Role of Women in Improving Productivity and Efficiency of Rice: Evidence from India

by

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ABSTRACT

Women's contributions to agriculture are an essential factor in achieving food security in developing countries. In rice production, women's involvement is usually limited to their labor participation. Differences in gender roles within the household hinder women from accessing productive resources and services compared to their male counterparts, leading to a gender gap in rice productivity. With the steady growth of rice productivity experienced in eastern India, it is essential to reduce the gender gap by providing women equal access to resources. However, there is little information on how the gender gap can be addressed between married couples in a patriarchal family structure like India.

This dissertation analyzes the potential impact on rice productivity and input use when the spouse (wife) in the household has given access to resources (e.g., rice variety and credit). The first chapter analyzes the impact of a married couple's decision-making strategy in choosing rice varieties on rice productivity and input use using an endogenous switching regression. The second chapter estimates the effect of access to financial services on technical efficiency using a stochastic production frontier framework. The last chapter evaluates how joint decision-making strategy influences the inverse relationship between farm size and rice productivity following a yield approach and quantile regression.

The findings show that joint decision-making strategy choice leads to a higher rice yield and fertilizer usage while lower labor requirements. Regarding spouse access to financial resources, results show a significant difference in technological and managerial gaps. However, that households with access have a lower predicted rice yield than households

without access. The last chapter shows that joint decision-making in the family still left the inverse relationship unchanged in examining the inverse relationship.

The dissertation provides two significant implications. First, results provide evidence of gender-differentiated preferences for rice variety within the household that can affect rice productivity and input use. Second, the spouse's access to credit does not necessarily lead to an increase in rice productivity. Thus, determining the primary purpose of why households avail financial services would be essential in analyzing its impact on productivity to avoid misleading results.

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1 INTRODUCTION

Increasing agricultural productivity has long been recognized as an essential factor in reducing poverty and increasing food security in developing countries (de Graft-Johnson et al., 2014; World Bank, 2018). The Green Revolution in the 1960s is considered one of the successful attempts to bridge the yield gap by adopting high-yielding varieties and improved farming practices for staple crops like rice (Tsusaka and Otsuka, 2012). Rice was heavily promoted, particularly in irrigated areas during the early Green Revolution. According to Herdt and Capule (1983), upon the release of the first modern rice variety (MRV) "IR8" in 1967, the area under MRV rapidly increased in most Asian countries. Given the high-yielding characteristics of the MRVs, the fast diffusion of MRVs coupled with public investments in complementary inputs led to an increase in rice production. In addition, the increase in rice production also resulted in a significant reduction of rural poverty and the development of the non-rural sector (Tsusaka and Otsuka, 2012).

India is one of the countries that benefited from the Green Revolution in rice. This crop is primarily grown in the eastern part of India, which covers 34 million ha, accounting for more than 60% of the total rice area in the country (GOI, 2016). The Eastern India region comprises seven states: Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal (Figure 1).[1] Rice is grown under a rainfed condition with three

[1] Map was created using shapefile with first-level administrative division of India and *GeoDa* (Hijmans, 2015; Anselin, Syabri, and Kho, 2006). In addition, the states included are based on the state boundaries when the survey was implemented.

cropping seasons: autumn rice or the Pre-Kharif (May - November); winter or the Kharif rice (June – December); and summer rice or Rabi (December - May) (GOI, 2021).

This dissertation will only focus on four states (Bihar, Odisha, Uttar Pradesh, and West Bengal) which are primarily considered rainfed areas that differ in socio-economic development and rice production (Table 1). It shows that Uttar Pradesh has the highest land area and population among the four states, with 240,928 sq km and 199 million people in

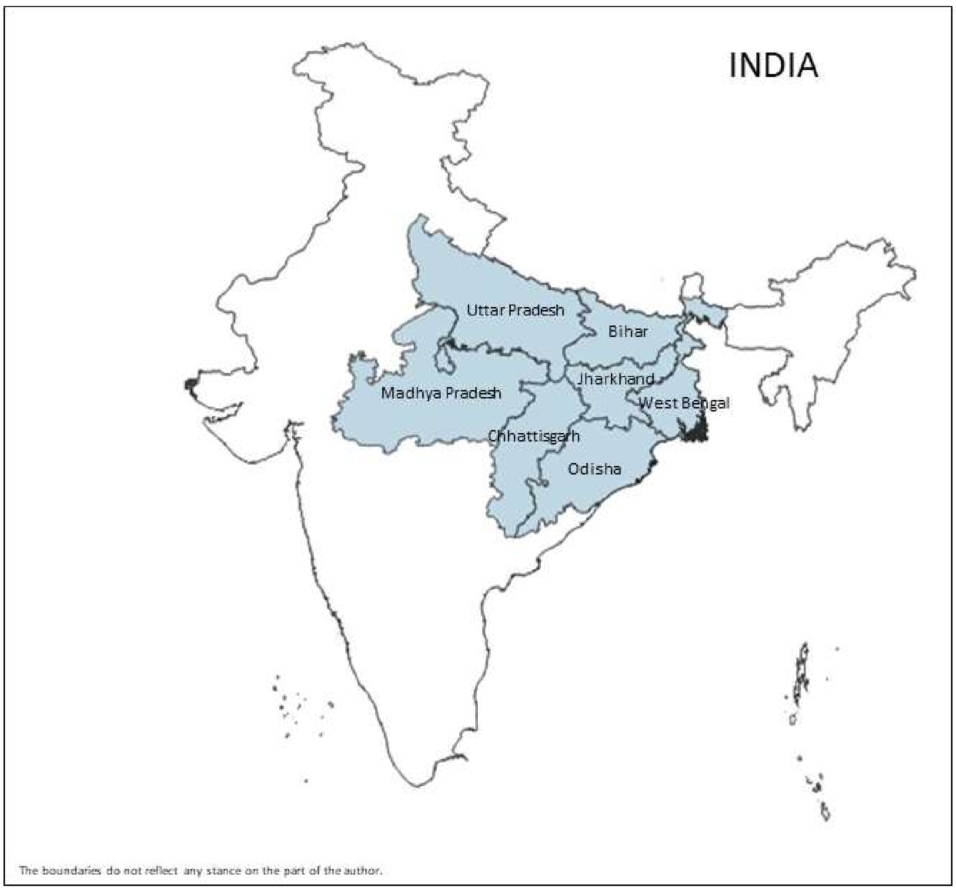

Figure 1: Map of Eastern India.

Table 1: Socio-economic Characteristics and Rice Production in Bihar, West Bengal, Uttar Pradesh, and Odisha.

	Bihar	West Bengal	Uttar Pradesh	Odisha
Geographical area (sq km)[1]	94,163	88,752	240,928	155,707
Population (million in 2011)[1]	104.1	91.28	199.21	41.97
Percentage female in the total population[2]	48	49	48	49
Literacy rate (%)[1]	61.8	77.1	67.7	72.87
Gross State Domestic Product (USD billion) 2019-2020[1]	86.79	117.87	239.44	73.79
Percentage of population below poverty line (%)[2]	34	23	30	36
Percentage of irrigated rice area[2]	68	45	83	40
State average yield 2015-2016 (kg/ha)[3]	2,749	4,491	3,585	3,529

[1]Information about Bihar, West Bengal, Uttar Pradesh, and Odisha: Agriculture, Industries, Economy Growth, and Geography.
[2] Population Census 2011.
[3] Agricultural Statistics at a Glance 2018.

2011, respectively. Nearly half of the population in all four states comprises women and a literacy rate of more than 60%. In terms of the Gross State Domestic Product (GSDP) in 2019-2020, Uttar Pradesh has the highest GSDP of USD 239.44 billion, followed by West Bengal (USD 117.87 billion). Rice state average yield varies from 2,749 kg/ha to 4,491 kg/ha. Most of the households use supplemental irrigation that covers 40-83% of the total rice area.

Steady growth in rice productivity was observed in recent years in eastern India compared to the early Green Revolution years (Gollin et al., 2005). Though India did not experience a vast production and consumption gap compared to other countries, this is still critical since smallholder production dominates the rice sector.[2] Smallholder producers are

[2] Smallholder producers cultivate less than 1 ha.

characterized for cultivating small fragmented land, often faced with production constraints like limited access to resources, and mainly produce crops for home consumption (Rapsomanikis, 2015). These smallholder rice producers comprised most of the rural population (80% of the total population) with a high percentage under poverty (with 22% to 35%) (GOI, 2016). This sector also serves as the primary source of livelihood among women by participating in production labor (Gollin, 2014). According to Pandey et al. (2012), women in eastern India share at least 58% of the total labor requirement in rice production, primarily in land preparation, weeding, and harvesting activities.

Despite the significant contribution of women in agriculture, their participation is still underestimated. Women continuously experience limited access and control on critical resources and agricultural inputs that affect agricultural productivity compared with their male counterparts, which led to a gender gap (Huyer, 2016).[3] To reduce the gender gap, the United Nations has set eight Millennium Development Goals (MDG). The third MDG emphasizes the promotion of women empowerment and gender equality (UN, 2000). In agriculture, the gender gap was raised by the Food and Agriculture Organization of the United Nations (FAO) in their "The State of Food and Agriculture 2010-2011: Women in Agriculture Closing the Gender Gap for Development" publication. FAO (2011) pointed out several areas where the gender gap exists in agriculture: land, labor, livestock, education, information and extension, financial services, and technology.

[3] Gender refers to the social norms and identities associated with what it means to be a man and woman and can be changed through social action or change in public policy (FAO, 2011). On the other hand, the gender gap is defined as the disparity between women and men, girls and boys, in their access to resources, education, health services, or power (IFAD, 2012).

In rice production, women empowerment is one of the Sustainable Rice Platform (SRP) indicators that assumes that empowering women involved in rice production would lead to higher productivity (SRP, 2010). However, empowerment is considered a broad concept, and the definition varies depending on the writer or different development agencies based on their organization's mandate. The earliest study that included this concept in the research mainstream was that of Kabeer (1999), which define *women empowerment* as "the expansion of assets and capabilities of poor people to participate in, negotiate with, influence, control, and hold accountable institutions that affect their lives" (pp. 437). Focusing on empowering women alone is not enough since the role and status of women in society may vary depending on women's characteristics, social norms, and institutional environment (FAO, 2011). The differences in gender roles within the household can be the significant constraints for women in accessing productive resources and services compared to their male counterparts resulting in a gender gap. According to FAO (2011), closing the gender gap by providing female farmers equal access to resources is estimated to increase production by 2.5-4% and reduce undernourished people by 12-17%. Several studies have looked at how the gender gap affects the productivity of the household. However, there is little information on how this gender gap can be addressed between married couples in a society with a patriarchal family structure like India.

Thus, the objective of the dissertation is to analyze the potential impact on rice productivity when the spouse was given access to resources (e.g., rice variety and credit) in the household. Specifically, this dissertation measures the impact of the married couple's joint decision-making regarding rice variety on rice productivity. Second, analyze the effect of the spouse 's participation in financial organizations (access to financial services) on rice productivity, managerial and technology gaps. Lastly, this dissertation evaluates if the joint decision-making strategy by the couple influence the existence of an inverse relationship between farm size and rice productivity.

The first chapter focuses on spouse’s participation in decision-making in adopting rice technology. This chapter (**Married Couples, Joint Involvement in Decision-making, Productivity, and Input Use: Evidence from Rice Producers in eastern India**) shows joint decision-making regarding rice variety choice under a male-headed household in eastern India. Using comprehensive Rice Monitoring Survey (RMS) data, the potential gains in yield, labor, and active fertilizer based on the decision-maker will be estimated using Endogenous Switching Regression (ESR). This method accounts for endogeneity issues, mainly when technology adoption is voluntary or given to a targeted group. Results aim to provide evidence of how differentiated preferences of the principal decision-makers (husbands are solely or jointly deciding) affect the potential gains in yield, labor, and active fertilizer usage.

In addition, the rice variety choice should also be accompanied by complementary inputs to achieve its potential yields. Credit is considered one of the essential inputs in rice production. The Self-help groups (SHGs) are sources of credit and extension services that help improve women’s status in society and household productivity (Meizen-Dick et al., 2019). This second chapter (**Access to Financial Services by Spouses, Technological and Managerial Gaps in Rice Production**) will address the second objective. The chapter shows the importance of the spouse's participation in credit-related farmer organizations and its impact on rice productivity. Using the Rice Monitoring Survey (RMS) data, rice production efficiency will be estimated using a stochastic production frontier (SPF) analysis. This method will compare the rice technical efficiency of farming households with access to financial services versus those without access, considering the observable and unobservable household characteristics to account for selectivity biases.

The last chapter revisits the inverse relationship between farm size and productivity in rice. This chapter **(Assessing Inverse Productivity Relationship in a Joint Decision-making Framework)** will examine if the spouse's participation in farm decision-making may affect the inverse relationship condition using the Rice Monitoring Survey (RMS) data. A quantile regression approach will also be used in examining if the inverse relationship varies in terms of the level of productivity.

2 MARRIED COUPLES, JOINT INVOLVEMENT IN DECISION-MAKING, PRODUCTIVITY, AND INPUT USE: EVIDENCE FROM RICE PRODUCERS IN EASTERN INDIA

2.1 Introduction

Increased crop productivity through the adoption of modern technologies (improved seeds, synthetic fertilizer, irrigation, and mechanization) is considered one of the greatest legacies of the Green Revolution in South and Southeast Asia (Tsusaka and Otsuka, 2013). The introduction of modern technologies has increased food security and reduced poverty in developing and emerging economies (de Graft-Johnson et al., 2014). Asia has the highest median rate of returns of public research investments that reached 50% compared to other regions (Hazell, 2009). Crop genetic improvements through breeding programs attribute most of the crop productivity. It is estimated that from 1960 to 1998, the average annual growth productivity in all crops from CGI reached 0.718% (Evenson, 2003). Rice is one of the crops that benefited from genetic improvement. For instance, Brennan and Malabayabas (2011) found that the impact of rice varietal improvement to production in selected Southeast Asian countries (1985-2009) resulted in a Net Present Value (NPV) (at 2019 USD) of US$ 4.2 billion to US$ 6.8 billion.[4] In India alone, there are more than 900 modern rice varieties (1975-2010) (MRV), and around 47 hybrid rice varieties (1994-2010)

[4] The values are converted using the 2019 GDP deflator from the World Bank Economic Indicators.

were released by the government of India (DRR, 2010; DRD, 2020).[5,6] Rice plays a vital role in Indian agriculture as a major supplier of calories in the Indian diet and covers approximately 35% of the total area under the food grains area (IRRI, 2019). Despite the rice varietal developments, there is noticeable slow productivity growth in food grains in recent decades, compared to the early decade of the Green Revolution (Khush, 1999). Eastern India is one region that experienced slow rice productivity. Two possible reasons that may contribute to low growth include the lack of desirable traits of high-yielding varieties (Hossain et al., 2003) and adverse effects of climatic conditions (e.g., drought, flood, submergence, salinity, toxicity, and nutrient deficiencies) (Tsusaka and Otsuka, 2013). For example, Pandey et al. (2007) estimated that drought events between 1970 and 2000 resulted in an average loss in rice production of 5.4 million tonnes or USD 226 million (at 2019 prices). This low yield growth will substantially impact the region since rice farming is characterized by the dominance of fragmented and smaller holdings, lack of irrigation facilities, and frequent adverse climatic conditions. Given the rice farming status in eastern India, this may trigger the continuing vicious circle of low input-low output agriculture (Pandey et al., 2012).

To reduce the variability in farm income and precarious livelihood, male heads of households have sought off-farm employment or dual employment to increase family

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[5]MRV refers to improved rice varieties released by the Indian government, except for hybrid rice varieties (Mehar et al., 2017). Improved rice varieties usually undergo conventional rice breeding, which allows itself to produce through self-pollination (in-breeding) (Barclay, 2007). These rice varieties have more desirable traits (e.g., high yielding, multiple resistance to diseases, short duration, and tolerance of soil problems) than pre-Green Revolution varieties (Khush, 1995).

[6]Hybrid rice varieties (HRV) refer to all first-generation offspring of crossbred rice varieties between two genetically diverse parents resulting in higher yields (Barclay, 2007).

income. The booming non-farming sectors (such as construction, service, manufacturing, and industrial) have pulled both hired labor and family labor out of the agricultural sector. The labor movement from agriculture has led to an increase in the daily nominal wage rate for various farm activities, including plowing, sowing, and rice transplanting.[7] A report by the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) shows that the nominal wage rate increased 3.6 to 4.2 times during the 2004-2014 period (Bhattarai et al., 2014). The movement to the non-rural sector was further enhanced by government programs like the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), leading to labor shortages in agricultural production.[8]

However, low productivity affects household income structure and the gender roles within the households. Studies of Datta and Mishra (2011) and Maharjan et al. (2012) found that Indian rice farmers' income sources have become more diversified in recent years, which has led to significant changes in gender roles within the households. Recall that in most societies, farming decisions (such as selecting crops, technology, and labor) traditionally have been made by the male household heads, who represent the whole household (Orr et al., 2016). However, in the absence of male decision-makers, wives are increasingly responsible for making farming-related decisions. Women's new responsibilities pose significant constraints, particularly in accessing productive resources and services

[7]During the 2004- 2014 period, the cultivation cost of major crops (paddy and wheat) increased at an annual rate of 10% due to the rise in labor costs. Labor costs account for up to 50% of the total production cost of paddy cultivation.

[8]The Mahatma Gandhi National Rural Employment is enacted by the National Rural Employment Guarantee Act of India (2005) is a public policy in India that pays people to seek employment. The wage rate is higher than the daily wages of agricultural workers.

compared to their male counterparts. Thus, resulting in inappropriate farming decisions. Existing studies tend to rely on household heads' information in analyzing the adoption of technologies (Mehar et al., 2017; Quisumbing and Kumar, 2014). The characteristics of women who are not household heads are essential in understanding the decision-making processes within households (Doss, 2001; Orr et al., 2016). Moreover, with the increased educational attainment of the wife, it is more likely today than in the past that farming-related decisions are made jointly. Joint decision-making is gaining significant traction in the literature (Ibrahim et al., 2011; Aregu et al., 2011; Damisa and Yohanna, 2007). To this end, studies investigating technology adoption focus on male decision-makers may lead to biased estimates (Agarwal et al., 2013; Quisumbing and Pandolfelli, 2009). There is little information regarding rice adoption studies that examine the married couple's participation in the decision-making process. The nearest study that assessed the intrahousehold decision-making of married couples was the study of Maligalig et al. (2019). The authors examined the intrahousehold bargaining of couple's in farming areas in the Philippines using field experiments to determine each couple's preferences regarding rice varietal trait improvement. The results show that women with off-farm employment empower women in making investment decisions regarding rice breeding. However, Maligalig et al.'s (2019) only estimated the intrahousehold bargaining. They did not estimate the impact of the couple's decision-making status on rice productivity indicators (yield, total labor, and total fertilizer).

Thus, this chapter aims to investigate how married couples' decision-making strategy in terms of choosing a particular rice variety affects rice productivity and input use (labor, and total fertilizer).[9] This chapter used the 2016 Rice Monitoring Survey, a nationally representative household-level survey data which contains both households that adopt and did not adopt joint decision-making strategy for choosing rice varieties. This chapter contributes to the literature in several ways. First, this chapter incorporates married couple's decision-making strategies regarding rice variety choice, which is often not included in technology adoption studies. Usually, existing studies only consider the husband's decision which later relates to the increase in women's responsibilities as a form of empowerment (Datta and Mishra, 2011; Maharjan et al., 2012).[10] There are also instances when technology preferences were compared between male and female-headed households, ignoring the dynamic relationship within the households. This chapter uses gender-differentiated data, which enables creating a joint decision-making strategy that defines how married couple decides which variety to use: jointly choosing the rice variety or the husband solely deciding the rice variety. Incorporating decision-making between married couples will enable to explain a more realistic decision-making process since it acknowledges the existence of an intra-household dynamic process regarding the choices of variety that may affect rice productivity of the household. In addition, a modern variety classification is defined based on the year release and agronomic characteristics of Indian

[9] Sustainable Rice Platform was co-founded by the United Nations Environment (UNE) and the International Rice Research Institute (IRRI) in 2011 to promote resource efficiency and sustainable practices throughout the rice value chain (http//:www.sustainablerice.org). Twelve sustainable performance indicators are used to assess the sustainability of rice farming (SRP, 2020). Only three indicators were included in this chapter: yield, total labor, and total fertilizer.

[10] Men in rural India still have the upper hand in decision-making. However, in recent decades, due to non-farm employment and internal migration, women make farming and household decisions in consultation with their husbands.

rice varieties following the works of Laborte et al. (2015) and Launio et al. (2008). Second, information comes from survey data, and strategy choices are not randomly distributed, making the two groups systematically different. According to Alene and Manyong (2007), there are farmers' abilities or conditions that affect the initial adoption of joint decision-making strategy that is unknown to the researchers. These factors cannot be directly controlled in generating the pure effect of the couple's strategy on productivity. Employing the Endogenous Switching Regression (ESR) will account for selection bias and endogeneity issues (Pitt, 1983; Fuglie and Bosch, 1995; Alene and Manyong, 2007; Di Falco et al., 2011). Finally, this chapter will generate counterfactual estimates to compare the expected productivity and input use under households that adopt or did not adopt joint decision-making in choosing rice varieties. In addition, the treatment and heterogeneity effects are calculated to understand the difference in the major rice productivity indicators between households under joint decision-making and husband sole decision-making. These kinds of estimates often lack in most rice adoption studies, which only provide information about the major constraints in rice technology adoption.

Findings from this chapter will help in identifying primary decision-makers in rice production in eastern India. Investigating the primary decision-maker and the constraints the person is facing will help the fast adoption of new technologies. Knowing the primary decision-maker will also guide the extension service programs regarding the type of extension delivery method, frequency of delivery, and the content of included information that will help to increase rice productivity.

2.2 Review of Literature

Women participation in farm decision-making

Women's participation in rice farming is often associated with their share in production labor. In eastern India, women provide at least 60% of total rice labor requirements (crop establishment, weeding, and harvesting) (Pandey et al., 2010). However, it is not always guaranteed that women significantly influence decision-making regarding critical issues about farming and household matters. Behura et al. (2012) and Bagchi et al. (2012) found that while women contribute substantial labor, the male household head is still the one who decides on which technology or farming practices to adopt, while women are responsible for decisions about the selling of rice.

In the increasing movement to the non-rural farm sector among men, women are increasingly responsible for making farming-related decisions. Most of the literature still tends to rely on household heads' information to analyze the adoption behavior and exclude women who are not household heads. Focusing on the household head is a standard method used in most existing literature, particularly in the South Asian setting, due to its simplicity. Doss (2014) pointed out that this underscores the contribution of women, particularly in male-headed households, since there are gender-differentiated preferences on farming decisions such as crop choice and labor use (Bourdillon et al., 2007). However, with the changes in the sources of income from farm to nonfarm rural sources among rice farming households, there is evidence of changing gender roles within the household which result in high participation of women in decision-making not only regarding the household but also farming decisions (Paris et al., 2005; Paris et al., 2010).

