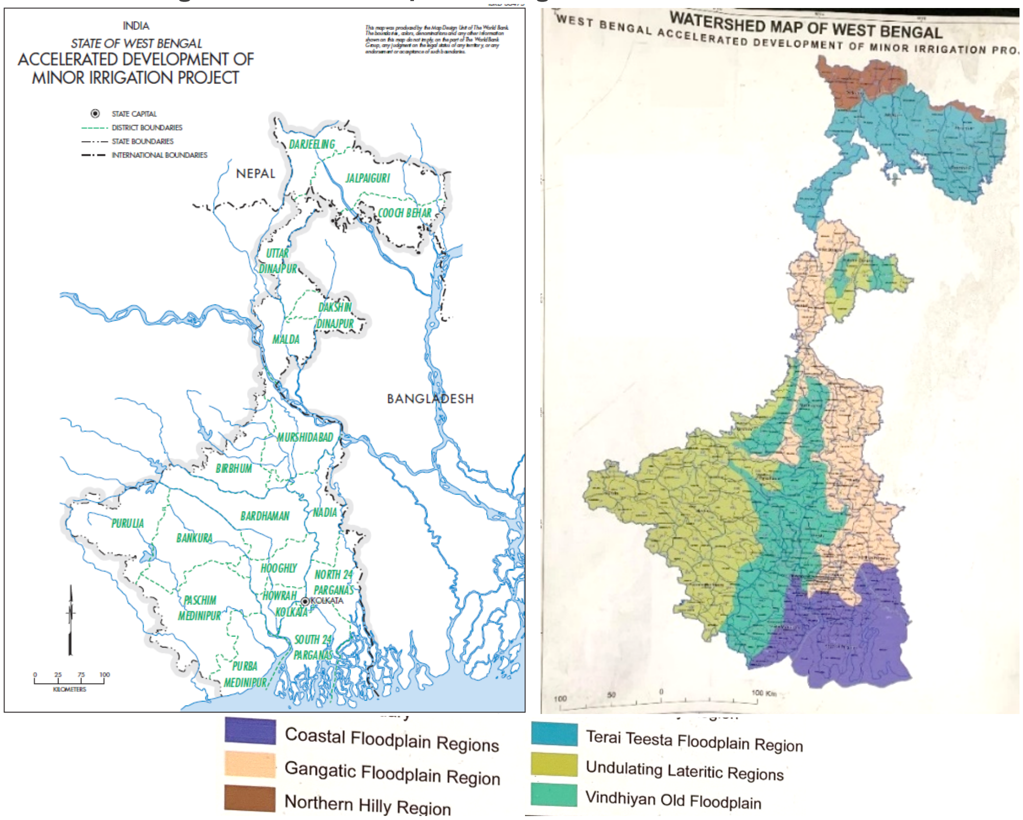
9. Appendices

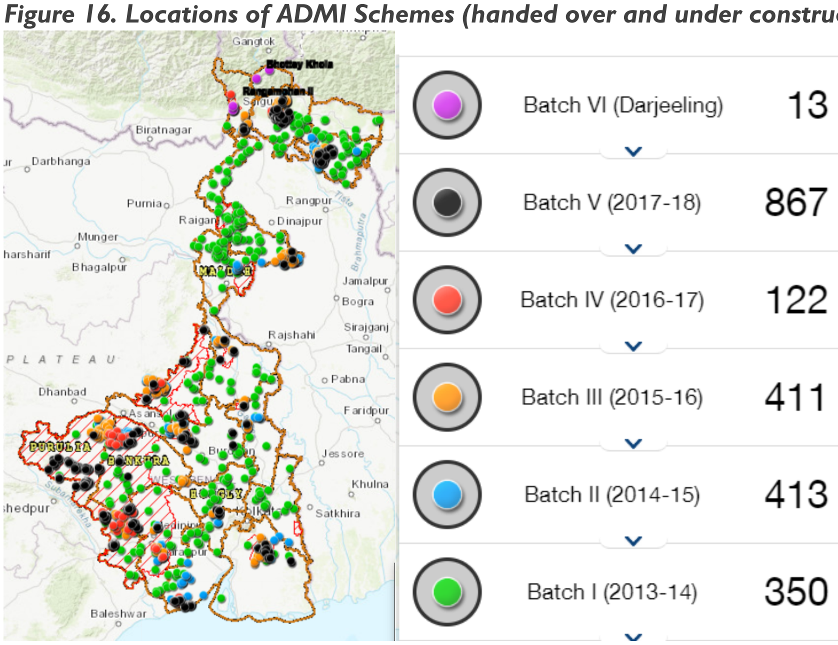
9.1. Hydrology of West Bengal and locations of ADMI schemes

Figure 15. Districts and Agroclimatic Zones of West Bengal



Source: World Bank (2011), ADMI

Figure 16. Locations of ADMI Schemes (handed over and under construction)



Source: ADMI.

9.2. Description of data

Table 9. Descriptive statistics of individual survey respondents by district and scheme type

District	Freq.	Percent	Scheme Type	Freq.	Percent
Jalpaiguri	88	13.94	Groundwater	347	61
Bardhhaman	62	9.73	River Lift	115	20.21
Birbhum	56	8.85	Surface	107	18.79
Kochbehar	48	7.64	**Total**	**568**	**100**
Dakshin Dinajpur	47	7.42			
Purulia	42	6.67			
Paschim Midnapur	36	5.65			
South 24 Parganas	35	5.45			
Malda	34	5.42			
Jhargram	30	4.74			
Bankura	26	4.17			
Uttar Dinajpur	25	3.87			
Purba Midnapur	22	3.47			
Nadia	21	3.36			
Darjeeling	21	3.36			
North 24 Parganas	16	2.56			
Hooghly	14	2.21			
Murshidabad	8	1.2			
Howrah	2	0.32			
Total	**634**	**100**			

