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ADOPTION OF FARM MECHANIZATION FOR CLEAN AIR

EVIDENCE FROM FARM TRIALS IN PAKISTAN

Ashok K. Mishra, Jaweriah Hazrana, Takashi Yamano, Noriko Sato, and Babur Wasim Arif

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ABSTRACT

Many rice farmers burn stubble and straw after harvest, which worsens air pollution. This paper examines the impact of training on the adoption of advanced rice harvesting technologies that reduce the need for crop burning. It uses data from a cluster randomized controlled trial in Pakistan. The results reveal that the training program improved the farm performance of rice growers. The cost–benefit analysis shows that farmers who received the training and used improved mechanical rice harvesting generated higher profits, an average gain of PRs19,784 per acre. The results highlight the potential of targeted extension strategies to accelerate the adoption of productivity-enhancing and sustainable technologies among smallholder farmers.

Keywords: rice farming randomized control trial, difference-in-difference method, revenues, harvest losses

JEL codes: C31, O33, Q12, Q16

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1. Introduction

Increasing agricultural productivity remains a key priority for policymakers and development organizations in many developing and emerging economies, where a significant proportion of the population lives in rural areas and relies on agricultural activities for their livelihood (Gollin and Udry 2021; Mcarthur and Mccord 2017). The situation is particularly stark in South Asia, where approximately 80% of the population lives in rural areas. The agriculture sector contributes a large share of the region's gross domestic product (55%), provides 45% of employment opportunities, and employs more than two-thirds (65%) of the total labor force (World Bank 2017). Increasing productivity could potentially initiate a positive cycle of development, leading to improved livelihoods, increased food security, and equitable access to economic opportunities.

Agricultural mechanization is broadly viewed as a crucial way to increase productivity, livelihood strategy, yields, and income. For this reason, governments and development partners in many developing and emerging economies allocate substantial resources to boost agricultural productivity. For instance, programs such as input subsidies, machinery financing schemes, extension services, and infrastructure development have been geared toward improving agricultural outcomes (Diao, Silver, and Takeshima 2016; Kienzle et al. 2013). Furthermore, mechanization is anticipated to catalyze structural transformation by diverting labor from agriculture and into more productive nonfarm sectors, ultimately contributing to overall economic growth (Gollin, Parente, and Rogerson 2002).

However, inappropriate use of agricultural machinery can have unintended consequences. In Punjab, Pakistan, wheat is the main staple crop, and wheat combine harvesters have been promoted in the past. Because of their relatively high availability,

farmers use wheat combine harvesters to harvest rice, even though wheat harvesters cut the rice crop in the middle, leaving shredded rice straws and high stubbles in the fields. Unable to remove shredded rice straws and high stubbles, farmers tend to burn them. The practice of burning crop residue has significant environmental and health implications (Kumar, Kumar, and Joshi 2015; Kaushal and Prashar 2021) and contributes to air pollution and greenhouse gas (GHG) emissions (Bhattacharyya and Barman 2018).¹ Proper rice harvesters, on the other hand, can cut the rice plants at the bottom, leaving only short stubble in the fields. In addition, long rice straws, properly cut at the bottom, can be sold at a higher price than shredded straws. The use of proper rice harvesters, therefore, is expected to reduce crop burning and help farmers increase their postharvest income.

The objective of this study is to assess the impact of the ADB technical assistance program Enhancing Technology-Based Agriculture and Marketing (ETAM) in Rural Punjab on the farm performance indicators (outcome variables) of rice farmers. The ETAM program is a multifaceted intervention that aims to promote improved mechanization and enhance the livelihoods of smallholders. The ETAM program includes training on harvesting technologies and improved cultivation practices, postharvest processing methods, market linkages, and increased profitability along the rice value chain. An important component of the ETAM program is the promotion of a proper rice harvester, which can cut the rice crops at the lowest possible height.

¹ In a more recent study, Bhattacharyya et al. (2021) estimated a net gain (both economic and environmental) of \$664 per hectare from the production of bioethanol from straw, followed by the conversion of biochar (\$183 per hectare) and conservation agriculture practices worth \$131 per hectare.

To estimate the treatment effects of the ETAM program on farm performance indicators, we have conducted a standard difference-in-differences (D-I-D) analysis by comparing the change in farm performance indicators (outcome variables) between the treated and control samples before and after the implementation of the program. In addition, we have used a triple difference (DDD) strategy to examine the specific impact of adopting rice harvesters in the treated group. The DDD analysis has compared the change in farm performance indicators (outcome variables) for the adopters and non-adopters within the treated villages relative to the change in farm performance indicators profitability for the control sample.

The study contributes to the literature on agricultural mechanization in several ways. First, by leveraging data from a randomized controlled trial, we can estimate the causal impacts of an intervention promoting mechanized rice harvesting and postharvest technologies. In contrast to many previous observational studies, our experimental design mitigates concerns about self-selection bias and endogeneity that often plague impact evaluations. Second, while most existing studies have primarily examined the effects of mechanization on productivity and/or profit, we discuss several potential pathways through which mechanization influences farm performance and profitability. The pathways include changes in crop yields, postharvest losses, output prices, and costs. Third, our study contributes to the limited evidence on the impact of agricultural mechanization² in the context of Pakistan. This study provides valuable insights into the

² Agricultural mechanization has the potential to boost productivity and increase profitability. The extent of the economic benefits often depends on contextual factors and the effective implementation of targeted interventions.

potential impacts, challenges, and scalability of policy initiatives in a low-income developing country setting like Pakistan.

The remainder of the paper is organized as follows. Section 2 describes the background, while section 3 describes the conceptual framework of the study. Section 4 contains the survey and data as well as descriptive statistics. Section 5 outlines the empirical framework. Section 6 presents the results of the study. Section 7 reports on the benefit-cost analysis. Finally, section 8 presents a discussion and conclusions as well as policy implications.

2. Background

Pakistan is home to 8.2 million farm families (Pakistan Bureau of Statistics 2010) who are responsible for meeting the basic food and nutrition needs of an estimated population of 212 million people. Approximately 65% of Pakistan's total population lives in rural areas and is directly or indirectly dependent on agriculture for their livelihood. Agriculture is an important sector in Pakistan, employing over 37% of the labor force and contributing nearly 30% to gross domestic product (GDP) (Government of Pakistan 2023). Over the last few decades, the contribution of agriculture to GDP has declined in proportion to changes in the composition of the sector. However, the agricultural industry has a much greater potential to contribute to Pakistan's GDP if it adopts innovative and modern technologies to replace traditional and outdated agronomic and farming techniques (USAID 2018). Mechanization of farming in Pakistan is still in its early stages, with limited adoption of modern machinery and technologies, especially among smallholders (Government of Pakistan 2023). The level of farm mechanization in Pakistan is estimated

to be around 50%, which is relatively low compared to other developing countries in the region (Amir et al. 2020). The low level of farm mechanization can be attributed to several factors, including small landholdings, lack of access to credit, inadequate infrastructure, and a shortage of skilled labor (Ahmed et al. 2013). Insufficient knowledge of new agricultural technologies or their availability, often due to inadequate extension services and information barriers, can also impede adoption (Mumin, Abdulai, and Goetz 2023; Adhvaryu 2014; Bandiera and Rasul 2006; Beaman et al. 2021; Conley and Udry 2010; de Janvry et al. 2015).

Indeed, farmers in Pakistan lack infrastructure, equipment, tools/implements, and other appropriate technologies for cultivation, harvesting, sorting, grading, collection, storage, cold storage, and transportation. As a result, farmers incur heavy losses (preharvest and postharvest) of major commodities and quality degradation of perishable products, especially fruits, vegetables, and dairy products (Government of Pakistan 2020). Postharvest losses in Pakistan are estimated at 20%–40% for various crops, which not only contributes to food insecurity but also leads to significant economic losses for farmers (State Bank of Pakistan 2020; Kumar and Kalita 2017; Gunasekera, Parsons, and Smith 2017; Gustavsson et al. 2011). The Pakistan government has recognized these challenges and has taken several initiatives to promote agricultural mechanization (e.g., subsidies for agricultural machinery, machinery banks, and extension services). However, the adoption of mechanized technologies remains low, highlighting the need for targeted interventions and evidence-based policymaking to address the barriers to mechanization. Removing these barriers would unlock the potential benefits of

mechanization for agricultural productivity, food security, and rural development in Pakistan.

3. Conceptual Framework

Agricultural mechanization is widely regarded as a critical pathway to increase farm profitability and performance in developing countries, as it can boost productivity, reduce costs, and improve resource use efficiency (Diao, Silver, and Takeshima 2016; Kienzie et al. 2013). In Pakistan, the adoption of mechanized technologies can work through multiple pathways to improve farm performance and profitability. First, mechanization can lead to higher crop yields by enabling timely and precise field operations, such as land preparation, sowing, and harvesting. This is particularly important in regions with short growing seasons and narrow planting windows, where delays in field operations can significantly affect yields. Mechanized tools and equipment allow farmers to perform these tasks more efficiently, resulting in higher yields and increased output per unit area of land. Another potential avenue is that mechanization can reduce harvest losses, which are often significant in developing countries due to traditional manual harvesting methods and limited postharvest handling capabilities. Therefore, the use of mechanical harvesters and efficient postharvest processing equipment can minimize losses during harvesting, transportation, and storage, thus increasing the overall amount of marketable produce (Nath et al. 2017).

Mechanization can lead to the valorization of agricultural by-products, such as straw, which are often underutilized or wasted in traditional farming systems. Mechanical harvesters and balers can efficiently collect and process straw, enabling farmers to sell it

as livestock feed or for other purposes, generating additional income for farm households. In developing countries such as Pakistan, the issue of straw management is crucial. Traditionally, rice crops were manually cut at the bottom by hand and collected by farmers and farm workers. However, as labor shortages became severe, inappropriate harvesters, i.e., wheat harvesters in Punjab, Pakistan, were used on rice crops, leaving high rice stubble in the fields or burning it, resulting in environmental pollution, GHG emissions, and the loss of valuable rice straw. Efficient harvesting, collection and utilization of straw can reduce the practice of stubble burning in many agricultural regions in Pakistan and India. Proper rice harvesters can cut the rice straws at the bottom, leaving long straws that are more valuable and easier to collect. Pakistan farmers can sell them at a high price.

In addition, mechanization can improve the quality of agricultural products, which can command higher prices on the market. Mechanized processes can result in cleaner, more uniform, and better-graded products that meet the standards expected by buyers and consumers. This can translate into higher farm-gate prices and better farm performance and profitability indicators for farmers. Mechanization can reduce labor costs associated with land preparation, sowing, and harvesting, which are typically labor intensive in most developing countries. By replacing manual labor with mechanized equipment, farmers can reduce their dependence on hired labor, thereby lowering their production costs and improving their profit margins. It is important to note that the benefits of agricultural mechanization can be influenced by various factors, such as the availability of complementary inputs (e.g., improved seeds and fertilizers), access to financing, and the presence of supporting infrastructure (e.g., roads and access to markets,

transportation, machinery repair shops, fuel stations). Therefore, efforts to promote mechanization should be accompanied by complementary interventions and policies to improve farm performance. Land preparation costs can be reduced through better harvesting techniques facilitated by mechanization. Efficient mechanical harvesters leave fields in better condition, with minimal soil compaction and residue management, which reduces the need for intensive land preparation before the next planting season. Therefore, mechanization could lead to cost savings in terms of labor, machinery, and fuel expenses associated with land preparation.