Studies that examine intra-household decision-making are from sub-Saharan Africa (SSA) and Latin America. These studies typically find that the wife and husband had contrasting views of who had more control over agricultural production decision-making. For example, Twyman et al. (2015) showed that husbands in Ecuador reported their spouse's time spent on decision-making to be lower than those reported by their spouses. In a recent study of Ecuadorian farmers, Alwang et al. (2017) found that the husband claimed sole responsibility over the decisions while the spouse contended that the decisions were made jointly. In some instances, the wife in rural Tanzania disagreed on who had the authority over decision-making in the households (Anderson et al., 2017).

Orr et al. (2016) found that women in Zambia perceived themselves to have more control than men perceived women to have. However, there is little evidence on the intrahousehold decision-making process between men and their spouses in determining rice varietal choice in India. According to Upadhyay (2003), social norms and customs under patriarchal societies play an essential role in male domination in households that hinder women's rice farming participation. Though the Indian government has implemented several programs to improve women's status, it is still necessary to know women's involvement, particularly in making decisions in agriculture. Alderman et al. (1997) noted that ignoring household members' different responsibilities over the choice of crop and technologies is the primary reason why technology adoption studies often fail. Thus, investigating who is making decisions and the constraints facing the decision-maker is an effective way of understanding technology adoption by households (Deerie, 2005). Recognizing gender differences will benefit intervention policies more effectively (Akter et al., 2017; Doss, 2011).

Rice adoption studies

The development of modern rice varieties has been one of the major focus areas as early as 1950 in India through different rice programs such as the Rice Hybridization scheme and the High-Yielding Variety Program (Herdt and Capule, 1983). Since then, the government of India has released more than a thousand rice varieties since 1932 (DRR, 2010). Despite the high number of released varieties, only a few rice varieties were used by farmers (Pandey et al., 2012). Indian farmers continuously use varieties for more than a decade (12-15 years) with 18-23 years upon year of release (Tsusaka et al., 2013). The early studies of rice adoption by Herdt and Capule (1983) found that a combination of household characteristics and farm conditions affects modern rice varieties' adoption. Since then, several studies have identified major rice adoption constraints. For most of the existing literature, demographic characteristics include household heads' age, education (David and Otsuka, 1994; Joshi and Bauer, 2006), and family wealth or income (Langyintou and Mungoma, 2008) affects the adoption of rice varieties. In India's case, caste plays an essential role since households belonging to a lower caste, such as scheduled tribes, are less likely to choose hybrid varieties than traditional ones (Mehar et al., 2017). In some places in eastern India, strict social norms prohibit women from the upper caste from working in their field compared to women from the lower caste (Pandey et al., 2010). The effect of farm size and the inclusion of climate variables such as flood and drought are becoming essential since several varieties are released to cope with these problems (Dar et al., 2013; Azam,1996; Mehar et al., 2017; Kijima et al., 2008). The influence of the neighbors also affects the rapid adoption of a variety. For example, Yamano et al. (2018) found a high adoption of stress-tolerant seeds in Bangladesh when they are considered neighbors to earlier adopters. There is also a greater focus given to hybrid rice in India due to its yield advantage over the inbred varieties, particularly when accompanied by complementary inputs (fertilizer) (Janaiah and Xie, 2010; Janaiah and Hossain, 2003; Gars and Ward; 2019). Several studies found that farmer characteristics (like caste) (Gars and Ward; 2019); availability of land infrastructure (irrigation system) (Mottaleb et al. 2015); spatial proximity from other adopters (Ward and Pede, 2015), and the farmer perception about the grain quality of hybrid varieties are the major barriers for adoption. Janaiah and Xie (2008) also found that older hybrid rice has an inferior quality (taste, smell, and grain stickiness) than inbred varieties that hinder consumer acceptance.

In most rice adoption studies, two issues are often disregarded, which may have some implications regarding adoption analysis. First, household head's gender and investigate the link between rice variety choice. It assumes that farming decisions (such as the selection of crops, technology, and labor) have been made by the male household heads who also represent the decisions of the whole household (Orr et al., 2016). However, incorporating the household head’s gender may lead to biased estimates, particularly in the Indian setting, since most respondents are male. Focusing on male household heads underscores the importance of women's participation in a male-headed household (Agarwal et al., 2013; Quisumbing and Pandolfelli, 2009; Doss, 2001; Quisumbing et al., 2014; Twyman et al., 2015; Alwang et al., 2017; Anderson et al., 2017). Second, rice adoption choices only limit to rice variety categories: local rice, modern rice, and hybrid rice varieties. The literature only focuses on the adoption constraints to each rice variety category but there is limited research that focuses on the different categories within modern rice varieties. Thus, incorporating women's participation in choosing modern rice varieties may help identify the major barriers in adoption that address issues regarding slow rice yield growth in eastern India.

Impact assessment

The development of rice varieties through crop genetic improvement research has been one of the focuses of international institutions and national agricultural research extension systems (NARES) due to a high and consistent rate of returns to research investments. In rice, one of the standard impact evaluation methods is the use of economic surplus analysis. For example, Fan et al. (2007) found that 12% to 64% of the USD 2.6 billion (at 2019 prices) gains in rice improvement in India can be attributed to the International Rice Research Institute’s (IRRI) rice breeding programs.

In terms of evaluation of adoption rates, Diagne (2006) and Diagne and Demont (2007) employed an average treatment effect methodology in assessing the adoption rates of New Rice for Africa (NERICA) varieties. They found that if the population is exposed to NERICA varieties, then the potential adoption rate would be 27%, which is more than six times the actual adoption rate of 4%. In addition, adopting a variety generates additional income for the household. For example, Kijima et al. (2008) found that adopting NERICA varieties combined with other Natural Resource Management (NRM) practices in central and western Ghana have improved the per capita income by 20% and decreased poverty incidence by 5% points. Similar results were found by Nguezet et al. (2011), which assessed the impact of the adoption of NERICA varieties in Nigeria and found that aside from increasing the farmer's income by 46%, their per capita expenditure also increased by 49%.

However, the methodologies discussed above mainly used cross-sectional data with a descriptive analysis that usually has some selectivity issues that lead to bias estimation (Yamano et al., 2016). To address this issue, de Janvry et al. (2010) suggest using a randomized control trial (RCT), which accounts for spillover effects and provides a more credible counterfactual. In rice research, Dar et al. (2013) used this method to assess the impact of a flood adopting flood-tolerant rice varieties in India. Results show that yield advantage (Swarna-Sub1) by 66% over other varieties. Though RCT provides credible outcomes, the difficulty in setting up the experiment and its costs makes this method not often used. In the study of Yamano et al. (2016), only a few of the impact assessment studies in rice from 2005 to 2015 used advanced estimation techniques since most used cross-sectional data and descriptive analysis.

To make use of cross-sectional data in estimating the impact of a particular technology that accounts for selection bias, a simultaneous model with endogenous switching regression (ESR) is commonly used. Earlier ESR studies like Fuglie and Bosch (1995) assessed soil testing's impact on Nitrogen use. On the other hand, Di Falco et al. (2011) used ESR to analyze the adoption of climate change technology and its effect on household productivity in Ethiopia. In rice, Mishra et al. (2018) used ESR in analyzing the impact of contract farming of organic basmati rice on yield, prices received, and livelihood of producers.

However, there is a shortage of information about the impact of women's participation in decision-making on rice production. This chapter will be the first to use this method in analyzing the effects of women's participation decision-making on major SRP indicators such as yield, total labor, and total active fertilizer use by rice variety.

2.3 Theoretical Model

The theoretical framework for this chapter follows the work of Fernandez-Cornejo et al. (2005), an extension of Huffman's (1991) agricultural household model that accounts for technology adoption and input allocation (fertilizer and labor). The model appropriately shows how joint decision-making of married couples affects rice variety choice on rice yield, total labor use, and total fertilizer). For this chapter, the household is defined as a single-farm family household. The analysis for time allocation only considers two persons, husband (M) and wife (F). Following the agricultural household model, the farm households maximize the utility function:

$$U = U(G, \boldsymbol{L}, \boldsymbol{H}, \psi) \qquad (1)$$

where G are the goods purchased for home consumption, $\boldsymbol{L} = (L_M, L_F)$ is the leisure (including free time) of the household members, $\boldsymbol{H} = (H_M, H_F)$ human capital is considered exogenous to current household decisions, and ψ (e.g., household characteristics and flood/drought events). The household utility is subject to income, production technology, and time constraints:

$$P_g G = P_q Q - \boldsymbol{W}_x \boldsymbol{X}' + \boldsymbol{W}\boldsymbol{M}' + A \qquad \text{(income constraint)} \qquad (2)$$

$$Q = Q[X(\Gamma; \mathrm{Z}), \boldsymbol{F}, \boldsymbol{H}, \boldsymbol{R}], \Gamma \geq \boldsymbol{0} \qquad \text{(technology constraint)} \qquad (3)$$

$\boldsymbol{T} = \boldsymbol{F} + \boldsymbol{M} + \boldsymbol{L}, \boldsymbol{M} \geq \boldsymbol{0}$ (time constraint) (4)

where P_g and G are the price and quantity of goods purchased for consumption; P_q and Q are the price and quantity of rice output; $\boldsymbol{W}_x$ and $\boldsymbol{X}$ are the price and quantity (row) vectors of inputs; $\boldsymbol{W} = (W_{M,} W_F)$ are the off-farm wages paid to husband and wife; $\boldsymbol{M} = (M_{M,} M_F)$ is the amount of time working off-farm by husband and wife; $\boldsymbol{F} = (F_{M,} F_F)$ is the amount of time working on the farm by husband and wife; A is other income that the household receives aside from off-farm employment; $\boldsymbol{R}$ is a vector of exogenous production shifters; and $\boldsymbol{T} = (T_{M,} T_F)$ represents the (annual) time endowment of the husband and wife. The use of inputs will also depend on rice variety (Γ) and the household decision-maker (Z) which can be define as joint decision-maker or husband solely deciding. The production function is assumed to be concave. To obtain a technology-constrained measure of (cash) household income, the technology constraint Equation (3) is substituted in the income constraint Equation (2):

$$P_g G = P_q Q\ [X(\Gamma; \mathrm{Z}), \boldsymbol{F}, \boldsymbol{H}, \boldsymbol{R}] - \boldsymbol{W}_x \boldsymbol{X}' + \boldsymbol{W}\boldsymbol{M}' + A \tag{5}$$

The first-order conditions for optimality (Kuhn-Tucker conditions) are obtained by maximizing the Lagrangian expression $\mathcal{L}$ over $(G, \boldsymbol{L})$ and minimizing the Lagrange multiplier (λ, μ), where $\mu = (\mu_M, \mu_F)$:

$$\mathcal{L} = U(G, \boldsymbol{L}, \boldsymbol{H}, \psi) + \lambda\{P_q Q\ [X(\Gamma; \mathrm{Z}), \boldsymbol{F}, \boldsymbol{H}, \boldsymbol{R}] - \boldsymbol{W}_x \boldsymbol{X}' + \boldsymbol{W}\boldsymbol{M}' + A - P_g G\} + \mu[\boldsymbol{T} - \boldsymbol{F} - \boldsymbol{M} - \boldsymbol{L}] \tag{6}$$

The following Kuhn-Tucker conditions are used to derive the demand and supply functions

$$\partial\mathcal{L}/\partial\boldsymbol{X} = \lambda[P_q\ (\partial Q/\partial\boldsymbol{X}) - \boldsymbol{W}_x] = 0 \tag{7}$$

$$\partial\mathcal{L}/\partial\boldsymbol{F} = \lambda P_q\ (\partial Q/\partial\boldsymbol{F}) - \ \mu = 0 \tag{8}$$

$$\partial\mathcal{L}/\partial\Gamma = \ \lambda\ P_q[(\partial Q/\partial X)\ (\,dX/d\Gamma)' + (\partial Q/d\,\Gamma)]\ \leq\ 0,\ \ \Gamma \geq 0,\quad \Gamma\,(\partial\mathcal{L}/\partial\Gamma) = 0 \tag{9}$$

Since this chapter is interested in analyzing the adoption of rice variety and its impact on rice productivity and input use, the adoption rice variety can be obtained from the optimality conditions of Equation (9), where in the expression within bracket in Equation (9) pertains to the total derivative $dQ/d\Gamma$ (Fernandez-Cornejo et al., 2005). Note that the adoption of rice variety can be affected by the decision-maker in the household (joint decision-maker or husband sole decision-maker). The equation would be:

$$P_q\ dQ/d\Gamma - W_x(d\boldsymbol{X}/d\Gamma)' \leq 0 \tag{10}$$

The left-most term in Equation (10) is considered the marginal benefit (MB) of production, while the following terms are defined as the marginal cost (MC) of inputs. Equation (10) implies that it is not optimal to adopt a certain rice variety if marginal benefits to adopt are less than the marginal cost. Rice productivity is affected rice variety, managerial skills, major decision-maker involved in rice farming, and crop management.

The reduced form for input and output supply can be expressed as:

$$X = \ X(NB, P_q, W_x, \Theta) \tag{11}$$

$$Q = Q(NB, P_q, W_x, \Theta) \tag{12}$$

where Θ is a vector of household information, farm characteristics, and joint decision-maker. Thus, Equations (11) and (12) show that prices, household, farm, and joint decision-maker affect the quantity of rice and inputs use in rice production.

2.4 Econometric Specification

To analyze the impact of joint decision-making to rice productivity and input use, this chapter employs a two-stage estimation which starts by estimating a simultaneous model with endogenous switching regression (ESR) using a full maximum likelihood estimation. The second stage examines the impact of the chosen decision-making strategy on rice sustainability indicators (e.g., yield, labor use, and total fertilizer).

Selection of strategies in choosing rice varieties

In adopting rice varieties, the couple chooses the decision-making strategy that maximizes the expected benefits. Thus, a joint decision-making strategy is adopted when there is a positive difference between the marginal benefit of adopting and not adopting the joint decision-making strategy. Let the difference be A^* and if the net benefits is $A^* > 0$, then the household adopts a joint decision-making strategy. However, A^* is not observable and the only observable is A which is the observed behavior of the couple regarding the adoption of joint decision-making, which is given as

$$A_i^* = \alpha X_i + \mu_i \qquad with \ A_i = \begin{cases} 1 \ if \ A_i^* > 0 \\ 0 \ Otherwise \end{cases} \tag{13}$$

where A_i^* is a binary variable wherein A_i^*=1 if the household has joint decision-making and 0 if the husband is solely deciding, α is a vector of parameters to be estimated, X is a vector of the farm and farmer characteristics; and μ_i is error term with mean zero and variance σ^2. However, the decision of the couple to adopt a joint decision-making strategy may be potentially endogenous. According to Alene and Manyong (2007), endogeneity may be due to people who voluntarily adopt the technologies or technologies targeted in a particular group, which may result in self-selection in both cases. Households that decided to adopt joint decision-making strategy may be systematically different from households with husbands solely deciding. In addition, unobservable characteristics of the households and their farm that may influence their adoption strategy decision which may affect rice productivity indicators resulting in inconsistent estimates. To account for endogeneity due to self-selection, a simultaneous equation model for adoption of joint decision-making strategy and rice productivity using endogenous switching regression model will be used.

Endogenous Switching Regression (ESR)

The Endogenous Switching Regression (ESR) was used to account for endogeneity. This method was developed by Lee (1978) and later applied in agriculture by Pitt (1983). Since then, this method has been used in several empirical studies (Fuglie and Bosch, 1995; Alene and Manyong, 2006; Di Falco et al., 2011; Mishra et al., 2018). Separate outcome equations are specified if the couple has joint decision-making as well as husband solely deciding as

$$Y_{1i} = \alpha_1 Z_{1i} + \varepsilon_{1i} \qquad if \quad A_i = 1 \qquad (14)$$

$$Y_{2i} = \alpha_2 Z_{2i} + \varepsilon_{2i} \qquad if \quad A_i = 0 \qquad (15)$$

where Y_i is the outcome variable (yield, labor use, and active fertilizer use) of the i^{th} household when using couple's participation strategy (1= joint decision-making; 0= husband sole decision-making), Z is a vector of explanatory variables (farmer and plot characteristics), and α are parameters to be estimated. The outcome variable Y_{1i} when the couple jointly decide the rice variety while Y_{2i} is observed when the husband solely decides the rice variety. In using OLS, the estimates α_1 and α_2 in Equations (14) and (15) will suffer selection bias since the choice of strategy is endogenous. This implies that error terms in Equations (14) and (15) will have a non-zero expected value (Lee, 1978; Maddala, 1986). The error terms in Equations (13), (14), and (15) are assumed to have a tri-variate normal distribution with mean zero and non-singular covariance matrix which given as

$$Cov\ (\varepsilon_{1i}, \varepsilon_{2i}, \mu_i) = \left[\sigma_{\varepsilon 2}^2 \,.\, \sigma_{\varepsilon 2\mu} \,.\, \sigma_{\varepsilon 1}^2\ \sigma_{\varepsilon 1\mu} \,..\, \sigma_{\mu}^2\ \right] \quad (16)$$

where σ_{μ}^2 is the variance of error term of the selection equation; $\sigma_{\varepsilon 1}^2$and $\sigma_{\varepsilon 2}^2$ are variances of the error terms of the outcome functions in 14 and 15; $\sigma_{\varepsilon 1\mu}$ and $\sigma_{\varepsilon 2\mu}$ are the covariance of μ_i, ε_{1i}, and ε_{2i}. According to Maddala (1986), since Y_{1i} and Y_{2i} are not simultaneously observed, the covariance between ε_{1i} and ε_{2i} are not defined. Based on the given assumptions, the expected values of ε_{1i} and ε_{2i} conditional on sample selection are non-zero:

$$E[\varepsilon_{1i}|\ A_i = 1] = \ \sigma_{\varepsilon_{1i}\mu} \frac{\phi\ (\alpha X_i)}{\Phi(\alpha X_i)} = \ \sigma_{\varepsilon_{1i}\mu}\lambda_{1i} \quad (17)$$

$$E[\varepsilon_{2i}|\ A_i = 0] = \ \sigma_{\varepsilon_{2i}\mu} \frac{\phi\ (\alpha X_i)}{1-\Phi(\alpha X_i)} = \ \sigma_{\varepsilon_{2i}\mu}\lambda_{2i} \quad (18)$$

where ϕ is a standard normal probability density function and Φ standard normal cumulative functions. The ratio between ϕ and Φ evaluated at αX_i is the inverse Mills ratio (λ_{1i} and λ_{2i} in Equations 9 and 10). Substituting $\lambda_{1i} = \frac{\phi\ (\alpha X_i)}{\Phi(\alpha X_i)}$ and $\lambda_{2i} = \frac{\phi\ (\alpha X_i)}{1-\Phi(\alpha X_i)}$ in Equations (6) and (7), then the outcome equations can be expressed as

$$Y_{1i} = \alpha_1 Z_{1i} + \ \sigma_{\varepsilon_{1i}\mu}\lambda_{1i} + \ \varepsilon_{1i} \qquad if \quad A_i = 1 \quad (19)$$

$$Y_{2i} = \alpha_2 Z_{2i} + \sigma_{\varepsilon_{2i}\mu}\lambda_{2i} + \ \varepsilon_{2i} \qquad if \quad A_i = 0 \quad (20)$$

where ε_{1i} and ε_{2i} have zero conditional means. If the estimated $\sigma_{\varepsilon_{1i}\mu}$ and $\sigma_{\varepsilon_{2i}\mu}$ are statistically significant, then the null hypothesis is rejected, suggesting endogenous switching. Since the generated regressors arising from two-stage estimation often results to heteroscedastic error terms ε_{1i} and ε_{2i} , OLS estimates for Equations (14) and (15) will be inefficient (Antle 1983; Khonje et al., 2018). An efficient method in estimating endogenous switching models using the full information maximum likelihood (FIML) (Alene and Manyong, 2006; Di Falco et al., 2011; Lokshin and Sajaia, 2004). The FIML simultaneously estimates the selection equation and the outcome equation to have a consistent standard error and given as:

$$\ln\ L_i = \sum_{i=1}^{N} A_i \left[\ln\ \phi\left(\frac{\varepsilon_{1i}}{\sigma_1}\right) - \ln\ \sigma_1 + \ln\ \Phi(\theta_{1i})\right]$$

$$+(1 - A_i)\left[\ln \phi\left(\frac{\varepsilon_{2i}}{\sigma_2}\right) - \ln \sigma_2 + \ln\big(1 - \Phi(\theta_{2i})\big)\right] \quad (21)$$

$where\ \theta_{ji} = \frac{(\alpha X_i + \rho_j \varepsilon_{ji}/\sigma_j)}{\sqrt{1-\rho_j^2}}$, $\mathrm{j} = 1, 2$ and σ_j which denotes the correlation coefficient between the error term μ_i in selection Equation (5) and ε_{ji} outcome Equations (14) and (15).

Estimation of the effects of couple's decision-making strategy on rice yield, labor use, and active fertilizer use

The average treatment effect on the treated (ATT) is estimated by comparing the expected outcome of a household with joint decision-maker and husband solely deciding in actual and counterfactual scenarios (Di Falco et al., 2011; Shiferaw et al., 2014). In this paper, the treated outcome is when the household has a joint decision-maker, while the base category is when the husband is the sole decision-maker in the family. The conditional expectations for each outcome expectations are the following:

Household with joint decision-maker (actual adopters):

$$E(Y_{1i}|A = 1) = \alpha_1 Z_{1i} + \sigma_{\varepsilon_{1i}\mu} \lambda_{1i} \tag{22}$$

Households with husband as sole decision-maker (actual non-adopters):

$$E(Y_{2i}|A = 0) = \alpha_2 Z_{2i} + \sigma_{\varepsilon_{2i}\mu} \lambda_{2i} \tag{23}$$

Households with husband as the sole decision-maker that decided to have a joint decision-maker (counterfactual):

$$E(Y_{2i}|A = 1) = \alpha_2 Z_{1i} + \sigma_{\varepsilon_{2i}\mu} \lambda_{1i} \tag{24}$$

Households with joint decision-makers that decided for a husband to decide solely (counterfactual):

$$E(Y_{1i}|A = 0) = \alpha_1 Z_{2i} + \sigma_{\varepsilon_{1i}\mu} \lambda_{2i} \tag{25}$$

Recall that the ATT estimates the actual effect of participation strategy on yield, labor use, and total fertilizer use of households with joint decision-maker. Specifically, it is the difference between Equation (22) and Equation (24):

$$ATT = E(Y_{1i}|A = 1) - E(Y_{2i}|A = 1) = Z_{1i}\,(\alpha_2 - \alpha_1) + \lambda_{1i}(\sigma_{\varepsilon_{1i}\mu} - \sigma_{\varepsilon_{2i}\mu}) \tag{26}$$

The impact on yield, labor use, and total fertilizer use for husband solely deciding had they jointly decide is estimated using the average treatment effect on the untreated (ATU) is the difference between Equation (23) and Equation (25) specifically:

$$ATU = E(Y_{1i}|A = 0) - E(Y_{2i}|A = 0) = Z_{2i}\,(\alpha_1 - \alpha_2) + \lambda_{2i}(\sigma_{\varepsilon_{1i}\mu} - \sigma_{\varepsilon_{2i}\mu}) \tag{27}$$

The treatment effects can be further identified through heterogeneity effects (Carter and

Milon, 2005). A household with joint decision-makers (actual) may have a higher outcome (yield, labor use, and active fertilizer use) than those households with husbands solely deciding regardless of their strategic decision but due to other unobservable characteristics. This effect is termed as the “effect base heterogeneity” (BH) and is defined as:

$$BH_{JD} = E(Y_{1i}|A = 1) - E(Y_{1i}|A = 0) \tag{28}$$

$$BH_{MD} = E(Y_{2i}|A = 1) - E(Y_{2i}|A = 0) \tag{29}$$

Therefore, the BH for a household with a joint decision-maker is the difference between Equation (22) and Equation (25), while BH for a husband solely deciding is the difference between Equation (23) and Equation (23).