Table 10. Demographic characteristics of the individual survey sample

	ADMI		Non-ADMI		*Difference in means*
	Missing Obs	Mean	Missing Obs	Mean	
Female	0	15%	0	7%	-0.082***
Age	3	47	5	42	-4.486***
Living in brick house	0	41%	0	36%	-0.048
Area cultivated pre-ADMI	100	5.173	49	3.486	-1.687***
Practicing double or triple cropping pre-ADMI	100	48%	49	31%	-0.173***
Number of crops sold pre-ADMI	100	1.4	49	0.8	-0.651***
Agricultural revenue pre-ADMI	100	Rs. 16824	49	Rs. 12565	-4258.652
Total sample	**422**		**206**		

The value displayed for t-tests are the differences in the means across the groups.
***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

9.3. Complete results tables and figures

9.3.1. Institutional effects of the WUA

Figure 17. Inclusion in WUA

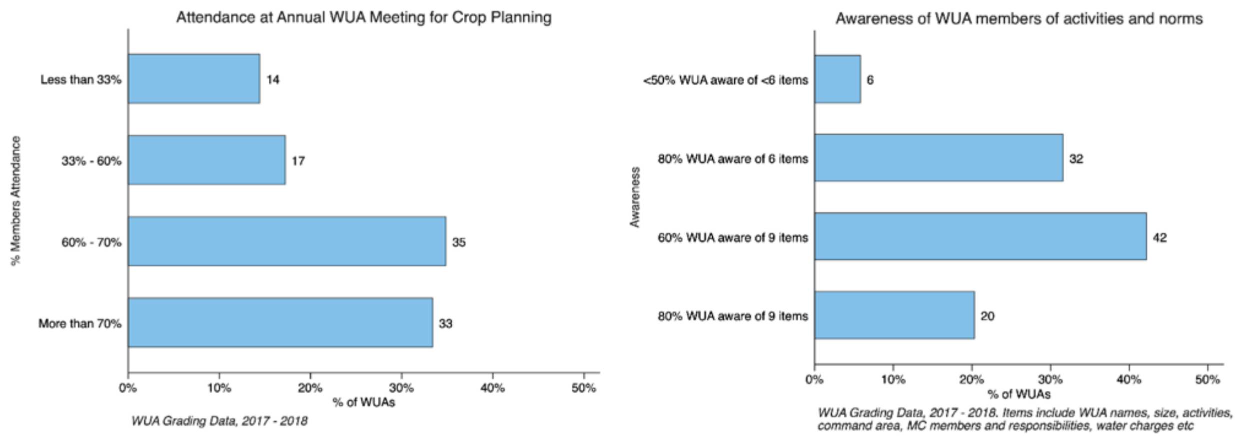


Figure 18. WUA Revenue generation methods

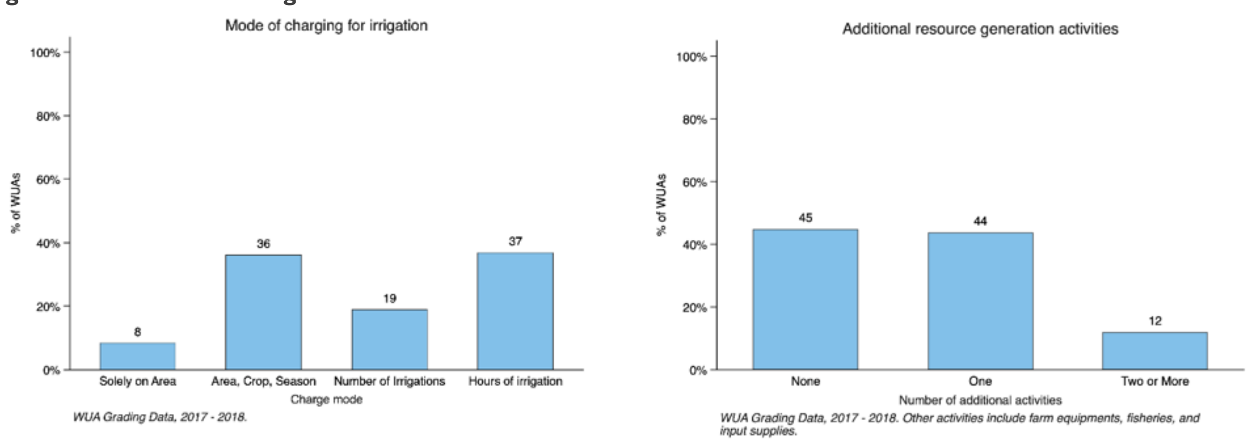


Figure 19. Adequacy of WUA funds

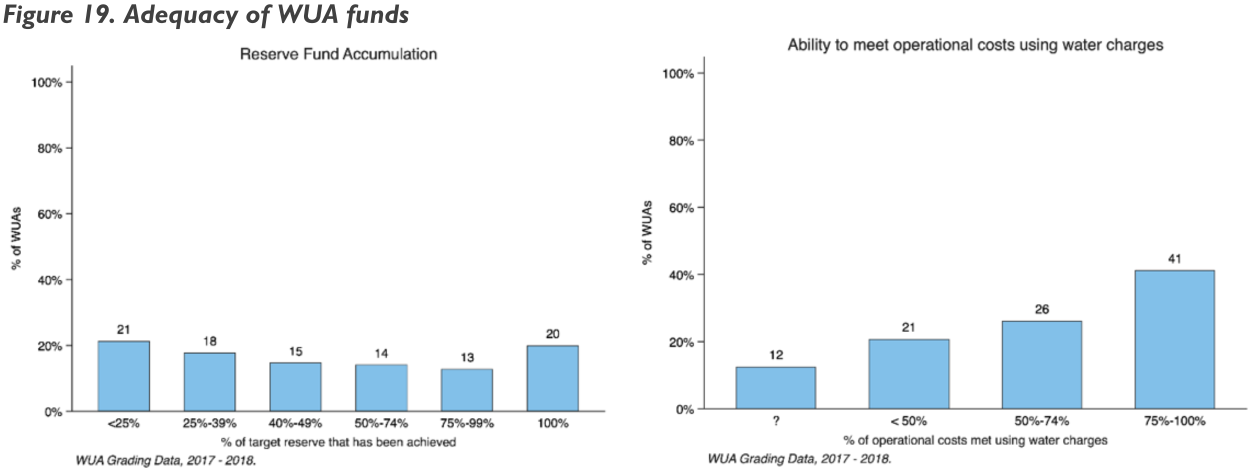


Figure 20. WUA Corpus Fund

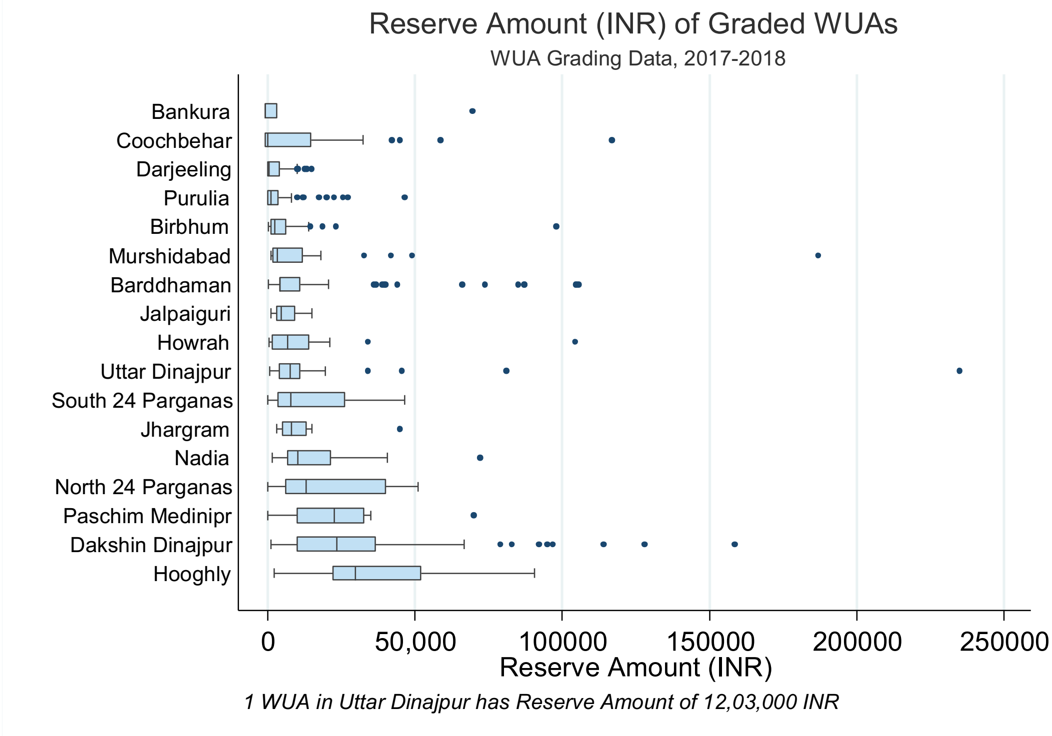


Figure 21. Maintenance status of irrigation structure

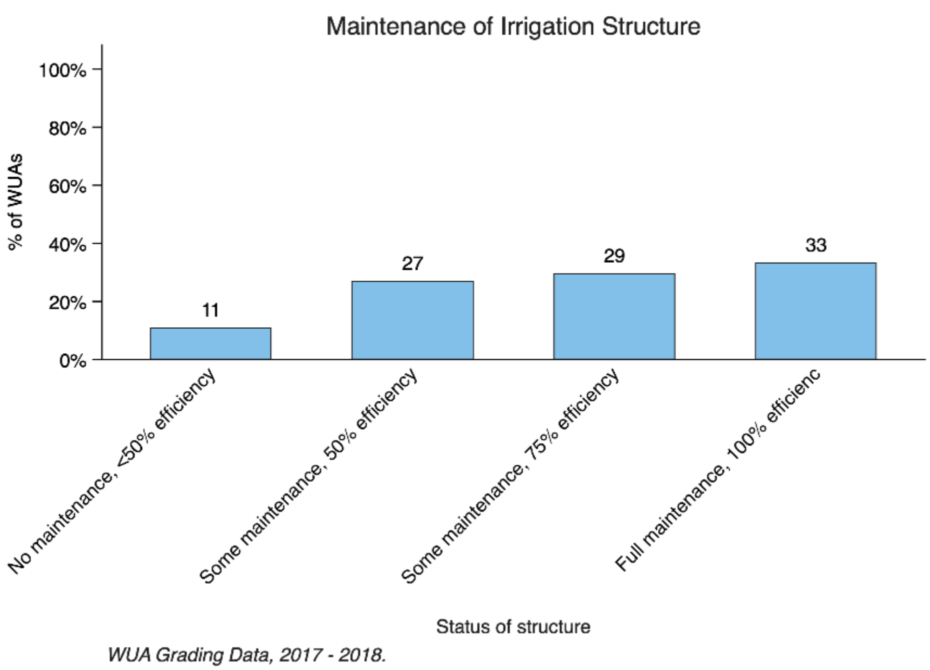


Table 11. Determinants of WUA quality

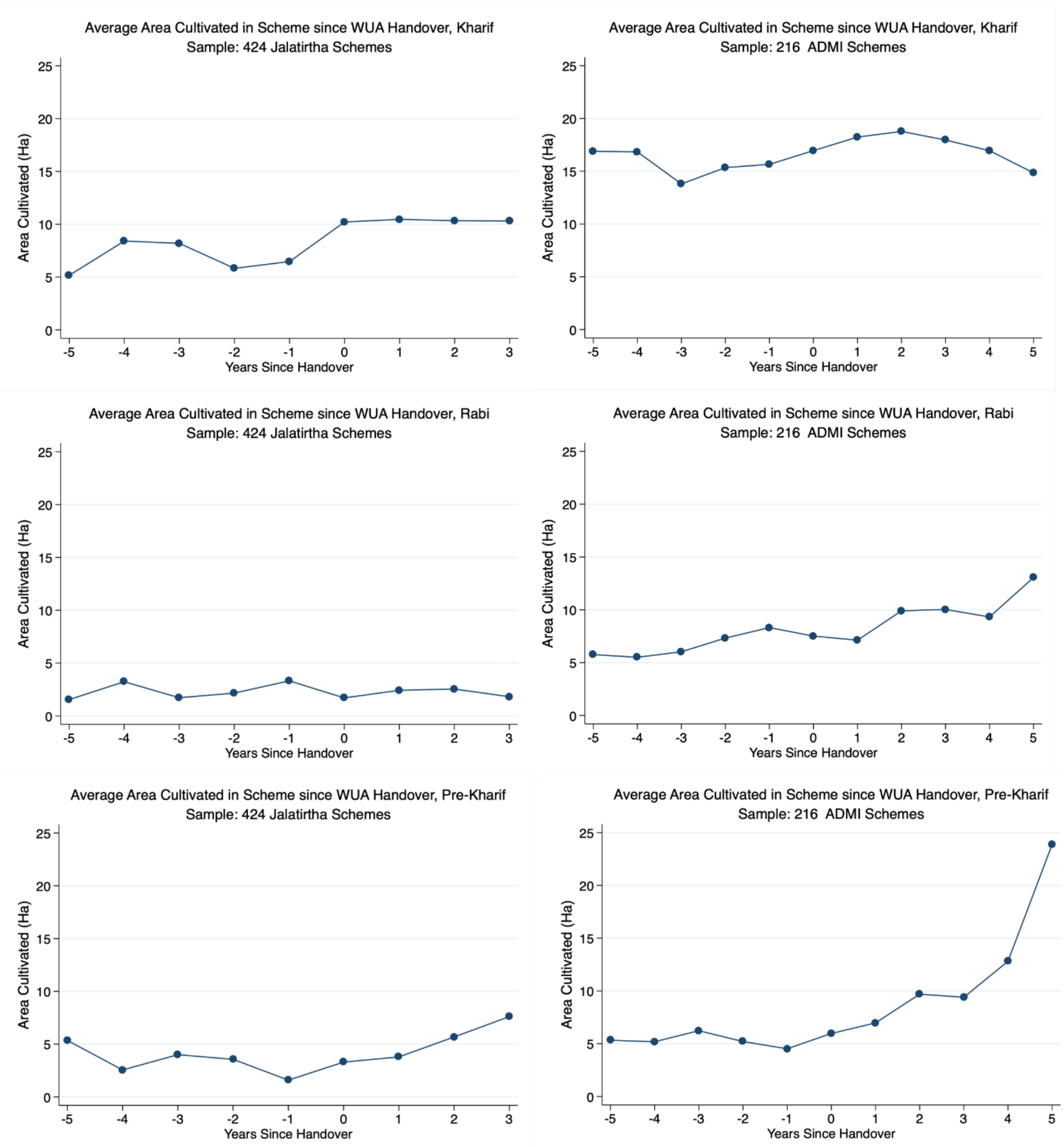
		(1)
		Index of perceived WUA Quality
Individual Characteristics	Female	-0.149
		(0.151)
	Age	-0.00288
		(0.00619)
	Scheduled castes *(relative to General)*	0.0620
		(0.337)
