Productivity Effect of Credit Access for Microenterprises: Separating Technical Change from Technical Efficiency Change

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Productivity improvements among microenterprises are important, especially for low-income countries where market imperfections are pervasive and resources are scarce. Relaxing credit constraints can influence input choice of microenterprises and the efficiency of transforming inputs into output. Using a field experiment among agricultural microenterprises in Bangladesh, we estimate the impact of expanding credit access on productivity of rice farmers and disentangle the total effect into technological change (frontier shift) and efficiency change. We find that, relative to the baseline rice output per decimal, credit access resulted, on average, in approximately 13 percent increase in yield. The effect is doubled on modern hybrid rice and almost zero on traditional rice types. Approximately 9 percent of the output effect comes from change in technology and 3 percent increase in output is attributed to improvement in technical efficiency, on average. Within the treatment group, the effect is larger among pure tenant and mixed tenant microenterprise households than microenterprises who cultivate only their own lands.

Keywords: field experiment, microfinance, credit, efficiency, productivity

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1. Introduction

Subsistence farm microenterprises in developing countries generally have few financial instruments at their disposal to facilitate complex financial decisions. They also face poor financial environment often characterized by missing financial markets, high input costs and time-inconsistent preferences. These factors shape microenterprise business practices, production and investment decisions, and performance (Stiglitz, Emran and Morshed 2006; Bruhn, Karlan and Schoar 2010; Karlan, Savonito, Thuysbaert and Udry 2016). Provision of agricultural credit at a subsidized interest rate can be an effective tool to enhance the production and transformation of rural farm microenterprises. Relaxing the credit constraint for microenterprises could lead to higher adoption of modern inputs and better ability to turn inputs into output, both of which can boost productivity. Productivity and efficiency underscore the organizational capacity of subsistence farm microenterprises to deal with external shocks and has far-reaching implications on ensuring their sustainable livelihood. Furthermore, understanding the relationship between credit constraints and farm efficiency has a crucial policy implication: the benefits of credit programs may be underestimated if they do not account for potential efficiency improvements due to the presence of credit constraints.

In this paper, we examine how access to microcredits influences farm microenterprise productivity and whether the output effect comes from changes in technology or from improved efficiency.[1,2] We do so by using survey data from a field experiment[3] by exploiting the random assignment of credit services to agricultural microenterprises by Bangladesh Rural Advancement Committee (BRAC)[4] and employing the stochastic production frontier model.[5] First, we examine the impact of credit access on the productivity of rice producing farms. Then, we disentangle the productivity effect into technological change and efficiency change. In addition to identifying the impacts of credit access on the productivity, technological change and technical efficiency, we examine how the effect varies by several demographic and farm characteristics.

[1]We define productivity as yield, output per unit of land (kilogram of rice per decimal land).
[2]A farm's technical efficiency is the maximum output possible from a given set of inputs and the production technology. We estimate the production frontier using simple Cobb-Douglas technology.
[3]As per the taxonomy put forth in Harrison and List (2004).
[4]The largest NGO in Bangladesh.
[5]Conventional production function approach does not allow us to separate the technological change and efficiency improvement from the overall productivity effect. Because the stochastic frontier model allows us to decompose the two effects, we use this approach as a tool to answer our research question.

Conceptually, relaxing credit constraints has an ambiguous effect on the technical efficiency of farm microenterprises (Hadley et al. 2001; Davidova and Latruffe 2003). On one hand, less credit-constrained farms can procure more inputs and can better finance operating expenses in the short run (Singh, Squire, and Strauss 1986), thereby enabling them to make better microenterprise-related investments in the long run.[6] Credit can also mitigate consumption risk and enable more adoption of modern inputs among risk-averse small farms (Liu and Zhuang 2000; Easwaran and Kotwal 1989). On the other hand, if farm microenterprises face other constraints, such as lack of access to insurance, missing markets or high input costs, then credit alone will not translate to higher productivity and technical efficiency.

Previous empirical studies attempt to measure the inefficiency in agricultural microenterprises and examine the factors that determine or explain inefficiency. However, those estimates are based on observational study designs and the determinant factors are not comprised of any exogenous change rather chosen by researchers. Moreover, the studies document mixed results. Taylor et. al (1986) and Brummer (2000), using parametric efficiency analysis, find a negative relationship between credit constraints and efficiency of farm microenterprises. Other studies focus on the Philippine, West Bengal, Pakistan and on Bangladesh and find that relaxing credit constraints is as an important determinant with positive effect on farm efficiency (Martey, Wiredu and Etwire 2015; Islam, Sipilainen and Sumelius 2011).

This paper makes several important contributions to the existing empirical literature. First, we isolate more credible causal impacts of credit access on the productivity and efficiency of small farm enterprises in a low-income country context as we combine an experimental design with the stochastic frontier approach. Because of the random assignment of access to agricultural microcredit, we can rely on a more credible counterfactual that holds the technologies of the microenterprises we compare same (on average) at baseline. Second, our paper complements previous field experiments (Banerjee et al. 2015) by its focus on the impact of credit on productivity and on technical efficiency.

We find that relaxing the credit constraint has a sizable and positive impact on output yield – both on the frontier shift of rice production and on the technical efficiency. Among the microenterprises assigned to credit, we find positive impacts of credit access on total rice yield,

[6]Credit has been shown to affect risk behavior of producers (Boucher, Carter and Guirkinger 2005; Eswaran and Kotwal 1990), thereby affecting technology choice and adoption by farmers.

specifically the high yielding variety (HYV) rice and hybrid rice, while finding no impacts on traditional rice variety. We find that, relative to the baseline yield, expanded credit access increases productivity by approximately 13 percent on average, with the highest impact on modern hybrid rice growing farms. In terms of technical efficiency, small-scale farms with access to subsidized credit are, on average, 3 percent more efficient than farm households[7] with no credit access (which, relative to the average baseline rice yield of 18-kilogram per decimal, implies approximately half a kilogram less output loss due to inefficiency). This positive effect is even more pronounced among producers of the hybrid rice variety – they exhibit an efficiency gain of 9 percent, on average. We detect differential impacts among marginal and tenant farm households.[8] Our results show that among the farms with credit access, enterprises with cultivated land less than 50 decimals are on average 3 percent less efficient than larger farms with credit access. We also find strong evidence of a positive effect of credit access (at 95th percentile level) on efficiency for tenant farm households compared to pure owner farms.

Our findings highlight the likely mechanisms that explain the positive impacts of microcredit on productivity and efficiency. In the absence of insurance and credit markets, credit-constrained households are highly risk-averse in their farming practices. Credit access enables farm households to adopt riskier, but more productive crop varieties and utilize complementary production inputs in more timely manner. Credit can also boost the farms' potential to manage and allocate the resources more effectively, something that also results in them producing higher output. We find that households with credit access, on average, procure more pesticides, which are essential in the production process and for the yield of riskier crops, than control farm households. In addition, we find an increase in the adoption of riskier crops (hybrid and HYV) and larger productivity increases among the adopters of these crop types. One explanation for the difference in magnitude of impacts across rice varieties might be that modern varieties offer more potential yield but also create more risk, which requires more complementary inputs and timely use of those variable inputs.[9]

The structure of the rest of the paper is as follows. Section 2 presents the program design, data sources, and summary statistics. Section 3 describes the conceptual framework and the channels through which credit influences the two study outcomes. Section 4 describes the

[7]Throughout the paper, we use farm households, farm or agricultural microenterprises interchangeably.
[8]Tenant farm households are the farms that cultivate other people's land- either through sharecropping or renting or both.
[9]For simplicity, we have not modeled risk in this paper.

empirical strategy. Section 5 presents the main results. Section 6 concludes with discussion of our findings.

2. Project Background

2.1 The BCUP Credit Program

In 2009, BRAC introduced the Tenant Farmers Development Project known as 'Borga Chashi Unnayan Prakalpa (BCUP).' The project was initiated with Tk. 5,000 million (USD 70 million) as a revolving loan fund from the Central Bank of Bangladesh with an interest rate of 5 percent per month, the rate at which commercial banks can borrow funding from the Central Bank. Funding was initially given for three years with the target of providing credit to 300,000 farmers. Subsequently, in 2012, Bangladesh Bank approved the extension of the project for another three years.

The main objective of the BCUP program was to reduce the dependence of tenant farmers on high-cost informal markets for financing their working capital needs. Tenant farmers are typically bypassed by the conventional micro-finance institutions as well as formal banking sectors, which results in an inadequacy of working capital, thus, lower access to inputs and lower productivity (Hossain and Bayes 2009; Lianto 2005). By reducing credit constraints faced by these farm microenterprises, the BCUP program attempted to improve farm productivity as well as the livelihoods of rural small-scale farm households of Bangladesh significantly.

BCUP provides a customized credit service based on the proprietary composition of the recipient farms—i.e. pure tenant, mixed tenant or pure owner. Loans are provided at a subsided interest rate – a flat rate of 10 percent per year (See Figure 3). The effective rate of interest is 15 to 20 percent, and includes declining balance depending on the mode of repayment of the principal and interest due. The credit limit ranges from \$62 to \$375 (*i.e.,* taka 5,000-120,000); duration is 6-10 months; the grace period is 1 month and the repayment installment is monthly. BCUP was targeted to reach all 484 Upazilas (sub-districts) of Bangladesh in successive phases. By September 2012, the program reached 212 Upazilas.