4. Experimental Design and Intervention

4.1. *Enhancing Technology-Based Agriculture and Marketing in the Rural Punjab*

Technical Assistance Program

The Asian Development Bank funded the technical assistance program, Enhancing Technology-Based Agriculture and Marketing (ETAM) in Rural Punjab, in Pakistan. The ETAM program started in 2020 in collaboration with national and consulting agencies and ended in 2023. The program aimed to promote the use of advanced agricultural technologies, particularly the Kubota rice harvester.³ Its primary goals included enhancing agricultural productivity, reducing postharvest losses, improving market linkages, and ultimately increasing farmers' incomes in rural Punjab, Pakistan. Between 2020 and 2023, the ETAM program rolled out four primary goals: (1) demonstration of advanced harvest and postharvest technologies; (2) development and installation of an information and communication technology-based direct marketing platform; (3) capacity

³ See Appendix Box.

building of stakeholders for the development and adoption of advanced technologies; and (4) formulation of investment opportunities to scale up the adoption of technologies. In this study, we focus primarily on the first goal, the demonstration of advanced harvest and postharvest technologies.

The ETAM program focused on two main components aimed at promoting the adoption of advanced harvest and postharvest technologies among smallholder farmers in the Punjab region of Pakistan. First, the program conducted technology and marketing demonstrations at the treated village level, showcasing modern agricultural machinery and practices. The demonstrations targeted small-scale rice, wheat, and maize producers in the program's target areas, as well as private sector service providers offering mechanized harvesting and technology-based postharvest solutions. During the demonstrations, the smallholder farmers had the opportunity to learn about the operation and benefits of advanced equipment such as rice harvesters, mechanical dryers, and storage facilities. The farmers were also introduced to the concept of outsourcing harvesting, drying, storage, and marketing services to local agro-machinery service providers. This is because rice harvesters are expensive machinery that farmers cannot afford due to cash flow constraints, farm size, and debt repayment capacity. The aim of the campaign was to generate awareness and demand for labor-saving and productivity-enhancing technologies among the farmers.

The ETAM program also covered a range of postharvest technologies and practices, including techniques for proper drying, processing, storage, and quality management of agricultural products. The demonstrations focused on minimizing postharvest losses, preserving product quality, and maximizing market value through the

adoption of the improved methods mentioned above. The second component of the program involved targeted training sessions on the specific benefits of switching to the rice harvesters. The training sessions aimed to educate farmers on how mechanical harvesting can reduce the incidence of stubble burning, a common practice that contributes to air pollution and environmental degradation. The training highlighted the advantages of rice harvesters in terms of efficiency, labor savings, and minimizing the burning of crop residues.⁴ Rice produces a considerable amount of crop residue (see Lin and Begho 2022, for an overview). Instead of using the crop residues for alternative sustainable uses, they are burned (Azhar, Zeeshan, and Fatima 2019; Das et al. 2020; Lin and Begho 2022). Through a combination of practical demonstrations and targeted training, the program sought to address both technological awareness and knowledge barriers, thereby facilitating the adoption of advanced harvest and postharvest technologies by smallholder farmers.

The Kubota ER-112 rice harvester, which was specially designed for paddy harvesting, was demonstrated as part of the program. The ER-112 is a state-of-the-art machine that responds to diverse field conditions and can effectively harvest both erect and lodged rice crop stands at maturity. It is the latest available model of a specialized, half-feed paddy harvester in Punjab (Pakistan), equipped with six straw walkers, a cutter width of 7 feet, and a 112-HP common rail engine. The design of the harvester consists of four major components: the header, the conveying chains, the threshing drum, and the grain storage tank. The header cuts the paddy at the lowest possible height, while the conveying chains with the mounted tines gently guide the harvested crop to the threshing

⁴ A large majority of 86.37% of farmers in our survey responded that they do not believe that burning crop residues improves yields.

drum. The tines effectively pick up and transport the paddy through the harvester's system.

The threshing drum, which is attached to the rear of the machine, separates the grains from the straw through a high-velocity threshing and cleaning process. The threshed grains are then collected in an integrated storage tank with a capacity of 0.8–0.9 tons. Meanwhile, the intact straw is discharged from the harvester and laid back in the field in neat rows, making subsequent field operations easier. By demonstrating this advanced machinery, the program aimed to show smallholder farmers the efficiency, precision, and labor-saving potential of mechanical harvesting. The demonstrations highlighted the harvester's ability to minimize crop losses, improve the timeliness of operations, and reduce the drudgery associated with traditional manual harvesting methods, ultimately contributing to higher productivity and better farm performance for adopters.

4.2. Sample Selection

The surveys were conducted in three distinct phases in the agriculture sector of rural Punjab, covering the districts of Sheikhpura and Hafizabad. In the baseline survey, which was conducted in September–October 2020, 978 farmers were interviewed. The same farmers were interviewed in the midline and endline surveys in September–December 2021 and 2023. The study used a cluster randomized control trial (CRCT) design to prevent information and services from spilling over between farmers in the treatment and control groups, which is difficult to avoid when both groups live in the same village. To minimize such contamination, the study used the CRCT in which villages,

rather than individual farmers, were randomly assigned to treatment and control groups. A three-stage process was used to assign the villages.

In the first stage, the tehsils were selected. One tehsil was deliberately selected in each target district, considering criteria such as homogeneity in terms of soil salinity, depth and quality of groundwater, and the availability of service providers, processors, and exporters. In the second stage, the qanungo halqas (QH) was selected. Each selected tehsil consists of four to seven QHs. In each selected tehsil, two QHs were selected based on the criterion of access to paved roads adequate for the movement of combine harvesters to the villages and transportation of produce to the location of traders, processors, and exporters. After listing all smallholder farmers through complete enumeration, one of the two selected QHs from each tehsil was randomly assigned to the treatment group. Finally, within each selected QH, a few villages in similar geographic proximity were chosen based on having access to a suitable road for transporting machinery and produce. Villages that were very large or had extreme socioeconomic diversity, conflicts, or influential people who could influence project implementation were excluded.

A comprehensive enumeration exercise was carried out in each village to list all smallholder farmers producing the target crops. During the listing activity, information was collected on household land ownership under various tenancy contracts, land size, crops grown in different seasons, sources of livelihood of landless households and their involvement in farm labor, and contact details. In the villages within the treatment QH, all smallholder farmers were invited to participate in the demonstrations and use the services of the providers. Table 1 shows the tehsils, the QHs selected from each tehsil, and the

number of villages from each QH. A total of 41 villages were selected from the rice-wheat cropping zones. About 978 smallholder farmers randomly selected from the QHs participated in each survey. Table 2 provides information on the participants from the treatment and control QHs for the baseline survey.

4.3. Data Description

During the surveys, comprehensive data were collected in eight thematic blocks to develop a detailed understanding of the respondents' agricultural practices and livelihoods. This multifaceted approach was designed to provide a thorough analysis of the impact of the research interventions and to capture different aspects of the respondents' agricultural activities and socioeconomic conditions. The survey collected general information about the respondents and key demographics such as gender, age, marital status, education level, and farming experience of the household head. In addition, this section asked about households' primary sources of livelihood, housing conditions, and land ownership status, which provides information on respondents' general livelihood strategies and standard of living. Information was also collected on land ownership, an important aspect of agricultural production. Respondents provided detailed information on the type of land tenure arrangements they had entered into, including ownership, rental, or other contractual agreements. Furthermore, the number of cultivated plots, the total cultivable area, soil characteristics, and irrigation sources were recorded, all of which influence agricultural productivity and farm decision-making.

A specific part of the survey focused on cropped areas to gain a comprehensive understanding of respondents' cropping patterns. Respondents provided information on

the specific crops grown in different seasons and the area allocated to each crop. These data were crucial for analyzing crop choices, diversification strategies, and the potential impact on income and food security. The survey also requested information on respondents' agricultural practices, such as land preparation methods, use of inputs (e.g., seeds, fertilizers, pesticides), and postharvest handling techniques. This information was crucial for identifying potential areas for improvement, promoting sustainable practices, and assessing the impact of interventions on agricultural productivity and resource efficiency.

Finally, a separate section looked at agricultural production and asked about the rice varieties grown, irrigation methods used, seed quantities utilized, seed procurement sources, production levels, planting techniques, agronomic practices used, and harvesting methods. The survey collected vital information from farmers on the marketable surplus and marketing channels for the rice produced. This section also included information on total production disaggregated by variety, quantities reserved for household consumption, quantities stored for future sale, and the various means farmers use to facilitate the sale of their rice produce. Furthermore, the survey included a section on access to agricultural extension services, sources of market information, credit providers, asset ownership, and poverty levels.

4.3.1. Outcome variables

We use multiple outcome variables to rigorously evaluate the impact of the ETAM program on the farm performance of rice-producing households in Punjab province. The selection of performance indicators across the entire production cycle, from harvest to

postharvest processes, provides a comprehensive picture. Our first outcome is yield (maunds [Md] per acre),⁵ which is a direct measure of productivity. By making harvesting operations more efficient and reducing crop losses with manual methods, the use of rice harvesters can increase rice yield on cultivated plots. Second, we also quantify the losses and damage to the rice crop during harvest. Note that such measurements provide direct evidence of whether the technologies improve the efficiency of the harvesting process. Crop loss and damage rates during harvest capture the efficiency of the process itself. Manual harvesting often results in spillage, broken grains, and loss of output. Mechanized harvesting with specialized rice harvesters can minimize such losses, which benefits farmers. Third, we check if there is a price premium or incentive for paddy harvested mechanically. This measure sheds light on the potential revenue benefits for farmers resulting from the adoption of mechanical rice harvesters. A price premium for mechanically harvested paddy reflects the market demand for higher quality grain with less impurities (such as broken rice and rice husk). This premium represents a potential revenue benefit for farmers from adoption.

Fourth, we also assess the value of extra straw by-products that are made available as fodder through mechanical harvesting. The by-products, such as baled rice straw, provide additional ancillary benefits, for example, livestock feed, animal bedding and fuel—rice pallets.⁶ The amount of straw by-products available for use as fodder or fuel also has monetary value. During mechanical harvesting, the pieces of straw are not damaged or shortened, which increases the usable straw output and thus offers an

⁵ 1 maund = 37.32 kilograms.