	Scheduled tribes *(relative to General)*	0.424
		(0.313)
	Other backward castes *(relative to General)*	-0.0451
		(0.338)
	Muslim *(relative to Hindu)*	-0.243
		(0.363)
	Other *(relative to Hindu)*	0.0466
		(0.304)
	Primary *(relative to incomplete primary)*	-0.0781
		(0.197)
	Secondary or more *(relative to incomplete primary)*	0.0751
		(0.255)
	Brick house *(relative to mud house)*	-0.245
		(0.235)
WUA role	Member of Managing Committee *(relative to just member)*	0.144
		(0.225)
	Member of Sub-Committee *(relative to just member)*	0.588**
		(0.288)
District	Bankura *(relative to Howrah)*	1.792**
		(0.885)
	Bardhhaman *(relative to Howrah)*	1.734**
		(0.798)
	Birbhum *(relative to Howrah)*	1.614**
		(0.701)
	Dakshin Dinajpur *(relative to Howrah)*	1.807***
		(0.454)
	Darjeeling *(relative to Howrah)*	0.823
		(0.511)
	Hooghly *(relative to Howrah)*	2.340***
		(0.664)
	Jalpaiguri *(relative to Howrah)*	1.235**
		(0.568)
	Jhargram *(relative to Howrah)*	0.0856
		(0.560)
	Kochbehar *(relative to Howrah)*	1.479**
		(0.620)
	Malda *(relative to Howrah)*	-2.312***
		(0.487)

	Murshidabad *(relative to Howrah)*	1.730*
		(0.935)
	Nadia *(relative to Howrah)*	0.653
		(0.792)
	North 24 Parganas *(relative to Howrah)*	1.591***
		(0.579)
	Paschim Midnapur *(relative to Howrah)*	1.667***
		(0.478)
	Purulia *(relative to Howrah)*	1.332**
		(0.638)
	South 24 Parganas *(relative to Howrah)*	2.197***
		(0.458)