Households are selected for a loan disbursement based on a few stages of verification. The first stage entails initial selection of members. Members are selected by matching each household against the BCUP eligibility criteria and orienting the farmers with the BCUP program and its terms and conditions.[10] The second stage is the formation of the Village Organization (VO). After initial verification of information, if the VO members agree to the terms and conditions of the BCUP, a small group of five farmers are informally created. Stage three entails the collection of member information. In the fourth and final stage, the members list is finalized through verification by a Branch Manager, who determines eligibility of the selected members.

After this selection process, new members are formally admitted and attend an orientation meeting. An important feature of the BCUP is the formation of the VO and its use as a platform for service delivery. In the VO, members are grouped in teams of five with a total of four to eight teams consisting of 20 to 40 members, forming the village level informal tenant farmer association. The VO meets once every month on a fixed day and time, and the meetings include the BCUP Program Organizer and an Agriculture Development Officer. Apart from the discussion of loan proposals and collection of installment payments, dues and savings deposits, farmers can get agricultural information and advice from the Agriculture Development Officer. Table 1 presents the summary statistics of baseline household composition for program participants on various inputs used and on output of rice production.

[Table 1 about here]

2.2 Random Assignment of Credit Services, Balance Check and Attrition

The BCUP program was established as a clustered randomized control trial (RCT) design. Initially, the program identified 40 potential sub-districts/branch[11] offices for program scale-up in 2012. The research team randomly drew twenty (20) treatment branches for intervention while the other twenty (20) branches were designated as control branch offices. Then, we randomly selected six out of the 10-12 villages within an eight-kilometer radius of the center point of each branch location. The eight-kilometer periphery was chosen because BRAC branch offices usually operate within eight kilometers for administrative purposes. Thus, the sub-district/branch is the first unit of randomization followed by village/community.

[8] The selection criteria were: 1) The farmer has National ID card, 2) Age of the farmer is between18 and 60 years, 3) Education of the farmer is at the most SSC pass or below, 4) Permanent resident of the concerned area for at least 3 years, 5) Has at least 3 years of prior experience in farming activities, 6) Maximum land holding limits 33 decimal- 200 decimal, 7) Not an MFI (Micro Finance Institution) member, 8) Willing to take credit from BCUP.

[11] Sub-district (also called upzila) is an administrative unit in Bangladesh. There are total 491 sub-districts in Bangladesh.

We conducted a household level census in all 240 villages to identify eligible households. The census covered a total of 61,322 households, among which 7,628 households fulfilled the program eligibility criteria[12] and were willing to take agricultural credit – 4,228 and 3,400 from the treatment and control areas, respectively. Then, we randomly selected households from the eligible household list for detailed data collection. We adopted a simple random sampling method to select households from each village. 2,164 households from treatment villages and 2,167 households from control villages were selected as sample households – therefore, a total of 4,331 households were surveyed.[13] The baseline survey on various farm inputs and output for rice farmers was conducted in 2012 and a short-term follow up survey was carried out in 2014. Figure 1 outlines the complete experimental study design. Figure 2 provides the spatial overview of treatment and control areas. Households in the treatment eligible units were provided with credit access of up to 120,000 Taka (≈1500 USD). Figure 3 describes the features of the program intervention.

[Figure 1 about here]
[Figure 2 about here]
[Figure 3 about here]

Under random assignment to one of the two groups, the baseline census characteristics should be the same on average across the groups, except for variation due to sampling. Table 2 shows the means of baseline variables by treatment assignment. We test the equality of means by random assignment and Table 2 presents the p-values. We find that none of the 22 differences between the control group and the two treatment groups have a p-value of less than 0.10. We also present the balancing tests by rice variety in Appendix A (Tables A1-A2). This pattern is quite consistent with a successful implementation of random assignment.

[Table 2 about here]

We also checked whether subjects in the credit treatment groups dropped out of the study at rates that differ from dropout rates of subjects in the control group. Substantial differential attrition could result in a biased study attrition if it is related to treatment assignment. We record

[12] Mentioned in footnote 7.
[13] The Survey was successfully conducted on 4,301 households which included 2,155 in treatment areas and 2,146 in control areas. Therefore, the final sample includes 4,301 households.

an attrition rate of around 10 percent in the panel data used in the field experiment, and no significant difference between the attrition rates among the treatment group (11 percent) and control group (9 percent) for rice producing farm households.[14]

[Table 3 about here]

2.3 Data

We use the baseline and endline survey data at farm-household level from the BCUP program. Among the study households, a total of 4,331 households were randomly selected for a quantitative baseline survey (2,155 in treatment areas and 2,146 in control areas) in 2012. A follow-up endline survey was conducted in 2014. In this paper, for simplicity, we focus our analysis only on rice producing farms.[15] The data comprises economic and demographic variables of farm households, as well as the inputs and output of rice production. Our production input variables include land (decimals), labor (days), plough for land preparation (number of times), seed (kilogram), irrigation (hours), fertilizer (kilogram) and pesticide (number of times used).

3. Conceptual Framework: Credit to Output, Change in Technology and Efficiency

Once a farm microenterprise obtains credit access C, output can be affected via various channels. On one hand, C can increase the input use of a credit constraint farm and can also lead to a shift of production frontier. On the other hand, it can improve the output by increasing efficiency. There might also be a synergistic effect of both technological change and efficiency improvement. We represent the general production function as:

$$Y = f(X, C) - u(C) \qquad (1)$$

[14]In Table 3, we also present regression results for attrition status in the follow-up wave on baseline treatment assignment and household covariates. The statistical test exhibits no evidence that treatment assignment is statistically significantly related to household attrition status.

[15]Rice is a major crop for all households in Bangladesh and all small farms produce at least some quantity of rice. Almost all the 13 million farm families of the country grow rice. Rice is cultivated on 75 percent of the total cropland (Ganesh-Kumar, Prasad and Pullabhotla, 2012) and it is the primary source of income and employment of nearly 15 million farm households in Bangladesh (Bangladesh Bureau of Statistics, 2008).

where Y is rice output (in log), X is the vector of inputs including land, labor, machineries, seed, irrigation, fertilizer, pesticide, etc., C is the expanded credit access, and u is production inefficiency. Our primary objective is to examine the effect of C on output, holding the input vector unchanged, i.e.,

$$\frac{\partial Y}{\partial C} = \frac{\partial f}{\partial C} - \frac{\partial u}{\partial C} \qquad (2)$$

where $\frac{\partial f}{\partial C}$ captures the production frontier shift due to credit expansion and $-\frac{\partial u}{\partial C}$ captures the efficiency improvement effect. $\frac{\partial Y}{\partial C}$ can be viewed as productivity effect of C. Efficiency is defined as exp(-$u(C)$) and $u(C)$ is inefficiency. We discuss our identification strategy in the following section.

4. Identification Strategy

We start by estimating the impact of credit expansion to farm households on rice productivity. We use a simple Cobb-Douglas (CD) production technology to represent the relation between inputs and output. To estimate the technology, first we consider using the ordinary least square (OLS) method and discuss the problem of this approach in decomposing the total output effect into technological change effect and efficiency improvement effect. Next, we present the stochastic production frontier approach and explain how we use this model as a tool to disentangle the two effects - frontier shift versus efficiency improvement.

4.1 Effect of Credit Access on Productivity: Overall Effect

To formalize our analysis, let Z_i be an indicator variable taking a value of 1 if the farm household is assigned to the treatment group or eligible for credit services under BCUP program, and 0 otherwise. Therefore, Z_i denotes the expanded credit access C used in equation (1). We rewrite equation (1) as (using the CD production technology):

$$Y_i = \beta_0 + \sum_j \beta_j X_{ji} + \gamma_1 Z_i - u(Z_i) \qquad (3)$$

where i denotes each farm household, Y_i is the outcome variable rice per decimal (in log), Z_i is an indicator for assignment to treatment or control group, X_{ji} is input variable j (in log) of farm i, and $u(Z_i)$ is the inefficiency term.[16] Adding a noise term v_i, we can rewrite (3) as

$$Y_i = \beta_0 + \sum_j \beta_j X_{ji} + \gamma_1 Z_i - u(Z_i) + v_i$$

To explore the consequence of applying OLS in the presence of inefficiency, we further rewrite it as

$$Y_i = \beta_0 + \sum_j \beta_j X_{ji} + [\gamma_1 Z_i - E(u(Z_i))] + v_i \equiv \beta_0 + \sum_j \beta_j X_{ji} + \gamma Z_i + \epsilon_i \quad \text{(3a)}$$

where $\epsilon_i = \{v_i - [u(Z_i) - E(u(Z_i))]\}$ and $\gamma Z_i = \gamma_1 Z_i - E(u(Z_i))$. By construction, ε_i has zero mean so that one can use OLS to estimate equation (3a). Therefore, as shown in (3a), the Z term will have two effects- viz., $[\gamma_1 Z_i - E(u(Z_i))]$. The first term is the direct effect on the technology and the second term captures efficiency effects. If inefficiency is not explicitly modeled, the coefficient of Z_i in (3) will capture the overall mean effect of expanded credit access on rice productivity.[17] In other words, if one does not include inefficiency explicitly and $E(u(Z_i))$ is approximately linear in Z_i, (i.e., $E(u(Z_i)) = \gamma_2 Z_i$ so that $\gamma = \gamma_1 + \gamma_2$) then the coefficient of Z_i will capture both the technology change (frontier shift, γ_1) and efficiency change effect (γ_2). From the estimated coefficient on Z_i in (3a), we cannot disentangle the frontier shift and efficiency improvement effect.