2.5 Empirical Strategy

The main motivation of this chapter is to assess the impact of the adoption of joint decision-making on rice varieties among married couples on rice productivity indicators (yield, labor use, and total fertilizer use). A simultaneous equation with ESR was used in estimating the rice productivity indicators (outcome variables) [11] and specified as

$$Adopt_i = \alpha_0 + \sum_{j=1}^{13} \alpha_j lnX_{ij} + \sum_{j=1}^{16} \gamma_j D_j + \sum_{j=1}^{3} \delta_j Z_j + \mu_i \tag{30}$$

$$lnY_{1i} = \alpha_{10} + \sum_{j=1}^{13} \alpha_{1j} lnX_{ij} + \sum_{j=1}^{16} \gamma_{1j} D_j + \varepsilon_{1i} \qquad if \;\; Adopt = 1 \tag{31a}$$

$$lnY_{2i} = \alpha_{20} + \sum_{j=1}^{13} \alpha_{1j} lnX_{ij} + \sum_{j=1}^{16} \gamma_{1j} D_j + \varepsilon_{2i} \qquad if \;\; Adopt = 0 \tag{31b}$$

[11] FIML estimates are obtained using *movestay* command in STATA (Lokshin and Sajaia, 2004).

where Y_{1i} and Y_{2i} are rice productivity outcomes (yield, labor use, and fertilizer use) of the ith household that adopted joint decision-making and husband solely deciding, respectively. The vector X is composed of household characteristics (age and education of the respondent, household size, number of members with off-farm employment, share of women's ownership to productive assets); farm characteristics (share of irrigated area, proportion of medium land, and total plots cultivated); and farm inputs (seed use, total fertilizer use, total family labor, total hired labor, and total contract labor). The vector D is composed of dummy variables which include the following: farm location (Bihar; Odisha; West Bengal, with Uttar Pradesh as the base group); caste (D_4= Scheduled tribe; D_5= Other Backward; and general caste as the based group); the occurrence of flood/drought in 2015 wet season (=1 if there was flood/drought); uses machines (=1 if uses machines); use pesticide (=1 if applied pesticide); transplanted rice (=1 if transplanted rice) and; type of rice varieties (MRV1, MRV2, MRV3, MRV4, MRV5, MR6, and local varieties users as the base group).

The variables in vectors X and D used in Equations (22), (23a), and (23b) are similar. For the model to be fully identified, an additional vector Z (instrumental variables) was included in Equation (22). The instrumental variables used for this chapter include the existing credit the household availed in the past 12 months (Z_1); the difference in the age of the couple (Z_2); and distance to the nearest market (Z_3). The instruments used are existing credit of the household in the past 12 months, differences in the couple's age (husband-wife), and distance to the nearest market. The household access to credit, when availed by women, was found to benefit the household by increasing household assets and savings (Amin et al., 1998). Women's credit participation also increased their self-confidence and recognition of their role in the household (Sharma and Varna, 2008). Kabeer (1998) found that access to credit among households in Bangladesh impacted women's participation in the household decision-making processes. However, access to credit does not necessarily mean high rice productivity. For instance, Chavas et al. (2005) found that Gambian farmers who availed loans from *Osusu*[12] often used the funds for non-farming-related activities. For this study, only a few households have existing agricultural loans in our sample, and most of the loans were used for medical and school expenses. Thus, existing credit can be used as an instrument since it may influence decision-making but may not directly link to rice productivity. The second instrument used is the difference in the couples' age which affects how decisions are made - joint or solo. This instrument represents the power relation between the couple. For instance, Kantor (2003) examined Indian female participants in the home-based garment sector and found that a couple with a large age difference would place more power on the husband. In addition, Schneebaum and Mader (2013) found that smaller age differences foster a joint decision-making process among married couples. Therefore, the age difference may affect women's participation in deciding rice variety but not necessarily the outcome variables. Lastly, the distance to the nearest market could be a barrier for women to select a given rice variety. For example, Nakazi et al. (2017) found that women in Uganda who spend more time walking to the market tend to participate minimally in bean production. Additionally, cultural norms

[12] This means local rotating saving and credit associations in Gambia.

prohibit women from riding a bicycle (major transportation) to access the market. A bicycle is an important form of transportation in Uganda. In eastern India, few women own assets used for transportation (e.g., bicycle, motorbike, and automobile). Thus, if the spouse spends time traveling to the market, she is less likely to participate in the farm decision-making. Any additional time for the spouse for travelling could have been spent in household production (such as cooking, child-rearing, and maintaining livestock). It is hypothesized that the farther the market location, the less likely that women participate in decision-making. The validity of the instruments is presented in Appendix Table 1. The choice of instruments is considered valid if it can influence the selection (joint decision-making strategy) equation but not the outcome equation (productivity indicators). Results confirm that the instrumental variables affect joint-decision for yield and labor equation ($\chi^2 = 39.88; p = 0.000$) and fertilizer equation ($\chi^2 = 11.15; p = 0.000$), which does not affect the outcome variable (yield, labor use, and active fertilizer use).

Several diagnostics tests were performed to know if there are violations when using OLS. To know if there is multicollinearity, the variance inflator factor or *vif* command using the command in Stata 16. Results show that estimated variance inflation factor are below 10, suggesting that multicollinearity is not an issue in our estimation (StataCrop, 2019). Heteroskedasticity using Breusch-Pagan/ Cook-Weisberg was used to reject a constant variance in yield ($\chi^2 = 123.36,\ p - value = 0.000$) and total fertilizer equations. ($\chi^2 = 29.23,\ p - value = 0.000$) suggesting that heteroskedasticity is present. To address heteroskedasticity, the simultaneous equations for yield and total fertilizer equations were re-estimated using a robust standard error or the Huber/White/robust alternate estimate of variance using *vce(robust)* command in Stata 16 (StataCrop, 2019).

The signs of the correlation coefficients ρ_1 and ρ_2 also have economic implications (Fuglie and Bosch, 1995; Alene and Manyong, 2007). If ρ_1 and ρ_2 have alternating signs, households who adopt joint decision-making will have above-average benefits for adopting the strategy. In contrast, those households that chose not to adopt the joint decision-making strategy will have above-average benefits for not adopting. In cases when ρ_1 and ρ_2 have the same signs indicates hierarchical sorting. This means that households under joint decision-making will have above-average benefits whether they adopt or not adopt the strategy but are better off adopting it. In contrast, families with husbands solely deciding to have below-average benefits for not adopting joint decision-making will be better off not adopting.

Results of ESR were then used to estimate the counterfactual outcomes for the two regimes. This allows to compare conditionally expected outcomes (yield, total labor use, and total fertilizer use) and to generate the average treatment effect on treated (ATT) and average treatment effect on untreated (ATU) with joint decision-maker and husband sole decision-maker. In addition, the impact of the selected decision strategy on these outcome variables can also be used depending on the rice variety type adopted by the households. Results can explain the benefits of adopting old released despite a large number of newer rice varieties.

2.6 Survey Data

The study uses the 2016 Rice Monitoring Survey conducted by IRRI. A rice-producing household is defined as a household that produced rice during the past 12 months. The survey targeted the rural population of eastern India by randomly selecting rural areas based on the 2011 Census of India. Four states in the eastern part of India are considered in the study: eastern Uttar Pradesh, Odisha, Bihar, and West Bengal (Figure 2). A multi-stage sampling technique was adopted in selecting the respondents. In the first stage, the number of districts was randomly selected in each state using the Census of 2011. [13] The second stage involves selecting the number of villages based on the proportion of each state's total rice area, keeping the total number of villages at 720. Among the selected villages, household samples are randomly selected using the household census village data. A total of 101 districts and 2,471 rice-producing households are included in the survey (Table 2). All respondents are considered male-headed households.

A structured questionnaire was used to interview the primary male and female decision-makers of the household. Aside from rice variety participation, information regarding the household and rice production were collected from male respondents while information about livestock and household assets were collected from the female respondents. To elicit unbiased responses, the survey employed male and female enumerators in the interview process. The male enumerator interviewed the male respondents while the female

[13] This data set contains information about all the districts, villages, towns, and cities in urban and rural India.

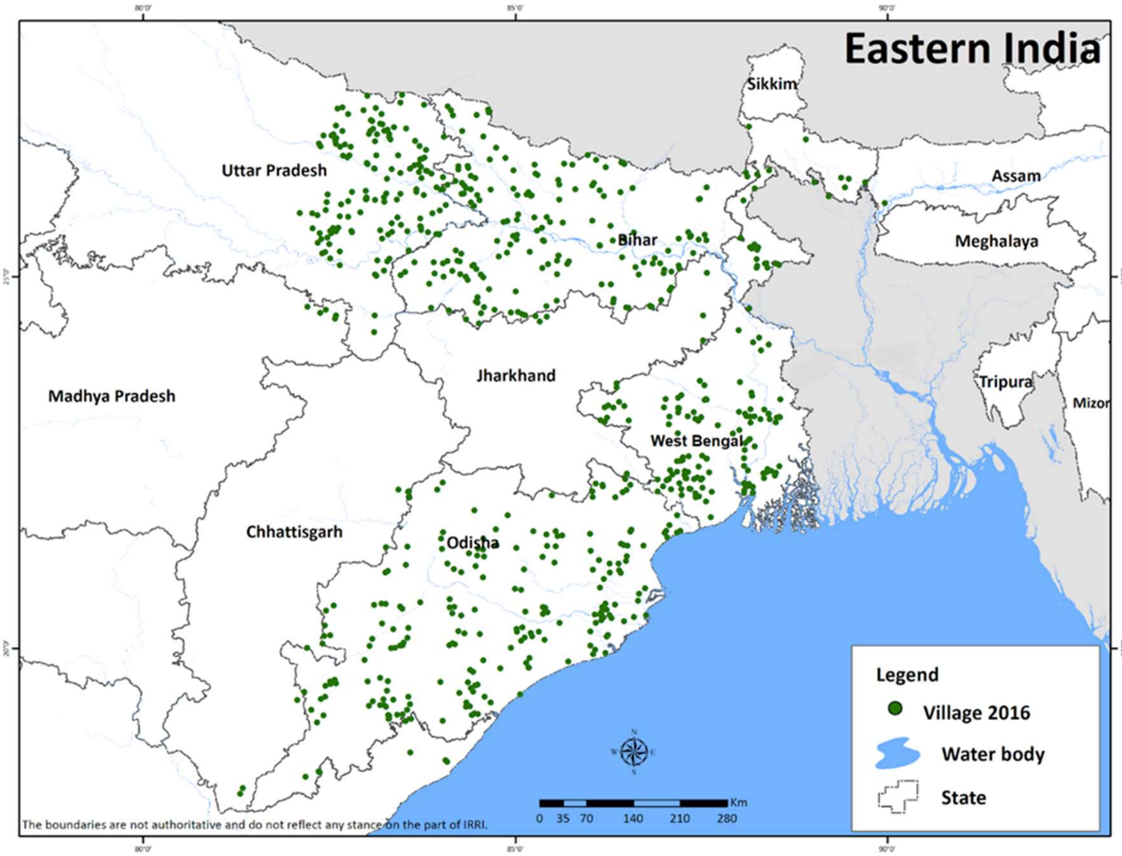

Figure 2: Sample Sites in Eastern India (Photo: IRRI, 2018)

Table 2: Sample Districts and Smallholder Households in Eastern India, 2016.

State	Number of districts	Number of Households
Eastern Uttar Pradesh	37	617
Odisha	30	827
Bihar	16	413
West Bengal	18	614
Total	101	2,471

Source: 2016 Rice Monitoring Survey conducted by IRRI.

enumerator interviewed the female respondents. The study focused on information regarding the 2015 wet season, the primary rice-growing season in eastern India. A computer-assisted personalized interview (CAPI) program, *Surveybe,* was used to collect the data.

To examine the intra-household decision-making, households with married couples and at the same time identified to be the male and female decision-makers were included in the sample. Choosing the married couple as a major criterion is necessary since it is common for Indian households to have an extended family living in one house. Each couple were queried about seven farm production-related decisions but for this chapter, only the decision-making regarding the selection of rice seed varieties was included. The decision-making can be classified as (1) husband only decides in the presence of the spouse; (2) spouse only decides in the husband's presence; and (3) both husband and spouse participated in determining the choice of a rice variety to be used in the coming season. Based on the data category, the data is deficient on households where the spouse solely makes the decision on the choice of selecting rice varieties. Thus, the joint decision-making and husband solely deciding were included in the choices, which takes the value of 1 and 0, respectively.

The rice variety type that the farmer adopted can also be an essential factor in identifying the participation of women. Rice varieties can be classified as traditional varieties and modern rice varieties (MRV).[14] This study further classified modern rice varieties

[14] Traditional rice varieties (TV) are indigenous varieties that farmers have been using for a long time (Mehar et al., 2017).

following the rice variety generation classification done by Laborte et al. (2015) and Launio et al. (2008) and used information such as date of variety release and their distinctive characteristics from the Indian Institute of Rice Research (IIRR). The modern rice variety categories and descriptions used in this chapter are presented in Appendix Table 2.

The summary statistics and definitions of the variables used in the analysis are presented in Appendix Table 3 and 4, respectively. It reveals that more than half of the sample has a husband solely participating in deciding the rice variety. The operator's average age is about 48 years old, almost the same regardless if the household is adopting or not adopting joint decision-making. In addition, households with husbands solely deciding have significantly higher educational attainment and larger family size than households under joint decision-maker. Most of the smallholder households in the sample are dominated by persons of the other backward caste (OBC) class (41%), followed by general caste (30%) and scheduled tribe/scheduled castes (29%).[15] Regarding decision-making, the data shows a significantly higher number of scheduled tribe/caste under joint decision-makers than with husband sole decision-makers. The data also indicates that there are considerably higher households under joint-decision makers in Odisha and Uttar Pradesh compared to households under sole husband decision-makers. Aside from rice production, several

[15] Other backward caste includes castes that are marginalized sectors of the Indian society. On the other hand, general caste is a group of people who do not qualify for any of the affirmative action schemes operated by the Government of India (excludes scheduled castes and scheduled tribes, and other backward classes). This group of people does not qualify for any of the affirmative action schemes operated by the Government of India (excludes scheduled castes, scheduled tribes, and other backward classes). Lastly, the scheduled tribe/caste are considered designated groups of historically marginalized indigenous people in India and recognized by the Government of India (GoI). Since independence, the Scheduled Castes and Scheduled Tribes (SC/ST) were given reservation status, guaranteeing political representation.

households have other sources of income from small businesses, salaried jobs, and employment in the service sector. The data shows that there is at least one member of the family employed in off-farm work. In addition, only a few households have a member who is a migrant worker.[16] The spouses in households with husbands solely deciding have a significantly higher share of productive farm assets than in joint decision-making households.

Rice producers in our sample are considered marginal farmers, with an average cultivated rice area of 0.43 ha. Households under joint decision-makers, however, have significantly larger rice areas than households under husband sole decision-makers by 0.04 ha. Families allocated at least one plot for rice production during Kharif season and mainly planted in a medium land part of the landholdings by 53% of the households. [17] In terms of irrigation, 58% of the total rice area uses supplemental irrigation, such as shallow or deep tube wells. This suggests that some farmers still rely on rainfall as the primary source for irrigation and only irrigate part of their field during the cropping season. Water-related problems are also common in the area, such as floods and droughts. In 2015, around 57% of the smallholder rice producers were affected by flood and drought, particularly households with sole husband decision-makers. Recall that Pandey et al. (2007) note that one reason for the low adoption of technology in eastern India is the frequent flooding and droughts, thus hindering productivity.

[16] At least one household member who is away from home for at least one continuous month at any time during the last 12 months to search for a job or to work in another village, district, state, or country.
[17] Medium land are lands that is intermediate between lowland and upland.

Rice yields in the sample were significantly lower, with an average of 1,615 kg/ha, compared to the national average of 3,700 kg/ha (IRRI, 2019). Husband sole decision-making households have significantly higher rice yield by 134 kg/ha than households under joint decision-makers. The major inputs used in rice production are seeds, labor, and fertilizer (NPK, DAP, and Urea).[18] Families under joint decision-makers apply higher seeds than households under husband sole decision-makers by 4 kg/ha. In terms of fertilizer (NPK, DAP, and Urea), households with husband sole decision-makers apply significantly higher total fertilizer and total active fertilizer ingredients than their counterparts by 45kg/ha and 21kg/ha, respectively. Finally, Appendix Table 3 reveals that smallholder rice producers in eastern India used three types of farming laborers, including family, hired, and contract labor.[19] Family labor provided the largest number of days worked on the rice farm (31 person-days/ha), followed by hired labor (16 person-days/ha) and contract labor (14 person-days/ha). Almost all the households employ the same number of persons in rice production except in contract labor. Households under the husband sole decision-maker employ use significantly higher contract labor than a household with joint decision-maker by 7 (persons day/ha). In terms of total labor, households under husband sole decision-makers employ higher total labor by 4 (person day/ha) than their counterparts.

The adoption of rice variety also differs depending on the decision-making strategy of the couple. It shows a significantly higher number of households under joint decision-making that adopt MRV4 (1996 and later) and MRV6 (mixed generation) than husband sole

[18] NPK fertilizer is composed of nitrogen, phosphorus, and potassium. On the other hand, DAP fertilizer is referred to as diammonium phosphate.

[19] Based on person-days per hectare. Person-days is the same as man-days (1day=6 hours).

decision-making households. On the other hand, there is a significantly higher number of households under husband sole decision-makers that adopt MRV1 (before 1977), MRV3 (1986-1995), and MRV5 (hybrid) than joint decision-making households. Clear distinctions regarding the two household types are very evident in rice variety adoption. Since the sample area is a flood/drought-prone area, MRV4 (primarily for the adverse environment) and MRV6 (mixed generations) serve as safety nets for household production since most households produce rice for home consumption. For instance, Gauchan et al. (2012) and Behura et al. (2012) found that farmers use multiple rice varieties depending on the land types that vary according to topographical sequence and moisture level to ensure production that will supply their family consumption needs.

2.7 Results and Discussions

Determinants of rice yield

The correlation (ρ_i) between the error terms and yield outcomes for joint decision-making and husband solely deciding are presented in Table 3. Results show that there is self-selection for households with joint decision-makers since the selection correction term ρ_1 is 0.535 (*p-value = 0.020*), implies that unobserved factors influence couple's decision in choosing the joint decision-making strategy. On the other hand, the selection correction term ρ_2 is insignificant, meaning that rice yield is the same for a household with joint decision-makers and husband sole decision-makers given their observable characteristics. Since there is evidence of sample selection, the use of OLS will result in biased and inconsistent estimates, requiring the use of ESR. The determinants of the rice yield using

ESR are presented in Appendix Table 5. The first column is the OLS estimation of rice yield without switching. The effect of the decision strategy is through a dummy variable joint decision-making where the value 1 if there is joint decision-making and 0 if the husband solely decides. The third and fourth columns result from the ESR with yield equations under joint decision-making households and husband sole decision-making households. Results show that a larger family has a negative effect on rice yield under

Table 3: Summary of Correlation Coefficients in Yield, Labor Use, and Total Fertilizer Using Endogenous Switching Regression (ESR).

Outcome Equation	Regime 1 (Joint decision-making =1)	Regime 2 (Joint decision-making =0)
Yield		
Square root of the variance of the error term (σ_i)	1.635***	1.365***
	(0.060)	(0.027)
Correlation (ρ_i)	0.535**	0.014
	(0.096)	(0.118)
Labor use		
Square root of the variance of the error term (σ_i)	0.476***	0.578***
	(0.010)	(0.027)
Correlation (ρ_i)	0.132	-0.724***
	(0.179)	(0.090)
Total Fertilizer use		
Square root of the variance of the error term (σ_i)	0.442***	0.612***
	(0.011)	(0.018)
Correlation (ρ_i)	0.166	0.868***
	(0.167)	(0.024)

*** p<0.01, ** p<0.05, * p<0.1.
Standard errors in parentheses.
Note: Full results are in Appendix Tables 5, 6, and 7.

husband sole decision-making households. Additional adult members in the family will decrease the yield by 30% (*p-value=0.010*). The result differs from Mehar et al. (2017) and Manjunatha et al. (2013) found that family size represents the available labor force, which reduces the risk of not having enough labor needed for rice production. Bannor et al. (2020) argued that the negative effect of household size to rice productivity may be linked to the growing lack of interest among younger family members in farming in rural India. In terms of caste, households that belong to Other backward caste (OBC) significantly affect rice yield under joint decision-making households by 31% (*p-value=0.023*). Women from the lower caste can work in the field compared to women in the upper caste. Appendix Table 5 also indicates geographical heterogeneity that affects rice productivity. For instance, in households with the husband sole decision-maker in West Bengal, the yield increased by 42% (*p-value=0.032*) compared to families located in Uttar Pradesh.

The inputs used in rice production have different effects on rice yield. Total hired labor and contract labor negatively affect yield under joint decision-making households by 3% (*p-value=0.014*) and 2% (*p-value=0.09*), respectively. Meanwhile, total family labor and total contract labor positively affect yield under husband sole decision-making households by 8% (*p-value=0.000*) and 2% (*p-value=0.033*), respectively. According to Otsuka et al. (2016), farmers use family labor, particularly when entering a contract labor scheme to ensure labor productivity. Recall that in the sample, households under husband sole decision-maker employed more contract labor than joint decision-making households, which requires family supervision. This result can be related to the method of planting rice. Transplanting is mainly adopted under husband sole decision-making households compared to households under joint decision-making.[20] This method also serves as a safety net used by farmers since most are prone to floods and drought. Farmers usually used an extra quantity of seeds that can be used to replant/resow the same variety if the planted rice is damaged, particularly when flash floods happen in the earlier rice production (Behura et al., 2012).

Regarding land topography, it shows that a higher proportion of medium land negatively affects yield by 43% (*p-value=0.000*) under households with sole husband decision-makers. Recall that these households under the husband's sole decision-makers have a relatively higher proportion of older MRV (1985 and earlier) adopters. Behura et al. (2012) found that older varieties do not perform well in medium land compared to newer varieties. In terms of rice variety, results show that there is a positive effect on yield regardless of decision-maker that adopts MRV1 (before 1977), MRV3 (1986-1995), MRV5 (hybrid rice), and MRV6 (mixed) compared to traditional varieties. For instance, the adoption of MRV6 has a positive effect in yield by 45% (*p-value=0.034*) and 46% (*p-value=0.000*) compared to local varieties under joint decision-maker and sole husband decision-maker households, respectively.

Determinants of total labor use

In estimating the total labor use, the results show that there is self-selection for households under sole husband decision-makers since selection correction term ρ_2 is -0.724 (*p-value=0.000*). This implies that unobserved factors influencing couples to choose the

[20] Transplanting is a method of panting wherein rice seeds are grown in nurseries and pulled and transplanted to the leveled fields (IRRI, 2020)

husband as the sole decision-maker (Table 3). The selection correction term ρ_1 is insignificant. Thus, suggesting that labor use is the same for households with joint decision-makers and husband sole decision-makers given their observed characteristics.