	Uttar Dinajpur *(relative to Howrah)*	0.820
		(0.583)
Demographic	Percent of members that are female	0.670
		(0.778)
	Percent of members that are marginal farmers	-0.536
		(0.766)
Handover	Handover in 2014 *(relative to 2013)*	-0.986*
		(0.588)
	Handover in 2015 *(relative to 2013)*	-0.792
		(0.548)
	Handover in 2016 *(relative to 2013)*	-1.119**
		(0.537)
	Handover in 2017 *(relative to 2013)*	-0.918*
		(0.548)
	Handover in 2018 *(relative to 2013)*	-1.088*
		(0.581)
	Handover in 2019 *(relative to 2013)*	-0.926
		(0.754)
	Constant	4.097***
		(0.653)
	Observations	232
	R-squared	0.316

Robust standard errors in parentheses. Includes ADMI members only. Index ranges from 1 to 5, with additional points for positive responses to the following questions: Are you satisfied with the WUA leadership? Has the WUA generated kinship among members? Has the WUA helped improve maintenance of the minor irrigation scheme? Has the WUA served as a platform for collective action?
*** p<0.01, ** p<0.05, * p<0.1
Source: Individual ground-truthing survey.

9.3.2. Comparing ADMI and control schemes using satellite data

Figure 22. Time series trends of cultivation in Jalatirtha and ADMI schemes



Counted as cultivated if NDVI level above 0.4. Levels should not be compared as ADMI schemes are based on actual potential command area and Jalatirtha are based on 0.5km buffer around scheme location.
Source: Landsat 7.