⁶ Palletization of rice straw is a form of mass and energy densification (Ishii and Furuichi 2014). The pellets are easy to handle, transport, store, and utilize because of the increase in bulk density.

additional benefit. Finally, we estimate the cost savings from the adoption of the mechanical rice harvester in preparing the land for the next crop cycle. This indicator demonstrates a longer-term impact on time and budget management. Timely and efficient harvesting can facilitate the timely planting of the next crop and save land preparation costs. Indeed, such longer-term cost savings from the use of mechanical rice harvesters further contribute to farm profitability. In sum, the selected indicators include metrics that are directly linked to productivity and profitability throughout the production cycle—quantifying harvesting efficiency, cost savings, revenue gains, and ancillary benefits. The comprehensive coverage thus provides appropriate evidence for assessing the impact of the transition from traditional rice harvesting methods to mechanical rice harvesting technologies at the farm level.

4.4. Descriptive Statistics

Table 3 presents the descriptive statistics for the pooled sample, the treated and the control groups. Of note is the first panel of Table 3, where the rice yield for all sampled farmers in the survey region was about 36 Md per acre. However, the yield of the treated group of farmers (37 Md per acre) is higher than that of the control group of farmers (35 Md per acre). The straw price received by farmers in the region also varied between the treatment and control groups. The price of straw for all sampled farmers in the survey region was about PRs7,589 per acre. However, the price of straw received is higher for the treated group of farmers (about PRs7,696 per acre) than for the control group of farmers (PRs7,384 per acre). The last row of the top panel in Table 3 shows the cost savings in preparing the land for the next sowing by using the mechanical rice harvester. In fact, these cost savings are much higher for the treated group of farmers, whose

average savings are PRs3,421 per acre compared to the control group of farmers (PRs2,855 per acre) and the farmers of the entire sample (PRs3,251 per acre). The second panel of the table shows the socioeconomic characteristics of the households in the sample. Farmers in the treated group are slightly younger (44 years old), have less farming experience (22 years), and derive a lower proportion of their income from farming (47%) than farmers in the control group.

Figure 1 presents the kernel densities of the outcome variables for the control and treatment groups. The figure reveals that the distribution of rice yields for the treatment group is slightly shifted to the right compared to the control group, indicating higher average yields for the treated farmers. The distribution of harvest losses for the treatment group is skewed toward lower values compared to the control group. The pattern implies that the ETAM program was effective in reducing harvest losses for the treated farmers, possibly through improved harvesting techniques and technologies. Similarly, the distributions for the price of paddy and the additional price of straw are shifted to the right in the treatment group compared to the control group. The result suggests that the treated farmers were able to fetch higher prices for their paddy and earn additional income from straw sales. This is likely due to improved quality, better market linkages, or greater bargaining power promoted by the ETAM program.

An important component of the ETAM program is the promotion and use of the Kubota rice harvester, a mechanized harvesting technology designed to address the labor-intensive and time-sensitive nature of rice harvesting operations. Figure 2 illustrates the proportion of farmers who used rice harvesters in both the control and treatment groups over the three waves of the survey. A notable upward trend in adoption can be

observed in both groups, with a particularly pronounced increase in the treatment group. In the baseline wave of the survey before the implementation of the ETAM program, the adoption rates of rice harvesters were relatively low at 7.95% in the control group and 19.11% in the treatment group. In the course of the subsequent survey waves, the proportion of farmers using rice harvesters increased in both groups. However, the difference in adoption rates between the control and treatment groups widened over time, from 11.16 percentage points (19.11–7.95) at the baseline survey to 18.25 (34.62–16.37) at the midline, and 22.65 percentage points (44.03–21.65) at the endline survey. The results indicate that the widening gap in the adoption of the rice harvesting machinery suggests that the ETAM program, with its targeted training and demonstrations, played a significant role in accelerating the adoption of rice harvesters by treated farmers compared to the control group.

5. Empirical Framework

We begin by estimating a difference-in-differences (D-I-D) specification of the model. The D-I-D technique compares the outcomes in the treated and control groups before and after the technical assistance demonstrations. This allows us to measure the average effect of the demonstrations on outcomes. Formally, we estimate equation:

$$FP_{it} = \alpha + \beta_{TP}(Treated_{it} * Post_t) + \beta_X X_{it} + \delta_i + \varepsilon_{it} \quad (1)$$

where FP_{it} represents the outcome variable for farm performance (yields, harvest losses, additional price of paddy, price of straw saved, and cost savings in land preparation⁷ for the next sowing) of household h and period t . $Treated_{it}$ is a binary variable that takes the

⁷ All continuous variables in the regression are in logarithmic form.

value of 1 if a household is in the treatment group, 0 otherwise. $Post_t$ is a binary variable that takes the value of 0 if the year is before the ETAM program and the value of 1 after the implementation of the program. X_{it} is a vector of household characteristics, δ_i is the panel fixed effects, and ε_{it} is the error term. Note that the standard errors are clustered at the village level, which is consistent with the level of treatment assignment (Bertrand, Duflo, and Mullainathan 2004; Abadie et al. 2017).

The coefficient of interest is β_{TP} , which measures the D-I-D estimate of the average effect of ETAM on the outcome variables of farm performance; in other words, the change in outcomes between households that received the ETAM program intervention (i.e., treated) and those that did not (i.e., control) compared to the period before the intervention. However, the analysis assumes that without the treatment, both the treated group and the control group would have followed the same path with respect to their farm performance indicators (outcome variables). A positive coefficient β_{TP} indicates that the farm performance indicators of the farm households receiving treatment improved after the intervention compared to those not receiving the treatment. Although the D-I-D model is informative in obtaining the average treatment effects of the ETAM demonstrations, it does not allow us to measure the differential or additional impact of the Kubota rice harvester—an important component of the ETAM program. Therefore, to estimate the effect of the Kubota rice harvester on farm performance indicators, we modified our main specification and specified a triple difference design (DDD). The DDD approach allows us to compare the impact of the ETAM program on the treated group, which was differentiated by the adoption of the Kubota rice harvester (KRH) relative to the control group.

$$FP_{it} = \alpha + \beta_{TPK}(Treated_{it} * Post_t * KRH_t) + \beta_{TP}(Treated_{it} * Post_t) + \beta_X X_{it} + \delta_i + \varepsilon_{it} \quad (2)$$

where KRH_t is a dummy variable that indicates the adoption of the Kubota rice harvester in the posttreatment period; KRH takes the value of 1 if the household adopted the Kubota rice harvester in the posttreatment period; 0 otherwise. The remaining variables in equation (2) are defined as in the D-I-D model presented in equation 2. In the DDD specification, β_{TPK} measures the effect of the ETAM program on the farm performance indicators (outcome variables) for households that adopted the Kubota rice harvester. The coefficient captures the variation in outcomes specific to adopter households in the treated group (relative to the control group) before and after the program rollout. In contrast, β_{TP} measures the overall effect of the ETAM intervention on farm performance indicators (outcome variables) of households that were exposed to the treatment.

Parallel trends assumption

The D-I-D methodology relies on the assumption of “parallel trends,” according to which, without treatment, the treated group and the control group would have followed the same trend in the outcomes studied. This assumption is crucial because it helps to ensure that the observed effects after treatment are due to the treatment itself and not to preexisting trends. We test this parallel trend assumption by providing some suggestive evidence. First, we rely on baseline data collected in 2020 before the implementation of the ETAM program to show that household farm performance indicators (or outcome variables used in this study) followed similar trends in the treated and control groups. However, the present study has data limitations that prevent the establishment of parallel pretreatment trends. In particular, households were observed only once before treatment.

Nevertheless, evidence suggests that the treated and control households followed parallel trends despite their differences. Figure 3 provides evidence of parallel pretreatment trends for the households.

6. Results and Discussion

6.1. *Impact of the ETAM Program on Farm Performance Indicators: A D-I-D*

Specification

We begin by presenting the results of the impact of the ETAM program on farm performance indicators (rice yields, reduction in harvest losses, additional paddy price, price of straw, and land preparation cost savings) for rice cultivation, using the DID specification in equation (1). The impact of the ETAM program on rice yields (Table 4, column 1) is positive and statistically significant at the 5% level of significance, suggesting that the difference in rice yields due to farmers' participation in the ETAM program is about 8%. The difference in rice yields could be due to the adoption of improved cultivation practices, such as timely sowing, application of adequate fertilizers, and better crop management techniques, which were promoted through the program's training and demonstrations. Column 2 of Table 4 indicates that the ETAM program has led to a reduction in harvest losses of approximately 9%. The positive impact of reduced harvest loss could be attributed to the technical demonstrations and training provided to farmers on proper harvesting techniques and the use of appropriate machinery, such as the Kubota rice harvester, which likely minimized postharvest losses. Similarly, column 3 of Table 4 shows that the ETAM program helped farmers obtain higher prices for their paddy, with farmers receiving an average price increase of approximately 5%. This higher

price could be the result of improved quality due to better harvesting practices, reduced postharvest losses, and possibly better market linkages or bargaining power facilitated by the program.

Finally, column 4 of Table 4 shows the estimates of the impact of the ETAM program on the price of straw. The results show that the coefficient is statistically significant at the 5% level of significance. This indicates that farmers who participated in the ETAM program obtained higher prices for their rice straws (19% higher) than their counterparts. The sale of straw can be an important source of additional revenue for farmers, especially in areas where straw is in high demand for various purposes, such as animal fodder or thatching material. Selling rice straw as an extra output from rice farming could help to increase and diversify the income of farming families in the region.

6.2 Heterogeneity Analysis

First, we estimate the heterogeneous effects of the D-I-D model specified in equation (1) to understand the potential variations in the impact of the ETAM program on different subgroups of farmers. The subgroups are classified based on farm size and access to information (extension services), two critical factors that may influence the adoption and effectiveness of the technologies and practices promoted by the ETAM program. Currently, 90% of all farmers (7.4 million) in Pakistan are categorized as smallholders, owning less than 12.5 acres or 5 hectares (Pakistan Bureau of Statistics 2022). Starting with the first subgroup, Figure A1 in the Appendix shows the distribution of farm size based on the operational landholdings of the surveyed households. For the heterogeneity analysis by farm size, we classified the farms into two groups: smallholding farms (<12.5

acres) and large farms (≥ 12.5 acres). Several studies have highlighted the potential constraints faced by smallholder farmers in adopting mechanized technologies, including limited access to credit, inadequate extension services, and economies of scale (Takeshima et al. 2015). Smallholder farmers may also be more risk averse and less inclined to invest in capital-intensive technologies, especially in the absence of well-functioning input and output markets (Mottaleb, Krupnik, and Erenstein 2016). On the other hand, larger farmers may be in a better position to adopt mechanized technologies due to their relatively higher resource endowments, access to credit, and economies of scale in production (Kienzle et al. 2013). They may also have greater exposure to extension services and be more inclined to adopt innovations to improve productivity and profitability.

Table 5 presents the impact of the ETAM program on farm performance indicators by farm size. Indeed, it is no surprise that the effect of participation in the ETAM program is stronger on larger farms (Table 5, panel 2) than on smallholding farms (Table 5, panel 1). For instance, the results in Table 5 show that the effect of the treatment on rice yields is four times higher on large farms relative to small and marginal farms. Likewise, the reduction in harvest losses is three times higher on larger farms than on smallholding farms. The differential impacts could be attributed to several factors, including better access to credit and resources for larger farms, which enable them to more effectively adopt and implement the technologies and practices promoted by ETAM. In addition, larger farms can benefit from economies of scale, making the adoption of mechanized technologies more cost-effective.