4.2 Effect of Credit Access on Productivity: Separating Frontier Shift Effect from Efficiency Effect

In this sub-section, we use the stochastic frontier approach instead of the earlier

[16]Our input variables include land (decimals), labor (days), plough for land preparation (number of times), seed (kilogram), irrigation (hours), fertilizer (kilogram) and pesticide (number of times).

[17]One might argue that the effect of credit access on the production frontier is operated through inputs- credit enables poor farmers to use pesticides, fertilizer and buy modern seeds in a timely manner: thus, affecting the frontier. However, the interacted relation might be linear for some inputs while for other inputs, it might be nonlinear. For simplicity, we are trying to find the overall effect of credit access, therefore, we add credit access as a separate factor in the production frontier (i.e. $\gamma_1 Z_i$) rather than examining the effect of credit interacted through input.

distribution-free[18] approach, to separate the frontier shift from inefficiency.

We specify our production model as:

$$Y_i = Y_i^* - u(Z_i), \qquad u_i \geq 0 \qquad (4)$$

$$Y_i^* = f(\boldsymbol{X_i}; \boldsymbol{\beta}) + v_i \qquad (5)$$

Equation (5) defines the stochastic production frontier function. For a given level of ***X***, the frontier gives maximum possible level of output (Y_i^*), and it is stochastic because of the presence of v_i. Rearrangement of equation (4) gives, $\exp\,(-\mathrm{u}\,(Z_i)) = \frac{Y_i}{Y_i^*}$ (ratio of actual output to maximum possible output) and the value of $\exp\,(-\mathrm{u}(Z_i)) \times 100$ is the percentage by which actual output falls short of the maximum output. Since $\exp\,(-\mathrm{u}(Z_i)) \approx 1 - \mathrm{u}(Z_i)$, $u(Z_i)$ is referred to as the technical inefficiency of farm household i with a value close to 0 implying full efficiency. The presence of inefficiency gives rise to a composed error term $[v_i - u(Z_i)]$ which is negatively skewed because $u(Z_i)$ is one-sided.[19] We perform simple OLS residual test to check for the skewness of error terms and, therefore, the appropriateness of using the stochastic frontier specification. We also do a sample moment based test following Coelli (1995). Both results confirm the rejection of the null hypothesis of no skewness in the OLS residuals in baseline.

As before, we use a simple CD technology to represent $f(.)$. Additionally, we assume that the inefficiency variable ($u(Z_i)$) follows a half-normal distribution. We parameterize $u(Z_i)$ as a function of the treatment assignment variable (Z_i) and therefore allow the access to credit (Z_i) to affect the expected value of inefficiency. Then, we obtain the maximum likelihood (ML) method to estimate the parameters in $f(.)$ as well as inefficiency in a single step. Specifically, our model is:

$$Y_i = Y_i^* - u_i(Z_i) \qquad u_i \geq 0 \qquad (6)$$

[18]In this approach, estimation results do not impose any distributional assumption on $\mathrm{u}(Z_i)$. However, the major drawback of this approach is that inefficiency effect cannot be separated from noise (Z) if inefficiency is i.i.d. (a function of Z).

[19]For a production-type stochastic frontier model with the composed error $v_i - u(Z_i)$, $u(Z_i) \geq 0$ and $\mathrm{v_i}$ distributed symmetrically around zero, the residuals from the corresponding OLS estimation should skew to the left (i.e., negative skewness) regardless of the distribution function of $u(Z_i)$ in the model estimation after the pretesting. A test of the null hypothesis of no skewness as opposed to the alternative hypothesis can thus be constructed using the OLS residuals. If the estimated skewness has the expected sign, rejection of the null hypothesis provides support for the existence of the one-sided error.

$$Y_i^* = \boldsymbol{X_i \beta} + \gamma_1 Z_i + v_i \quad (7)$$
$$u_i(Z_i) \sim N^+(0, \sigma_u^2(Z_i) \quad (8)$$
$$\sigma_u^2(Z_i) = \exp(\delta_0 + \delta_1 Z_i) \quad (9)$$
$$v_i \sim i.i.d\ N(0, \sigma_v^2) \quad (10)$$

where $\boldsymbol{X}$ is the vector of inputs; β, γ_1, δ_0, δ_1 and σ_v^2 are the parameters to be estimated, γ_1 captures the effect of credit access on frontier shift, while δ_1 captures the effect (not its marginal effect) of credit access on inefficiency. After estimating the model parameters, we obtain the (in)efficiency index and estimate the marginal impact of credit access (Z_i) on expected value of inefficiency u(Z_i), i.e. $\partial E(u(Z_i))/\partial Z_j$ where $E(u(Z_i)) = \sqrt{\frac{2}{\pi}}\sigma_u(Z_i) = \sqrt{2/\pi}$ [.5(exp($\delta_0 + \delta_1 Z_i$))]. Therefore, the marginal effect of Z_i is decomposed into frontier shift (given by the coefficient of Z_i in the production frontier, γ_1) and technical efficiency effect (obtained from -$\partial E(u(Z_i))/\partial Z_i$). The sum of these two gives us the overall effect of Z_i on output, holding all other inputs unchanged. Note that the sum of the two effects does not necessarily equal γ in (3), unless $E(u(Z_i))$ is approximately linear.[20] We report bootstrapped standard errors of the estimates of marginal impact on efficiency.

5. Empirical Results

This section presents our estimates of the impact of treatment assignment or expanded credit access on rice productivity, technological change (frontier shift), and technical efficiency of farm microenterprises. We performed the impact analysis over a 24-month period and present the results in two subsections. Subsection 5.1 first shows the overall impact on productivity using OLS estimation method on equation (3). Then we decompose and analyze sources of the output effect. We find significant impacts of access to microcredit, both economically and statistically, on rice productivity and efficiency. We also examine the impacts by the amount of credit used. Subsection 5.2 examines credit access impact broken down by several demographic and farm

[20]Another reason why the sum of the two effects (from OLS) does not necessarily equal γ estimated from using ML method is that ML uses distributional assumptions while OLS does not.

characteristics variables from the baseline survey and we detect some heterogeneity of impacts within the treatment group.

5.1 Effect of Credit on Productivity, Technical Change, and Efficiency Change

Our baseline rice yield was 18.12 kilogram per decimal land. We estimate the overall effect of being offered access to the credit program on changes in rice productivity 24 months after the intervention, using OLS in equation (3). Table 4 presents the estimates. For microenterprises assigned to credit services, we detect a positive increase of rice yield of around 13.5 percent compared to the control farm households, and the impact is statistically significant at the 95th percentile level. In terms of the average baseline yield of 18.12 kilogram rice per decimal, this implies approximately two kilogram more rice per decimal. In Appendix Table A4, we categorize total rice varieties into modern hybrid and High Yielding variety (HYV). We find positive and statistically significant treatment effect for both HYV and modern Hybrid rice yield (13 and 12 percent, respectively). Overall, we find a positive effects of expanded credit access on productivity of rice farms.

[Table 4 about here]

Table 5 presents the results from the stochastic frontier model, which decomposes the impact of credit expansion to frontier shift and efficiency change. Before disentangling the two effects, we estimate the frontier model (equations 6-10) using baseline data and find a mean inefficiency of around 17 percent. It implies that, before expanding the credit access, on average, farmers lose 17 percent of the potential rice output due to inefficiency. Columns (1) and (2) capture the output effect of credit access that comes from the frontier shift. We find a positive and statistically significant effect of credit access on the frontier shift. After estimating the model parameters, we obtain the efficiency index—figure 4 shows the density plot of inefficiency index—and then examine the impact of credit access on inefficiency. Columns (3) and (4) show the results. We find that small-scale farms with access to subsidized credit are on average 3 percent more efficient compared to farm households with no credit access. In terms of the average baseline rice yield of 18.12 kilograms per decimal, this implies that credit access enabled the treatment households to produce approximately a half kilogram more rice (per decimal land) than control farms due to efficiency improvement. This positive effect of credit on efficiency is even more pronounced among producers of modern Hybrid rice varieties—they exhibit efficiency gains, due to credit access, on average from 9 percent (appendix table A5). One explanation for this difference in magnitude of impacts across rice varieties might be that modern varieties offer more potential yield but more risk, which requires more timely use of complementary inputs.

[Table 5 about here]

To explore the reason of the positive effect of credit access on frontier shift, we examined the effect of credit access on adoption of modern Hybrid rice and important complementary inputs of modern rice production (pesticide, fertilizer, etc.). Table A6 shows that credit access has a significant positive effect on adoption of modern rice varieties and use of pesticides, which is an important input for Hybrid rice. Regarding the increase in efficiency, we note that the increase is likely driven by the increase of the demand for inputs (cash, pesticide, fertilizer, etc.), which exhibit increasing complementarity in the production process.[21]

We also examine the impacts of the Amount of Credit Taken to explore the marginal returns to incremental changes in the amount of credit taken as an input, while the amounts of all other factors of production stay constant. In Figures 4, we present our estimates of rice yield and efficiency, but disaggregate the estimates (in 10 groups) by amount of credit taken. These sub-analyses show how the distribution of impacts varies by credit amount taken. Once the confidence intervals are considered, we find that yield impacts are uniform across credit amount taken, and we fail to detect evidence that the changes in the amount of credit taken impacts the microenterprise yield (Figure 5 Panel A). In other words, in the range of the credit mounts taken, we see stable marginal productivity impacts. We also find no evidence of different technical efficiency among microenterprises by the amount of credit taken (Figure 5 panel B).