9.3.3. Comparing ADMI and non-ADMI farmers using survey data

Figure 23. Observed difference-in-difference of ADMI on intermediate outcomes (A)

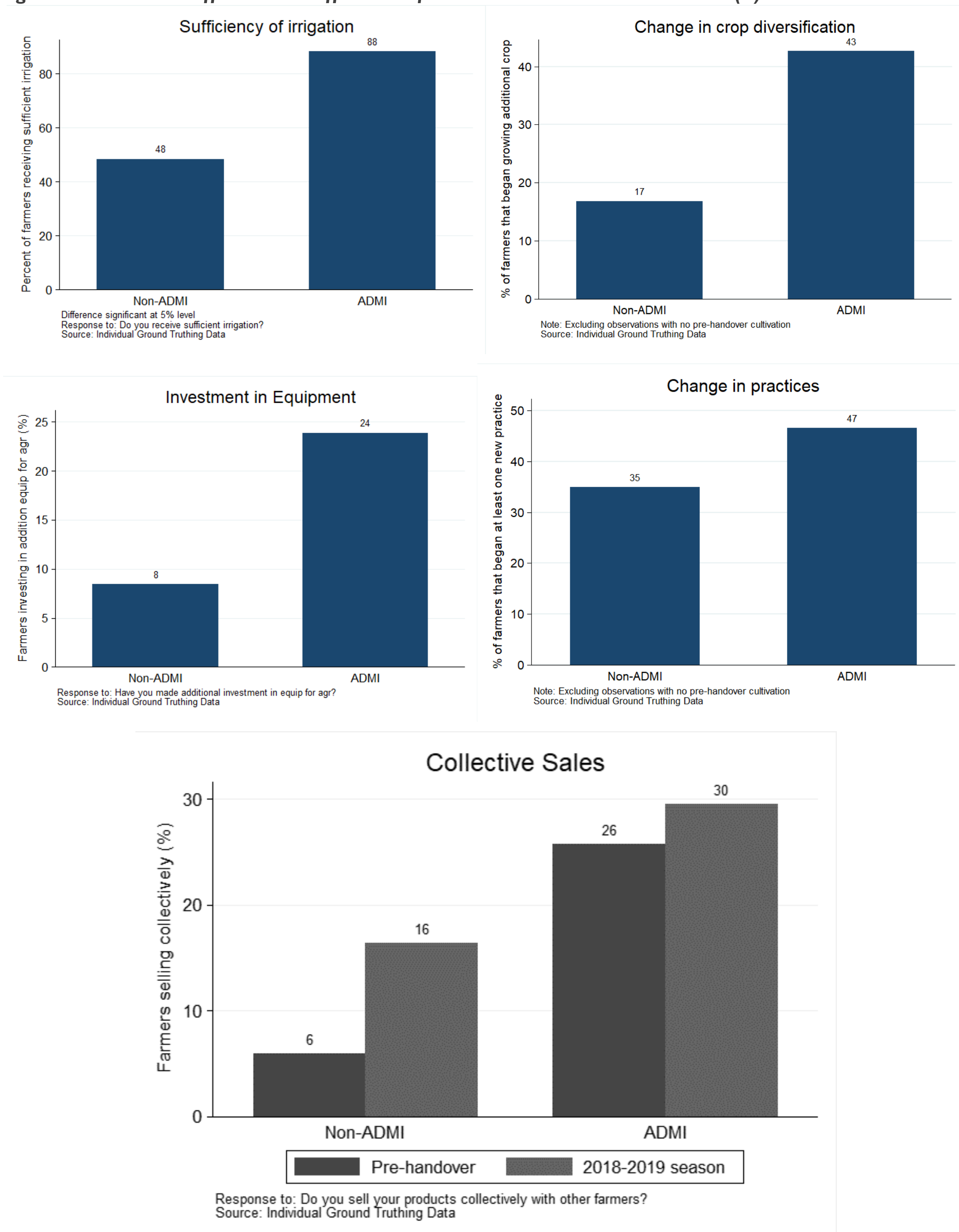


Figure 24. Observed difference-in-difference of ADMI on intermediate outcomes (B)