The factors affecting total labor use in rice production are presented in Appendix Table 6. The first column is the OLS estimation of labor use without switching. The effect of the decision strategy is through a dummy variable joint decision-making where the value 1 if there is joint decision-making and 0 if the husband solely decides. The third and fourth columns results from ESR with labor use equations under joint decision-making households and husband sole decision-making households. Findings show that caste, where the household belongs affects labor use. For example, belonging to Other Backward castes negatively affect total labor use by 11% (*p-value=0.004*) and 13% (*p-value=0.002*) for households under joint decision-making and sole husband decision-maker. Recall that household members, particularly women, can cultivate their land compared to women in a higher caste. It might be the case that with available family labor, the total family labor supply may not all be intended for farming their land but also for other off-farm work. In the case of farm location, households under husband sole decision-makers located in Odisha will decrease labor use by 32% (*p-value=0.014*) than households in Uttar Pradesh. In terms of inputs, the quantity of seeds and fertilizer and employing hired labor affect the total labor use for both households. For example, a 1% increase in seed use will result in a 13% (*p-value=0.000*) and 8% (*p-value=0.003*) increase in labor use for households under joint and husband sole decision-makers. In addition, the topography also plays a role in affecting labor use. The results show that a larger proportion of medium land reduces labor use by 7% (*p-value=0.035*) and 17% (*p-value=0.000*) in households with joint decision-making and sole husband decision-makers. This result is consistent with Gauchan et al.'s (2012) findings that there are high labor requirements in rice production in Nepal when rice areas are situated in small terraces in the hills since workers have shorter working hours due to the difficulty reaching the area. In addition, the use of machines requires additional labor use by 19% (*p-value=0.000*) among households under joint-decision-making. This result contrasts with Otsuka et al.'s (2016) findings that households use machines to lessen labor costs in rice farming, particularly the larger farms. In this case, most are considered marginal farms, and machines used may be lower-capacity equipment that still requires additional labor. In addition, the use of pesticides increases labor used in farming by 16% (*p-value=0.000*) among households with husbands solely deciding. There are several pests and diseases that some rice varieties are not resistant to damage the farm and decrease rice production. The application of pesticides will depend on the virus or disease that affects rice which entails additional labor.

Determinants of total fertilizer use

The increase in rice productivity can also be attributed to complementary inputs such as fertilizer (Nitrogen and Phosphorus). The most common chemical fertilizers used among farmers are NPK (15-15-15) and Diammonium phosphate (18-44-0). Nitrogen is essential to rice to improve grain yield, while phosphorus is critical for the reproductive and ripening stage (IRRI, 2020). Among the elements, Nitrogen and Phosphorus are essential for rice growth, and excessive use will not be absorbed by the plant that may affect yield and harm the environment (SRP, 2020). Results show that there is self-selection for households with sole husband decision-makers since the selection correction term ρ_2 is -0.868 (*p-value=0.043*) implying that unobserved factors influence the decision of the couples in choosing the strategy (Table 3). On the other hand, the selection correction term ρ_1 is insignificant, which means that rice yield is the same for both groups, given their observed characteristics.

Appendix Table 7 presents the factors affecting the total fertilizer using ESR. Results show that as the family size increases, the use of active fertilizer decreases by 11% (*p-value=0.010*) among joint decision-making households. This result is consistent with Farouque's (2007) findings in Bangladesh, which relates the fertilizer use to low education common to large families, resulting in unbalanced fertilizer dosages. Recall that though these decision-making groups have almost the same number of household members, the operator under joint decision-making households is less educated than households under the husband's sole decision-maker. The castes also have a significant effect on the use of fertilizer. For instance, if families belonging to Other Backward castes increase total fertilizer use by 15% (*p-value=0.000*) and 12% (*p-value=0.003*) compared to general caste in joint and husband sole decision-making households, respectively. These results are not consistent with the findings of Aryal and Holden (2011), in which there is a lower fertilizer use among the lower caste. Aryal and Holden (2011) found that farmers under low caste usually rent the plots and prefer improved soil conservation technologies that require less chemical fertilizer compared to farmers from the upper caste.

There is also geographical heterogeneity in terms of the use of active fertilizer. The results show that the use of fertilizer has a negative and significant effect in all the households under joint decision-making while a positive effect when the household is under the joint decision-making household in Odisha. For instance, when the household is in Odisha, fertilizer increases by 34% (*p-value=0.012*). There is also a negative effect on fertilizer use when flood/drought occurs in both groups. For instance, if the farmer experienced flood/ drought, fertilizer use will decrease by 9% (*p-value=0.003*) and 10% (*p-value=0.005*) in households under joint decision-maker and husband sole decision-maker, respectively. The result is consistent with Behura et al.'s (2012) findings that less fertilizer was applied due to reducing the area allocated to rice which serves as farmers coping practices due to flood and drought among the farmers in eastern India. In terms of the major inputs, the quantity of seeds and total labor contribute to the increase total fertilizer use in both households. In contrast, pesticides negatively affect fertilizer use only for households where the husband is the sole decision-makers by 11% (*p-value=0.002*).

Among the rice varieties, a positive effect on total fertilizer use is noticeable when adopting MRV5 (hybrid) for both households and MRV3 (1986-1995) for husband sole decision-making households. For instance, when the household adopts MRV5 (hybrid), the total fertilizer use will increase by 28% (*p-value=0.002*) and 33% (*p-value=0.000*) for households under joint decision-making and husband decision-making, respectively. An additional proportion of medium land in households where husbands are sole decision-makers increases the total fertilizer use by 13% (*p-value=0.001*). This result is expected since MRV5 (hybrid) production requires complementary inputs, particularly fertilizer, to meet the potential yield (Mottaleb et al., 2015).

Impact of joint decision-making strategies on rice yield

Table 4 shows the expected quantity of rice produced (kg/ha) under actual and counterfactual conditions. For instance, the cells (A) and (B) represent the expected rice yields (kg/ha) observed in the sample. Cells (C) and (D) represent the expected rice yields (kg/ha) in the counterfactual case. Results show that the expected rice yield of households under joint decision-making was about 844 kg/ha and 1,049 kg/ha for husband sole decision-making households. However, this simple comparison could be misleading in attributing the different values of expected yields for both groups.

Column 3 of Table 4 shows the treatment effect on the adoption of joint decision-making strategy on rice productivity. In the counterfactual case (C), joint decision-making households would have produced less (about 125 kg/ha, or 17%) if they had not adopted a joint decision-making strategy. Similarly, in the counterfactual case (D), households with husband decision-makers who decided to switch to joint decision-making strategy would have produced about 81% less if they had adopted joint decision-making. In addition, the transitional heterogeneity is positive (978 kg/ha) and the effect is significantly smaller for families with husband solely deciding than with joint decision- making (Table 4).

The last row adjusts for potential heterogeneity shows that families with joint decision-maker that decided not to follow the strategy would have produced significantly lower yield than households with husband sole decision-maker (counterfactual) by 331 kg/ha. The results suggest that there are sources of heterogeneity that makes the household with husband sole decision-maker better off than household with joint decision-maker that did

Table 4: Average Treatment Effect on Treated/Untreated and Heterogeneity Effects to Rice Yield (Kg/ha).

Type of household	Decision strategy		ATE/ATU	
	Adopt joint decision-making	Did not adopt (Husband solely deciding)	Change	%
	(1)	(2)	(3)	
Joint	843.96[A]	718.56[C]	125.40***	17.45
	(21.97)	(15.37)	(26.82)	
Husband solely	196.70[D]	1,049.24[B]	-852.54***	-81.25
	(4.87)	(21.29)	(21.84)	
Heterogeneity	647.26***	-330.68***	977.94***	
	(21.89)	(26.54)	(27.98)	

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Note: [A] and [B] represents expected yield (kg/ha) observed in the sample while [C] and [D] represents expected yield (kg/ha) in the counterfactual case. (1 tonne=1000 kg).
Full results are in Appendix Table 8.

not adopt the strategy. Further, households with joint decision-maker that adopted the strategy has higher rice productivity by 647 kg/ha than households with husband sole decision-maker that decided to adopt joint decision-making (D). This suggests that household with joint decision-making are better off following the strategy than a household with husband sole decision-makers who follow the joint decision-making strategy.

In terms of adopted rice varieties, Appendix Table 8 shows that yield advantage among rice varieties. Most rice smallholder households show a yield advantage when following joint decision-making and using local varieties, MRV2 (1977-1985), MRV3 (1986-1995). Among these rice varieties, joint decision-making on rice variety selection has the highest yield impacts for MRV2 generation of rice variety. Appendix Table 8 (Columns 3 and 4) show that households' expected rice yield under joint decision-making was about 827 kg/ha and 509 kg/ha for husband sole decision-making households. Following joint decision-making, households would have produced less (about 317kg/ha, or 62%) if they had not adopted a joint decision-making strategy. Similarly, in the counterfactual case (D) in MR2, rice farmers under husband sole decision-maker households would have produced about 71% less if they had adopted joint decision-making (Appendix Table 8). The results show that the difference in rice variety affects household productivity. The study by Paris et al. (2008) found that male and female farmers in eastern Uttar Pradesh have sets of preferred traits in choosing a particular variety based on varying factors (e.g., environmental, socio-economic, and cultural, and cultural gender roles). Specifically, Paris et al. (2008) shows that male farmers prefer rice varieties based on agronomical traits (e.g., tolerance to submergence, resistance to pests, and responsiveness to fertilizer). In contrast, women farmers prefer more intrinsic qualities of rice varieties (e.g., taste, cooking qualities, and grain shape). However, both men and women farmers prefer high yielding, good taste and aroma, and postharvest quality. One of the popular mega-varieties is Swarna, which covers almost 30% of the total rice area in eastern India as of 2015 (Tsusaka et al., 2015), and belongs to the MRV2 category. High productivity and consumer preference may be driving factors. MRV2 contains attributes that are attractive to both farmers and spouses. For instance, studies (Tsusaka et al., 2015; Mehar et al., 2017) have shown that farmers prefer most mega-varieties due to their higher yield and good eating quality. A sensory evaluation analysis done by Champagne et al. (2010) shows that Swarna has a rough cooking surface suited to the thick sauce prominent in Indian cuisine. Thus, it is no surprise that the study found positive effects of joint decision-making on rice yields in MRV2—rice varieties that were bred for grain yields and consumer preference attributes.

Impact of joint decision-making strategies to labor use

The impact of labor requirements on the choice decision-making strategy is presented in Table 5. Results show that the total labor under joint decision-making households requires 33 person-days/ha less labor (by 107%) if they had not adopted the decision strategy. The same is true for families with husband sole decision-maker in which it will require 8 person-days/ha less (about 11%) if they had not adopted the decision strategy. In addition, the transitional heterogeneity is positive (25 persons-day/ha), and the effect is significantly smaller for households with husbands solely deciding than with joint decision-making. The last row of Table 5 adjusts for potential heterogeneity, showing that households with joint decision-makers that decided to follow the strategy would have required significantly lower labor than households with sole decision-maker (D) by 11 persons-day/ha. Further, households with joint decision-makers who decided not to adopt the strategy also has a lower labor requirement by 36 persons-day/ha than households with husband sole decision-maker (C). The results suggest that heterogeneity sources make the joint decision-making households who decided to follow and not follow the strategy require less labor than the husband's sole decision-maker.

Regarding rice variety type, results show that households under joint decision-makers that adopt MRV4 require the highest labor requirement than its counterpart (by 140%) (Appendix Table 9). On the other hand, households under husband sole decision-makers that also adopt MRV4 have the highest reduction of labor requirement of 25% if they had not adopted the strategy. The low labor requirement among husband sole decision-makers may be due to increased dependence on hired labor, particularly contract labor arrangement

Table 5: Average Treatment Effect on Treated/Untreated and Heterogeneity Effects to Total Labor Use (Person day/ha).

Type of household	Decision strategy		ATE/ATU	
	Adopt joint decision-making (1)	Did not adopt (Husband solely deciding) (2)	Change (3)	%
Joint	63.11^{A}	30.43^{C}	32.68***	107.42
	(0.57)	(0.26)	(0.63)	
Husband solely	74.04^{D}	66.22^{B}	7.82***	11.81
	(0.62)	(0.53)	(0.82)	
Heterogeneity	-10.93***	-35.80***	24.86***	
	(0.85)	(0.60)	(0.52)	

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Note: ^{A} and ^{B} represents expected yield (kg/ha) observed in the sample while ^{C} and ^{D} represents expected yield (kg/ha) in the counterfactual case. (1 tonne=1000 kg).
Full results are in Appendix Table 9.

in this group. Since labor costs are one of the major costs in rice production, covering 25%-40% of the total cost, additional labor would mean lowering profitability among the farmers (Chengappa et al., 2003; Janaiah and Xie, 2010).

Impact of joint decision-making strategies to fertilizer use

Table 6 shows the impact of decision-making strategy on active fertilizer use. Results show that joint decision-making households used 163 kg/ha (by 60%) more fertilizer if they did not adopt the strategy. On the other hand, the households where husband solely deciding used 124 kg/ha of active fertilizer (by 14%) less than if they had not adopted the strategy. In addition, the last row of Table 6 shows the transitional heterogeneity, which is (-159 kg/ha). The potential heterogeneity shows that households with joint decision-makers that decided not to follow the strategy would have required significantly higher total fertilizer than households with sole decision-maker (C) by 146 kg/ha. The results suggest that there

Table 6: Average Treatment Effect on Treated/Untreated and Heterogeneity Effects to Total Fertilizer Use (Kg/ha).

Type of household	Decision strategy		ATE/ATU	
	Adopt joint decision-making (1)	Did not adopt (Husband solely deciding) (2)	Change (3)	%
Joint	106.85^{A}	269.40^{C}	-162.55***	-60.34
	(1.81)	(4.71)	(5.04)	
Husband solely	106.20^{D}	123.90^{B}	-17.80***	-14.34
	(1.77)	(1.98)	(2.66)	
Heterogeneity	0.70	145.50***	-158.50***	
	(2.53)	(5.00)	(3.06)	

Standard errors in parentheses: *** p < 0.01, ** p < 0.05, * p < 0.1.
Note: ^{A} and ^{B} represents expected total fertilizer (kg/ha) observed in the sample while ^{C} and ^{D} represents expected total fertilizer (kg/ha) in the counterfactual case.
Full results are in Appendix Table 10.

are sources of heterogeneity that make the household with husband sole decision-maker require less total fertilizer than with joint decision-maker that did not adopt the strategy. Further, households with husband sole decision-makers who decided to follow joint decision-making strategy would have required the same amount of labor as the joint decision-makers who followed the strategy. In terms of variety, husband sole decision-making households require a high amount of total fertilizer use, particularly when adopting MRV 5 (Hybrid), which requires 27% higher than its counterpart Appendix Table 10.

2.8 Conclusions and Implications

The choice of rice varieties is critical and often is assumed to be the decision of the male household head. However, with the household head frequently absent from the farm due to off-farm work or dual employment, women are increasingly taking charge of jointly participating in decision-making-related farming activities. This chapter examined the impact of how married couples' decision-making strategy regarding the rice variety choice on yield, total labor use, and total fertilizer use in eastern India. The study used the Monitoring Survey, which provides gender disaggregated data to assess the households' decision-making status and rice production during Kharif season. A simultaneous equation using an endogenous switching regression was used to account for unobservable factors that affect rice productivity indicators (yield, total labor, and total fertilizer) and the joint decision-making in choosing rice variety.

The findings showed that farming households under joint decision-making tend to have higher rice yields than their counterparts. Rice farmers who adopted joint decision-making have some attributes, such as skills, that make them more productive with implementing joint decision-making strategies. Further, the joint decision-making strategy has positively impacted the rice yield of MRV2 (rice varieties released between 1977-85) by producing more MRV2 rice yield than farmers who did not adopt a joint decision-making strategy in the counterfactual. The yield advantage of MRV2 rice variety among joint decision-making households increases rice yield due to familiarity with the rice variety. The impact of the joint decision-making strategy is also evident in the complementary inputs such as labor and total fertilizer. Results show that households where the husband sole decision-maker requires lower labor and higher fertilizer usage than households with joint decision-makers regardless of rice variety type. The reduction of inputs such as labor is essential for a smallholder since labor comprised the major costs of rice production that lowers the overall profitability (Janaiah and Hossain, 2013; Pampolino et al., 2007).

Findings from this study confirmed that the joint decision-making strategy of the couple results in a gender-differentiated impact on rice productivity indicators (yield, total labor, and total fertilizer). Thus, identifying the primary decision-maker is very important for the implementation of rice technology programs. An allocation of beneficiaries based on a percentage of farmers would not maximize the adoption of a variety since the decision-maker varies in each household. Information regarding who is responsible for making varietal decisions should be acknowledged and incorporated into program interventions. Indeed, this study provides a starting point for research on women's strengths and limitations in male-headed households. It is often preconceived that women's rice farming participation is limited only to family labor contributions. Since joint decision-making households perform well in producing MRV2, which is commonly composed of mega varieties like Swarna, increasing awareness about the flood-tolerant version of Swarna (Swarna-Sub1) should be targeted in this group. Studies show no significant difference between Swarna and Swarna-Sub1 in terms of agronomical, grain quality, taste, grain length, and grain yield under normal conditions (Sarkar et al., 2006; Neeraja et al., 2007).

There are three potential interventions where women can further participate in rice production activities. First is participation in varietal development, which can verify the acceptability of newly developed rice variety lines through the Participatory Varietal Selection (PVS). Using this method, male and female farmers can participate in the initial screening of rice variety lines before releasing for public use (Paris et al., 2011). Usually, participants are selected based on the proportion of the male-headed and female-headed rice farming households in the area. Since the sample shows that eastern India is mainly composed of male-headed households, women's participation can still be included. In a PVS strategy for submergence tolerant varieties in Southeast Asia, researchers involved the spouse of the participating households by selecting only a sub-sample of the farmer participants (Paris et al., 2011). Manzanilla et al. (2013) found that female farmers are knowledgeable as the male farmers in evaluating the lines/variety visible characteristics of submergence tolerant varieties in Southeast Asia.

Second, targeting women's self-help groups (WSHG) is one of the most pathways in reaching women. It is well known in the literature that WSHGs serve as channels in disseminating information, particularly in areas that are hard for extension workers to enter. Since MRVs are composed of specific agronomical characteristics (e.g., potential yield, grain size, resistance to pests and diseases), information can be disseminated through farmer field's schools or demonstration plots. Farmer schools enable women to be exposed to new labor-saving technologies and proper farm management practices that can lead to adoption.

Lastly, women can be educated regarding proper fertilizer management. Though the use of N and P may improve yields, however, there is growing evidence that excessive use of these chemical fertilizers may lead to lower yield and may cause environmental problems such as soil acidification, greenhouse gas emission (Peng et al., 2006; Guo et al., 2010; Cassman et al., 2003; Smil, 2004). Several natural techniques help manage soil nutrients. For example, the site-specific nutrient management (SNNM) technique adjusts Nitrogen, Phosphorus, and Potassium management. The technique is based on the plot's specific season and field conditions to fill the nutrient deficit to sustain fertility (Buresh, 2009). One of the components of the SSNM is the use of Leaf Color Chart (LCC), which is a tool in assessing the leaf greenness that serves as a guide on when to apply N (Witt et al., 2005; Buresh 2009). A cross-country comparison study in India, Vietnam, and the Philippines show that SSNM users increased their yield and reduced their labor and fertilizer cost (Pampolino et al., 2007). Using LCC, women can learn how to manage the nutrient condition in their field and apply fertilizer with the appropriate amount and proper timing, which is critical in achieving a higher yield.

This study has two important caveats. First, the study uses cross-sectional data for one rice season, which suggests that the findings are applicable only on a short-run basis and should be interpreted accordingly. To capture long-term adoption impacts, one needs to have panel data. Second, the results for joint decision-making show women's participation but did not provide information regarding the measure of control between women and men in the joint decision-making process. The degree of women's control within the joint decision-making framework is worth exploring in future studies.

3 ACCESS TO FINANCIAL SERVICES BY SPOUSES, TECHNOLOGICAL AND MANAGERIAL GAPS IN RICE PRODUCTION

3.1 Introduction

The improvement of farm productivity among smallholder producers has been identified as one of the critical strategies for increasing income and reducing poverty among developing countries (World Bank, 2008). In India, smallholder families (< than 1 ha land) constitute around 85% of the agricultural producers in the country (GOI, 2017). These smallholder farmers face significant farming hurdles and complex production constraints such as low technology adoption rates due to poor farming services, lack of access to credit, and low income due to low marketing efficiency (NABARD, 2018). To reduce poverty and increase competitiveness among smallholders, government and donor institutions have emphasized the role of farmers' organizations (FOs) that serve as an alternative approach for disseminating technology and extension services (Meinzen-Dick, 2014; Chamala and Shingi, 1997). Also, these FOs (e.g., cooperative or self-help groups) provide smallholders access to financial services opportunities in improving agricultural productivity and food security (Fletschner and Kenney, 2014). According to the International Labor Organization (ILO), the availability of rural financial services is essential for smallholder farmers' areas to support agricultural (e.g., asset building and working capital) and non-agricultural activities (e.g., education and health) (ILO, 2019). With budgetary pressures in many developing and emerging economies like India, the intensification of rural financial sector reforms through FOs has become a dominant means in shaping its agricultural policies (Rivera and Blum, 2009).

The importance of access to financial services and agricultural productivity has been established in the literature. Several studies have found that membership in FOs specializing in financial services provided a faster way to disseminate and adopt technologies (Abate et al., 2014; Bernard and Spielman, 2009; Abebaw and Haile, 2013; Ainembabazi et al., 2017). FOs influence policies for rural development, such as lowering transaction cost, access to inputs, and production commercialization (Bosc, 2018; Meinzen-Dick, 2002; Hellin et al., 2009; Bernard and Spielman, 2009; Verhofstadt and Maertens, 2014; Mudege, 2015; Chagwiza et al., 2016). Additionally, access to financial services has improved farmers' production efficiency (Khanal and Regmi, 2018; Abdallah, 2016; Duy et al., 2015; Laha, 2013; Backman et al., 2011). However, most studies investigating the impacts of financial services have only considered the household heads' (HH) access to finances, and most HHs tend to be men.

According to Fletschner (2008), the household as a unit of analysis that entirely depends on the husband for decision-making may lead to incorrect results since it does not consider gender differences in terms of roles, responsibilities, and rights. Ragasa (2014) and Fletschner and Kenney (2014) found that most financial programs are designed for men, who usually own the land, have greater access to credit, and are usually willing to invest in more productive inputs. Zeller et al. (1997) pointed out that incorporating women in most agricultural credit schemes is often overlooked. Further, the importance of women has significant potential in exploring the expansion of output and processing. Women are often discriminated against due to low levels of education and ownership of assets needed for collateral, thus, leading to gender differences in accessing financial services. For example, Demirguc-Kunt et al. (2018) found that in 2017, around 83% of Indian men had an account at a formal financial institution which is higher than women with an account holding rate of 77%. This suggests that despite government efforts in promoting different financial policies based on gender, there still exists a gender differential in terms of access to financial services. Women's inability to source funds from formal lenders (e.g. banks and cooperatives) left them with no choice but to seek funds from informal sources, including moneylenders who charge high interest rates pushing the household more to extreme poverty.