Turning to the second subgroup—access to information⁸ (or extension services), information and access to agricultural extension services play a crucial role in the adoption and effective use of new technologies and practices. Figure A2 in the Appendix presents the percentage of households in the sample that accessed information during the surveys. For the heterogeneity analysis by access to information, we categorized farms into two groups: farms with and without access to information. Farmers with access to information and extension services are more likely to be aware of the benefits of mechanized technologies and the associated cultivation practices promoted by the ETAM program. The insights from the analysis could inform policymakers and organizations in the design and implementation of future agricultural development programs and highlight the importance of integrating information dissemination and extension components alongside the promotion of new technologies.

Table 6 shows that the farm households that had access to information and extension services were significantly more likely to participate in the ETAM program. In particular, farmers with access to information and extension services were able to reduce harvest losses, obtain higher prices for straw, and reduce land preparation costs. A plausible explanation for this could be that households with access to information are more likely to have a better understanding of the optimal timing and methods for implementing the technologies offered by the ETAM program, allowing them to maximize the benefits in terms of minimizing postharvest losses, valorizing by-products like straw, and reducing input costs. Interestingly, the impact on yields is not statistically significant

⁸ The survey collected information on households' access to the following information sources: weather information; market price information for outputs; input price information; guidance on mitigating crop damage (weeds, insects, pests, crop diseases, etc.); information about new varieties; and agricultural practices (machines, agronomy, input use, etc.).

for households with better access to information. This is surprising as one would expect that access to agricultural information and extension services would translate into higher yields through the adoption of recommended cultivation practices. However, this finding could be due to factors such as the timing and relevance of the information provided and the effectiveness of the extension delivery mechanisms, which may have influenced the ability of households to translate the information into tangible yield gains. It is also worth considering that the impact on yields could be more pronounced in the long term as farmers gain experience in implementing the recommended practices and technologies over several cropping seasons. Our study may have captured the initial phase of technology adoption where the impact on yields is not yet fully realized.

6.3 Impact of the ETAM Program and the Kubota Rice Harvester on Farm

Performance Indicators: A DDD Specification

Table 7 presents the results of the DDD approach using equation (2). Recall that the DDD approach allows us to capture the differential effect of the ETAM program on the farm performance indicators (or outcome variables) by adopting the KRH within the treatment group. Recall that while all treated farmers received training and demonstrations under the ETAM program, some rice farmers adopted the promoted KRH technology while others did not. Interestingly, Table 7 shows that the impact of the ETAM program on KRH adoption is stronger for those farmers who just participated in the ETAM program. A plausible explanation for this is that the KRH technology directly addresses the constraints observed in the most labor-intensive and time-sensitive stages of the rice production cycle—harvesting. Adopting the mechanized KRH likely complements the

cultivation practices and postharvest handling methods promoted by the ETAM program. This leads to substantial benefits in terms of rice yield gains, reduced harvest losses, and improved quality of output.

For example, column 1 in Table 7 shows that rice yields increased by about 12% for the treated farmers who adopted the KRH, compared to an increase of 6.4% for the overall treatment group. Similarly, the reduction in harvest losses (Table 7, column 2) was more pronounced among farmers who participated in the ETAM program and adopted the KRH technology, at 9.5% among adopters compared to 9% among farmers in the full treatment sample. The increase in paddy prices (Table 7, column 3) was higher for farmers who participated in the program and adopted the KRH technology (21%) compared to farmers in the full treatment sample (19%). Finally, the price of straw (Table 7, column 4) for farmers who participated in the program and adopted the KRH technology was about the same as for adopters of the KRH technology versus farmers in the full treatment sample. The results in Table 7 indicate that while the ETAM program had an overall positive impact, the benefits were even greater for rice farmers who fully embraced the promoted KRH technology. This underscores the importance of not only providing training and awareness in rice farming but also facilitating access to and adoption of complementary mechanized technologies to maximize potential gains from farming interventions.

7. Benefit-Cost Analysis

The results presented above show that participation in the ETAM program improved farm performance indicators, namely a reduction in harvest losses, an additional price premium

for paddy, income from straw sales, higher yields, and cost savings in land preparation. In this section, we present a comprehensive benefit–cost analysis of the ETAM program using average values from the survey data. Table 8 shows the benefit–cost analysis of the ETAM program across the three survey rounds for the treatment group that also adopted the mechanized rice harvester (KRH). While the initial cost of adopting a KRH is higher than that of a traditional combined harvester, this additional investment is offset by the numerous benefits derived from adopting the KRH and implementing the ETAM program’s training and practices. One of the significant advantages of the ETAM program is the reduction of harvest losses. Harvest losses are a major source of inefficiency in traditional rice farming, as a considerable portion of the crop is lost during harvesting and postharvest handling. The ETAM program helped farmers minimize these losses by training them in proper harvesting techniques and promoting the KRH technology. In all survey rounds, the reduction in harvest losses due to the adoption of KRH ranged from 3.5 to 3.8 Md per acre. This translates into additional revenue attributed to the reduction in harvest losses, which ranges from PRs6,243 to PRs14,062 per acre and contributes directly to farm income. In addition, the ETAM program enabled farmers to fetch a higher price for their paddy by improving the quality of the rice and facilitating better market linkages. Farmers who participated in the ETAM program with the KRH can earn additional revenue due to a higher price premium ranging from PRs75 to PRs138 per acre, depending on the survey round.

Complementing the advantages mentioned above, participation in the ETAM program and the adoption of KRH generated additional income to farmers through the sale of straw. Traditionally, a significant amount of straw is lost or wasted during

harvesting and postharvest operations. However, by adopting the KRH and implementing the ETAM program's practices, farmers were able to efficiently bundle the straw using the KRH and sell a larger portion of the straw. In this way, farming families were able to earn an additional income ranging from PRs5,273 to PRs11,441 per acre during the survey rounds. This additional income from straw sales can be an important source of revenue, especially in areas where straw is in high demand. Moreover, the adoption of advanced technologies and mechanization through the ETAM program has reduced the cost of land preparation for the next sowing cycle. By implementing efficient land preparation techniques, improved farm machinery, and better resource management practices promoted by the ETAM program and the adoption of KRH, farmers saved costs ranging from PRs2,196 to PRs5,690 per acre during the survey rounds. This cost-saving aspect further contributes to the overall economic viability of the ETAM program and the adoption of the KRH. The last row of Table 8 indicates that the net benefit per acre from participation in ETAM program practices and KRH adoption ranges from PRs10,584 in the baseline survey to PRs25,079 in the endline survey. The significant net benefits highlight the economic viability and potential for scaling up ETAM interventions to improve farm performance, reduce postharvest losses, and promote sustainable agricultural development in the region.

8. Conclusion and Implications

Pakistan's agriculture sector faces numerous challenges, such as low productivity, postharvest losses, and limited mechanization, especially among smallholder farmers. Despite the potential of agricultural mechanization to boost productivity, the adoption of

harvesting technologies among smallholder farmers in developing countries remains low. The Government of Pakistan and national research agencies have been working with the Asian Development Bank to educate and provide extension services and new technologies to increase rice productivity and farm performance in the rice value chain. This study examined the impact of the ETAM program on the farm performance of rice farmers in the rural Punjab province of Pakistan. The results revealed that the ETAM program had a positive impact on a variety of farm performance outcomes, including higher rice yields, reduced harvest losses, additional income from the sale of paddy and straw, and cost savings in land preparation. The increased adoption of a proper rice harvester is expected to reduce crop burning in open fields. The positive impact of the ETAM program aligns with the government's efforts to increase agricultural productivity, achieve food self-sufficiency, and reduce air pollution.

In addition, the reduction in harvest losses observed in this study is particularly noteworthy, as postharvest losses are one of the main causes of inefficiency in Pakistan's agriculture sector. The ETAM program focused on promoting improved harvesting techniques and mechanized technologies such as the Kubota rice harvester. In addition to yield gains and reduced harvest losses, the ETAM program also enabled higher prices for paddy and additional income from the sale of straw. The long rice straws left by the Kubota harvester are more valuable than shredded rice straws left by wheat combined harvesters. Therefore, the findings of this study highlight the role of the ETAM program in improving market linkages, bargaining power, mechanization, and the overall value chain for rice cultivation in Pakistan.

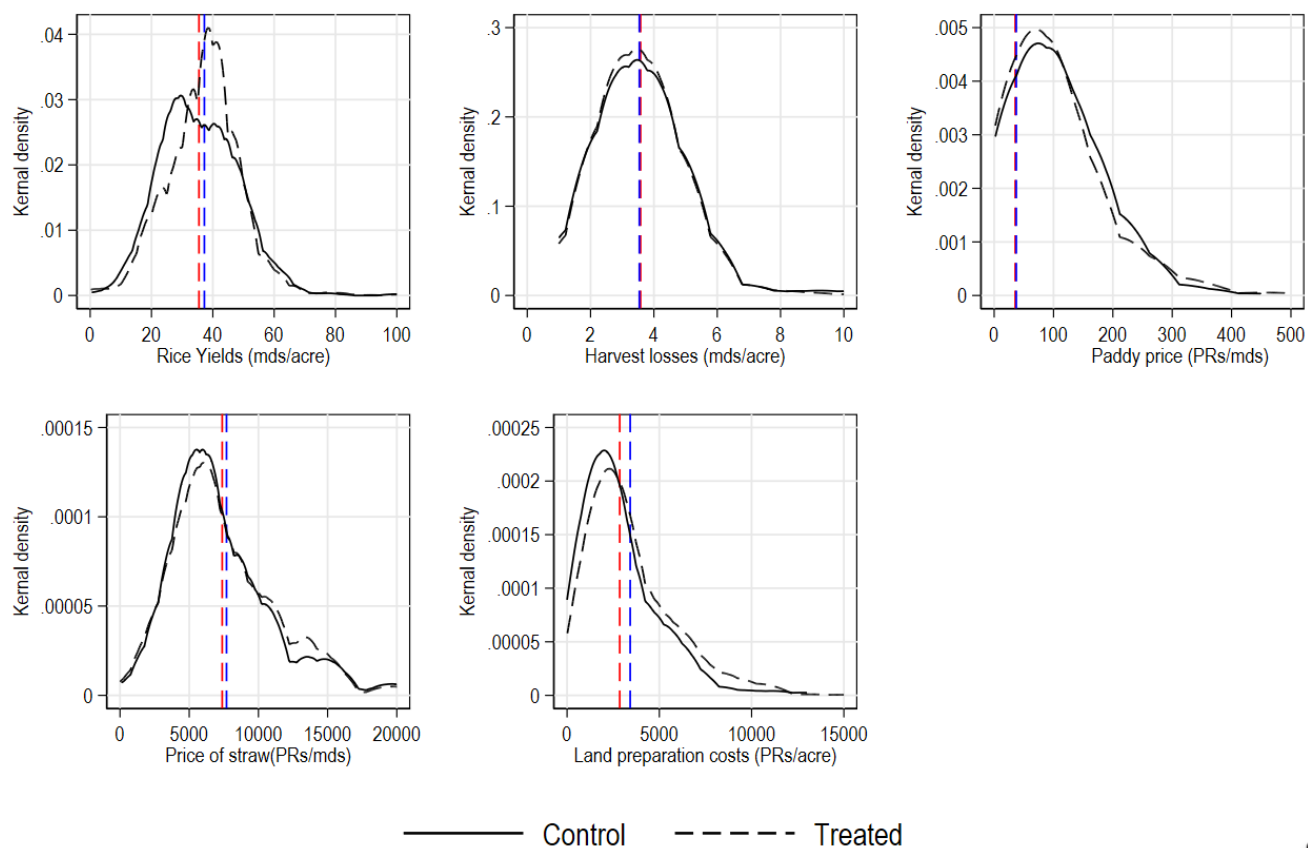
Overall, the heterogeneity analyses underscore the importance of considering farm size and access to information when designing and implementing agricultural development programs. Tailored strategies, support mechanisms, and complementary policies may be required to address the varying constraints and needs of different subgroups and ensure equitable and inclusive benefits from such initiatives. It is noteworthy that the ETAM program had a positive and significant impact on farm performance indicators in the small and large holding farm categories, highlighting the potential for inclusive benefits from the interventions. Nonetheless, the results underscore the need for tailored support mechanisms and complementary policies to address the specific constraints and challenges faced by smallholder farmers in adopting and maximizing the benefits of mechanized technologies. Similarly, our findings highlight the critical role of access to information and extension services in facilitating the effective adoption and utilization of new technologies and practices. Households with better access to information are more likely to be aware of the potential benefits, optimal timing, proper implementation methods, and farm performance. The finding underscores the need to strengthen agricultural extension services and improve information dissemination mechanisms in Pakistan, especially for marginalized and resource-constrained farming communities.