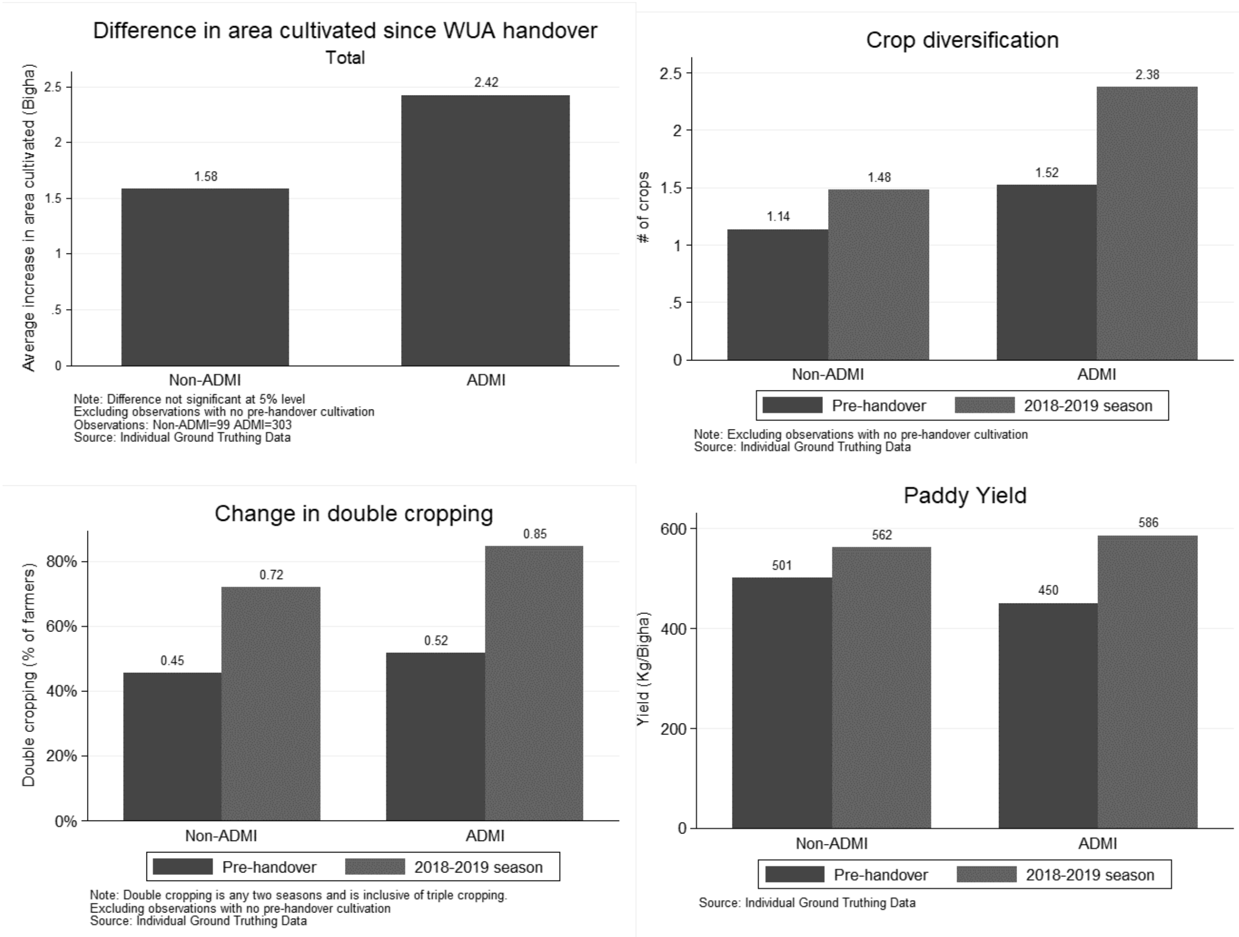


Table 12. Change in practices of ADMI and non-ADMI members (The Akhilesh Table)

	WUA Members		Non-WUA Members		*Difference-in-difference*
	Pre-Handover (1)	Now (2)	Pre-Handover (3)	Now (4)	(2-1) - (4-3)
System of Rice Intensification (SRI)	1%	23%	2%	9%	*15%*
Intercropping	5%	26%	4%	13%	*13%*
Seed treatment	8%	27%	9%	17%	*11%*
Pest management	8%	34%	7%	23%	*10%*
Pulse intensification	5%	17%	5%	7%	*10%*
Organic farming	8%	19%	4%	7%	*9%*
Farm mechanics	5%	25%	2%	14%	*8%*
New high value crops	3%	16%	2%	8%	*8%*
Mulching	2%	11%	2%	4%	*7%*
Vermi compost	3%	14%	3%	7%	*7%*
Seed preservation	14%	24%	14%	18%	*7%*
Protected polyhouse	1%	5%	0%	0%	*4%*
Zero tillage	2%	6%	0%	1%	*3%*
Climate resilient	6%	8%	4%	5%	*1%*

Source: Individual ground-truthing survey.

Table 13. Heterogeneity of ADMI impact by demographic characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
	Change in Revenue					
ADMI	30,682					
	(19,756)					
Age	-342.7					
	(294.0)					
ADMI*Age	-71.07					
	(427.8)					
Female		5,483				
		(5,688)				
ADMI*Female		10,180**				
		(4,326)				
ADMI*Male		26,694***				
		(6,062)				
Brick house			2,353			
			(4,080)			
ADMI*Brick house			24,716***			
			(6,698)			
ADMI*Mud house			23,658***			
			(5,154)			
Scheduled Caste *(relative to General Caste)*				-7,138		
				(8,811)		
Scheduled Tribe *(relative to General Caste)*				2,149		
				(10,877)		
Other Backward Caste *(relative to General Caste)*				-13,126		
				(11,833)		
ADMI*General Caste				24,807***		
				(7,845)		
ADMI*Other Backward Caste				27,759*		
				(13,186)		
ADMI*Scheduled Caste				30,313*		
				(14,280)		
ADMI*Schedule Tribe				12,289		
				(11,149)		
Muslim *(relative to Hindu)*					-9,313	
					(8,886)	
Other religion (Tribal) *(relative to Hindu)*					5,957	
					(6,313)	
ADMI*Hindu					22,479***	
					(7,224)	
ADMI*Muslim					32,503***	
					(8,830)	
ADMI*Other religion					-2,815***	
					(652.8)	
Primary *(relative to incomplete primary)*						12,565**
						(4,819)

Secondary or more *(relative to incomplete primary)*						10,542
						(10,612)
ADMI*Incomplete primary						23,400*
						(11,456)
ADMI*Primary						26,584**
						(9,380)
ADMI*Secondary or more						17,974*
						(9,324)
Constant	36,190**	20,818*	20,148*	23,183**	22,226**	14,849
	(12,783)	(9,810)	(9,795)	(9,071)	(9,861)	(8,698)
Scheme type and district controls	X	X	X	X	X	X
Observations	343	346	346	336	346	346
R-squared	0.200	0.190	0.186	0.193	0.190	0.202

Robust standard errors in parentheses. Standard errors clustered at district level.
*** p<0.01, ** p<0.05, * p<0.1
Source: Individual ground-truthing survey.