[Figure 5 Panel A and Panel B about here]

[21]It is also tempting to consider that unmeasured or poorly measured inputs will show up as efficiency. However, because of the experimental design, this potential measurement bias is likely to be the same in the treatment and control groups and thus will cancel out.

5.2 Heterogeneous Effect of Credit Access

In this section, we explore any differential impacts of credit access along several demographic and farm characteristics. In particular, we focus on gender and education of the household head, microenterprise size of farming land, and tenancy arrangements. We augment specifications (3) and (9) to estimate the heterogeneous impact (for the output and efficiency outcomes, respectively). To capture the heterogonous effects on rice productivity, we estimate:

$$Y_i = \gamma_0 + \gamma_1 Z_i + \sum_{k=1}^{l} \beta_k X_{ki} + \sum_{j=1}^{m} \theta_j I_{ji} + \sum_{j=1}^{m} \delta_j I_{ji} * Z_i + v_i \qquad (12)$$

where Y_i is rice per decimal (in log), X_{ki} are the log of production inputs (land, labor etc.), I_{ij} is a vector of economic and demographic variables j for farm household i. We interact I_{ij} with household's treatment assignment status (Z_i).

Since Z is a dummy variable from (12), one can compute the marginal effect of Z on technology as: $E(Y|I, Z=1) - E(Y|I, Z=0) = [\gamma_0 + \gamma_1 + \sum_{k=1}^{l} \beta_k X_{ki} + \sum_{j=1}^{m} \theta_j I_{ji} + \sum_{j=1}^{m} \delta_j I_{ji}] - [\gamma_0 + \sum_{k=1}^{l} \beta_k X_{ki} + \sum_{j=1}^{m} \theta_j I_{ji}] = \gamma_1 + \sum_{j=1}^{m} \delta_j I_{ji}$. The coefficient of the interaction term, δ_j in (12) captures the heterogeneous effect of expanded credit access within the treatment group. Note that this depends on the values of I_j. Our I_j variables are dummy variables indicating demographic and farm characteristics. The means of I_j variables are reported in appendix Table A7. For examining the difference in inefficiency between the heterogeneous and homogeneous models, one should be looking at the difference between the mean inefficiency, i.e., $E[u(M_i)|Z=1] - E[u(M_i)|Z=0]$. Within the treatment group, to capture the heterogonous effects of credit access on efficiency, we re-estimate our frontier model (equation 6-10) with equation (9) modified as follows:

$$\sigma_u^2(M_i) = exp(\delta_0 + \delta_1 Z_i + \sum_{j=1}^{m} \rho_j I_{ji} + \sum_{j=1}^{m} \eta_j I_{ji} * Z_i) \quad (13)$$

where $M_i = \delta_0 + \delta_1 Z_i + \sum_{j=1}^{m} \rho_j I_{ji} + \sum_{j=1}^{m} \eta_j I_{ji} * Z_i$. Marginal effects of Z on mean inefficiency can be calculated from the formula: $E[u(M_i)|Z=1] - E[u(M_i)|Z=0] = \sqrt{2/\pi} *$ $.5\,[\exp\big(\delta_0 + \delta_1 + \sum_{j=1}^{m} \rho_j I_{ji} + \sum_{j=1}^{m} \eta_j I_{ji}\big) - \exp(\delta_0 + \sum_{j=1}^{m} \rho_j I_{ji})]$. Clearly, the marginal effects depend on the *I* variables.

Table 6 and 7 presents our estimates of the heterogeneous effect of credit access.

[Table 6 about here]

[Table 7 about here]

Columns 1-4 of table 6 and 7 examine the differential effects of credit access by sex and education of household head. Several studies point to gender differences in take-up of credit, fertilizers, capital use, and technological adoption (Udry 1996; Deininger and Olinto 2000; Tiruneh et al. 2001). Belanger and Li (2009) find that women have less control over assets, credit access and influence in decision-making regarding extension services and inputs—a difference that results in lower microenterprise productivity. We detect that female-headed microenterprises that are provided access to credit, on average, generate approximately 7 percent more in output yield than male-led microenterprises assigned to credit access (Table 6). In terms of efficiency change (Table 7), we find that female-led microenterprises with access to credit are 1.5 percent more efficient than male-led enterprises with credit access. However, the results are not statistically significant. Our findings for education of head are similar and not statistically significant.

Next, we consider the baseline farm size. Previous empirical studies document an inverse relationship between farm size and output per hectare in agriculture (Cornia 1985; Fan and Chan-Kang 2003). Some studies posit that this relationship is due to measurement error in measuring soil quality and land size (Fan and Chan-Kang 2003), and other studies show that this inverse relationship disappears at high levels of technology adoption (Cornia 1985). We examine the relationship between credit access and yield or efficiency by microenterprise land size, and find a negative relationship which suggests that, within the treatment group (i.e., enterprises assigned to credit access), the average effect of the treatment assignment is higher for farms cultivating in larger land size. However, we did not find a statistically significant difference in the estimates of the heterogeneous effect between large and small farms.

Finally, we examine for differential impacts by land ownership and tenancy status. For both technological change and efficiency outcomes, we detect positive and significant effects of being a pure tenant and mixed-tenant farm rather than farm enterprises who only cultivate their own land. Marginal effect of credit access on rice productivity is around 14 percent for pure tenant farm households (cultivate only other people's land).[22] Columns 7 and 8 of Table 6 show that, within the treatment group, the effect of credit on productivity is approximately 3.5 percent higher for tenant farm households than farmers who cultivate their own land. In case of efficiency change, the impact for pure tenant farms is on average 5 percent higher than owner farms (column 8 of Table 7). Examining the farming practices, we find that adoption of hybrid rice is significantly higher among tenant farm enterprises with credit access than farms with credit access and cultivating their own land. This finding suggests that resource-poor farm enterprises gain more from credit access compared to less resource-poor farms.

6. Discussion and Conclusions

Access to subsidized credit can aid small farm households in increasing their productivity via moving to a better technology and or via efficiency improvements. In this paper, we use data from a field experiment that relies on random assignment of credit access in Bangladesh and we estimate the impact of credit expansion on productivity. In particular, we examine whether the productivity increase is due to changes in technology or due to an efficiency improvement. First, using an ordinary least squares estimation, we estimate the overall average effect of being offered access to the credit program on output yield. Then, we examine the source of the output effect. We use the stochastic production frontier model as a tool to disentangle the two effects - technological change versus efficiency change.

We find that relaxing the credit constraint has sizable positive impacts on output yield of rice, via both technological change and technical efficiency of farm microenterprises. Among farm households assigned to credit, we find a positive impact of credit access on total rice productivity, statistically significant at the 1 percent level. On average, for microenterprises

[22] From column 7 and 8, we have γ_1= 13.06, δ_j=3.45. Mean of pure tenant farm households is 0.32 which implies that 32 percent farm households of the sample are farms who cultivate only other people's land. therefore, the effect of treatment assignment is [13.06+(3.45*0.32)] =14.16.

assigned to credit services, we find a productivity increase of 13.5 percent. After decomposing the overall output effect into frontier shift and efficiency change effect, we find that most of the effect, around 10.5 percent, is driven from a frontier shift – i.e., adoption of modern varieties and use of complementary inputs. In terms of technical efficiency, we find that small-scale farms with access to subsidized credit, on average, experience a 3 percent efficiency gain compared to households with no credit access. This positive effect is even more pronounced among producers of modern hybrid rice varieties with credit access– they exhibit efficiency gains, on average around 9 percent. We do not detect evidence of more sizable impacts on yield and efficiency among microenterprises that take up higher amounts of credit.

A simple story can explain the positive impacts that we observe. When microenterprises have no formal recourse to insurance markets or well-functioning credit markets, they are highly risk-averse in their farming and crop adoption practices. Provision of credit provides a liquidity buffer against potential future risks. Even more importantly, it enables such household microenterprises to consumption smooth and to take on more risk by adopting riskier crop varieties. We find that households with credit access, on average, procure more pesticides which are especially essential in the production process and for the yield of riskier crops. In addition, we detect an increase in the adoption of riskier crops (hybrid and HYV) and larger productivity increases among the adopters of these crop types. One explanation for this difference in the magnitude of impacts across rice varieties is that modern varieties offer more potential yield but also more risk, as they require more complementary inputs and time-sensitive use of various inputs.

The results presented have important implications for policy especially as it pertains to resource-constrained contexts. We add to the array of potential benefits of credit programs targeting subsistence farm enterprises and our results can inform considerations regarding more informed targeting of such programs.