The findings of this study have several policy implications for promoting sustainable agricultural development and improving farm performance in Pakistan. First, policies such as the ETAM program, which promotes mechanization, improved cultivation practices, and market linkages, need to be scaled up and incorporated in the mainstream. These measures contribute significantly to achieve the country's agricultural development

goals by boosting productivity, reducing postharvest losses, and increasing farmers' incomes. Second, targeted support mechanisms such as subsidies, credit facilities, and capacity-building programs could be designed to address the specific constraints and needs of smallholder farmers. The heterogeneity analysis revealed that while the ETAM program had a positive impact on all farm sizes, the benefits were more pronounced for larger farms. The results of this study underscore the importance of ensuring that mechanization initiatives benefit all by providing tailored support to smallholder farmers who often face limitations in accessing credit, extension services, and economies of scale.

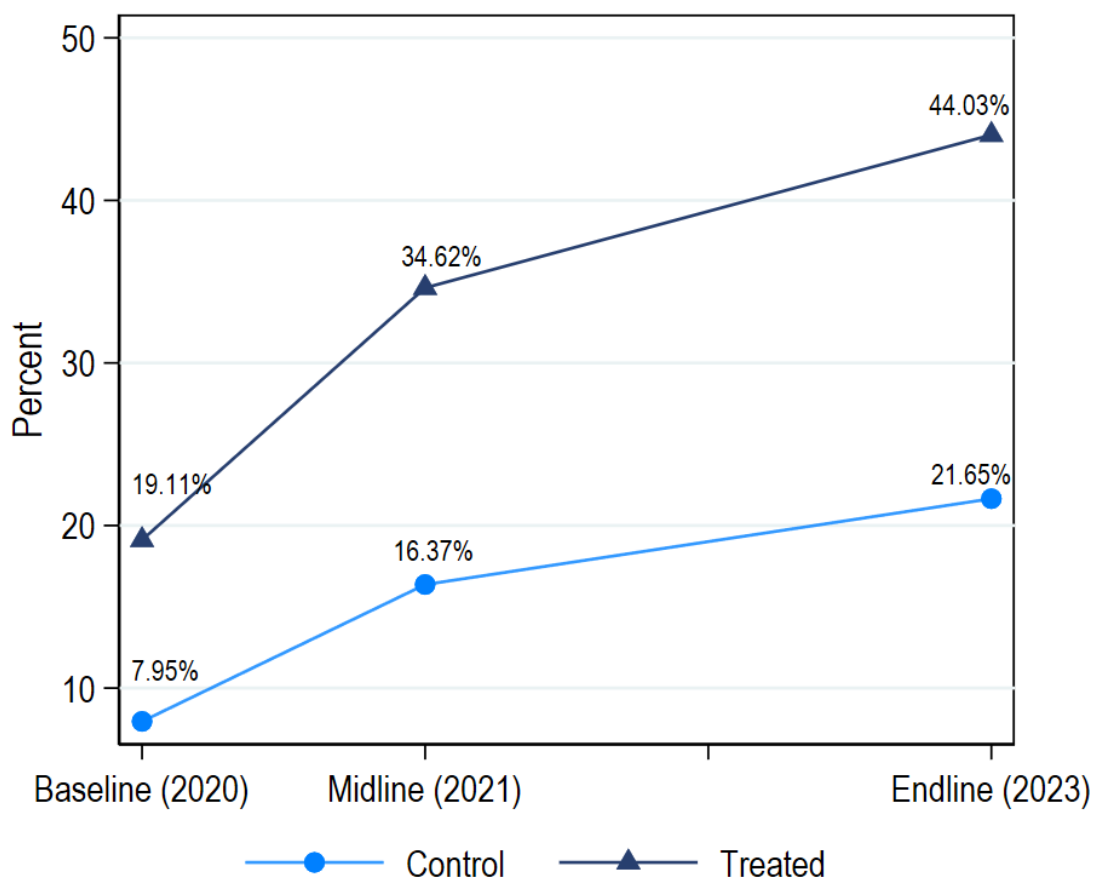
Third, strengthening agricultural extension services and improving information dissemination mechanisms are crucial to facilitate the effective adoption and utilization of new technologies and practices. Targeted efforts to improve the reach and quality of extension services, coupled with effective communication strategies, can empower farming communities, particularly in resource-constrained areas, to maximize the potential benefits of such initiatives. Finally, complementary policies and investments in infrastructure, such as rural roads and storage facilities, are essential to support the adoption and scalability of mechanized technologies. Improved infrastructure can reduce postharvest losses, enhance market access for farmers, and facilitate the efficient transportation and handling of agricultural produce, thus contributing to the overall economic viability and sustainability of mechanization initiatives.

Figure 1: Kernel Density Estimates of Outcomes by Treatment Groups of Sampled Households, Pakistan



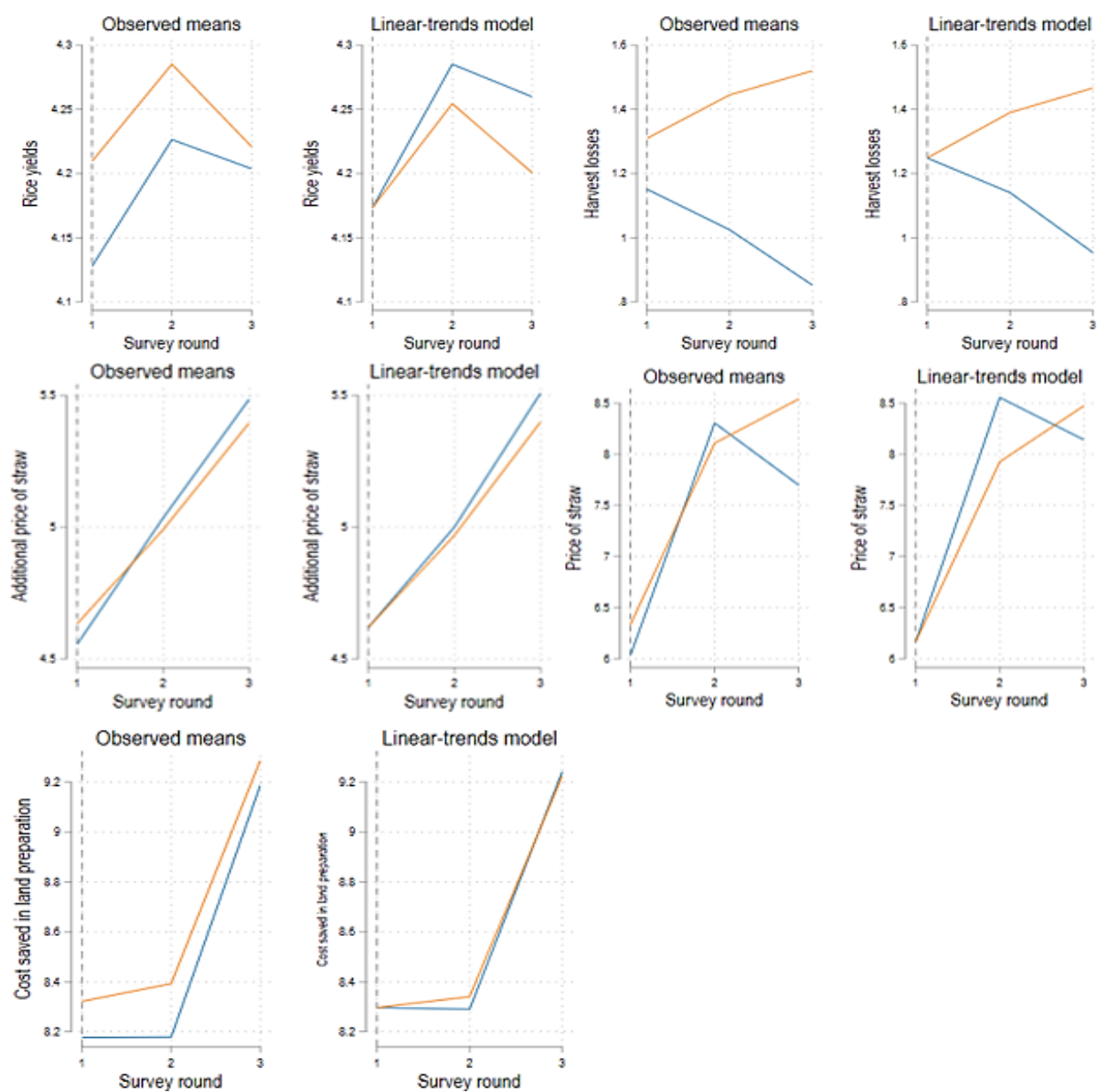
Md = maund. 1 maund = 37.32 kilogram.
Source: Authors' calculation.

Figure 2: Percentage of Farmers Adopting the Kubota Rice-Harvester Before and After the Technical Assistance Demonstrations



Source: ADB. Pakistan: Enhancing Technology-Based Agriculture and Marketing in Rural Punjab.
<https://www.adb.org/projects/52232-001/main>.

Figure 3: Diagnostics for Parallel Trends



Source: Authors' calculations.

Table 1: Zone, Selected Tehsil, Selected Qanungo Halqas, and Number of Selected Villages for the Surveys

Tehsil	Qanungo Halqa	No. of Selected Villages
Muridke	Ahdian	8
	Muridke	11
Hafizabad	Chak Chattha	9
	Hafizabad	13

Source: ADB. Pakistan: Enhancing Technology-Based Agriculture and Marketing in Rural Punjab.
<https://www.adb.org/projects/52232-001/main>.