The increasing male migration from rural to urban areas due to income diversification has brought significant changes in gender roles for women in farming and financial literacy due to remittance flows (Pingali et al., 2019; ILO, 2019). With limited access to rice production resources, yield gaps have been growing concerns despite the extensive rice technology promotion (Laborte et al., 2012). According to Hazell (2009), to achieve the maximum potential of Green Revolution technologies, a set of affordable, relevant inputs, including credit, should be available. Thus, it is essential to empower women with knowledge of production and financing by providing access to improved agricultural practices and links to markets by participating in FOs and contract farming. Empirical evidence shows mixed impacts on women's access to financial services.

Evidence shows that women with access to credit provided opportunities for personal growth, improved household economic situation, and adopted new technologies (Sharma and Varma, 2008; Swain and Wallentin, 2002; Fletschner and Carter, 2008; Raghunathan et al., 2018). Previous studies suggest an intra-household spillover effect on the husband.

For example, Chowdhury (2009) found that women in Bangladesh with credit from the Grameen Bank positively affected male-operated micro-enterprises performance but did not affect the performance of women-managed enterprises. Results further show that women members of the Grameen Banks hand their loans to their husbands who started the micro-enterprise, which women only manage. Another study by Fletschner (2006) found that households in Paraguay experienced a 25% loss in production efficiency when the husband experienced credit constraints, while an additional decrease in efficiency by 11% when the spouse also faced credit constraints.

There is still a gap in the literature that fails to directly link women's membership in financial service organizations (FSOs) that offer financial services and rice technical efficiency. [21] This study attempts to fill the gap. Specifically, this chapter analyzes the impact of women's access to financial services through membership in FSOs on rice production efficiency. It separates technological and managerial gaps among the two rice producers' with access and without access to financial services through membership to FOs. The study uses an extensive nationally representative household-level survey, the 2016 Rice Monitoring Survey, deployed by the International Rice Research Institute (IRRI). The study contributes to the literature in several areas. First, this chapter uses an econometric method that corrects selectivity bias due to women's decisions to participate in FSOs. The econometric method approach incorporated the Propensity Score Matching (PSM) addresses the selectivity bias due to observable characteristics. Also, the study uses Greene's (2010) selection-correction stochastic frontier approach for the unobservable

[21] Financial Service Organizations (FSO) provide access to financial services by membership).

attributes to examine the separate impact of the two groups' technological and managerial gap.

Second, this chapter focuses on spouses' access to financial services and their impact on rice production efficiency. [22] Most studies only include the male household head, which fails to recognize the importance of women's access to financial services. Since there is an increase in women's access to financial services through FSOs, the study provides information on whether access to financial resources (e.g., loans or savings) can translate into higher production efficiency. Lastly, following Villano et al. (2015), the study estimates the meta-frontier to directly compare technical efficiencies that reflect technical efficiency and managerial gaps in households with and without access to financial services by spouses. Thus, rigorous assessment of the impact of spouses' access to financial services on technical efficiency is essential and the first step towards increasing rice smallholders' income and food security. Accounting for selection bias will provide real contributions of women in rice production. This result will send a positive message, particularly at a local level, regarding women's importance to farming and increasing competitiveness in India's agricultural sector. In addition, the results can offer a justification for a strong commitment from national institutions such as the Ministry of Finance and Ministry of Rural Development by introducing policy changes that increase women's access to financial services.

[22] The term "spouse" refers to the wife in this chapter.

3.2 Review of Literature

Farmers Organizations (FOs) in India

In fast-growing local and international markets, farmers should have equal access to inputs (e.g., seeds and fertilizers) and output markets. However, with the widening equality gap between men and women, particularly in rural areas, India's government and development organization has been implementing projects to improve farmers' livelihoods, in particular female farmers. National policies regarding rural development were designed in a structure wherein smallholders were organized into groups that serve as channels for delivering services to rural people. FOs are groups are typically selected to provide various inputs, marketing, and educational services in agriculture. The common farmer organization where smallholders participate are producer associations, cooperatives, unions, and federations (IFAD, 2016). Chamala and Shingi (1997) broadly classified FOs into two categories: community-based/resource-orientated organizations and commodity-based/market-oriented organizations. The former generally deal with small clients like village-based cooperatives and similar organizations. Simultaneously, the latter consists of the organization specializing with single commodity or value-added products with the expanded market.

In India, cooperatives are one of the common FOs and have existed since 1904 under the Cooperative Law of India and later became the Multi-state Cooperative Societies Act 1984. These laws enable cooperatives to operate in multiple states (FAO, 2019). In 2010, the Primary and Agricultural Cooperative Societies (PACS) reported that credit cooperatives membership covers 72% of the total cooperative members in India (NCUI, 2019). Self-help groups (SHG) are another popular FO that was first implemented under India's Ninth Five-Year Plan (1997-2002). In 2011, the SHG program was elevated to a national level and is considered the most extensive poverty alleviation program under the National Rural Livelihood Mission (NRLM) (MoSPI, 2014). The primary purpose of SHG is to empower women by assisting with regard to financial problems and personal issues (Swain and Wallentin, 2012). Usually, a group comprises 10-20 adult women who collectively save money that will eventually be used as loans for its members (Raghunathan et al., 2018).

Women and financial services

The expansion of financial resource availability has been one of the major policies among developing countries to accelerate agricultural productivity (Binswanger and Khandker, 1995). However, the availability of financial services is affected by geographical factors (e.g., limited bank service and serving less populated areas) and socio-economic factors (e.g., income, ethnicity group, and financial illiteracy). Thus, geographical location may hinder women's access to financial resources (Beck and De la Torre, 2007). India's government has been implementing policy interventions designed to deliver credit services to smallholders. The rural credit reforms in India started in the early 1970s. Commercial institutions increased their agriculture presence through policies like the Lead Bank Scheme and regulatory prescription of Priority Sector Lending and enactment of the National Bank for Agriculture and Rural Development (NABRD) (RBI, 2019). In recent years, several financial programs have been implemented for the financing of agricultural production. These programs, such as Pradhan Mantri Jan Dan Yojana (PMJDY) and

Pradhan Mantri Mudra Yojana (PMMJ), provide universal access to banking facilities (GOI, 2021).

The recognition of inequality between men and women started in the 1970s, leading to the Women in Development (WID) reform (Fernando, 1997). One of the effects of WID reforms is the adoption of gender mainstreaming which incorporates gender issues in all government institutions and policies (Oklai, 2011). In the Millennium Development Goals of 2015, promoting gender equality empowered women by eliminating barriers in achieving the goals (FAO, 2019). Several government policies and developmental programs organizing women are identified as fuel for empowering women. In India, self-help group (SHG) is often linked to credit, one of the most extensive programs in developing countries. A growing literature shows how financial services helped change women's roles in the household through self-improvement. For instance, Desai and Olosfgard (2019) show that Indian women who belong to SHGs increased bargaining power and enhanced cooperation among themselves, which can be a promising avenue in improving the delivery quality of public goods like water roads and health.

On the other hand, Sharma and Varma (2008) find that women who became members developed self-confidence, recognized their status in the family, and participated in the organization's activities. Patil and Kokate (2017) and Swain and Wallestin (2012) also found that SHG helped Indian women be more financially independent of informal lenders (e.g., moneylenders that charge high interest rates) and helped promote savings. Furthermore, Amin et al. (1998) find that women in Bangladesh who participated in credit through SHG are more confident, self-reliant, and know their rights. These organizations provide a flexible space for these women to interact within a group that results in social change (Fernando, 1997).

Households who are members also tend to build up assets through livestock accumulation and savings. Women who are SHG members also increased their assets, income, and savings since they can diversify the sources of income since members ventured to livestock farming (Swain and Varghese, 2002). It was estimated that women members increase their assets by 34% and employment by 30% (Swain and Varghese, 2002; Deininger and Lui, 2003). However, credit alone is not enough to make women confident. Banerjee and Ghosh (2012) found that training about credit will help women use credit for their enterprise to make them more independent. Membership in FSOs also makes women aware of their rights against domestic violence. Membership in FSOs protects women against domestic abuse since some groups included condemnation of domestic violence in their charter which stipulates that violators can result in membership expulsion (Mudege et al., 2015). Women's membership in financial institutions can also be used to channel faster technology adoption among farmers. Raghunathan et al. (2018) found that Indian women members of PRADAN's livelihood program tend to improve their decision-making regarding agricultural matters and access to bank accounts and loans unrelated to food and consumer durables. However, existing social norms can hinder women's decision-making in participating in organizational activities. For example, Fletschner and Cater (2008) found that membership in women's groups affected entrepreneurial capital demand. Similarly, Magnan et al. (2015) found that women in Uttar Pradesh (India) are less likely to adopt new technologies if they belong to poor households.

Despite the considerable evidence about the impact of financial institutions on women, there is scarce information about women's access to financial resources through FOs and the technical efficiency of rice farming in India. One related study by Rahman (2010) examined the relationship between female labor participation and technical efficiency of rice producers and found that female labor input significantly increases the technical efficiency of rice producers in Bangladesh. In another study, Seymour (2016) developed and used the women empowerment index to explain technical efficiency in Bangladesh and found that a reduction in the gender empowerment gap positively affects the technical efficiency of crops. In other words, empowering women in terms of their roles and participation in agriculture increased the technical efficiency of crop farms in Bangladesh. Though financial inclusion is essential, particularly in rice production, recent studies on access to credit and its effect on production efficiency are usually focused on Southeast Asia or Sub-Saharan Africa. For instance, Khanal and Regmi (2018) found financial constraints due to drought decreased rice technical efficiency of Indonesian farmers. Abdallah (2016) also found that access to credit increased technical efficiency (by 3.8%) of maize farmers in Ghana. Concerning financial institutions, most studies have examined the impact of cooperative membership on technical efficiency. For example, Abate et al. (2014) found that membership in a cooperative tends to lower inefficiency due to the number of plots, crop diversification, and gender of the member. In another study, Ainembabazi et al. (2017) found that membership in farmer groups (MFG) in Africa decreased technical inefficiency in input usage and increased farm productivity. Several studies (Rahman, 2010; Abdul-Rahman and Abdulai, 2017; Ma et al., 2017; Ma et al., 2018; Mishra et al., 2019) have considered selection bias and technical efficiency. This chapter also argues that spouses (wife) decision to join or not join FSOs may be influenced by unobserved spouses' attributes like skills, experiences, and social status resulting to potential selection bias. Thus, accounting for this bias is essential in order to have unbiased and consistent estimates. The latest studies incorporate selectivity correction in SPF while estimating the impact of household head membership on production efficiency (Rahman, 2010; Abdul-Rahman and Abdulai, 2017; Ma et al., 2017; Ma et al., 2018).

3.3 Theoretical Model

This chapter's theoretical framework conceptualizes the linkage between spouse's access to financial service from FSO and farm output. Smallholder households maximizes the utility from profit (R). Limited or binding credit can lead to productivity and efficiency differentials between families where spouses have access to financial service from FSOs and their counterparts (Carter, 1989; Mukasa et al., 2017). Smallholder families that receive credit through spouses' membership in FSOs are expected to increase profits that could be achieved through given resources and selling of products to the market. The spouses' access to credit enable farming families to buy quality inputs, hire additional labor, and enhance their ability to make sound investment decisions.

Consider a smallholder family with L total land availability and X variable inputs (seeds, fertilizer chemicals, family, and hired labor). Thus, the farm production function is represented as $f(X, L, \Theta)$ where Θ is a vector of production shifters. Let p_q and w represent the unit market price of output and inputs, respectively. Thus, the profit can be defined as:

$$R = p_q f(X, L, \Theta) - wX \quad (1)$$

where $f(X, L, \Theta)$ is a concave production function. The family is also assumed to have a certain income Y that is allocated for consumption C at unit price p_c. If $Y \geq p_c C + wX$, then smallholder families can finance the production and consumption expenses without seeking out external financial resources. However, in most smallholder families in India, the farmer's income is insufficient to pay for both production and consumption expenses. In this situation, the farmer can only pay for fraction *s,* where $0 < s < 1$, of the variable inputs. Hence, $(1 - s)$ portion of variable inputs should be financed through loans from formal and informal sources. In this case, the spouse's membership in FSOs provides credit and saving that fills the financial gap. Spouses in the sample were queried about assets, savings, and borrowing. More than half of the sampled spouses had access to financial services through membership in FSOs. These FSOs provide loans (*K*) to spouses who are members of the FSOs and charge interest rates *r* on the loans. Thus, smallholder's problem is to maximize the utility of profit *U*(*R*) as follows:

$$Max\ U[R(X)] = U\left[p_q f(X, L, \Theta) - swX - (1 - s)wX\right] \qquad (2)$$

subject to:

$$(1 - s)wX \leq K(\Phi, \Theta) + (I - p_c C - swX) \qquad (3)$$

$$0 \leq K(\Phi, \Theta) \leq \tau L \qquad (4)$$

Equation (3) shows that expenditures on variable input, *X* are limited by smallholder's initial income *Y*, consumption expenditures $p_c\ C$, and credit limit $K(\Phi, \Theta)$. The maximum amount of credit available to the spouse depends on production attributes Θ (factors affecting rice production such as labor, farm size, farmer's farming experience, and intended use of credit) and family consumption shifters Φ (family size, financial status, and wealth). Equation (4) shows the smallholder family's credit limit and is determined by the value of land owned (L) at unit price τ. This can be interpreted as collateral that farmers or spouses use to seek credit[23]. In other words, the amount of land could be considered as the creditworthiness of the family. In addition, the two inequalities in Equation (4) represents two constraints scenarios of the farmers: credit-constrained without binding and with binding (Mukasa et al., 2017). The farmer's problem can be solved using a Lagrangean function:

$$L = U\left[p_q f(X, L, \Theta) - swX - (1-s)wX\right] + \lambda[K(\Phi, \Theta) + (\mathrm{I} - p_c C - swX) - (1-s)wX] + \Gamma[K(\Phi, \Theta) - \tau L] \quad (5)$$

where λ and Γ are shadow prices of the credit constraint and loan limit, respectively. Solving Equation (5), one can obtain the following Kuhn-Tucker conditions:

$$U'(.)\left[p_q f(.) - sw - (1-s)w\right] + \lambda[sw - (1-s)w] = 0, \; X \geq 0 \quad (6)$$

$$\lambda[K(\Phi, \Theta) + (I - p_c C - swX) - (1-s)wX] = 0, \; \lambda \geq 0 \quad (7)$$

$$\Gamma[K(\Phi, \Theta) - \tau L] = 0, \quad \Gamma \geq 0 \quad (8)$$

If the credit constraint is not binding, then $\lambda = 0$ thus Equation (6) results in $U'(.)[p_o f_x(.) - sw - (1-s)w] = 0$ implying that $p_o f_x = 0$. In other words, the marginal value product $p_o f_x(.)$ of inputs, at the optimum, should be equal to the marginal cost w of inputs, independent of consumption. On the other hand, if the credit constraint is

[23] There is usually asymmetric information resulting in lenders using collateral when the farmer will not abide once the loan was granted (Mukasa et al.,2017).

binding, then $\lambda > 0$ the optimality condition is given as $U'(.)[p_o f_x(.) - w] - \lambda w] = 0$, then $p_o f_x\ [1 + \lambda/U'(.)] > w$ because both λ and $U'(\ .)$ are strictly positive. For a credit-constrained smallholder, the marginal value product of variable inputs is higher than the marginal costs by the factor of $[1 + \lambda/U'(.)]$. The results imply that credit-constrained smallholder rice farmers in India may use sub-optimal levels of variable inputs. In other words, the higher the shadow price of the credit constraint, the optimal level of inputs used by Indian rice farmers lowers which may affect in achieving its potential profits. Thus, relaxing credit constraints through loans from FSOs where spouses have access to financial services (credit) may help rice farmers to use better and required inputs to improve rice productivity and farm profitability.

3.4 Estimation Strategy

The study's motivation is to assess the impact of spouses' access to financial services and rice production efficiency to estimate rice producers' technology and managerial gap in eastern India. The study uses a multi-step approach. In part one, the major constraints that affect women's access to primary financial services were evaluated by employing Propensity Score Matching (PSM) to control selection bias for observed characteristics. This study utilizes stochastic production frontier (SPF) with the corrected sample to control the unobserved characteristics in rice production efficiency estimation in the second stage. Lastly, meta-frontiers analysis is used to compare the impact of financial services and technical efficiency (TE) for households where the spouse has access to (without access to) financial services.

The study assumes that the spouse decides (binary choice) to have access to financial services in a FSOs or not. Using the utility maximization framework, the probability of women with access to financial services is determined by comparing the expected benefits from having an access (F_A^*) and the expected benefits of not having an access (F_{NA}^*). As expected, women will choose to have access to financial services if the expected benefits are greater than the expected benefit of not having an access; i.e. $F^* = F_A^* - F_{NA}^* > 0$. The latent variable F^* is unobservable, which can be influenced by socio-economic and farm characteristics. The decision model can be written as:

$$F_i^* = \gamma Z_i + \varepsilon_i \qquad F_i = \begin{cases} 1 \ if \ F^* > 0 \\ 0 \ otherrwise \end{cases} \tag{9}$$

where F^* is women access indicator that equal to 1 if women have access to financial services and 0 when women do not have access. The Z represents a vector of observable characteristics, i is the ith farmer, γ is a vector of unknown parameters to be estimated, and ε is an error term with mean zero and σ^2. The probability of participating in an organization is given as:

$$Pr\ (F_i = 1)\ = Pr\ (F_i^* > 0\ ) = Pr\ (\varepsilon_i > -Z_i\gamma)\ = 1 - F - (-Z_i\gamma) \tag{10}$$

where F is the cumulative distribution of ε_i. Women's possibilities to access financial services in the area depend on the constraints women face are based on socio-economic and geographical characteristics (Beck and De la Torre, 2007).

Stochastic production frontier: Impact of women's access to financial services

The Stochastic Production Frontier (SPF) function developed by Aigner, Lovell, and Schmidt (1977) and Meeusen and Van den Broeck (1977) is used in this study. The SPF function acknowledges other factors such as unpredictable weather, drought, and flood that often experienced in rice production, preventing from reaching the potential productivity (Koirala et al., 2016; Ma et al., 2018). The SPF is defined as:

$$Y_i = f(X, F) + (\varepsilon_i) \qquad where \;\; \varepsilon_i = v_i - \mu_i \tag{11}$$

where Y_i represents the production function for i farm; X is the vector of inputs and other variables, and F is the women's access to financial services. The error component is composed of two parts: v_i and μ_i. The v_i is a random error associated with factors that are outside the control of the farmer (e.g., measurement error and weather) and assumed to be independent and identically distributed random errors with $N(0, \sigma_v^2)$ and independent of the μ_i's. On the other hand, μ_i is a non-negative random variable associated with farm-specific factors that contribute to why the ith farm is not attaining maximum efficiency of production, and assumed to be independent and identically distributed with non-negative (one-sided) half-normal distribution $|N(0, \sigma_\mu^2)|$. The value of μ_i can take the value of zero if the farm is technically efficient and one if it is technically inefficient (Kalirajan and Shand, 1999).

Stochastic Production Frontier (SPF) and selection correction

In estimating SPF, addressing self-selection among farmers in accessing financial services is essential to avoid selection bias due to the observable and unobservable factors that play an important role in determining membership's impact on efficiency. To account for selection issues due to observed and unobserved attributes, a multi-stage approach was adopted following the studies of Abdul-Rahman and Abdulai (2018), Ma et al. (2019), Villano et al. (2015), and Bravo-Ureta et al. (2012). The first stage addresses the selection bias of the observable attributes using the Propensity Score Matching (PSM) technique by Rosenbum and Robin (1983). This technique matches spouses with and without access to financial services based on their observable characteristics. A Probit modeling approach is used to estimate Equation (1). A propensity score for every farmer in the sample based on their observed characteristics.

Several studies have examined the SPF and at the time addressing selection bias due to unobservable attributes. For instance, Lai et al. (2009) assume that selectivity bias is related to error term in the sample selection Equation (11) while Kumbhakar et al. (2009) pointed out that selectivity bias is due to the correlation of error term in Equation (11) and μ_i in the SPF. However, these studies mentioned the need to use computationally demanding log-likelihood function, yet do not provide superiority in results. Therefore, this chapter follows the SPF model by Greene (2010). This model is an extension of Heckman's approach, which assumes that the error in the selection Eq. (3) is correlated with the noise in the stochastic frontier $\rho = corr(e_i, v_i) \neq 0$. The sample selection model with the error structure is given by the following equations:

$$Sample\ Selection: F_i = 1\ [\gamma' Z_i + \omega_i > 0], \quad \omega_i N(0,1) \tag{12}$$

$$SPF: Y_i = \beta' X_i + \varepsilon_i, \quad \varepsilon_i\, N(0, \sigma^2) \tag{13}$$

$where\ (Y_i, x_i)$ are observed when $F_i = 1$. Error structures: $\varepsilon_i = v_i - \mu_i$

$$\mu_i = |\sigma_\mu U_i| = \sigma_\mu |U_i|, \text{ where } U_i(0,1)$$

$$v_i = |\sigma_\mu V_i| = \sigma_\mu |V_i|, \text{ where } V_i(0,1)$$

$$(e_i\, v_i) \sim N_2\left[(0,0), \left(1, \rho\sigma_v, \sigma_\mu^2\ \right)\right]$$

where Y_i is logarithmic rice yield of farmer $i = 1,2, \ldots, n$, X_i are the logarithmic input quantities, F_i is a binary variable which is equal to 1 if the spouse has access to financial services and 0 otherwise. The Z_i represents the covariates of the sample selection model, ε_i is the error term of the stochastic frontier model where v_i is the conventional error term and u_i is the efficiency term, ω_i is the error term of the selection equation, and β and γ are parameters to be estimated. The efficiency term μ_i follows a half-normal distribution with dispersion σ_μ while ω_i and v_i follow a bivariate normal distribution with variances 1 and σ_v^2, respectively. The correlation coefficient, $\rho\sigma_v$, which means that there is a selection bias due to unobservable attributes if the term is significant. In cases where ρ is insignificant, the maximand will reduce to that of the maximum simulated likelihood estimator of the basic frontier model. Two separate selection correction SPF are estimated to derive a TE for the spouse with and without access to financial services from FSOs.