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Figure 1: Design of Field Experiment and Treatment Assignment

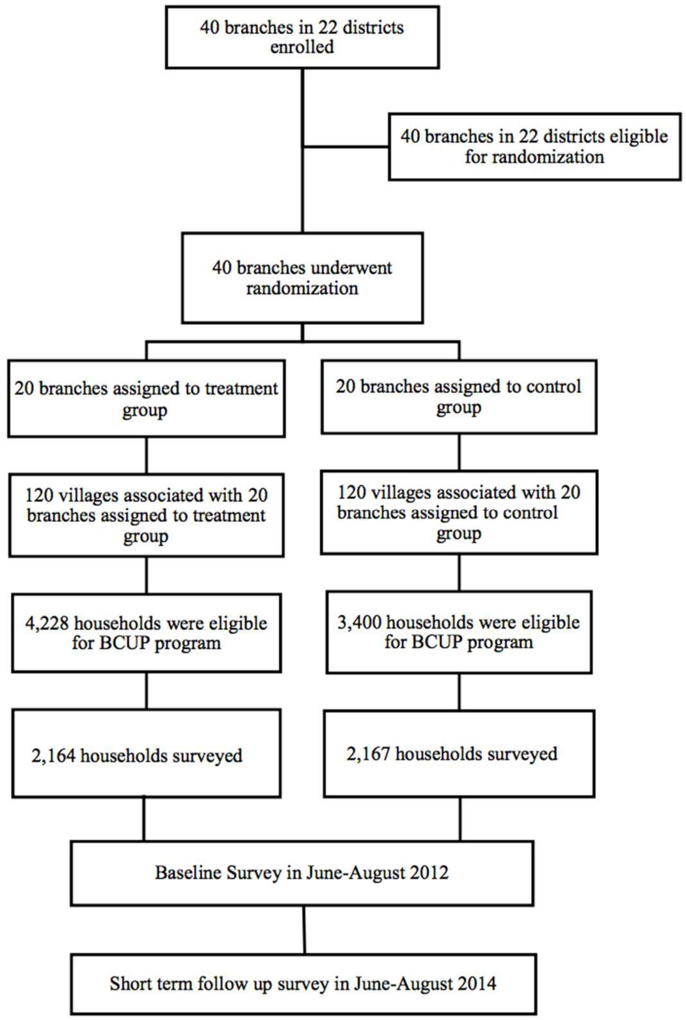


Figure 2: Map of Treatment and Control Areas

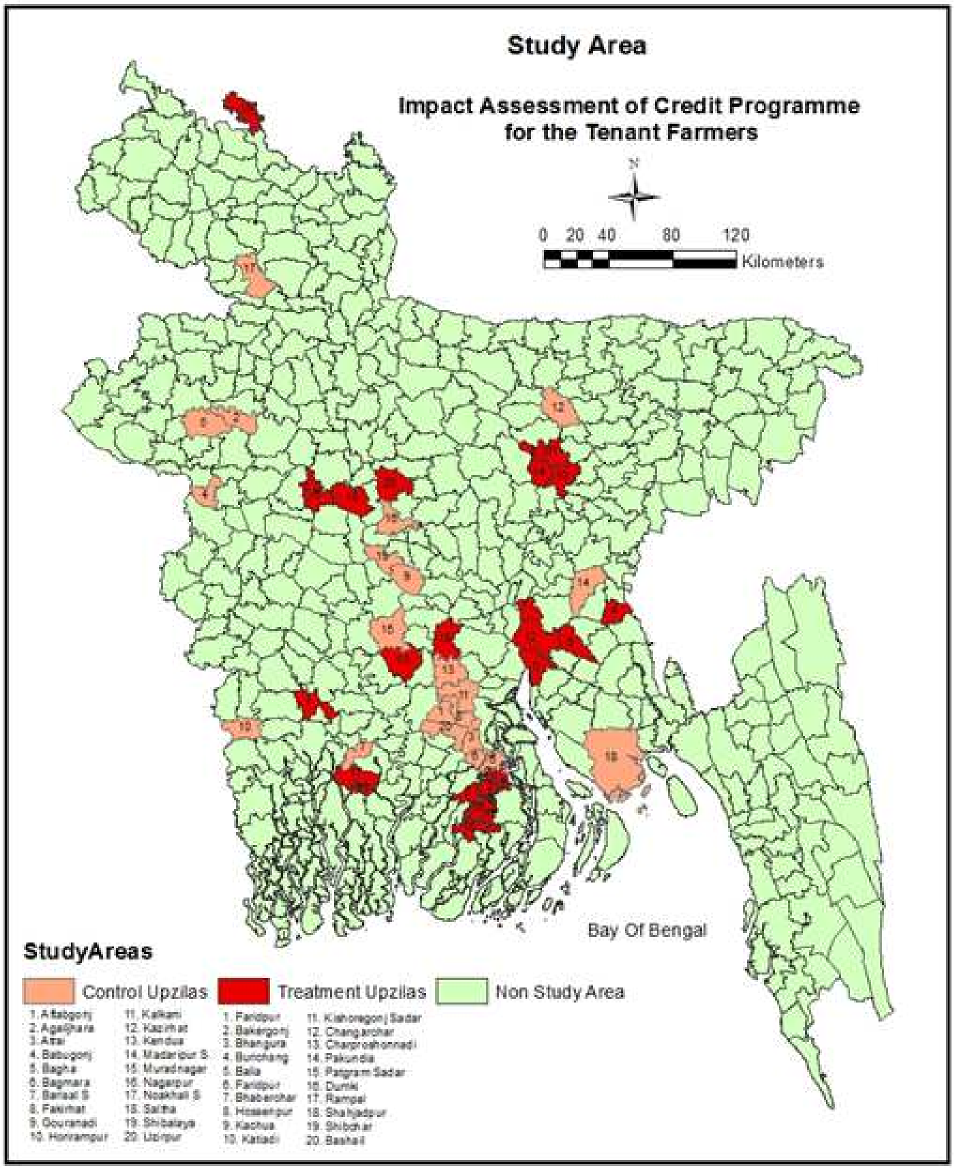


Figure 3: BCUP Program Features

Treatment Groups	Program Features
Treatment Group	Credit Limit: 5,000 taka-120,000 taka* Duration: 6-10 months Grace Period: 1 month Installment: monthly Interest Rate: 10percent (flat)**
Control Group	None

Note: *79 taka=$1; **In the flat rate method, interest is charged on the full original loan amount throughout the loan term whereas in the declining balance method, interest calculation is based on the outstanding loan balance – the balance of money that remains in the borrower's hands as the loan is repaid during the loan term. BCUP provided loans to farmers at subsided interest rate of 10 per cent per year (flat rate). The effective rate of interest is about 15 to 20 per cent on declining balance method, depending on the mode of repayment of the principal and interest due. As per the rules of the Microcredit Regulatory (MRA) of the Bangladesh Bank, NGOs can charge up to a maximum of 27 per cent rate of interest on declining balance for their microfinance operations.

Figure 4: Density Plot of Inefficiency Index

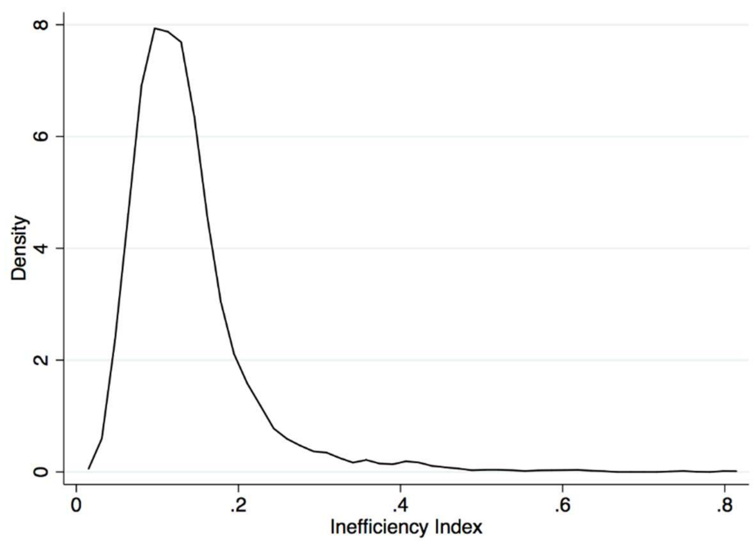
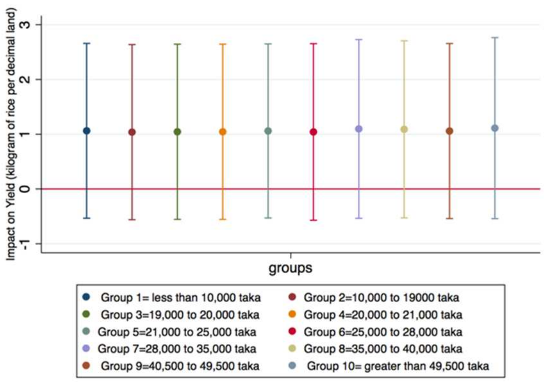


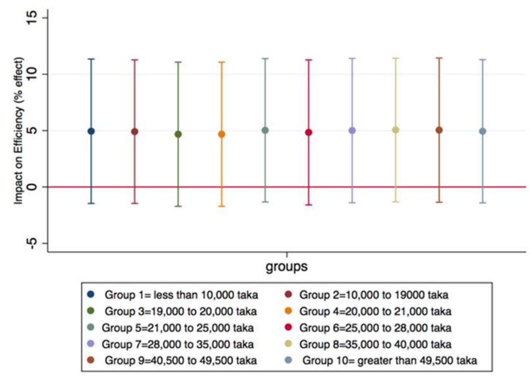
Figure 5: Impact of Credit by the Amount of Credit Taken