Table 2: Control and Treatment Samples in the Baseline, Midline, and Endline Surveys in Rural Punjab, Pakistan

Group	Qanungo Halqa	Number of Participants			Percentage of Participants		
		Baseline	Midline	Endline	Baseline	Midline	Endline
Control	Ahdian	169	151	137	90.01	95.45	90.31
	Chak Chattha	176	165	153	91.01	96.85	91.64
<i>Subtotal</i>		<i>345</i>	<i>316</i>	<i>290</i>	<i>90.49</i>	<i>96.12</i>	<i>90.95</i>
Treatment	Hafizabad	317	293	250	88.07	96.75	87.28
	Muridke	316	308	273	90.05	98.54	90.67
<i>Subtotal</i>		<i>633</i>	<i>601</i>	<i>523</i>	<i>89.13</i>	<i>97.70</i>	<i>89.08</i>
Total		978	917	813	89.60	97.15	89.74

Source: ADB. Pakistan: Enhancing Technology-Based Agriculture and Marketing in Rural Punjab.
<https://www.adb.org/projects/52232-001/main>.

Table 3: Summary Statistics of Farm, Household, and Plot Attributes of Sampled Households in Punjab, Pakistan

	Total Sample		Treated		Control	
	Mean	SD	Mean	SD	Mean	SD
Yields (Md/acre) ^a	36.62	13.04	37.25	13.13	35.49	12.79
Harvest losses (Md/Acre)	3.55	1.29	3.539	1.25	3.58	1.41
Paddy price (PRs/Md)	97.88	76.59	97.363	78.50	99.05	72.18
Price of straw (PRs/acre)	7,589.04	4,150.24	7,695.85	4,264.06	7,384.00	3,916.36
Cost savings in land preparation for next season (PRs/acre)	3,251.31	2,202.74	3,421.02	2,253.99	2,855.08	2,025.62
Household Controls						
Household size (number)	8.361	4.26	8.44	4.26	8.32	4.26
Income from crops (%)	58.22	325.57	78.13	548.65	47.49	22.70
Farming experience (years)	22.44	13.29	23.34	13.31	21.953	13.26
Literacy of household head (%)	75.64	42.93	77.06	42.05	73.00	44.41
Age of household head (years)	44.74	14.56	45.18	14.33	44.51	14.68
Marital status (%)	88.06	32.43	89.20	31.05	87.44	33.14
Plot Controls						
<i>Soil type (%)</i>						
Clay loam	35.10	47.73	34.37	47.51	35.49	47.85
Clay	11.19	31.53	8.44	27.81	12.68	33.28
Loam	22.66	41.86	24.26	42.88	21.79	41.29
Others	0.35	5.88	0.15	3.89	0.45	6.70
Sandy	0.27	5.16	0.23	4.77	0.29	5.35
Sandy loam	5.52	22.83	4.94	21.69	5.83	23.43
Silty loam	24.92	43.26	27.60	44.72	23.47	42.39
<i>Irrigation source (%)</i>						
Canal	24.92	43.26	27.61	44.72	23.47	42.39
Tubewell	52.98	49.92	70.95	45.42	43.29	49.56
Canal + Tubewell	1.57	12.44	0.99	9.89	1.89	13.61
Observations	3,233		2,083		1,150	

Md = maund, PRs = Pakistan rupees, SD = standard deviation.

^a1 maund = 37.32 kilograms.

Source: ADB. Pakistan: Enhancing Technology-Based Agriculture and Marketing in Rural Punjab.

<https://www.adb.org/projects/52232-001/main>.

Table 4: Double Difference (D-I-D) Estimates of the ETAM Program Effects on Farm Profitability Outcomes

	Yield (Md/acre) ^a	Harvest Losses (Md/Acre)	Paddy Price (PRs/Md)	Price of Straw (PRs/acre)	Land Preparation Cost (PRs/acre)
	[1]	[2]	[3]	[4]	[5]
ETAM * Post	0.082** (0.025)	0.091*** (0.027)	0.202* (0.094)	0.198** (0.069)	-0.009 (0.091)
Household Controls					
Household size	0.027 (0.027)	-0.061 (0.037)	-0.202 (0.152)	-0.006 (0.054)	-0.074 (0.088)
Income from crops	0.004*** (0.001)	-0.073 (0.052)	0.669*** (0.187)	0.004** (0.002)	0.475*** (0.121)
Farming experience	0.036 (0.112)	-0.045 (0.141)	0.718 (0.737)	-0.635 (0.428)	-0.984 (0.579)
Literacy (Yes=1)	-0.022 (0.053)	-0.025 (0.047)	0.317 (0.201)	-0.017 (0.067)	0.094 (0.100)
Age of household head	-0.317 (0.419)	-1.1 (0.620)	5.655* (2.806)	9.631*** (2.256)	12.042*** (2.731)
Marital status (Base=Married)	0.017 (0.055)	-0.036 (0.061)	-0.036 (0.205)	-0.294* (0.139)	-0.347** (0.121)
Plot Controls					
Soil type (Base = Clay_loam)					
Clayey	-0.033 (0.033)	0.001 (0.035)	0.106 (0.124)	-0.089 (0.057)	0.042 (0.087)
Loam	0.014 (0.024)	0.03 (0.028)	0.105 (0.115)	-0.021 (0.059)	0.095 (0.055)
Others	-0.136 (0.243)	0.031 (0.105)	-0.113 (0.365)	0.004 (0.110)	-0.097 (0.224)
Sandy	0.179 (0.120)	-0.429 (0.374)	-2.170*** (0.241)	-1.143 (1.164)	0.924*** (0.146)
Sandy loam	0.034 (0.038)	0.008 (0.049)	0.188 (0.146)	-0.122 (0.131)	0.079 (0.137)
Silty loam	0.021 (0.024)	0.024 (0.028)	0.027 (0.097)	0.041 (0.043)	-0.008 (0.069)
Irrigation source (Base=Canal)					
Tubewell	-0.007 (0.081)	0.153* (0.062)	-0.057 (0.331)	-0.065 (0.174)	-0.234 (0.123)
Canal+Tubewell	-0.011 (0.023)	0.029 (0.027)	-0.079 (0.095)	0.009 (0.050)	0.069 (0.055)
Knowledge of ICT	-0.266*** (0.072)	-0.183* (0.088)	-0.203 (0.216)	-0.339*** (0.074)	-0.690* (0.275)
Constant	5.391*** (1.556)	7.132** (2.334)	-22.855* (10.206)	-30.774*** (8.487)	-41.146*** (10.220)
Panel FE	Yes	Yes	Yes	Yes	Yes
Observations	3,233	2,494	1,573	2,984	1,674

D-I-D = difference in difference, ETAM = Enhancing Technology-Based Agriculture and Marketing, FE = fixed effects, ICT = information and communication technology, md = maund, PRs = Pakistan rupees.

Notes: Standard errors reported in parentheses are clustered at the plot level; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

^a1 maund = 37.32 kilograms.

Source: Authors' calculation.

Table 5: Double Difference (D-I-D) Estimates of the ETAM Program Effects on Farm Profitability Outcomes by Seed Type

	Small Holding Farm (<12.5 acres of land)					Large Farm (>=12.5 acres of land)				
	Yield (Md/acre) ^a	Harvest Losses (Md/acre)	Paddy Price (PRs/Md)	Price of Straw (PRs/acre)	Land Preparation Cost (PRs/acre)	Yield (Md/acre)	Harvest Losses (Md/Acre)	Paddy Price (PRs/Md)	Price of Straw (PRs/acre)	Land Preparation Cost (PRs/acre)
	[1]	[2]	[3]	[4]	[5]	[1]	[2]	[3]	[4]	[5]
ETAM * Post	0.065* (0.028)	0.074* (0.030)	0.226* (0.103)	0.161* (0.078)	0.008 (0.112)	0.243* (0.123)	0.244* (0.101)	0.627*** (0.139)	1.375* (0.589)	-0.187 (0.209)
Constant	2.557 (1.742)	6.831* (2.723)	-14.063 (10.968)	-25.638* (10.297)	-35.551** (12.362)	11.186 -10.185	27.562** -8.323	-100.03*** -18.085	-50.662*** -14.176	-64.182** -23.02
Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,233	2,494	1,573	2,984	1,674	464	348	223	440	242

D-I-D = difference in difference, ETAM = Enhancing Technology-Based Agriculture and Marketing, FE = fixed effects, Md = maund, PRs = Pakistan rupees.

Notes: Standard errors reported in parentheses are clustered at the plot level; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

^a1 maund = 37.32 kilograms.

Source: Authors' calculation.

Table 6: Double Difference (D-I-D) Estimates of the ETAM Program Effects on Farm Profitability Outcomes by Access to Information

	No Information Accessed					Information Accessed				
	Yield (Md/acre) ^a	Harvest Losses (Md/acre)	Paddy Price (PRs/Md)	Price of Straw (PRs/acre)	Land Preparation Cost (PRs/acre)	Yield (Md/acre)	Harvest Losses (Md/acre)	Paddy Price (PRs/Md)	Price of Straw (PRs/acre)	Land Preparation Cost (PRs/acre)
	[1]	[2]	[3]	[4]	[5]	[1]	[2]	[3]	[4]	[5]
ETAM * Post	0.145*** (0.040)	-0.023 (0.063)	0.228 (0.201)	0.115 (0.108)	-0.249 (0.132)	0.074 (0.066)	0.202** (0.070)	-0.095 (0.223)	0.368*** (0.099)	0.316** (0.106)
Constant	5.028 (3.845)	14.765*** (4.000)	-41.640** (12.730)	-37.532*** (7.088)	-63.111*** (18.252)	4.449 (2.976)	12.439** (4.377)	-50.911*** (13.667)	-39.086*** (7.473)	-50.571*** (5.722)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Panel FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,648	1,215	689	1,569	717	1,585	1,279	884	1,415	957

D-I-D = difference in difference, ETAM = Enhancing Technology-Based Agriculture and Marketing, FE = fixed effects, Md = maund, PRs = Pakistan rupees.

Notes: Standard errors reported in parentheses are clustered at the plot level; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

^a 1 maund = 37.32 kilograms.

Source: Authors' calculation.

Table 7: Triple Difference (DDD) Estimates of the ETAM Program Effects on Farm Profitability Outcomes

	Yields (Md/acre) ^a	Harvest Losses (Md/acre)	Paddy Price (PRs/Md)	Price of Straw (PRs/acre)	Land Preparation Cost (PRs/acre)
	[1]	[2]	[3]	[4]	[5]
ETAM * Post *	0.064*	0.088**	0.192*	0.202**	-0.010
KRH=0	(0.027)	(0.030)	(0.108)	(0.078)	(0.096)
ETAM * Post *	0.115***	0.095**	0.213*	0.193**	-0.008
KRH=1	(0.032)	(0.032)	(0.112)	(0.074)	(0.103)
Panel FE	Yes	Yes	Yes	Yes	Yes
Observations	3,233	2,494	1,573	2,984	1,674

DDD = triple difference design, ETAM = Enhancing Technology-Based Agriculture and Marketing, FE = fixed effects, KRH = Kubota rice harvester, Md = maund, PRs = Pakistan rupees.