Table 14. Heterogeneity of ADMI impact by scheme type, district, and year of handover

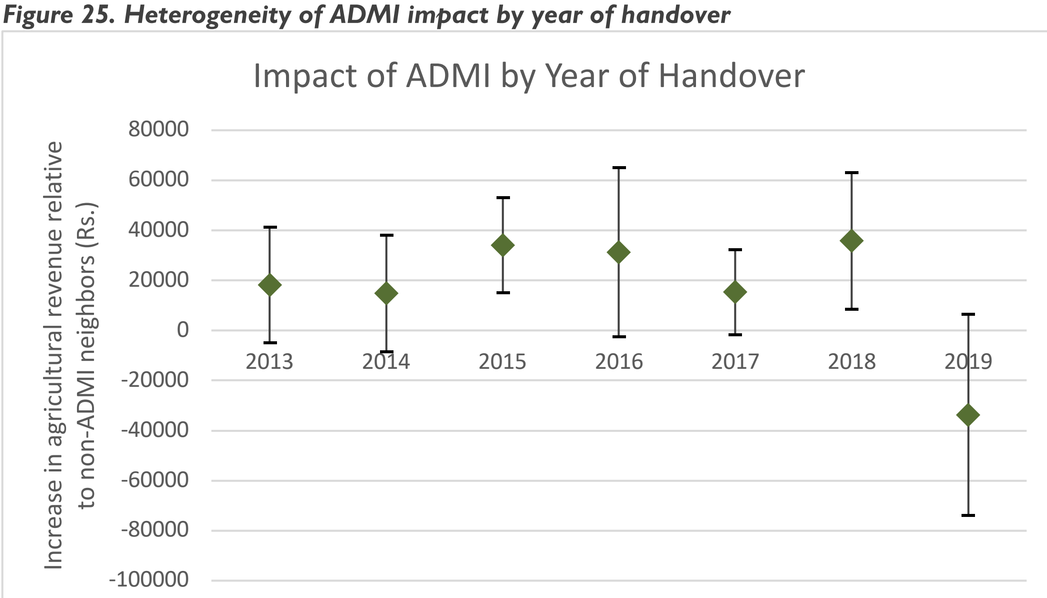
	(1)	(2)	(3)
	Change in Revenue		
River lift *(relative to groundwater)*	-2,601	-22,032**	-18,335*
	(9,177)	(9,250)	(9,976)
Surface water *(relative to groundwater)*	14,277*	-16,667**	-13,489*
	(7,277)	(6,624)	(7,487)
ADMI*Groundwater	40,264***		
	(8,333)		
ADMI*River lift	22,343*		
	(10,903)		
ADMI*Surface water	4,808		
	(5,037)		
Handover 2014 *(relative to 2013)*		55,635***	
		(14,309)	
Handover 2015 *(relative to 2013)*		25,056	
		(16,001)	
Handover 2016 *(relative to 2013)*		33,943**	
		(14,026)	
Handover 2017 *(relative to 2013)*		27,722	
		(19,821)	
Handover 2018 *(relative to 2013)*		14,638	
		(16,810)	
Handover 2019 *(relative to 2013)*		49,703***	
		(7,216)	
ADMI*2013		18,211	
		(11,787)	
ADMI*2014		14,943	
		(11,919)	
ADMI*2015		34,030***	
		(9,686)	

ADMI*2016		31,276*	
		(17,201)	
ADMI*2017		15,303*	
		(8,629)	
ADMI*2018		35,803**	
		(13,890)	
ADMI*2019		-33,639	
		(20,510)	
Bankura *(relative to Nadia)*	43,567**	51,533***	-4,600
	(18,726)	(16,619)	(17,861)
Bardhhaman *(relative to Nadia)*	49,012**	53,639***	2,006
	(17,185)	(16,928)	(20,371)
Birbhum *(relative to Nadia)*	25,313	28,612	-6,806
	(22,214)	(21,029)	(22,614)
Dakshin Dinajpur *(relative to Nadia)*	12,503	13,133	-3,215
	(19,269)	(19,024)	(21,334)
Hooghly *(relative to Nadia)*	27,458	32,208	-14,761
	(25,279)	(23,196)	(24,220)
Howrah *(relative to Nadia)*	48,653**	43,752*	33,680*
	(19,556)	(20,719)	(17,770)
Jalpaiguri *(relative to Nadia)*	55,300**	60,444***	-9,703
	(18,891)	(18,484)	(18,992)
Jhargram *(relative to Nadia)*	47,005*	51,311*	12,425
	(24,912)	(24,445)	(23,673)
Kochbehar *(relative to Nadia)*	34,162	33,513	3,811
	(19,816)	(19,276)	(19,924)
Malda *(relative to Nadia)*	18,982	12,515	2,529
	(20,100)	(20,443)	(20,941)
North 24 Parganas *(relative to Nadia)*	49,611***	44,901**	-20,522
	(15,665)	(18,201)	(16,891)
Paschim Midnapur *(relative to Nadia)*	25,944	23,590	-22,029
	(22,214)	(22,565)	(24,870)
Purulia *(relative to Nadia)*	38,575**	51,843***	-6,184
	(17,058)	(15,041)	(17,279)
South 24 Parganas *(relative to Nadia)*	26,896	33,850	1,526
	(21,370)	(23,342)	(22,556)
Uttar Dinajpur *(relative to Nadia)*	76,182***	70,615***	-13,515
	(12,709)	(13,512)	(14,035)
ADMI*Bankura			44,097***
			(4,295)
ADMI*Bardhhaman			27,284***
			(3,796)
ADMI*Birbhum			11,699***
			(2,563)
ADMI*Dakshin Dinajpur			-3,015
			(4,280)
ADMI*Hooghly			14,446
			(10,085)
ADMI*Howrah			†
ADMI*Jalpaiguri			49,323***
			(3,145)
ADMI*Jhargram			12,786***
			(1,805)
ADMI*Kochbehar			11,984***

			(2,270)
ADMI*Malda			†
ADMI*Nadia			-23,304***
			(3,444)
ADMI*North 24 Parganas			71,383***
			(1,946)
ADMI*Paschim Midnapur			28,664***
			(7,047)
ADMI*Purulia			28,616***
			(2,700)
ADMI*South 24 Parganas			-10,157
			(8,339)
ADMI*Uttar Dinajpur			84,384***
			(1,996)
Constant	-19,688	-38,457	35,811
	(29,638)	(37,036)	(33,626)
Demographic controls	X	X	X
Observations	333	333	333
R-squared	0.243	0.272	0.261

Robust standard errors in parentheses. Standard errors clustered at district level. Demographic controls include gender, age, caste, religion, education, and house type.
† Omitted, no non-ADMI farmer with clean data
*** p<0.01, ** p<0.05, * p<0.1
Source: Individual ground-truthing survey.