Panel A: Impact on Rice Yield



Note: 79 taka= $1

Panel B: Impact on Efficiency (percentage effect)



Note: 79 taka= $1

Table 1: Descriptive Statistics and Baseline Characteristics

Variables	Observations	Mean	Std. Dev.
Household Composition			
Female Headed household	3755	0.07	0.25
Age of household head (in years)	3755	44.94	11.65
Household size (number of members)	3755	4.88	1.78
Number of children (<16 years)	3755	3.13	1.35
Number of adult members (>16 years)	3755	1.75	1.25
Household head with no education	3755	0.44	0.5
Amount of Land and Credit			
Own cultivated land (in decimal†)	3755	39.24	51.1
Rented in land (in decimal)	3755	50.86	69.52
Rented out land (in decimal)	3755	7.71	26.89
Total cultivated land (in decimal)	3755	90.11	78.97
Formal and informal loan amount (in taka)	3755	5042.25	27449.67
Output and Input for Rice Production (yearly)			
Rice yield (total rice/total land) ††	3292	18.12	4.27
High Yielding Variety rice yield (HYV rice/ land in HYV rice)	3218	18.02	4.17
Hybrid rice yield (HB rice/ land in HB rice)	213	20.18	7.18
Traditional Variety rice yield (TV rice/ land in TV rice)	1307	9.83	3.44
Total land (in decimal)	3755	87.41	86.32
Total labor days (own as well as hired labor)	3755	40.65	40.26
Total plough (number of times)	3755	5.79	6.05
Total seed (kilogram)	3755	15.14	18.50
Total irrigation (hours)	3755	39.98	50.61
Total fertilizer (kilogram)	3755	147.55	151.49
Total pesticide (number of times)	3755	3.75	5.47

Notes: †A **decimal** (also spelled **decimel**) is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m²); 247 decimal=1 hectare. †† Rice in measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal.

Unit of observation: Household. Sample includes all rice producing farm households surveyed at baseline (2012). **Informal lenders** include moneylenders, loans from friends/family, and buying goods/services on credit from sellers. **Own land** refers to the cultivated crop land owned by the farm household. **Rented in** land means the land rented in from others for crop cultivation. **Rented out** land means the land rented to other farmers for crop cultivation.

High Yielding Varieties (HYV) rice seeds are land substituting, water economizing, more labor using, and employment generating innovation. HYVs significantly outperform traditional varieties in the presence of an efficient management of irrigation, pesticides, and fertilizers. However, in the absence of these inputs, traditional varieties may outperform HYVs.

Hybrid rice is any genealogy of rice produced by crossbreeding different kinds of rice. It typically displays heterosis or hybrid vigor such that when it is grown under the same conditions as comparable high yielding inbred rice varieties it can produce up to 30percent more rice. However, the heterosis effect disappears after the first (F1) generation, so the farmers cannot save seeds produced from a hybrid crop and need to purchase new F1 seeds every season to get the heterosis effect each time.

Table 2: Baseline Characteristics and Balancing

	Means by treatment		
	Control (1)	Treatment (2)	P-value (3)
Variables			
Household Composition			
Female headed household	0.05	0.08	0.10
	(0.01)	(0.01)	
Age of household head (in years)	44.57	45.32	0.32
	(0.28)	(0.26)	
Household size (number of members)	4.79	4.97	0.34
	(0.04)	(0.04)	
Number of adult members (>16 years)	3.13	3.13	0.99
	(0.03)	(0.03)	
Number of children (<16 years)	1.66	1.84	0.17
	(0.03)	(0.03)	
Household head with no education	0.45	0.42	0.6
	(0.01)	(0.01)	
Amount of Land and Credit			
Own cultivated land (in decimal†)	39.78	38.72	0.74
	(1.22)	(1.14)	
Rented in land (in decimal)	52.19	49.57	0.67
	(1.69)	(1.52)	
Rented out land (in decimal)	7.78	7.64	0.9
	(0.62)	(0.62)	
Total cultivated land (in decimal)	91.97	88.29	0.63
	(1.91)	(1.73)	
Formal and informal loan amount (in taka)	5,298.85	4,790.13	0.73
	(25128.52)	(29557.87)	
Access to Other Programs and Services			
Member of other BRAC loan programs (dummy)	0.02	0.01	0.76
	(0.00)	(0.00)	
Received other services besides credit (dummy)	0.01	0.00	0.51
	(0.00)	(0.00)	

Notes: †A **decimal** (also spelled **decimel**) is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m²); 247 decimals=1 hectares. ††**kilogram** (1 kilogram=2.204 pounds). Column 3 shows the P value of mean difference column 3=column1 - column2.

Unit of observation: Household. Sample includes all rice producing farm households surveyed at baseline (2012). Standard errors (in parentheses) are clustered at Branch level. Informal lenders include moneylenders, loans from friends/family, and buying goods/services on credit from sellers. **Own land** refers to the cultivated crop land owned by the farm household. **Rented in** land means the land rented in from others for crop cultivation. **Rented out** land means the land rented to other farmers for crop cultivation.

Table 2 (contd.): Baseline Characteristics and Balancing

	Means by treatment		
	Control (1)	Treatment (2)	P-value (3)
Variables			
Output and Input for Rice Production (yearly)			
Rice yield (total rice/total land) ††	18.79	17.40	0.24
	(0.12)	(0.10)	
High Yielding Variety rice yield (HYV rice/ land in HYV rice)	18.66	17.33	0.28
	(0.11)	(0.09)	
Hybrid rice yield (HB rice/ land in HB rice)	20.39	19.94	0.79
	(0.73)	(0.65)	
Traditional Variety rice yield (TV rice/ land in TV rice)	9.45	10.23	0.98
	(0.13)	(0.14)	
Total Land (in decimal)	83.19	91.56	0.58
	(1.85)	(2.12)	
Total Labor (days)	38.22	43.05	0.47
	(0.84)	(1.00)	
Total Plough (number of times)	5.82	5.78	0.96
	(0.14)	(0.14)	
Total Seed (kilogram)	15.80	14.49	0.64
	(0.46)	(0.39)	
Total Irrigation (hours)	40.29	39.68	0.95
	(1.19)	(1.15)	
Total Fertilizer (kilogram)	143.63	151.41	0.74
	(3.42)	(3.57)	
Total Pesticide (number of times)	4.17	3.34	0.28
	(0.14)	(0.11)	
Joint significance test		F (16, 39) =	1.54
		Prob > F =	0.13

Notes: †† Rice in measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal (247 decimals=1 hectares.) Column 3 shows the P value of mean difference column 3=column1- column2.

Unit of observation: Household. Sample includes all rice producing farm households surveyed at baseline (2012). Standard errors (in parentheses) are clustered at Branch level. **High Yielding Varieties (HYV)** rice seeds are land substituting, water economizing, more labor using, and employment generating innovation. HYVs significantly outperform traditional varieties in the presence of an efficient management of irrigation, pesticides, and fertilizers. However, in the absence of these inputs, traditional varieties may outperform HYVs.

Hybrid rice is any genealogy of rice produced by crossbreeding different kinds of rice. It typically displays heterosis or hybrid vigor such that when it is grown under the same conditions as comparable high yielding inbred rice varieties it can produce up to 30percent more rice. However, the heterosis effect disappears after the first (F1) generation, so the farmers cannot save seeds produced from a hybrid crop and need to purchase new F1 seeds every season to get the heterosis effect each time.

Table 4: Impact of Access to Credit on Productivity of Rice

Variables	Effect of Credit on Productivity	Effect of Credit on Productivity	Observations
	(1)	(2)	
Rice yield (Total rice/Total land) †	13.54***	13.80***	2,267
	[3.07]	[3.03]	
Average rice yield at baseline (Total rice/Total land)	18.12		
Control for Baseline covariates	No	Yes	

Notes: *** p<0.01, ** p<0.05, * p<0.1. †Rice is measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal (also spelled **decimel**) which is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m^2); 247 decimals=1 hectares. Column (1) and (2) shows the intent to treat (ITT) effect of the treatment on outcome of interest. Sample includes only rice producing farm households. Standard errors (in parentheses) are clustered at Branch level.