Stochastic Meta-Frontier

To directly compare technical efficiency between groups (e.g., spouse's with access and without access to financial services), the study follows O'Donnell and Villano's (2015) approach by estimating the meta-frontier which envelops the individual group (j). The deterministic meta-frontier production function is expressed as:

$$Y_i^* = f(x_i, \beta^*)\, e^{x_i \beta^*} \tag{14}$$

where $Y_i^*$is the meta-frontier output and β is the vector of meta-frontier parameters which satisfy the constraints $x_i\beta^* \geq\ x_i\beta_j$ where β_j are parameters from spouses with and without access to financial services group frontiers. Following O'Donnell (2008), the metatechnology ratio (MTR), which is the ratio of the output for frontier production for group j relative to highest possible meta-frontier output, which can be defined as:

$$MTR = \frac{e^{x_i \beta_j}}{e^{x_i \beta^*}} \quad (15)$$

The technical efficiency (TE_M) with respect to the meta-frontier can be calculated as:

$$TE_M = TE_j \; x \; MTR_j \quad (16)$$

3.5 Survey Data

The study uses the 2016 Rice Monitoring Survey conducted by IRRI. A rice-producing household is defined as a household that produced rice during the past 12 months. The survey targeted eastern India's rural population by randomly selecting rural areas based on India's 2011 Census. Four states in India's eastern part are considered in the study: eastern Uttar Pradesh, Odisha, Bihar, and West Bengal. The study adopted a multi-stage sampling technique in selecting the respondents. In the first stage, the number of districts was randomly selected in each state using the Census of 2011.[24] On the other hand, the second stage involves selecting the number of villages based on the proportion of each state's total rice area, keeping the total number of villages at 720. Among the selected villages, household samples are randomly selected using the household census village data. A total of 101 districts and 1,697 rice-producing households are included in the survey (Table 7).

[24] This data set contains information about all the districts, villages, towns, and cities in urban and rural India.

Table 7: Sample Districts and Smallholder Households, Eastern India, 2016.

State	Number of districts	Number of Households
Eastern Uttar Pradesh	37	472
Odisha	30	548
Bihar	16	299
West Bengal	18	378
Total	101	1,697

Source: 2016 Rice Monitoring Survey conducted by IRRI.

A structured questionnaire was used to interview the primary male and female decision-makers of the household. Only households with married couples and at the same time identified to be the male and female decision-makers were included in the sample. Choosing the married couple as a major criterion is necessary since it is common for Indian households to have an extended family living in one house. Information regarding rice production and farm-related decision-making were collected from husbands, and information regarding livestock, household assets, and decision regarding farming, savings and borrowing were collected from spouses. To elicit unbiased responses, the survey employed male and female enumerators in the interview process. The male enumerator interviewed the operator while the female enumerator interviewed the spouse. The study focused on information regarding the 2015 wet season, the primary rice-growing season in eastern India. A computer-assisted personalized interview (CAPI) program, *Surveybe,* was used to collect the data.

Membership in a group represents women's leadership and their influence in society following the International Food Research Institute (Malapit, 2015). Group membership varies from agricultural-related (e.g., cooperative, SHG, agricultural producers, water organization) to non-agricultural-related organizations (e.g., civic and religious groups). In this chapter, all the interviews queried the spouse regarding their participation in any group. Thus, the definition of access to financial services in this chapter includes access to financial services (e.g., saving accounts and loan participation) by the spouse through their participation in FSOs.

The definitions and summary statistics of the variables used in the analysis are presented in Appendix Table 11. The results show that 52% of the sample comprises households with a spouse who has access to financial services. The average spouse's educational attainment is very low. Nearly half of the spouses have reached more than primary education. The average household size across the sample was about four. The sample also shows that nearly half of the respondents have at least one member with off-farm work (e.g., business, salaried job, or government job). When it comes to social classification, most smallholder households in the sample (40%) belong to Other Backward castes (OBC) classes, followed by general caste and Scheduled Tribe/Scheduled Castes.[25] Interestingly, 45% of OBC families have spouses who have access to financial services, compared to 26% SC/ST families and 29% general caste categories. There are also many households below Poverty Line (BPL) cardholders, particularly under households without access (58%) compared to

[25] Other backward caste includes castes that are marginalized sectors of the Indian society. On the other hand, general caste is a group of people who do not qualify for any of the affirmative action schemes operated by the Government of India (excludes scheduled castes and scheduled tribes, and other backward classes). This group of people does not qualify for any of the affirmative action schemes operated by the Government of India (excludes scheduled castes, scheduled tribes, and other backward classes). Lastly, the scheduled tribe/caste are considered designated groups of historically marginalized indigenous people in India and recognized by the Government of India (GoI). Since independence, the Scheduled Castes and Scheduled Tribes (SC/ST) were given reservation status, guaranteeing political representation.

households with access. [26] The data suggests that most of the sample farmers are considered below poverty, receiving assistance from the government. In addition, nearly half of the households have kids ages nine years old and below. The sample also shows that only a few spouses own a mobile phone in terms of assets, and most of the households own at least two livestock (e.g., sheep or cattle).

Rice yields in the sample were significantly lower, with an average of 1,917 kg/ha, compared to the national average of 3,700 kg/ha (IRRI, 2019). The average cultivated rice among the sample is 0.41 ha, which is considered marginal under the Indian context. In terms of land topography, nearly half is considered medium land.[27] In addition, more than half of the households use supplemental irrigation (59%), mainly groundwater irrigation, such as shallow or deep tube wells, suggesting that farms in eastern India still rely on rainfall as the primary source for irrigation. Abiotic stresses, such as floods and drought, are the major problems that affect production in the area. In 2015, around 65% of the smallholder rice producers were affected by floods and drought. Recall that Pandey et al. (2007) note that one reason for the low adoption of technology in eastern India is the frequent flooding and droughts, thus hindering productivity (Appendix Table 11).

The major inputs used in rice production are seeds, fertilizer (NPK, Urea, and DAP), and labor. [28] On average, a rice farmer used about 34.6 kg/ha of seeds. Similarly, the average

[26] Below Poverty Line (BPL) is a population that the Indian government identified to be economically disadvantaged. BPL cards are issued to people who were considered to fall under the BPL category to benefit from the government's welfare programs (Ram et al., 2009).
[27] Medium land is the land that is intermediate between lowland and upland.
[28] NPK fertilizer is composed of nitrogen, phosphorus, and potassium while DAP fertilizer is referred to as diammonium phosphate.

rice farmer used 279 kg/ha fertilizer (NPK, Urea, and DAP). Interestingly, most households use machinery, but only a few (13%) own large farm equipment (such as threshers, tractors, and power tillers). Appendix Table 11 also reveals that smallholder rice producers require an average of 62 person-days/ha of total labor, and more than 60% of the households employ hired labor. Finally, Appendix Table 11 shows that farmers usually mixed the rice variety they use for cropping season. For example, around 30% of farmers used mixed rice varieties, while 18% only use rice varieties under MRV2 (1977-85). Surprisingly, 11% of the farmers still use solely local rice varieties despite the government's effort in developing and disseminating new rice varieties.

3.6 Econometric Strategy

A matching technique generates counterfactual groups to match households with spouses with access to financial services from FSOs. Following Greene (2010), the probit model was estimated using the observable characteristics to produce propensity scores. To mitigate bias in the matching process, the current study employs the nearest neighbor matching (NNM) algorithm with a maximum of five matches with a caliper of $0.025\sigma_p$ presented in Appendix Table 12.[29] The matching procedure yielded a total of 1,656 matched. A comparison of means was used to examine if there are no significant differences between the two groups in the matched sample, thus fulfilling the covariates'

[29] $\sigma_p = \sqrt{\sigma_0^2 + \sigma_1^2/2}$, where 0 and 1 are standard deviations of estimated propensity scores of the control and the treatment groups, respectively (see Cochran and Rubin, 1973).

balancing condition using the *pstest* command in STATA 16 (Appendix Table 13) (Caliendo and Kopeinig, 2008).

Table 8 shows the marginal effects from the estimated probit model for the matched and unmatched sample. Results show that households with BPL cards, that own livestock, and spouses who own mobile phones are more likely to have access to financial services from FSOs. In contrast, the presence of children under nine years old and below, and farm families located in Bihar, Odisha, and West Bengal, compared to eastern Uttar Pradesh, are less likely to have access to financial services from FSOs. The models (unmatched and matched) have similarities and differences.

Table 8 reveals that the signs of the coefficients are the same in both models. The key differences are that the matched sample shows fewer statistically significant coefficients, and the hypothesis that coefficients are simultaneously zero is only rejected in the unmatched model. The two differences are consistent with reducing the variability of the sample attributes induced by the PSM. Figure 3 shows the density plots of the propensity scores for spouses with and without access to financial service from FSOs. The common support is also satisfied with propensity scores ranging from 0.18 to 0.96.

In estimating production frontier efficiency, two functional forms were estimated namely, Cobb-Douglas (Ma et al., 2018; Abdul-Rahman and Abdulai, 2018) and the transcendental logarithmic (translog) function (Villano et al., 2015; Seymour, 2017; and Bravo-Ureta et al., 2011), that are commonly used in the literature. To identify the appropriate functional form, a likelihood ratio test was used against the translog form (Appendix Table 14). The decision led to the rejection of the Cobb-Douglas function (LR= 17.11, *p-value=0.06*). Thus, the translog function is given as,

$$lnY_i = \beta_0 + \sum_{j=1}^{4} \beta_j lnX_{ij} + \frac{1}{2}\sum_{j=1}^{4}\sum_{j=1}^{4} \beta_{jk}\, ln\, ln\, X_{ij}\, lnX_{ik} + Med + \sum_{j=1}^{16} \gamma_j D_j + FA + v_i - \mu_i \quad (17)$$

where Y_i is the rice yield (kg/ha) of the ith farmer, X_j denotes the vector of input used in the production, including the quantity of seeds (kg/ha), total fertilizer (kg/ha), total labor used in rice production (person-per-day/ha), and total cultivated rice area (ha). The land

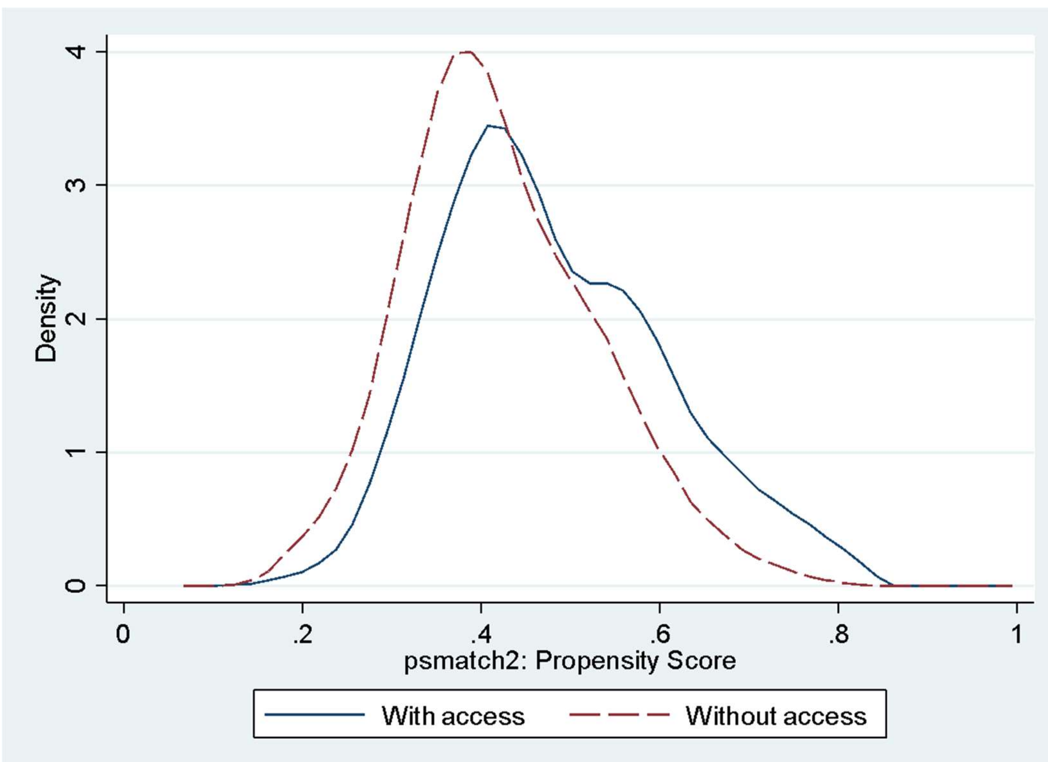

Figure 3: Density of the Propensity Score for Household where Spouses with Access and Without Access to Financial Services.

topography is included using the proportion of medium land (Med). There are 16 dummy D_j variables which include the following: farm location (D_1= Bihar; D_2= Odisha; and D_3= West Bengal); caste (D_4= Scheduled tribe; D_5= Other backward); the occurrence of flood/drought in 2015 wet season (D_6=1 if there was flood/drought); with supplemental irrigation (D_7=1 if the plot is irrigated); uses machines (D_8=1 if uses machines); large farming equipment ownership (D_9=1 if large equipment is owned); hired laborer (D_{10}=1 if hired labor is employed); type of rice varieties ($D_{11} - D_{16}$); and the spouse's access to financial access services (FA = 1 if the spouse has access). The parameters β and γ are parameters estimated, and v and μ are elements of the error term ε, which is an uncorrelated error term with $N(0, \sigma_\varepsilon)$ distribution.

A pooled SPF for the matched sample was estimated with the spouse's access to financial services (through FSOs) as a dummy variable in the rice production efficiency. To examine the technology difference between household with access and without access, the LR test was used following Battese and Coelli (1998). The null hypothesis assumes that there is no difference between the pooled frontier and two separate frontiers. The decision (LR= 92.59, *p-value=0.000*) to separate the group led to the estimation of SPF of each group for conventional and sample selection of Greene (2010) (Appendix Table 14). The analysis of SPF for conventional and sample-selection models was estimated using NLOGIT 6. The meta-frontier function was computed using linear programming for the optimization problem using MATLAB.

Table 8: Marginal Effects from Probit Estimates of the Unmatched and Matched Groups.

Dependent: Access to financial services	Unmatched		Matched	
	Marginal effects	SE	Marginal effects	SE
Spouse age (years)	-0.002*	(0.001)	-0.002	(0.001)
Spouse education: less than primary level (=1 if yes; 0 otherwise)[1]	0.051	(0.035)	0.047	(0.036)
Spouse education: more than primary level (=1 if yes; 0 otherwise)[2]	0.058*	(0.034)	0.055	(0.034)
Household size[3]	0.016*	(0.009)	0.014	(0.010)
With kids with 9 years below (1=yes; 0=otherwise)	-0.066**	(0.027)	-0.055**	(0.027)
With Below Poverty card (1=yes; 0=otherwise)	0.054**	(0.027)	0.052*	(0.027)
Number of livestock[4]	0.023**	(0.010)	0.021**	(0.010)
With off-farm source of income (=1 if yes; 0 otherwise)[5]	-0.028	(0.045)	-0.016	(0.046)
With ground water irrigation (1 if yes; 0 otherwise)[6]	-0.017	(0.036)	-0.018	(0.037)
Spouse owns phone (1 if yes; 0 otherwise)	0.138***	(0.031)	0.132***	(0.031)
Scheduled caste/tribe (=1 if yes; 0 otherwise)[7]	0.057	(0.036)	0.052	(0.036)
Other backward caste (=1 if yes; 0 otherwise)[8]	0.036	(0.034)	0.031	(0.034)
Farm located in Bihar (1=yes; 0=otherwise)	-0.347***	(0.057)	-0.352***	(0.057)
Farm located Odisha (1=yes; 0=otherwise)	-0.491***	(0.043)	-0.484***	(0.044)
Farm located West Bengal (1=yes; 0=otherwise)	-0.473**	(0.037)	-0.464***	(0.039)
Log-Likelihood	-1,049.50		-1,032.25	
Total observations	1,697		1,656	

Standard deviations in parentheses: *** p<0.01, ** p<0.05, * p<0.1 [1] Spouse completed class 5/primary or class below; [2] Spouse completed class 5/primary or degree above; [3] Adult (>15 years old) members of the household.;
[4] Livestock includes the following: buffalo, dairy cattle, goats, sheep, chicken, ducks, and pigs; [5] At least one of the couples has off-farm employment (such as service, business, or government); [6] Household uses groundwater irrigation source such as shallow and deep water tubewell.
[7] Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.; [8]Includes castes that are socially and educationally marginalized.
Source: 2016 Rice Monitoring Survey conducted by IRRI.

3.7 Results and Discussion

Stochastic production function estimates

Tables 9 and 10 provide the selected estimates of the conventional and selectivity-corrected SPF for unmatched and matched samples (Appendix Table 15 and 16 for all the estimates). The estimated models in Table 9 and Table 10 present the partial production elasticities of all models with different magnitudes and significance.[30] Results show that the technical inefficiency variable λ (LR=176.51, *p-value=0.000*) is significant, thus rejecting the null hypothesis ($\lambda = 0$) at the 1% level of significance (Appendix Table 14). This finding suggests that technical inefficiency is associated with output loss for farming families with and without access to financial services from FSOs where spouses are members. Results in Table 10 show that self-selection, denoted by ρ, in the matched sample households with spouses with access (-0.657, *p-value=0.042*) and without access to financial services (-0.838, *p-value=0.001*) from FSOs. The selectivity-correction term is significant, suggesting that unobserved factors influence the spouses' decision to engage or not to engage in financial assistance provided by FSOs. The results are consistent with the literature studies that found evidence of selection bias related to program participation (Rahman, Schmitz, and Wronka, 2009; Bravo-Ureta, Greene, and Solis, 2012; Villano et al., 2015; Mishra et al. 2018).

[30] The variables of the translog models used in Table 9 and 10 and Appendix Table 15 and 16 were normalized by their geometric means to be interpreted as partial elasticities (Coelli et al., 2003).

Table 9: Estimates of the Conventional and Sample Selection SPF: Unmatched sample.

		Pooled	Conventional		Sample Selection	
			With access	Without access	With access	Without access
Constant	β_0	7.688***	7.672***	7.814***	7.736***	7.767***
		(0.078)	(0.115)	(0.111)	(0.133)	(0.212)
Seed	β_1	-0.059**	-0.096***	0.020	-0.095**	-0.004
		(0.023)	(0.032)	(0.032)	(0.034)	(0.040)
Fertilizer	β_2	0.125***	0.094	0.142***	0.073	0.136**
		(0.040)	(0.062)	(0.049)	(0.067)	(0.056)
Labor	β_3	0.051*	0.080**	0.005	0.077*	0.006
		(0.027)	(0.037)	(0.033)	(0.042)	(0.042)
Area	β_4	0.121**	0.098	0.154**	0.073	0.118*
		(0.047)	(0.070)	(0.059)	(0.075)	(0.069)
Financial access	FA	-0.042*				
		(0.024)				
Lambda (λ)		4.533***	3.869***	8.712***		
		(0.362)	(0.388)	(1.370)		
Variance (σ^2)		0.926***	0.909***	0.939***		
		(0.000)	(0.001)	(0.001)		
Sigma -u (σ_u)					0.917***	0.904***
					(0.030)	(0.021)
Sigma – v (σ_v)					0.213***	0.145***
					(0.036)	(0.025)
Rho (ρ)					-0.431	-0.185
					(0.486)	(0.827)
Log likelihood function		-1,362.85	-714.74	-604.99	-1,235.00	-1,136.51

*p<0.10, **p<0.05, ***p<0.001. Standard errors are inside the parenthesis.
Full results are in Appendix Table 15.

Table 10: Estimates of the Conventional and Sample Selection SPF: Matched sample.

		Pooled	Conventional		Sample Selection	
			With access	Without access	With access	Without access
Constant	β_0	7.688***	7.672***	7.837***	7.781***	7.766***
		(0.079)	(0.115)	(0.103)	(0.134)	(0.078)
Seed	β_1	-0.067***	-0.096***	0.004	-0.090**	-0.006
		(0.023)	(0.032)	(0.030)	(0.033)	(0.022)
Fertilizer	β_2	0.126***	0.092	0.138**	0.093	0.097***
		(0.041)	(0.062)	(0.049)	(0.070)	(0.034)
Labor	β_3	0.048*	0.081**	-0.010	0.064	-0.010
		(0.027)	(0.037)	(0.032)	(0.042)	(0.026)
Area	β_4	0.114**	0.097	0.120**	0.081	0.068*
		(0.048)	(0.070)	(0.057)	(0.076)	(0.039)
Financial access	FA	-0.038				
		(0.024)				
Lambda (λ)		4.510***	3.915***	10.576***		
		(0.369)	(0.398)	(1.960)		
Variance (σ^2)		0.929***	0.912***	0.951***		
		(0.000)	(0.001)	(0.001)		
Sigma -u (σ_u)					0.919***	0.937***
					(0.033)	(0.012)
Sigma – v (σ_v)					0.241***	0.074***
					(0.049)	(0.018)
Rho (ρ)					-0.657**	0.838***
					(0.323)	(0.244)
Log likelihood function		-1,336.75	-714.74	-577.63	-1,224.64	-1,094.81

*p<0.10, **p<0.05, ***p<0.001. Standard errors are inside the parenthesis.
Full results are in Appendix Table 16.

In terms of major inputs, the results from the selectivity-corrected SPF of the matched sample (Table 10, last two columns) show that the total quantity of seeds used in rice production significantly reduces rice productivity, particularly in the household with access to financial services. In other words, a 10% increase in seed usage will result in a 9% (*p-value=0.007*) decrease in rice productivity. Most farmers in eastern India's flood-prone areas use the transplanting method to grow rice and use excessive seeds (seeding rate up to 60% higher than normal) to compensate for the potential crop loss. A negative relationship between seeds and output may result from farmers' over-utilizing seeds (Majumder et al., 2016). This finding is consistent with Mishra et al. (2015), who found a negative and significant relationship between the quantity of seeds and rice output in Bangladesh. However, the above finding contrasts with Mishra et al. (2018) and Mariano et al. (2011), who found a positive and significant relationship between the quantity of seeds and rice output. For spouses without access to financial resources, Table 10 shows that fertilizer usage (9.7%) contributes to rice productivity, followed by cultivated rice areas (7%).

Farm location has the highest contribution to rice productivity (Appendix Table 16). Results suggest geographical heterogeneity in terms of rice productivity. Farm location has the highest contribution to rice productivity (Appendix Table 16). Compared to farms located in eastern Uttar Pradesh, results indicate a significant potential of increasing productivity in Bihar, West Bengal, and Odisha, particularly in households where the spouse has access to financial services. The occurrence of drought and/or flood significantly reduces rice output for both groups in the sample-selection group of the matched sample (Appendix Table 16, last two columns). In particular, the occurrence of stress conditions (drought/floods) decreases rice output by 16% (*p-value=0.001*) and 19% (*p-value=0.000*) for farm families with spouses with and without access to financial services from FSOs, respectively. This finding is consistent with Mishra et al.'s (2015), who found that abiotic stresses (drought and flood) reduced rice production among rice farmers in Bangladesh.

While the labor input is insignificant for both groups (Table 10 last two columns), hiring laborers decreases rice output. For example, Appendix Table 16 shows (last two columns) that hired labor decreases rice output by about 17% (*p-value=0.000*) among households where the spouse has access to financial services. On the other hand, hired labor reduces rice output by about 8% (*p-value=0.001*) among families where the spouse has no access to financial services. Interestingly, Appendix Table 16 (last two columns) shows that the use of farm mechanization increases rice output by about 16% (*p-value=0.001*) among households where the spouse has access to financial services. Similarly, farm machinery increases rice output, but a smaller increase by 10% (*p-value=0.001*) in farms where the spouse has no access to financial services. Our finding is consistent with Mariano et al. (2011), who found that the use of machinery (e.g., harvester and thresher), labor-saving technologies, increased rice output among Filipino rice farmers.