Notes: Standard errors reported in parentheses are clustered at the plot level; ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

^a 1 maund = 37.32 kilogram.

Source: Authors' calculation.

Table 8: Benefit–Cost Analysis of the ETAM Program and Adoption of the Kubota Rice Harvester

Items	Wave 1– 2020	Wave 2– 2021	Wave– 2023
Additional Revenues			
1. Reduction in harvest losses (PRs/acre)	6,243	6,575	14,062
2. Increased prices, harvested by KRH ^b (PRs/acre)	75	99	138
3. Selling rice straw (PRs/acre)	5,273	6,536	11,441
Cost Savings in			
4. Hiring combine harvesters (PRs/acre)	2,656	3,430	7,945
5. Land preparation for next season (PRs/acre)	2,196	2,521	5,690
Additional Costs			
6. Hiring KRH harvesters (PRs/acre)	5,859	6,654	14,197
Net Benefit (PRs/acre) ^{b, c}	10,584	12,507	25,079

ETAM = Enhancing Technology-Based Agriculture and Marketing, KRH = Kubota rice harvester (see Appendix Table), Md = maund, PRs = Pakistan rupees.

Notes:

^a This is obtained by multiplying the average paddy yield attributed to KRH and the additional price of paddy.

^b Sum of rows in 2-5, subtracting row 6.

^c The average yield of paddy Md/acre is estimated to be 35.93 in baseline, 38.58 in midline, and 36.25 in endline. Average price of paddy/Md is estimated as PRs16,267 in baseline, PRs16,441 in midline, and PRs21,846 in endline.

Source: Authors' calculation.

APPENDIX

Table: Analysis of Identified Advanced Harvest Machines for Rice Harvesting

Advantage	Disadvantage	Overall Assessment
Kubota (ER-112)		
<ul style="list-style-type: none"> • Minimal grain loss • Negligible impurities • Less paddy broken • Efficient harvesting in standing crop • Best performance in muddy soil conditions • Low cutting height • No residue burning • Availability of leftover straw for feeding livestock 	<ul style="list-style-type: none"> • The harvester cannot perform well if the crop gets lodged due to harsh weather conditions (heavy rainfall, winds, etc.). • Lack of spare parts available in local markets • Lack of skilled operators 	<p>Very little grain loss and good cleaning efficiency can significantly add value to the farmers' net income. The harvester cuts the crop at the lowest possible height, leaving intact/whole straw and low stubble, which makes it easier for farmers to collect the straw to feed their livestock, clear the fields early, and avoid burning leftover straw. It also reduces tillage costs for the next crop.</p>
Thinker (XG750S)		
<ul style="list-style-type: none"> • Minimal grain losses • Negligible impurities • Less paddy broken • Efficient harvesting in lodged crop • Best performance in muddy soil conditions 	<ul style="list-style-type: none"> • Lack of spare parts available in local markets • Lack of skilled operators 	<p>The harvester is very efficient with both lodged and standing crops. Farmers are interested in using this harvester only on lodged crops, as the harvester can harvest the lodged crop very efficiently compared to other available large conventional full-feed combine harvesters. In contrast, farmers are not so much interested to use this harvester for standing crops as farmers cannot get intact/whole rice straw for feeding their livestock.</p>

Source: ADB. Pakistan: Enhancing Technology-Based Agriculture and Marketing in Rural Punjab.
<https://www.adb.org/projects/52232-001/main>.

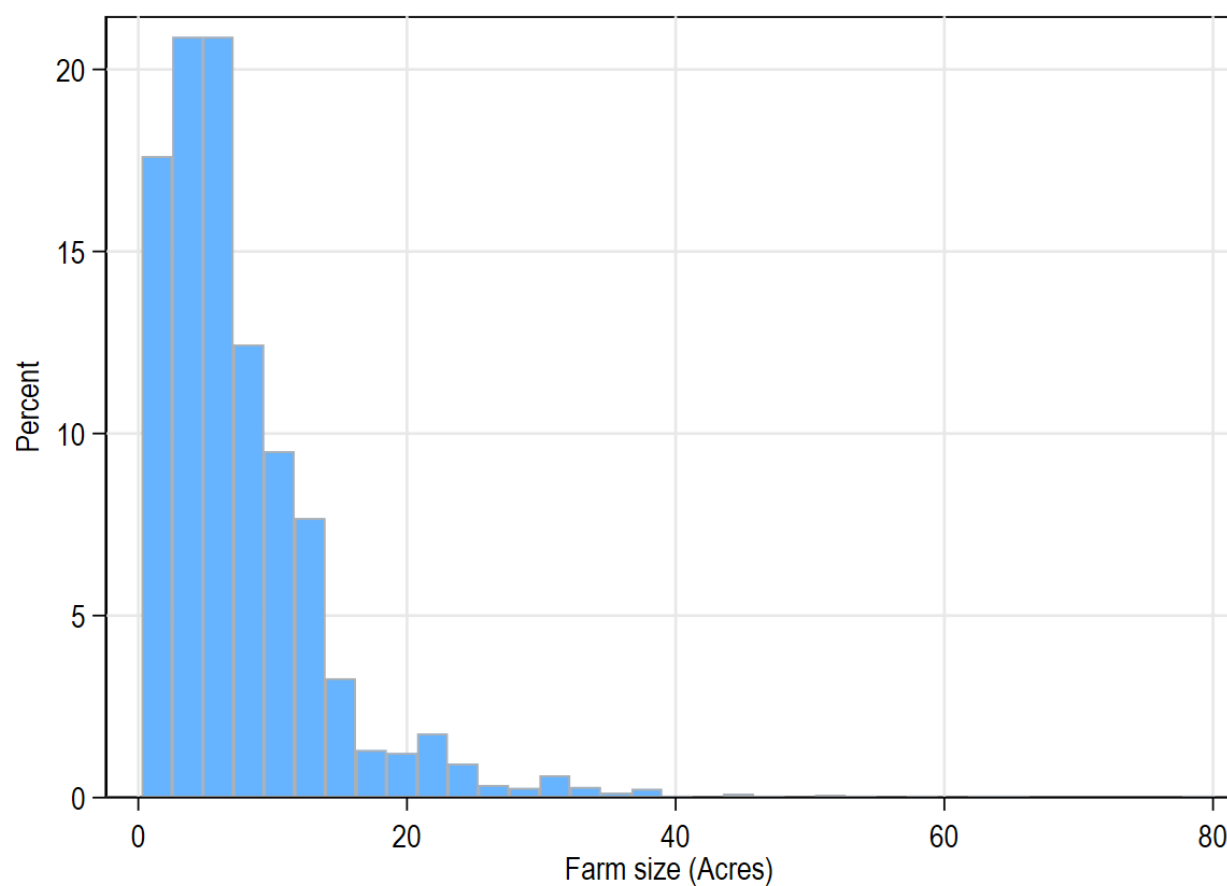
Box: Rice Harvester Type by Sampled Households, Pakistan

The Kubota rice harvester used by Centre for Agriculture and Biosciences International (CABI) as part of the technical assistance was responsive to all field conditions where the crop at maturity is either erect or lodged. The ER-112 was the latest model of paddy-specific half-feed harvester in Punjab having six straw walkers with a cutter width of 7 feet and 112-HP common rail engine. It essentially consists of four major parts: the header, the conveying chains, the threshing drum, and the grain storage tank. It cuts the paddy at the lowest possible height and the chains are installed on the header assembly with the tines mounted on the chains. The tines are used to grab the paddy and are guided through chains to the threshing drum. The grains are threshed and cleaned using high-velocity blowers and an integrated threshing drum mounted on the rear side of the machine. The threshed grains are stored in a storage tank with a capacity of 0.8–0.9 tons. The intact/whole straw is moved out of the harvester and thrown back onto the field in rows.

The Thinker XG750S is a full-feed paddy-specific harvester that performs three separate operations: reaping, threshing, and winnowing instead of separate machines. The wider header (7 feet) at the front of the harvester gathers the crop into the machine. The reel pushes the crop toward the cutter blade, which cuts the crop. The grains are then transported to the threshing drum via a conveyer belt. There, the grains are separated from the stalks and collected in a separate drum with a storage capacity of 0.3–0.4 tons, which is discharged through the machine's side pipe auger. The harvester is capable of harvesting both standing and lodged crops. However, farmers only interested in harvesting the lodged crop with this harvester.

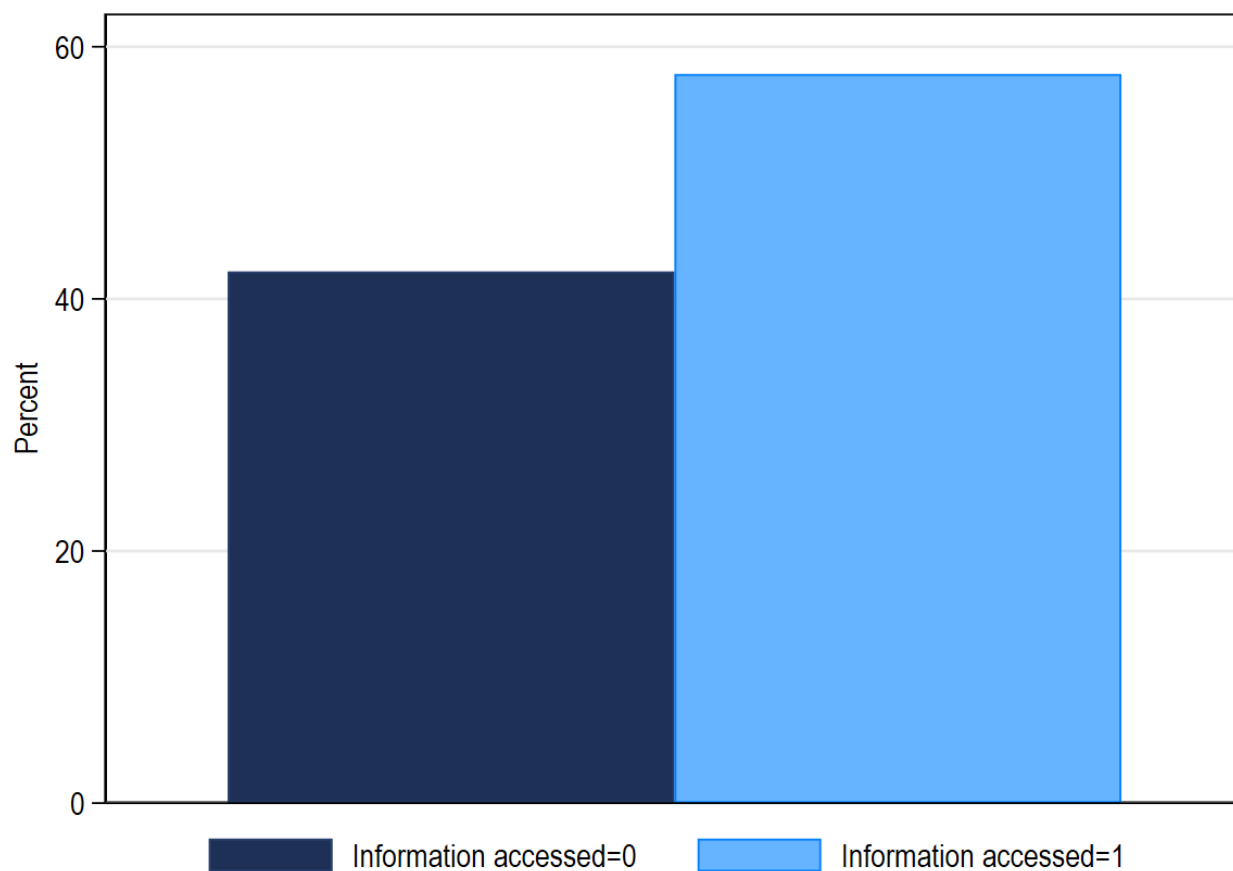
Source: ADB. Pakistan: Enhancing Technology-Based Agriculture and Marketing in Rural Punjab. <https://www.adb.org/projects/52232-001/main>.