Table 5: Impact of Access to Credit on Frontier Shift and Efficiency of Rice Production (percentage effect)

Variables	Rice Yield (Total Rice/Total Land)			
	Frontier Shift	Frontier Shift	Inefficiency	Inefficiency
	(1)	(2)	(3)	(4)
Credit access (1=assigned in treatment group)	10.67***	10.79***	-2.97*	-3.18**
	(1.15)	(1.11)	(1.57)	(1.42)
Mean Baseline Inefficiency in Rice Production	17.15 where does it come from?			
Baseline Covariates	no	yes	no	yes
Observations	2,267	2,267	2,267	2,267

Notes: Unit of observation is household. Sample includes rice producing farm households. Rice in measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal which is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m2); 247 decimals=1 hectares. Standard error in parenthesis and are clustered at branch level

Table 6: Heterogeneous Impact of Access to Credit on Rice Production

Variables	Dependent Variable: Rice Yield (kilogram of rice per decimal of land)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Credit access (1=assigned in treatment group)	13.31***	13.40***	13.31***	13.45***	14.27***	14.36***	12.96***	13.06***
	[3.04]	[3.09]	[3.23]	[3.20]	[3.04]	[3.00]	[3.01]	[2.99]
Female headed household (dummy)	-6.28	-6.42						
	[4.81]	[4.75]						
Access to credit*Female headed household	6.69	7.13						
	[4.87]	[4.82]						
Head with no education (dummy)			1.23	1.21				
			[1.30]	[1.41]				
Access to credit*Head with no education			0.47	0.45				
			[1.30]	[0.62]				
Small farm size (1=cultivated land<50 decimal)					1.73	1.65		
					[1.58]	[1.55]		
Access to credit*Small farm size (1=cultivated land<50 decimal)					-2.82	-0.27		
					[1.87]	[1.88]		
Control for Baseline Covariates	no	yes	no	yes	no	yes	no	yes
Mean Baseline Rice Yield (Total rice/Total land)	18.12							
Observations	2,267	2,267	2,267	2,267	2,267	2,267	2,267	2,267

Notes: *** p<0.01, ** p<0.05, * p<0.1. Sample includes all rice producing farm households. Rice is measured in kilogram. †Rice is measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal (also spelled **decimel**) which is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m²); 247 decimals=1 hectares. Results show the percentage effect of access to credit on rice production efficiency by different farm household characteristics. Small farm size takes a value 1 if total cultivated land by farm household is less than 50 decimals. Familiarity with agriculture extension service provider implies that farmers are acquainted with the persons/institution from whom they can seek information or advice on crop selection, crop rotation, modern cropping technology, appropriate use of fertilizer, pesticide etc. Standard errors (in parentheses) are clustered at Branch level.

Table 6 (contd.): Heterogeneous Impact of Access to Credit on Rice Production

Variables	Dependent Variable: Rice Yield (kilogram of rice per decimal of land)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pure tenant farm households (1= no own land rice cultivation)							-2.10*	-1.53
							[1.13]	[1.40]
Access to credit*Pure tenant farm households (1= no own land rice cultivation)							3.50**	3.45**
							[1.54]	[1.45]
Mixed tenant farms (1=cultivate own land as well as others land)							0.45	0.58
							[1.18]	[1.43]
Access to credit*Mixed tenant farms (1=cultivate own land as well as others land)							1.79	1.74
							[1.55]	[1.56]
Control for Baseline Covariates	no	yes	no	yes	no	yes	no	yes
Mean Baseline Rice Yield (Total rice/Total land)	18.12							
Observations	2,267	2,267	2,267	2,267	2,267	2,267	2,267	2,267

Notes: *** p<0.01, ** p<0.05, * p<0.1. Sample includes all rice producing farm households. Rice is measured in kilogram. †Rice is measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal (also spelled **decimel**) which is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m^2); 247 decimals=1 hectares. Results show the percentage effect of access to credit on rice production efficiency by different farm household characteristics. Pure owner farm households only cultivated their own land. Pure tenant farm households have no rice cultivation in own land- they chose either share cropping or rent or both. Standard errors (in parentheses) are clustered at Branch level.

Table 7: Heterogeneous Impact of Access to Credit on Efficiency of Rice Production (percentage effect)

Variables	Dependent Variable: Inefficiency in Total Rice Yield							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Credit access (1=assigned in treatment group)	-2.41	-2.41*	-2.7*	-2.7*	-4.03**	-4.03**	-2.38	-2.68*
	(1.50)	(1.39)	(1.56)	(1.55)	(1.55)	(1.44)	(1.47)	(1.54)
Female headed household (dummy)	5.85**	0.99						
	(2.61)	(2.72)						
Access to credit*Female headed household	-8.44**	-1.49						
	(3.08)	(3.19)						
Head with no education (dummy)			-1.23	-1.30				
			(1.03)	(1.03)				
Access to credit*Head with no education			-2.04	-1.69				
			(1.5)	(7.24)				
Small farm size (1=cultivated land<50 decimal)					-0.07	-0.44		
					(1.25)	(1.22)		
Access to credit*Small farm size (1=cultivated land<50 decimal)					3.10	2.98		
					(1.87)	(1.80)		
Control for Baseline Covariates	no	yes	no	yes	no	yes	no	yes
Mean Baseline Inefficiency in Rice Production	17.15							
Observations	2,267	2,267	2,267	2,267	2,267	2,267	2,267	2,267

Notes: Sample includes all rice producing farm households. Rice is measured in kilogram. †Rice is measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal (also spelled **decimel**) which is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m2); 247 decimals=1 hectares. Results show the percentage effect of access to credit on rice production efficiency by different farm household characteristics. Small farm size takes a value 1 if total cultivated land by farm household is less than 50 decimals. Standard errors (in parentheses) are clustered at Branch level.

Table 7 (contd.): Heterogeneous Impact of Access to Credit on Efficiency of Rice Production (percentage effect)

Variables	Dependent Variable: Inefficiency in Total Rice Yield							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pure tenant farm households (1= no own land rice cultivation)							2.41**	1.15
							(1.11)	(1.11)
Access to credit*Pure tenant farm households (1= no own land rice cultivation)							-5.05**	-4.77***
							(1.83)	(1.54)
Mixed tenant farms (1=cultivate own land as well as others land)							0.34	-1.54
							(1.32)	(1.32)
Access to credit*Mixed tenant farms (1=cultivate own land as well as others land)							-6.20**	-2.42**
							(2.19)	(0.76)
Control for Baseline Covariates	no	yes	no	yes	no	yes	no	yes
Mean Baseline Inefficiency in Rice Production	17.15							
Observations	2,267	2,267	2,267	2,267	2,267	2,267	2,267	2,267

Notes: Sample includes all rice producing farm households. Rice is measured in kilogram. Rice is measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal (also spelled decimel) which is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m2); 247 decimals=1 hectares. Results show the percentage effect of access to credit on rice production efficiency by different farm household characteristics. Pure tenant farm households have no rice cultivation in own land- they chose either share cropping or rent or both. Mixed tenants cultivate own as well as others land. Pure and Mixed tenants are compared to the base category of Pure owner farm households who only cultivated their own land. Standard errors (in parentheses) are clustered at Branch level.

Appendix A

Table A1: Baseline Characteristics and Balancing for HYV Rice Producing Households

	Means by treatment		
	Control (1)	Treatment (2)	P-value (3)
Variables			
Household Composition			
Female headed household	0.05	0.09	0.02
	(0.01)	(0.01)	
Age of household head (in years)	44.58	44.99	0.59
	(0.29)	(0.29)	
Household size (number of members)	4.83	4.93	0.6
	(0.04)	(0.05)	
Number of adult members (>16 years)	3.15	3.09	0.55
	(0.03)	(0.04)	
Number of child (<16 years)	1.68	1.84	0.22
	(0.03)	(0.03)	
Household head with no education	0.45	0.46	0.87
	(0.01)	(0.01)	
Amount of Land and Credit			
Own cultivated land (in decimal†)	40.96	37.8	0.35
	(1.31)	(1.27)	
Rented in land (in decimal)	50.04	46.82	0.51
	(1.71)	(1.40)	
Rented out land (in decimal)	8.40	7.97	0.71
	(0.69)	(0.70)	
Total cultivated land (in decimal)	91.00	84.62	0.37
	(2.00)	(1.64)	
Formal and informal loan amount (in taka)	5084.18	5304.47	0.89
	(591.44)	(810.23)	

Notes: †A **decimal** (also spelled **decimel**) is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m²); 247 decimals=1 hectares. ††**kilogram** (1 kilogram=2.204 pounds). Column 3 shows the P value of mean difference column 3=column1- column2.
Unit of observation: Household. Sample includes all rice producing farm households surveyed at baseline (2012). Standard errors (in parentheses) are clustered at Branch level. Informal lenders include moneylenders, loans from friends/family, and buying goods/services on credit from sellers. **Own land** refers to the cultivated crop land owned by the farm household. **Rented in** land means the land rented in from others for crop cultivation. **Rented out** land means the land rented to other farmers for crop cultivation.

Table A1 (contd.): Baseline Characteristics and Balancing for HYV Rice Producing Households

	Means by treatment		
	Control (1)	Treatment (2)	P-value (3)
Variables			
Output and Input for Rice Production (yearly)			
Rice yield (total rice/total land) ††	17.52	16.63	0.21
	(0.11)	(0.09)	
High Yielding Variety rice yield (HYV rice/ land in HYV rice)	18.66	17.33	0.07
	(0.11)	(0.09)	
Hybrid rice yield (HB rice/ land in HB rice)	19.09	21.73	0.17
	(0.9)	(0.66)	
Traditional Variety rice yield (TV rice/ land in TV rice)	9.45	9.96	0.53
	(0.16)	(0.20)	
Total Land (in decimal)	115.38	123.28	0.55
	(2.58)	(2.50)	
Total Labor (days)	47.69	55.44	0.07
	(1.04)	(1.15)	
Total Plough (number of times)	7.26	7.47	0.77
	(0.17)	(0.16)	
Total Seed (kilogram)	20.82	19.34	0.57
	(0.56)	(0.45)	
Total Irrigation (hours)	47.92	47.45	0.96
	(1.35)	(1.30)	
Total Fertilizer (kilogram)	174.78	189.24	0.36
	(4.1)	(3.97)	
Total Pesticide (number of times)	4.97	4.14	0.27
	(0.16)	(0.13)	

Notes: †† Rice in measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal (247 decimals=1 hectares.) Column 3 shows the P value of mean difference column 3=column1 - column2.