Lastly, Appendix Table 16 shows that farmers using MRV2 (1977-75) and MVR4 (1996 or later) rice varieties have significantly higher rice productivity than farmers using local rice varieties. However, the magnitude of the increased rice productivity is higher for farm households where the spouse has access to financial services access (21% for MRV2 and 23% for MRV4) than households where the spouse has no access to financial services (13% for MRV2 and 21% for MRV4). Familiarity and compatibility of a rice variety to the production conditions and environment may explain both groups' positive relationship. For example, MRV4 was developed for adverse environments, wherein *Swarna-Sub1* (flood-tolerant variety) is a popular variety. For instance, Dar et al. (2012) show that farmers who used *Swarna-Sub1* had a 66% yield advantage compared to other rice varieties, even up to 13 days of submergence. Indeed, findings underscore the importance of access to financial resources in rice production. The results show that spouses' membership in FSOs relaxed households' liquidity constraints and helped farmers purchase more and quality inputs.

Technical efficiency and yield performance

Table 11 shows the descriptive statistics for the MTRs (Equation 15) and metafrontier TEs (Equation 16) for matched samples. To contrast, the results for the metafrontier analysis with both conventional and sample selection models were reported. The signs and magnitude of the estimates of the effect of spouses' access to financial services on MTR and TE-metafrontier for unmatched and matched samples. The results for the matched sample (lower part of Table 11) shows the magnitude of the estimated technical efficiency coefficient in most of the variable is lower when correcting for sample-selection bias. In addition, the technical efficiency of smallholders whose spouses have access to financial services through FSOs is slightly higher (54%) than their counterparts (53%). The result is consistent with Heriqbaldi et al. (2015), who argues that economic incentives increased technical efficiency. Additionally, Brázdik (2006) found that farmers with credit constraints had lower technical efficiency. However, comparing TE between groups is inappropriate since estimates are computed based on each group's frontier. Table 11 reveals that smallholders who have access to financial services (via spouses' membership in FSOs) have a positive and statistically significant effect on technology gaps and managerial gaps, as shown by the last two rows of Table 11. Specifically, findings reveal that spouses' access to financial services increases the MTR by about 6.1% and the TE-metafrontier by about 3.6%.[31] In other words, the above results show that both technology

[31] The MTR was computed using O'Donnell's (2008) approach. The estimated parameters from TL selectivity-corrected SPF specified in Equation (16) were fitted using linear programming in MATLAB.

Table 11: Effects of Spouses' Access to Credit on Technical Efficiency, Technology, and Managerial Gap, Rice Production in Eastern India.

	With access (1)		Without access (2)		Difference (3)
	Mean	SE	Mean	SE	Mean
Unmatched sample					
Conventional SPF					
Pool TE[a]	0.557	0.006	0.573	0.007	0.017*
TE[b]	0.561	0.007	0.648	0.005	0.087***
Sample Selection SPF					
TE	0.552	0.007	0.545	0.009	0.006
Metatechnology ratio (MTR)	0.618	0.006	0.569	0.006	0.049***
TE-Metafrontier[c]	0.338	0.005	0.305	0.006	0.033***
Matched sample					
Conventional SPF					
Pool TE[a]	0.556	0.007	0.571	0.007	0.015
TE[b]	0.561	0.007	0.671	0.004	0.110***
Sample Selection SPF					
TE	0.542	0.007	0.533	0.009	0.009
Metatechnology ratio (MTR)	0.608	0.006	0.547	0.007	0.061***
TE-Metafrontier[c]	0.328	0.006	0.291	0.006	0.036***

*p<0.10, **p<0.05,***p<0.001.

[a] TE estimates using conventional SPF and pooled data set.

[b] TE estimates relative to the individual's group frontier using conventional SPF.

[c] TE estimates relative to the metafrontier.

and managerial gaps favor smallholders whose spouses have access to financial services via FSOs over their counterparts.

Other key input variables and output performance

The effect of spouses' access to financial services on key inputs used and output performance are presented in Table 12. The results show statistically significant differences between input usage by smallholders with access to financial services and their counterparts. On average, it was observed, after taking out biases from observable attributes, that smallholders with access to financial services applied about 38kg/ha more fertilizer than their counterparts. Of the three major fertilizer, smallholders with access to financial services used at least 20kg/ha of DAP than their counterparts. When it came to labor usage, smallholders with access to financial services used less labor. Most of the reduction in labor came from a reduction in the labor used in crop management (labor used in the application of fertilizer, pesticide irrigation, and weeding). Specifically, smallholders with access to financial services used about 2 person-days/ha less labor than smallholders without access to financial services. Among the type of labor, results show that smallholders without access to financial services use more family labor than households without access to financial services (Table 12). The high family labor requirement among households without access is more evident during harvesting and post-harvest, requiring at least two persons day/ha. In terms of hired labor requirements, results show that the two groups have different managing styles. Smallholders with access to financial services used 1.3 person-days/ha more, while households without access hired less than one person-days/ha for crop management. In terms of entering a contract labor arrangement, it shows that family with access requires 0.40 persons day/ ha higher than households without access to financial services. The above findings indicate that smallholders with access to financial services are clever businessmen who understand better the time value of money and allocate family labor to higher-paying off-farm jobs and hiring labor for crop establishment. Farmers should be cautious in employing labor in rice production since labor cost in rice production covers most of the total production cost, decreases productivity (Janiah and Hossain, 2013). Though sampled households have access to

Table 12: Effects of Spouses' Access to Credit on Key Input Variables, Rice Production in Eastern India.

	With Access (1)		Without Access (2)		Diff (3)
	Mean	SE	Mean	SE	
Seed (kg/ha)	33.63	0.88	35.60	1.08	-1.97
Total fertilizer (kg/ha)	298.01	6.56	259.56	5.71	38.44***
NPK	97.02	2.70	87.73	2.35	9.29**
DAP	100.77	2.67	80.40	2.28	20.37***
Urea	100.22	2.48	91.44	2.41	8.79***
Total labor (persons-day/ha)	61.57	1.49	63.30	1.62	-1.73
Crop establishment[1]	29.75	0.75	28.32	0.78	1.43
Crop management[2]	13.52	0.51	15.50	0.62	-1.98**
Harvesting/ post-harvest[3]	18.29	0.66	19.47	0.61	-1.18
Family labor (persons-day/ha)					
Crop establishment[1]	10.44	0.46	11.45	0.54	-1.02
Crop management[2]	8.06	0.33	9.20	0.41	-1.14**
Harvesting/ post-harvest[3]	11.99	0.57	13.58	0.57	-1.59**
Hired labor (persons-day/ha)					
Crop establishment[1]	8.05	0.44	6.78	0.40	1.27**
Crop management[2]	2.09	0.18	3.17	0.23	-1.08***
Harvesting/post- harvest[3]	5.44	0.35	5.43	0.33	0.01
Contract labor (persons-day/ha)					
Crop establishment[1]	11.26	0.63	10.09	0.65	1.17
Crop management[2]	3.37	0.34	3.13	0.34	0.24
Harvesting/post-harvest[3]	0.86	0.14	0.46	0.11	0.40**
Farmers with loans	0.31	(0.02)	0.14	(0.46)	0.17***
Total loan[4] (Rs)	12,377	2,472	3,576	411	8,801***
Proportion of loan for farming	0.54	0.03	0.67	0.04	-0.13**
Proportion of loan for non-farming	0.46	0.03	0.33	0.04	0.13**

*** p<0.01, ** p<0.05, * p<0.1.

[1]Crop establishment labor activities include land preparation, nursery and planting, and transplanting/planting.[2] Crop management labor activities include application of fertilizer, pesticide, irrigation, weeding, and irrigation.[3] Harvesting/post-harvesting labor activities include harvesting, bundling, threshing, drying, and transporting.

[4]These include all loans availed for the past 12 months from different sources.

financial services, only few have availed loans in for the past 12 months. Results show that only 13% of the household with access to financial services availed loans for the past 12 months. These results suggest that there are households with access to financial services, yet there are still low borrowers based on the sample.

Finally, Table 13 shows yield differentials between the two groups (smallholders with and without access to financial services from FSOs). The results show evidence of a yield gap between families where spouses have and do not have access to financial services from FSOs. Rice farming families where spouses have access to financial services have a significantly lower yield than their counterparts based on the observed farm-level and predicted (frontier-farmer) yields by 263.3 kg/ha and 528.6 kg/ha, respectively. However, the predicted rice yield for average smallholder for both groups is almost the same. The findings suggest an improvement in TE for households with access to financial services.

However, their rice frontier productivity is not increasing. In other words, having access to financial services do not help in improving rice productivity. These findings can be explained by the loan purposes that were availed in the past 12 months. Recall that Table 12 shows that households with access to services have significantly higher loans than their counterparts. However, nearly half of the loans are allocated to non-farm-related activities such as medical expenses or children's education. This finding is consistent with Chavas et al. (2005), who found that Gambian farmers with loans from *Osusu* often used the funds for non-farming-related activities.[32] Finally, evidence shows that farm families with access to credit tend to hire labor to replace family labor. The finding is consistent with the theory

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[32]*Osusu* is local rotating saving and credit association in Gambia (Chavas et al., 2005).

Table 13: Observed and Predicted Rice Yield (Kg/ha): Matched sample.

	With Access (1)		Without Access (2)		Difference (3)
	Yield (kg/ha)	Standard deviation	Yield (kg/ha)	Standard deviation	
Observed (farm-level)	1,787.05	36.82	2,050.35	38.99	-263.31***
Predicted (average farmer) [a]	3,617.09	35.54	3,531.88	40.72	85.21
Predicted (frontier farmer) [b]	6,131.43	40.55	6,660.06	43.56	-528.63 ***

*p<0.10, **p<0.05,***p<0.001.

[a] Predicted output using ordinary least square.

[b] Predicted output using SPF with sample selection.

and points out that family labor may be well suited for non-farm work or non-farm family business.

3.8 Conclusions and Implications

This chapter provides empirical evidence on spouse's access to financial resources on rice managerial and technology gaps in eastern India. To address selection bias due to observed and unobserved attributes, the study used the Propensity Score Matching (PMS) and the sample selectivity-correction SPF of Greene (2010) based on the translog functional form. Each group was estimated using selectivity-correction SPF, a deterministic meta-frontier production function fitted to the group frontier.

The Probit estimates in the selection model show that in the matched sample, spouses' access to financial services is influenced by the presence of young children, poverty status, ownership of mobile, and number of livestock. In terms of productivity, seed usage negatively affected rice output among spouses with access to financial services. Among farm households without access to financial services, fertilizer usage and area cultivated were significant drivers of rice output. The study also found that flood/drought occurrence reduced farmers' rice productivity for both groups. The choice of rice variety shows that MRV2 and MRV4 contribute to increased rice production. Results revealed that technical efficiency is higher for smallholders whose spouses have access to financial services through FSOs than the control group. There is also a significant difference in technological and managerial gaps between smallholders with access and without access to financial services. Specifically, the gaps between rice producers whose spouses have access to financial services through FSOs and their counterparts seemed more noticeable after considering selection bias. The difference between spouses with and without access to financial services becomes prominent when analyzing the impact on meta-frontier yield but not when comparing the average farmer's yield. Households without having access to financial services, have a higher predicted meta-frontier yield than spouses with access to financial services (by about 528.6 kg/ha).

Findings from this study have several important implications. First, this chapter only shows how the gender roles of spouses prevent them from participating in FSOs, particularly in the presence of younger children in the household. According to Shah and Panigrahi (2015), the number of children, who require more attention at home, often discourages women from participating in FSOs activities. Thus, FOSs could design programs that encourage the participation of young spouses with young children in their organization. Perhaps, future studies could focus on analyzing the intra-household dynamics between couples. Second, the study shows that there is a significant technological gap favoring the household with access. However, this study also shows a negative relationship among spouses with access to credit and rice productivity. Thus, it would be essential to determine why the spouses further asked for credit, household's financial condition, and constraints in accessing the financial services —a limitation of the current study. Third, machinery is an essential contributor to rice productivity and technical efficiency. Rapid growth in the rural non-farm sector in Asia has led to labor shortages in farm activities. Thus, crop production is increasingly relying on labor-saving technologies like farm machinery. Though the use of machines in rice farming has positive effects on technical efficiency for both groups (with and without access to financial services), the continuous decrease in land size in India poses a significant threat to food production and productivity. Future studies could investigate the threshold farm size that is profitable while using farm machinery among smallholders.

Lastly, the estimated technical efficiencies among rice farmers are relatively lower compared to other existing estimates. To this end, evidence suggests that despite extensive seed development and dissemination programs to increase rice yield, it is not enough to rely on the rice varieties' capabilities alone. Rice production needs necessary auxiliary inputs such as credit and information regarding the production practices to reach maximum yield potential. Since mobile phone ownership affects a spouse's access to financial sources, one can explore mobile phones as an information communication technology (ICT) tool in adopting and promoting technology. For example, India's Rice Knowledge Management portal (RKMP) provides information (e.g., variety selection, pest/disease management, site-specific question) to significant stakeholders (such as farmers, extension workers, and policymakers) in rice farming (Kumar et al., 2018). However, to ensure that women/spouses have access to this information, it is not enough to provide them with mobile phones. Women should also be prepared for the use of ICTs. Recall that most of the women in the sample have low educational attainment. Information content regarding financial services and rice production should be site-specific and compatible with women's availability in decision-making. It is also essential for women to have proper training on the necessary information and use of the ICT tools to reduce technology fear. In terms of infrastructure, the government and private sectors should strengthen partnerships in providing affordable infrastructure (e.g., internet connection) to guarantee continuous technology use among women.

4 ASSESSING INVERSE PRODUCTIVITY RELATIONSHIP IN A JOINT DECISION-MAKING FRAMEWORK

4.1 Introduction

Sustaining food security in developing countries is one of the major roles of smallholder producers.[33] In India, the majority of these smallholders are located in rural areas who depend on agriculture as their primary source of livelihood. Among the staple crops, rice is primarily produced by smallholder farmers. It is reported that smallholder rice farms comprise 75% of the total rice farms covering 37% of the total rice area (GOI, 2016). The significance of these smallholder rice producers became apparent during the height of the Green Revolution (GR) in the 1970s, where greater emphasis on crop genetic improvement through plant breeding programs. According to Pingali et al. (2019), Green Revolution technologies were effectively designed and implemented for smallholders since technologies are scale-neutral, and adequate institutional support was given through input subsidies. For instance, the impact of rice varietal improvement to production in selected Southeast Asian countries (1985-2009) has resulted in a Net Present Value (NPV) (at 2019 USD) of US$ 4.2 billion to US$ 6.8 billion (Brennan and Malabayabas, 2011).[34]

Despite the development of new technologies, rice productivity in recent years had a slow growth rate compared to the early Green Revolution (Khush, 1999). Eastern India is mainly composed of unfavorable rice areas (rainfed) prone to abiotic stress (flood, drought, and salinity). The dependence on single cropping during monsoon and the prevalence of

[33] Smallholder are farmers with area less than 1ha (GOI, 2020).
[34] The values are converted using 2019 GDP deflator from the World Bank Economic Indicators.

drought, flood, and salinity can be the major reasons for comparatively low and uncertain yields (Barah and Pandey, 2005). In 2015, the region recorded average rice productivity of 2.25 t/ha, below the national average of 3.35 t/ha (IRRI, 2019). With the continuous increase in rice consumption growth without a commensurate increase in production may significantly impact food security. In 2015, eastern India accounted for 66% of the total rice area in the country and produced more than half (52 million tons) of India's total rice production (GOI, 2016). Given a region that is primarily composed of the rural population (80% of the total population) and a high percentage under poverty (with 22% to 35%) (GOI, 2016), a sudden fall in household production will have a substantial impact not only on the household but also on the national food security.

Rice yield uncertainties in eastern India can also lead to changes in income structure among rice farmers that favor more non-rural farm income. The movement from agriculture to non-rural farm sectors is further facilitated by government programs like the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), which resulted in labor shortages in agricultural production[35]. This labor movement out of agriculture has led to an increase in the nominal wage rate in agriculture, which affected particularly smallholder producers who are neither MGNREGA nor beneficiaries (Bhattarai et al., 2014; Reddy et al., 2014). According to Niroula and Thapa (2005), the scarcity of agricultural employment combining with land-related issues (such as the inheritance laws and underdeveloped land markets), land fragmentation will continue. It was reported that the average farm size in

[35] Enacted as the National Rural Employment Guarantee Act of India, 2005 is a public policy in India that pays people to seek employment. The wage rate is higher than the daily wages of agricultural workers (MORD, 2019).

eastern India decreased from 2.03 ha in 1971 to 1.15 in 2010 (Heady et al., 2005; GOI, 2016). The importance of these small farms, particularly during the 1960s, is further highlighted due to their high productivity compared to larger farms, described as the inverse relationship (IR) or the tendency for the productivity decline as the farm size increases (Sen, 1962).

A large portion of the literature has looked at the inverse relationship between productivity and farm size. Earlier studies in Indian agriculture during the pre-Green Revolution years show strong evidence of inverse relationship (Sen, 1964; Khurso 1964; Rao, 1966; Srinivasan, 1972; Bhattacharya and Saini, 1972; Ghose, 1979). Suppose smallholders have higher productivity than large farms, particularly staple crops (e.g., rice, wheat, and maize), then this group will help address equity and poverty reduction (Hazell et al., 2010). Since most smallholders are also the major food producers, several development organizations have used inverse relationships in development strategies by promoting and supporting smallholder production through land reform laws (Gollin, 2019; IFAD, 2013). However, Deininger et al. (2017) pointed out that too much fragmentation beyond the threshold farm size below 2 ha and greater than 3.5 ha will be detrimental to farm productivity due to difficulty using machines that serve as substitutes to labor. In addition, Chakravorty et al. (2017) found out that an Indian farmer's monthly income with less than 0.5 ha of land can barely cover their monthly expenses.

However, the inverse relationship concept has become more ambiguous after recent empirical evidence showing different farm-size productivity relationships. For example, Dorward (1999) found a positive farm-size and profit relationship in Malawi, which may be linked to a lack of access to credit. Carter and Weibe (1990) found a U-shape relationship in Kenya in analyzing the output per acre and farm size, partly due to changing crop mixes across farm sizes. Recently, Savastano and Scandizzo (2017) found a direct-inverse-direct relationship between gross farm income and farm size in Ethiopia, which is linked to the household's managerial quality.

Smallholders will inevitably remain one of the major players in the Indian rice sector. Thus, understanding the relationship between smallholder farm area and rice productivity is essential in identifying the significant constraints faced by these smallholder farmers. Several studies in the literature found an inverse relationship between farm size and productivity caused by imperfect factor markets, land quality, and measurement errors. With the growing evidence of a non-linear relationship between farm size and productivity, it is necessary to know if an inverse relationship exists in rice production in eastern India. In addition, when analyzing the inverse relationship at the household level, it assumes that farming decisions (such as the selection of crops, technology, and labor) made by the male household heads represent the whole household's decisions (Orr et al., 2016). However, gender-differentiated preferences on farming decisions such as crop choice and labor use (Bourdillon et al., 2007) may affect managerial skills in the household. The increasing number of male household members moving to the non-rural farm sector may lead to changes in the gender roles within the family, allowing the spouse to make farming decisions in the absence of the husband.

Thus, this chapter analyzes the relationship between farm size and productivity among rice farmers in eastern India. Specifically, this chapter will examine if the intrahousehold issues in rice variety decision-making between married couples affect rice productivity. This chapter uses the 2016 Rice Monitoring Survey, a nationally representative household-level survey by the International Rice Research Institute (IRRI) which contains detailed information regarding the rice production and a gender-disaggregated information about rice production decisions. This chapter will contribute to the literature in two ways. First, this chapter will test for the inverse relationship between farm area and productivity. The common explanations based in the literature (such as market imperfection and soil quality omission) that support inverse relationship will be tested to determine if the same factors explain the inverse relationship in rice production in eastern India. Second, this chapter considers joint decision-making between a married couple in analyzing the inverse relationship between farm size and productivity. Usually, testing the household-related explanation for inverse relationship may ignore the possibilities of heterogenous choices correlated to varietal selection and productivity. Thus, incorporating a couple's decision-making strategy in deciding the rice variety is essential.

4.2 Review of Literature: Inverse Relationship (IR)

The inverse relationship between farm size and productivity has been one of the recurring topics in rural development, which sparks the interest of most policymakers and rural development practitioners. This inverse relationship phenomenon helped develop the country’s efforts to justifying the implementation of land reform programs that promote efficiency and equity among poor farmers (Hefland and Taylor, 2021; Rada and Fuglie, 2019). In India, the existence of an inverse relationship was first identified by Sen (1962) in defining Indian agriculture using the Farm Management data produced by the Ministry of Food and Agriculture. Sen (1962) showed that productivity decreases in most areas under study as farm size increases. The high productivity among small farms can be associated with the intensive use of family labor among small farms, which assumes that there is no outside employment opportunity resulting in surplus labor. In assessing the profitability in production, this family labor was often given value by imputing the current wage rate, resulting in losses among small farms compared to large farms. Similar findings were also found by Khurso (1964) using the same data but noticed that the family labor explanation only holds in specific landholding size. It shows that full employment of family labor holds when the landholdings range from 10 acres to 15 acres and hire additional laborers once the landholding goes beyond 15 acres. Since there is a threshold of landholdings area where family labor can be fully employed, Rao (1966) pointed out the size of the landholdings cannot be ignored in the analysis because it can affect labor and managerial aspects of production. The author further suggested that moving to more mechanized processes would be the best option for large farms to intensify inputs and avoid managerial difficulties. An additional study by Sen (1966) showed an inverse relationship between farm size and productivity exists due to an imperfect labor market. The Indian peasant farm sector tends to have a surplus of labor and wage gap. The wage gap exists when there is a seasonality in production and a proposed institutional minimum wage rate. Most of the studies mentioned above depend on aggregated data from the Farmer Management survey, which assumes an inverse relationship exists due to an imperfect labor market. However, using aggregated data from the Farm Management Survey may not necessarily capture the real reasons for the inverse farm-productivity relationship.

Rudra (1968) used data from Agro-Economic Research Center, which uses village-level information from Punjab and Uttar Pradesh (India). The study shows that the intensity of irrigation and inputs used in relation to productivity is constant regardless of the landholding sizes, contrary to when using the Farm Management data. A follow-up study done by Rudra (1968) analyzed the inverse relationship using correlation analysis of 20 villages in India. It shows that among the villages, only two villages show significant and inconsistent results. Results show that one village has an inverse relationship which only holds up to 20 acres, while the other village shows no systematic pattern. On the other hand, Deolikar (1981) found out that an inverse relationship exists in India with low agricultural technology and diminishes with farms using a high level of technology.

Other Studies also used disaggregated data which found an alternative reason that could explain the inverse relationship phenomenon in Indian agriculture. For example, Saini (1971) analyzed Farm Management data (1954-1957) that used the current market wage rate, explaining the profit losses among small farms. The author suggested that instead of imputing value in the family labor that leads to market distortion, one should also consider placing a rental value on owned land since this is often excluded in the calculation. Results show that positive profits were found even in the smallest landholdings when owned land was given value. Village-level variations can also be one of the reasons for inverse relationships. For example, Bhattacharya and Saini (1972) included a dummy variable of an Indian village in the testing of inverse relationships using data from 1955-1968 and found that the inverse relationship varies per village. In terms of weather variations, Srinivasan (1972) found out that even though farmers apply the optimal inputs in production, farmers experience yield uncertainties due to weather variations. To capture the full effect of weather on productivity, Srinivasan (1972) suggested dividing the stages of production, such as the early stage (sowing and early growing stage) and the late stage (flowering and harvesting stage).