Figure 25. Heterogeneity of ADMI impact by year of handover



Point represents coefficient estimate, controlling for district, scheme type, gender, age, caste, religion, education, and house type. Bars represent 95% confidence interval. Complete regression results are available in Table 14.
Source: Individual ground-truthing survey.

Table 15. Heterogeneity analysis by baseline market failures and characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Change in Revenue			
ADMI						23,164***	22,357***
						(8,091)	(7,864)
Has bank account pre-ADMI	-3,375						
	(8,478)						
ADMI*Has bank account pre-ADMI	37,812***						
	(9,476)						
ADMI*Does not have bank account pre-ADMI	17,200*						
	(8,863)						
Practiced collective sales pre-ADMI		-534.3					
		(13,451)					
ADMI*Practiced collective sales pre-ADMI		21,666					
		(16,111)					
ADMI*Did not practice collective sales pre-ADMI		33,378***					
		(8,638)					
Practiced SRI pre-ADMI†			37,750***				
			(10,242)				
ADMI* Practiced SRI pre-ADMI†			-25,115**				
			(12,263)				
ADMI*Did not practice SRI pre-ADMI			30,465***				
			(7,295)				
Sold to an aggregator at farm pre-ADMI				9,278			
				(13,247)			
ADMI*Sold to an aggregator at farm pre-ADMI				20,459			
				(13,410)			
ADMI*Sold elsewhere pre-ADMI				31,104***			
				(8,136)			
Double-cropped pre-ADMI					-16,253*		
					(9,134)		
ADMI*Double-cropped pre-ADMI					35,374***		
					(10,123)		
ADMI*Didn't double-crop pre-ADMI					22,281***		
					(8,378)		
Area cultivated pre-ADMI						197.3	
						(855.9)	
ADMI*Area cultivated pre-ADMI						1,188	
						(1,191)	
Revenue pre-ADMI							-0.268
							(0.198)
ADMI*Revenue pre-ADMI							0.344
							(0.299)
Constant	-12,942	-9,062	-5,023	-10,045	3,088	-12,496	-5,236
	(27,713)	(26,828)	(27,384)	(26,106)	(27,783)	(26,833)	(26,785)
Controls	X	X	X	X	X	X	X
Observations	328	328	333	333	333	333	333
R-squared	0.254	0.238	0.234	0.232	0.237	0.243	0.238

Robust standard errors in parentheses. Standard errors clustered at district level. Controls include gender, age, caste, religion, education, house type, district, scheme type, and the interaction of ADMI and being female (given sampling strategy).

† Note that only 11 farmers (ADMI and non-ADMI) reported practicing SRI pre-ADMI

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source: Individual ground-truthing survey.

Figure 26. Price for paddy and potato by distance to market

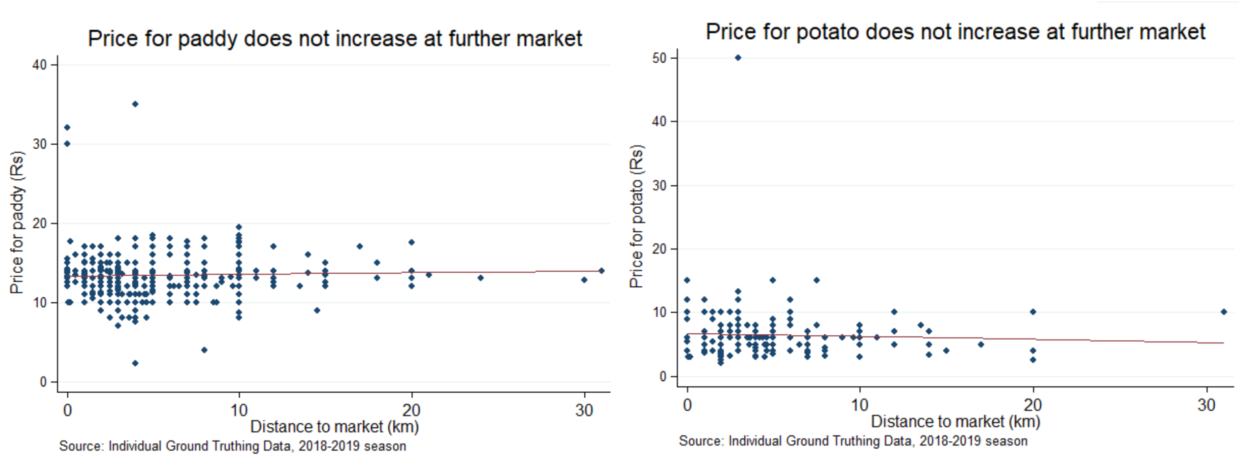
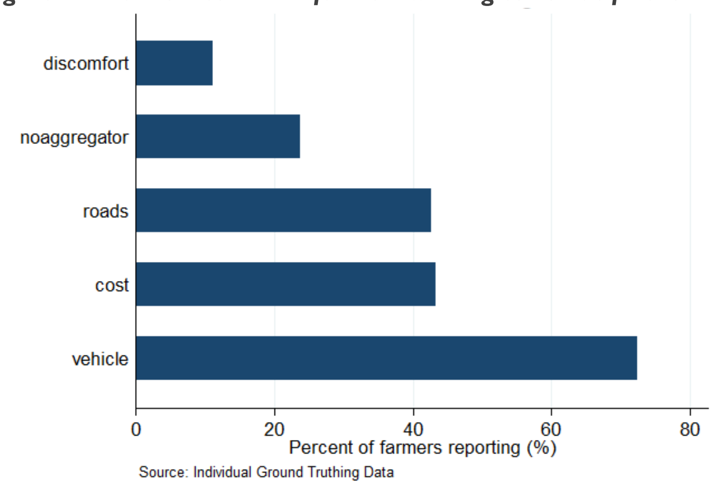


Figure 27. Barriers to ADMI farmers wishing to sell at further markets



9.4. Field visits (July-August 2019)

Table 16. Field visits conducted

Districts	Schemes
1. South 24 Parganas	ADMI schemes
2. North 24 Parganas	ADMI schemes
3. Hooghly	ADMI schemes
4. Jalpaiguri	ADMI and non-ADMI schemes
5. Darjeeling	ADMI and non-ADMI schemes
6. Bankura	ADMI schemes