Unit of observation: Household. Sample includes all rice producing farm households surveyed at baseline (2012). Standard errors (in parentheses) are clustered at Branch level. **High Yielding Varieties (HYV)** rice seeds are land substituting, water economizing, more labor using, and employment generating innovation. HYVs significantly outperform traditional varieties in the presence of an efficient management of irrigation, pesticides, and fertilizers. However, in the absence of these inputs, traditional varieties may outperform HYVs.

Hybrid rice is any genealogy of rice produced by crossbreeding different kinds of rice. It typically displays heterosis or hybrid vigor such that when it is grown under the same conditions as comparable high yielding inbred rice varieties it can produce up to 30percent more rice. However, the heterosis effect disappears after the first (F1) generation, so the farmers cannot save seeds produced from a hybrid crop and need to purchase new F1 seeds every season to get the heterosis effect each time.

Table A2: Baseline Characteristics and Balancing for Hybrid Rice Producing Households

	Means by treatment		
	Control (1)	Treatment (2)	P-value (3)
Variables			
Household Composition			
Female headed household	0.03	0.02	0.76
	(0.02)	(0.01)	
Age of household head (in years)	46.03	44.35	0.25
	(1.06)	(1.11)	
Household size (number of members)	4.72	4.69	0.93
	(0.17)	(0.16)	
Number of adult members (>16 years)	3.33	3.07	0.12
	(0.13)	(0.13)	
Number of child (<16 years)	1.39	1.62	0.33
	(0.10)	(0.12)	
Household head with no education	0.41	0.27	0.11
	(0.05)	(0.04)	
Amount of Land and Credit			
Own cultivated land (in decimal[†])	50.54	55.24	0.59
	(5.10)	(6.51)	
Rented in land (in decimal)	62.75	66.50	0.81
	(7.76)	(10.34)	
Rented out land (in decimal)	2.56	7.49	0.10
	(0.97)	(2.79)	
Total cultivated land (in decimal)	113.29	121.75	0.58
	(8.07)	(11.33)	
Formal and informal loan amount (in taka)	4669.64	3930.69	0.80
	(1363.97)	(1760.58)	

Notes: [†]A **decimal** (also spelled **decimel**) is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m²); 247 decimals=1 hectares. [††]**kilogram** (1 kilogram=2.204 pounds). Column 3 shows the P value of mean difference column 3=column1- column2.
Unit of observation: Household. Sample includes all rice producing farm households surveyed at baseline (2012). Standard errors (in parentheses) are clustered at Branch level. Informal lenders include moneylenders, loans from friends/family, and buying goods/services on credit from sellers. **Own land** refers to the cultivated crop land owned by the farm household. **Rented in** land means the land rented in from others for crop cultivation. **Rented out** land means the land rented to other farmers for crop cultivation.

Table A2 (contd.): Baseline Characteristics and Balancing for Hybrid Rice Producing Households

	Means by treatment		
	Control (1)	Treatment (2)	P-value (3)
Variables			
Output and Input for Rice Production (yearly)			
Rice yield (total rice/total land) ††	18.51	16.89	0.38
	(0.57)	(0.48)	
High Yielding Variety rice yield (HYV rice/ land in HYV rice)	17.66	15.48	0.18
	(0.63)	(0.47)	
Hybrid rice yield (HB rice/ land in HB rice)	20.39	19.94	0.87
	(0.73)	(0.65)	
Traditional Variety rice yield (TV rice/ land in TV rice)	9.60	10.21	0.54
	(0.44)	(0.74)	
Total Land (in decimal)	161.12	157.63	0.91
	(12.75)	(11.22)	
Total Labor (days)	69.14	70.32	0.93
	(5.24)	(5.31)	
Total Plough (number of times)	9.79	10.59	0.64
	(0.85)	(0.76)	
Total Seed (kilogram)	31.66	34.62	0.50
	(2.99)	(2.84)	
Total Irrigation (hours)	55.58	66.80	0.55
	(5.02)	(6.26)	
Total Fertilizer (kilogram)	218.08	258.82	0.44
	(18.58)	(19.14)	
Total Pesticide (number of times)	7.66	4.68	0.01
	(0.80)	(0.50)	

Notes: †† Rice in measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal (247 decimals=1 hectares.) Column 3 shows the P value of mean difference column 3=column1- column2.

Unit of observation: Household. Sample includes all rice producing farm households surveyed at baseline (2012). Standard errors (in parentheses) are clustered at Branch level. **High Yielding Varieties (HYV)** rice seeds are land substituting, water economizing, more labor using, and employment generating innovation. HYVs significantly outperform traditional varieties in the presence of an efficient management of irrigation, pesticides, and fertilizers. However, in the absence of these inputs, traditional varieties may outperform HYVs.

Hybrid rice is any genealogy of rice produced by crossbreeding different kinds of rice. It typically displays heterosis or hybrid vigor such that when it is grown under the same conditions as comparable high yielding inbred rice varieties it can produce up to 30percent more rice. However, the heterosis effect disappears after the first (F1) generation, so the farmers cannot save seeds produced from a hybrid crop and need to purchase new F1 seeds every season to get the heterosis effect each time.

Table A3: Attrition Rate

Dependent Variable: Attrited Households (1= household with baseline information but no follow-up information)		
	(1)	(2)
Treatment Assignment (1=household assigned to treatment group)	-0.02	-0.03
Female Headed household (percentage)		0.16**
Age of household head (in years)		0.00
Household head with no education (percentage)		-0.02*
Any baseline formal and informal loan (yes=1)		0.01
Observations	3,755	3,755

Notes: Unit of observation: Household. Sample includes all rice producing farm households surveyed at baseline (2012). Informal lenders include moneylenders, loans from friends/family, and buying goods/services on credit from sellers.

Table A4: Impact of Access to Credit on Rice Productivity

Variables	Effect of Credit Access (1)	Effect of Credit Access (2)	Observations
High Yielding Variety rice yield (HYV rice/ Land in HYV rice)	12.49***	12.61***	2,831
	[0.83]	[0.76]	
Hybrid rice yield (HB rice/ Land in HB rice)	10.77*	11.78**	412
	[1.37]	[1.09]	
Average rice yield at baseline (Total rice/Total land)	18.12		
Control for Baseline covariates	No	Yes	

Table A5: Impact of Credit Access on Frontier Shift and Efficiency of Rice Production (percentage effect)

Variables	High Yielding Variety Rice Yield (HYV Rice/Land in HYV)				Hybrid Rice Yield (HB Rice/Land in HB)			
	Impact on Frontier Shift	Impact on Frontier Shift	Impact on Inefficiency	Impact on Inefficiency	Impact on Frontier Shift	Impact on Frontier Shift	Impact on Inefficiency	Impact on Inefficiency
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Credit access (1=assigned in treatment group)	10.89***	9.94***	-1.68	-3.13**	2.70	3.17	-9.39**	-8.58**
	(1.15)	(1.15)	(1.60)	(1.58)	(3.81)	(3.86)	(3.99)	(3.94)
Mean Inefficiency in Rice Production	13.86	13.84	13.86	13.84	17.21	16.44	17.21	16.44
Baseline Covariates	no	yes	no	yes	no	yes	no	yes
Observations	2,187	2,187	2,036	2,036	269	269	269	269

Notes: Unit of observation is household. Sample includes rice producing farm households. Rice in measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal which is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m2); 247 decimals=1 hectares. Standard errors (in parentheses) are clustered at Branch level.

Table A6: Impact of Access to Credit on Input Use and Adoption of Modern Hybrid Rice

Variables	Effect of Credit Access	Observations
Total Land (in decimal)	2.03	3,172
	[14.68]	
Total Labor (days)	-0.83	3,172
	[7.88]	
Total Seed (kilogram)	4.15	3,172
	[3.27]	
Total Irrigation (hours)	-3.36	3,172
	[12.24]	
Total Fertilizer (kilogram)	27.19	3,172
	[29.73]	
Total Pesticide (number of times)	2.26**	3,172
	[1.04]	
Total Plough (number of times)	0.95	3,172
	[0.96]	
Control for Baseline Covariates	Yes	
Adoption of Modern Hybrid Rice (dummy)	15.64***	3,172
	[3.35]	

Notes: ***p<0.01, **p<0.05, *p<0.1. †Rice is measured in kilogram (1 kilogram=2.204 pounds). Land is measured in decimal (also spelled **decimel**) which is a unit of area in India and Bangladesh approximately equal to 1/100 acre (40.46 m²); 247 decimals=1 hectares. Standard errors (in parentheses) are clustered at the branch level.

Table A7: Mean of Demographic and Farm Characteristics

Variables	Observations	Mean	Std. Dev.
Household Composition			
Female Headed household (dummy)	3172	0.05	0.21
Head with no education (dummy)	3172	0.45	0.49
Small farm size (1=cultivated land<50 decimal)	3172	0.27	0.44
Pure tenant farm households (1= no own land rice cultivation)	3172	0.32	0.47
Mixed tenant farms (1=cultivate own land as well as others land)	3172	0.34	0.47

Unit of observation: Household. Sample includes all rice producing farm households surveyed in 2014.