Figure A1: Histogram of Farm Size and Sampled Households, Pakistan



Source: ADB. Pakistan: Enhancing Technology-Based Agriculture and Marketing in Rural Punjab.
<https://www.adb.org/projects/52232-001/main>.

Figure A2: Percentage of Sampled Households Accessing Information, Pakistan



Source: Source: Authors' calculation.

REFERENCES

- Abadie, A. S. Athey, G. W. Imbens, and J. Wooldridge. 2017. When Should You Adjust Standard Errors for Clustering? *National Bureau of Economic Research Working Paper Series*. No. 24003. <http://www.nber.org/papers/w24003.pdf>.
- Adhvaryu, A. 2014. Learning, Misallocation, and Technology Adoption: Evidence from New Malaria Therapy in Tanzania. *Review of Economic Studies*. 81 (4). pp. 1331–1365. <https://doi.org/10.1093/restud/rdu020>.
- Ahmed, A. U., K. Ahmad, V. Chou, R. Hernandez, P. Menon, F. Naeem, F. Naher, W. Quabili, E. Sraboni, and B. Yu. 2013. The Status of Food Security in the Feed the Future Zone and Other Regions of Bangladesh: Results from the 2011-2012 Bangladesh Integrated Household Survey. International Food Policy Research Institute. . <https://ebrary.ifpri.org/digital/collection/p15738coll2/id/127518>.
- Amir, S., Z. Saqib, M. I. Khan, M. A. Khan, S. A. Bokhari, M. Zaman-ul-Haq, and A. Majid. 2020. Farmers' Perceptions and Adaptation Practices to Climate Change in Rain-Fed Area: A Case Study from District Chakwal, Pakistan. *Pakistan Journal of Agricultural Sciences* 57. pp 465–475. doi: 10.21162/PAKJAS/19.9030
- Azhar, R., M. Zeeshan, and K. Fatima. 2019. Crop Residue Open Field Burning in Pakistan: Multi-Year High Spatial Resolution Emission Inventory for 2000–2014. *Atmospheric Environment*. 208. pp. 20–33. <https://doi.org/10.1016/j.atmosenv.2019.03.031>.
- Bandiera, O. and I. Rasul. 2006. Social Networks and Technology Adoption in Many in the Developing World. *Economic Journal*. 116 (1957). pp. 869–902.
- Beaman, L., A. BenYishay, J. Magruder, and A. M. Mobarak. 2021. Can Network Theory-Based Targeting Increase Technology Adoption? *American Economic Review*. 111 (6). pp. 1918–1943. <https://doi.org/10.1257/AER.20200295>.
- Bertrand, M., E. Duflo, and S. Mullainathan. 2004. How Much Should We Trust Differences-In-Differences Estimates? *The Quarterly Journal of Economics*. 119 (1). pp. 249–275.
- Bhattacharyya, P. et al. 2021. Turn the Wheel from Waste to Wealth: Economic and Environmental Gain of Sustainable Rice Straw Management Practices over Field Burning in Reference to India. *Science of The Total Environment*. 775. 145896.
- Bhattacharyya, P. and D. Barman. 2018. Chapter 21 – Crop Residue Management and Greenhouse Gases Emissions in Tropical Rice Lands. *Soil Management and Climate Change*. pp. 323–335. <https://doi.org/10.1016/B978-0-12-812128-3.00021-5>.
- Conley, T. G. and C. R. Udry. 2010. Learning About a New Technology: Pineapple in Ghana. *The American Economic Review*. 100 (1). pp. 35–69.

- Das, B., P. V. Bhawe, S. P. Puppala, K. Shakya, B. Maharjan, R. M. Byanju. 2020. A Model-Ready Emission Inventory for Crop Residue Open Burning in the Context of Nepal. *Environmental Pollution*. 266 (3). 115069. <https://doi.org/10.1016/j.envpol.2020.115069>.
- de Janvry, A., K. Emerick, E. Sadoulet, and M. Dar. 2015. The Agricultural Technology Adoption: What Can We Learn from Field Experiments? *Revue d'Economie Du Developpement*. 23 (4). pp. 129–153. <https://doi.org/10.3917/edd.294.0129>.
- Diao, X., J. Silver, and H. Takeshima. 2016. Agricultural Mechanization and Agricultural Transformation Xinshen. *IFPRI Discussion Paper 01527*. April.
- Gollin, D., S. Parente, and R. Rogerson. 2002. The Role of Agriculture in Development. *American Economic Review*. 92 (2). pp. 160–164. <https://doi.org/10.1093/0195305191.003.0008>.
- Gollin, D. and C. Udry. 2021. Heterogeneity, Measurement Error, and Misallocation: Evidence from African Agriculture. *Journal of Political Economy*. 129 (1). pp. 1–80. <https://doi.org/10.1086/711369>.
- Government of Pakistan. 2020. *Mechanization of Agriculture Sector of Pakistan*. Engineering Development Board.
- Government of Pakistan. 2023. Pakistan Economic Survey 2022–23. Finance and Economic Affairs Division, Ministry of Finance.
- Gunasekera, D., H. Parsons, and M. Smith. 2017. Post-harvest loss reduction in Asia-Pacific developing economies. *Journal of Agribusiness in Developing and Emerging Economies*, 7(3). pp. 303–317. <https://doi.org/10.1108/JADEE-12-2015-0058>.
- Gustavsson J., C. Cederberg, U. Sonesson, R. van Otterdijk, and A. Meybeck. 2011. Global Food Losses and Food Waste. Food and Agriculture Organization of the United Nations.
- Ishii, K. and T. Furuichi. 2014. Influence of Moisture Content, Particle Size and Forming Temperature on Productivity and Quality of Rice Straw Pellets. *Waste Management*. 34 (12). pp. 2621–2626. <https://doi.org/10.1016/j.wasman.2014.08.008>.
- Kaushal, L. A. and A. Prashar. 2021. Agricultural Crop Residue Burning and Its Environmental Impacts and Potential Causes – Case of Northwest India. *Journal of Environmental Planning and Management*. 64 (3). pp. 464–484. <https://doi.org/10.1080/09640568.2020.1767044>.
- Kienzie, J., Ashburner, J.E., Sims, B.G. 2013. Mechanization for Rural Development: a Review of Patterns and Progress from around the World. Food and Agriculture Organization, Rome

- Kumar, D. and P. Kalita. 2017. Reducing Post-Harvest Losses During Storage of Grain Crops to Strengthen Food Security in Developing Countries. *Foods*. 6 (1). pp. 1–22. <https://doi.org/10.3390/foods6010008>.
- Kumar, P., S. Kumar, and L. Joshi. 2015. Socioeconomic and Environmental Implications of Agricultural Residue Burning: A Case Study of Punjab, India. Springer.
- Lin, M. and T. Begho. 2022. Crop Residue Burning in South Asia: A Review of the Scale, Effect, and Solutions with a Focus on Reducing Reactive Nitrogen Losses. *Journal of Environmental Management*. 314. 115104. <https://doi.org/10.1016/j.jenvman.2022.115104>.
- Mcarthur, J. W. and G. C. Mccord. 2017. Fertilizing Growth: Agricultural Inputs and Their Effects in Economic Development. *Journal of Development Economics*. 127 (February). pp. 133–152. <https://doi.org/10.1016/j.jdeveco.2017.02.007>.
- Mottaleb, K.A., Krupnik, T.J. and Erenstein, O. 2016. Factors Associated with Small-Scale Agricultural Machinery Adoption in Bangladesh: Census Findings. *Journal of Rural Studies*, 46, 155-168. <https://doi.org/10.1016/j.jrurstud.2016.06.012>
- Mumin, Y., A. Abdulai, and R. Goetz. 2023. The Role of Social Networks in the Adoption of Competing New Technologies in Ghana. *Journal of Agricultural Economics*. 74 (2). pp. 510–533. <https://doi.org/10.1111/1477-9552.12517>.
- Nath, B. C., Y.-S. Nam, Md. D. Huda, Md. M. Rahman, P. Ali, and S. Paul. 2017. Status and Constrain for Mechanization of Rice Harvesting System in Bangladesh. *Agricultural Sciences*. 8. pp. 492–506. <https://doi.org/10.4236/as.2017.86037>.
- Pakistan Bureau of Statistics. 2010. Agriculture Census, 2010. Government of Pakistan Statistics Division Agricultural Census Organization.
- Pakistan Bureau of Statistics. 2022. Pakistan Statistical Year Book (2022). Pakistan Bureau of Statistics, Government of Pakistan.
- State Bank of Pakistan. 2020. Annual Report 2020-2021 (State of the Economy). <https://www.sbp.org.pk/reports/annual/arFY21/Anul-index-eng-21.htm>.
- Takeshima, H., H. O. Edeh, A. O. Lawal, M. A. Isiaka. 2015. Characteristics of Private-Sector Tractor Service Provisions: Insights from Nigeria. *Developing Economies*. 53 (3). pp. 188–217.
- United States Agency of International Development (USAID). 2018. Pakistan Agricultural Technology Transfer Activity. Project Stakeholders' Analysis Report (Primary Research Findings and Field Activity Status) USAID-391-C-17-00004.
- World Bank Group. 2017. *World Bank Annual Report 2017*. <http://documents.worldbank.org/curated/en/143021506909711004/World-Bank-Annual-Report-2017>.

Adoption of Farm Mechanization for Clean Air

Evidence from Farm Trials in Pakistan

Many rice farmers burn stubble and straw after harvest, which worsens air pollution. This paper examines the impact of training for farmers in Punjab, Pakistan, on the adoption of mechanized rice harvesters that leave short rice stubble, thereby reducing the need for crop burning. The results show that the training program increased farm performance among rice farmers who adopted the rice harvesters, highlighting the need for adoption of these harvesters to reduce open field burning and contribute to cleaner air.

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