However, the inverse relationship in Indian agriculture previously mentioned was based on the pre-Green Revolution, which is characterized by underdeveloped areas with diverse climatic conditions, landholding structures, and cropping conditions (Ghose, 1979). In introducing Green Revolution technologies, it is essential to know their impact on small and large farmers since Green Revolution technologies are considered scale-neutral.[36] Saini (1971) pointed out that the inverse relationship phenomenon is expected to change or disappear, particularly in areas where Green Revolution is highly promoted. Green Revolution technologies require complementary inputs (such as fertilizer and irrigation) to achieve their potential yield. Thus, dependence on purchased inputs and capital goods is readily available for large farmers with access to credit and savings (Heltberg, 1998). Several studies show that Green Revolution's introduction in Asia lessens or removes the inverse farm-size productivity relationship. For example, Deolikar (1981) examined the fertilizer application among Indian farms using district-level data. The study found that inverse relationships exist when fertilizer is excluded in the estimation and reversed once fertilizer usage intensifies and size increases. This finding suggests that large farms benefited more from the technological change through fertilizer than small farms.

[36] These are technologies that can be divided and distributed at no extra cost (Pingali, 2010).

Increased fertilizer use was found by Subbarao (1983) to explain the inverse relationship among rice and wheat producers in eastern India.

However, the study of Bhalla (1979) found that the inverse relationship persisted even during the Green Revolution. Larger farms increased their output per acre and proportion of area under modern varieties due to their accessibility to cheaper credit. In addition, Birthal et al. (2014) examined crop performance in 20 Indian states. They found that small farmers benefitted from technological development by allocating more high-yielding crops and applying more fertilizer and pesticide than larger farms. However, the inverse relationship is more prominent in high-value crops (e.g., fruits, plantation crops, and sugar crops) than in food crops such as rice and wheat.

High production mechanization also positively affected production efficiency, particularly on large farmers (rice and wheat). Otsuka et al. (2016) pointed out that with the development of non-rural farm sectors and increasing wage rates, larger farms prefer to use labor-saving technologies (farm machinery) to be efficient and reverse the farm-productivity relationship. Despite the weakening of the farm-productivity relationship in Green Revolution technologies, the common explanations in the literature that support inverse relationship include the following: market imperfections, land quality, intensive production, error in estimation, and household characteristics.

Market imperfection

Market imperfection was identified by Sen (1966) as one of the reasons for the existence of inverse farm size and productivity. An extensive part of the literature that focused on the inverse relationship found that the interplay of different sectors causes market imperfections. For example, Feder (1985) pointed out that inverse farm size-productivity exists when imperfect labor, credit, and land markets exist. Interestingly, Lamb (2003) found that when assessing labor by gender and controlling for village labor and land imperfections, the inverse relationship is completely removed only in male labor demand but not in female labor. This suggests that increasing own production is one way to address market failure in the female labor market. On the other hand, Barrett (1996) found an inverse relationship exists if there are differences in household marketed surplus and price risk-averse farmers.

The cost of supervision can also be the reason for an inverse relationship to exists. For example, Heltberg (1998) found that an inverse relationship exists where there are supervision constraints since outside labor is an imperfect substitute for family labor. In addition, Feder (1985) pointed out the efficiency of the hired labor depends on the intensity of the family labor supervision. Deininger et al. (2018) examined the changes in inverse relationships in 17 Indian states over 25 years. Results show that increasing wages in the 2000s led to more intensive capital, lessening the supervision cost among family labor.

However, this inverse relationship is not solely explained by market imperfections when using yield approach method. For example, Barrett et al. (2010) analyzed 17 villages in Madagascar in 2002, including multi-plot level information. The same is true in the study of Ali and Deininger (2014) when analyzing rural households in several villages in Rwanda, which found an inverse relationship between farm size and shadow profit. A reversed relationship happens when family labor is valued based on village market rates.

In the study by Wang et al. (2015), a comparison between rice farmers in China and India found that land crop yield increases with machine use in both countries. However, there were contrasting results when analyzing the inverse relationship. It shows that China has a positive plot size-productivity relationship, while India still follows the conventional inverse relationship. China's results may be due to the development of the land rental market, family labor outmigration, and high-quality farmland construction policy.[37] However, Assunção and Braido (2007) rejected the market imperfection explanation when plot-level data in India was used since inverse relationship still exists even after controlling for unobserved household characteristics.

Soil quality

Land quality is another reason that most studies used to explain the farm-size productivity inverse relationship. Often, these variables are omitted due to the unavailability of plot-level quality measures. With the increasing availability of more plot-level data, several studies included land quality indicators. Bhalla (1988) and Bhalla and Roy (1988) used extensive national farm-level data in India with land quality information from the Fertilizer and Demand Survey (FDS) 1975-1976. Their results show a negative relationship between farm size and productivity. However, when Bhalla and Roy (1988) consider land quality, the inverse relationship still exists but weakens. In addition, Bhalla (1988) also pointed out that though there was an inverse relationship when land quality was included, the

[37] This policy encourages farmers to increase operational farm sizes by developing public infrastructure (e.g. irrigation facilities and roads).

results may lead to large specification errors if it follows the conventional production function where land quality is ignored.

Some studies that analyzed the inverse relationship also used panel data. For example, Carter (1984) analyzed panel data from Haryana (India) during 1969-1970. The author found that the intervillage soil difference partly explains the farm size-productivity relationship and found that small farms are inefficient since these use more inputs than large farms. Lamb (2003) estimated the effect of land quality measures in the inverse relationship using panel data by International Crops Research in Semi-Arid and Tropics (ICRISAT) that covers several crops. Lamb (2003) also used random and fixed effects in estimating the relationship between land quality and profits. The difference in land quality explains the most evidence of an inverse relationship between farm size and profits when applying random effects. Aside from soil quality, Assunção and Braido (2007) used longitudinal village-level studies by ICRISAT (1975-1985) and found that inverse relationship is also related to land value. However, Barrett et al. (2010) rejected soil quality as the main reason for the inverse relationship. Results show that estimation did not suffer from omitted variable even if the specific soil quality (e.g., soil carbon, nitrogen, and potassium content, soil pH, clay, silt, and sand shares) was accounted for.

Measurement and misspecification errors

Increasing evidence of statistical modeling issues due to missing data or measuring errors may also lead to the existence of an inverse relationship. For instance, Lamb (2003) found that measurement errors may explain most of the inverse relationship, which is more pronounced when using fixed effects. Lamb (2003) also cautioned researchers in applying fixed-effects models to estimate the relationship between farm size and productivity. Barrett et al. (2010) found the same results in examining the inverse relationship using fixed effects to know if household and village market imperfections trigger the results. The results also showed that imperfect markets only contribute to one-third of the inverse relationship.

Other studies tried to control for farm attributes to remove the measurement error. For example, Assunção and Braido's (2007) controlled for plot attributes, irrigation status, and land value showed no effect for large farms. In addition, Ali and Deninger (2014) controlled the time-variant and invariant characteristics of the plot (soil quality and unfavorable productivity shocks) in estimating the inverse relationship. Feder and Rosenzweig (2017) found that area measurement error in Indian farms is small and does not explain the results. However, most of the land size information depends on farmers self-reporting. Thus, land area measurement is often imprecise.

More recently, several studies have implemented a global positioning system (GPS) to estimate the land area. This technique has become popular since it can provide more accurate land measures, particularly in larger household surveys (Carletto et al., 2013; 2015). The study done by Carletto et al. (2013) shows that using a GPS measured area indicates a stronger inverse relationship than using the self-reported area in Uganda. In addition, using the self-reported measure of the area shows that smaller farmers tend to over-report their land size. In contrast, large farmers underestimate their land resulting in higher yields. Similarly, Desiere and Jolliffe (2018) addressed the measurement error issue using crop cut estimates in Ethiopia.[38] It shows that an inverse relationship exists when using self-reported estimates and disappears when crop-cut area estimates. Carletto et al. (2013) also found that overestimating or underestimating farm size drives the inverse relationship. Similar results were found by Dillon et al. (2019) when using three land measurement methods (farmer estimates, GPS, and compass-and-rope). The study shows that self-reported leads to measurement error (overreporting for small farms and under-reporting for large farms). However, Bevis and Barrett (2017) rejected the idea of measurement error leads to an inverse relationship. The authors argued that crop yields along the perimeter might be higher than those in the interior due to less competition with nutrients and water that would result in an inverse relationship. The authors show that the inverse relationship disappears after controlling for the perimeter plot in Uganda.

Farmer related factors

The characteristics of the household influence on the inverse relationship between farm size and productivity. For instance, Rada et al. (2019) found that agricultural education among small farmers (0-5 ha) in Brazil has a positive impact on the total factor of productivity by 16%. Carter (1984) found the inverse relationship is not due to sampling bias resulting from farmer literacy but to a mode of production due to intensive use of inputs that generate higher income. Heterogeneity of skills also affects the inverse relationship. Assunção and Ghatak's (2003) study shows heterogeneity regarding farmers' skills, and an imperfect credit market was found to affect the inverse relationship. The

[38] Crop cut is a method to estimate crop yield. This method uses a random demarcation of plot of a specific size and shape and harvesting the crop from that particular plot in order to determine the weight (Sud et al., 2017).

authors pointed out that skilled peasants are more likely to become farmers, which entails a higher opportunity cost to be a wage earner than an unskilled peasant.

Some studies attempt to show the existence of inverse relationships through an intrahousehold bargaining context. For example, Udry (1996) found that allocating land to women would reduce marginal productivity and suggest reallocating the land to men to increase output. Assunção and Braido (2007) also attempted to study the effect of intrahousehold resource allocation by analyzing managerial resources and crop mix in India. However, results did not provide any support that intrahousehold issues result in an inverse relationship.

Thus, based on the existing literature, there are mixed explanations for the existence of an inverse relationship. Most of the studies assumed that only the household head is responsible for all farming decisions and represents all the household members. In the increasing number of studies about intrahousehold bargaining, each household member may have their preference which can affect the productivity of the household. Though few attempted to incorporate the intrahousehold issues in an inverse relationship, most failed to explain the relationship. This study will attempt to revisit the inverse relationship debate by incorporating a joint decision-making strategy among married couples in India.

4.3 Theoretical Framework

The study's theoretical framework shows the linkage between farm area and productivity. Following Assunção and Braido (2007), farm production is modeled using Cobb-Douglas expressed as

$$Y_i = A_i T_i^{\alpha_t} K_i^{\alpha_k} L_i^{\alpha_l} \exp(\varepsilon_i) \tag{1}$$

where Y_i is the yield of the ith household; T_i is the total cultivated area; L_i and K_i are the amount of labor and non-labor inputs used; A_i is the technological factor that represents observable household land characteristics, and specific characteristics associated with different factors like state and caste; and ε_i is the error term. It is also assumed there are constant returns to scale and a competitive market.

In order to represent the production function into monetary by multiplying $Y, L,$ and K with their respective prices $(p, w, and\ r)$ and given as

$$y_i = A_i T_i^{\alpha_t} k_i^{\alpha_k} l_i^{\alpha_l} \exp(\varepsilon_i) \tag{2}$$

For the household to choose the optimal amount of labor and non-labor inputs, the household would solve for the profit maximization problem given as

$$\max_{k_i, l_i} E\ (a_i\ T_i^{\alpha_i} k_i^{\alpha_i} l_i^{\alpha_i} \exp(\varepsilon_i) - k_i - \ l_i) \tag{3}$$

where $y_i = pY_i$ is the value of the output; $k_i = rK_i$ is the value of the non-labor inputs; $l_i = wL_i$ is the value of the labor inputs; and a_i is a price adjusted technological term ($a_i = \frac{A_i}{(r)^{a_i}(w)^{\alpha_i}}$). After solving the maximization problem, the optimal inputs for labor and non-labor inputs would be:

$$k_i^* = T_i \left(\alpha_k^{(1-\alpha_l)} \alpha_l^{\alpha_l} \alpha_i E(\exp(\varepsilon_i))\right)^{\rho} \tag{4}$$

$$l_i^* = T_i \left(\alpha_l^{(1-\alpha_k)} \alpha_k^{\alpha_k} \alpha_i E(\exp(\varepsilon_i))\right)^{\rho} \tag{5}$$

$$where\ \rho = \frac{1}{1 - \alpha_k - \alpha_l}$$

Assunção and Braido (2007) further assume that technological term a_i and error term ε_i should both be independent to cultivated area T. If that the case, then Y should also be independent to cultivated area T, which can be written as

$$\frac{y_i}{T_i} = (\lambda a_i)^{\rho} \exp(\varepsilon_i) \quad (6)$$

where $\lambda = \alpha_k^{\alpha_k} \alpha_l^{\alpha_l} [E(\exp(\varepsilon_i))]^{(\alpha_k + \alpha_l)}$

4.4 Empirical Strategy

Specifications of the models

The motivation of the study is to analyze the effect of farm size on rice productivity in eastern India. To assess the existence of an inverse relationship, this chapter follows the yield approach by Assunção and Braido (2007) and Barrett et al. (2010). The approach starts with a Cobb-Douglas production function. The farm size-productivity relationship is usually tested using an ordinary linear regression (OLS):

$$Y_i = \beta_0 + \delta_1 L_i + \varepsilon_i \quad (7)$$

where i is the ith household; Y is the yield; L is the cultivated land; β is the intercept, and ε is the error term with constant variance and mean zero $\varepsilon_i \approx i.i.d.\ N(0, \sigma^2)$. Equation (7) is an example of a naïve regression that only includes one independent variable. To know if there is a correlation between the cultivated area and productivity, rejecting the null hypothesis $H_0: \delta_1 = 0$ in favor of the alternative relationship $H_1: \delta_2 < 0$ would be evidence of an inverse relationship.

However, the estimates in Equation (7) will likely suffer from omitted variable bias. Equation (8) shows an expanded version of Equation (7) by adding household variables (e.g., household head age and years of education, family size, and with non-rural farm income) and farm variables (e.g., occurrence stress, percentage of irrigated land, the quantity of seeds used, the quantity of fertilizer (NPK) used, total labor used, and adopted rice varieties). The augmented Equation (7) can be defined as:

$$Y_i = x_i'\beta_2 + \delta_2 L_i + \nu_i \quad (8)$$

where β_2 represents all associations between productivity and vector of household and farm variables; ν_i an error term. If there is an existence of an inverse relationship, then the null hypothesis H_0: $\delta_2 = 0$ is rejected in favor of the alternative hypothesis, H_2: $\delta_2 < 0$.

In addition, joint decision-making regarding the selection of rice seed varieties is considered to capture intrahousehold issues that may affect an inverse relationship. The joint decision-making regarding rice variety takes a value of 1 when the couple jointly decide the rice variety and 0 if the husband solely decides the rice variety. The equation can be expressed as:

$$Y_i = x_i'\beta_3 + \delta_3 L_i + \theta_3 J_i + \vartheta_i \quad (9)$$

where β_3 represents all associations between productivity and vector of household and farm variables; J_i is the joint making variable which equals to 1 if the there is a joint decision-making in terms of deciding the rice variety; and ϑ_i an error term. If there is an existence of an inverse relationship, then the null hypothesis H_0: $\delta_3 = 0$ is rejected in favor of the alternative hypothesis, H_2: $\delta_3 < 0$.

Following Gaurav and Mishra (2015) and Barrett et al. (2010), the inclusion of additional control variables would test the inverse productivity relationship in rice production based on the common explanations in the literature such as household-specific market imperfections and soil quality. The household-specific market imperfections can be one of the reasons for the existence of an inverse relationship. In this case, shadow prices of inputs (such as land and labor) and outputs often create heterogeneity between households. According to Feder (1985), farm area is correlated to unobserved household-specific shadow prices, which may cause inverse relationship. The household-specific variables used are dummies for state and caste where the household belongs. Thus, accounting for the unobserved heterogeneity between families, the specification becomes:

$$Y_i = x_i'\beta_4 + \delta_4 L_i + \theta_4 J_i + \lambda_4 H + \omega_i \quad (10)$$

where δ_4 represents state and caste controls and ω_i is an error term. If the household-specific failure is the reason for an inverse relationship, controlling for the household-specific effect (λ_4) the existence of inverse relationship would lead to reject, $H_0: \gamma_4 = 0$. Soil quality is another common variable omitted due to data unavailability but considered one of the major reasons for inverse relationship existence. However, Barrett et al. (2010) pointed out that soil quality affects farm size and yield differently, resulting in biased estimates if ignored. In this study, the variable proportion of medium land was used as a proxy to account for soil quality.[39] The specification is given as:

$$Y_i = x_i'\beta_5 + \delta_5 L_i + +\theta_5 J_i + \lambda_5 H + \phi_5 Q_i + \eta_i \quad (11)$$

where ϕ_5 is coefficients for soil quality and η_i is the error term.

To test for heteroskedasticity, Breusch-Pagan/ Cook-Weisberg where the null hypothesis states that there is a constant variance. The results led to the rejection of a constant variance ($\chi^2 = 13.09,\ p - value = 0.000$), suggesting that heteroskedasticity is present. To

[39] Rice farms in India can be categorized as upland, medium land, and lowland. The lowlands are located in the lower top sequence of the fields while uplands are located in the upper part of the field with less moisture availability and poor soil quality (sandy soils with less water retention capacity). Lastly, medium land is intermediate between lowland and upland (Gauchan et al. 2012).

address heteroskedasticity the OLS was re-estimated using a robust standard error or the Huber/White/robust alternate estimate of variance using *vce(robust)* command in Stata 16 (StataCrop, 2019).

Quantile regression

The chapter also uses a quantile regression model (QRM) to test if farm area and productivity relationships exist at varying points. This model was first introduced by Knoecker and Bassett (1978) and used in different empirical studies (Buchinsky, 2001; Variyam et al.,2002; Savastano and Scandizzo, 2017). Since quantile regression provides conditional means in each quantile, this will show the entire distribution of the response variables given regressors. Variyam et al. (2002) shows the quantile regression's ability to characterize the whole conditional distribution is essential, mainly when the data is heteroscedastic. If there is heteroscedasticity, using a quantile regression will allow different marginal responses of the dependent variables due to changes of the independent variables at various points due to the changes in the distribution of the dependent variable (Buchinsky, 2001).

Following Buchinsky (2001), the quantile regression model of the farm yield function in Equation (1) can be expressed as:

$$y_i = x_i'\beta_\theta + \mu_\Theta, \quad Quant_\theta(y_i|x_i) = x_i'\beta_\theta \tag{12}$$

where $Quant_\theta(y_i|x_i)$ is the θth conditional quantile of y_i given vector x_i; and β_θ is a vector of unknown parameters; y is an Nx1. The distribution μ_Θ in Equation (12) also assumes to satisfy the quantile restriction $Quant_\theta(\mu_\Theta|x_i) = 0$. The quantile regression is obtained by solving a minimization problem presented as:

$$\min_{\beta_0} \frac{1}{N} \left\{ \sum_{i:y_i \geq x_i' \beta_\theta} \theta |y_i - x_i' \beta_\theta| + (1-\theta)|y_i - x_i' \beta_\theta| \right\} \tag{13}$$

Equation (13) shows that the parameter β_θ is obtained by minimizing the sum of absolute deviations of a chosen quantile of a rice yield across farmers, making the estimated coefficient vector not sensitive to outliers. The variables that were used in Equation (11) will be used to estimate the quantile regression for this chapter using the *qreg* command in STATA 16 (StataCrop, 2019).

4.5 Survey Data

The study uses the 2016 Rice Monitoring Survey conducted by IRRI. A rice-producing household is defined as a household that produced rice during the past 12 months. The survey targeted the rural population of eastern India by randomly selecting rural areas based on the 2011 Census of India. Four states in the eastern part of India are considered for this study: eastern Uttar Pradesh, Odisha, Bihar, and West Bengal. A multi-stage sampling technique was adopted in selecting the respondents. In the first stage, the number of districts was randomly selected in each state using the Census of 2011.[40] On the other hand, the second stage involves selecting the number of villages based on the proportion of each state's total rice area, keeping the total number of villages at 720. Among the selected villages, household samples are randomly selected using the household census village data. A total of 101 districts and 1,931 rice-producing households are included in the survey (Table 14).

[40] This contains information about the districts, villages, towns, and cities in the rural and urban India.

Table 14: Sample Districts and Smallholder Households in Eastern India, 2016.

State	Number of districts	Number of households
Eastern Uttar Pradesh	37	513
Odisha	30	627
Bihar	16	329
West Bengal	18	442
Total	101	1,931

Source: 2016 Rice Monitoring Survey conducted by IRRI.

A structured questionnaire was used to interview the primary male and female decision-makers of the household. Information regarding the household and rice production were collected from male respondents, while information about livestock and household assets were collected from the female respondents. To elicit unbiased responses, the survey employed male and female enumerators in the interview process. The male enumerator interviewed the male respondents, while the female enumerator interviewed the female respondents. The study focused on information regarding the 2015 wet season, the primary rice-growing season in eastern India. A computer-assisted personalized interview (CAPI) program, *Surveybe*, was used to collect the data.

To capture the influence of intrahousehold decision-making, the study considered only married couples and at the same time identified to be the male and female decision-makers. Choosing the married couple as a major criterion is necessary since it common for Indian households to have an extended family living in one house. Each of the couple were asked about seven farm production-related decisions, but for this chapter only the decision-making regarding the selection of rice seed varieties was included. The decision-making can be classified as (1) husband only decides in the presence of the spouse; (2) spouse only decides in the presence of the husband; and (3) both husband and spouse participated in determining the choice of a rice variety to be used in the coming season. Based on the data category, households with spouse solely participates does not exist in the sample. Thus, the joint decision-making and husband solely deciding were included in the choices, which takes the value of 1 and 0, respectively.

The definition of the variables used in the analysis is presented in Appendix Table 17 while summary statistics of the variables is presented in Appendix Table 18. The sample households can be categorized based on the rice productivity: low performing (yield less than 1,297.28 kg/ha); mid-performing farms (yields between 1,297.28 to 1,662.09 kg/ha); and high performing farms (yield greater than 1,662.09 kg/ha). It shows more than half of the sample households are composed of high-performing groups followed by low-performing (40%) and mid performing (8%). Rice yield in the sample has an average of 1,788 kg/ha, which is lower than the national average of 3,700 kg/ha (IRRI, 2019). The dominance of the marginal farms can be observed in the average cultivated area of the whole sample, which reached 0.42 ha. In terms of land ownership, all households owned their land but only 76% of the households have the land title of ownership.

Rice is mainly planted in the medium part of the land of nearly half of the households Appendix Table 18. Among the farm groups, around 63% of these low-performing farms used most of these medium lands compared to the other groups. In terms of irrigation, more than 41% of the cultivated rice area are irrigated through supplemental irrigation (such as deep or shallow tube well, canals, and ponds). The low-performing groups have a high percentage of irrigated areas (48%) than to the other groups. This result suggests that there are still farmers who rely on rainfall for water sources. However, rainfed rice production is prone to water-related problems like floods and drought, which can be one reason for the slow productivity growth (Pandey et al., 2007; Dar et al., 2013). In the study done by Gumma et al. (2010), it was estimated that an average of 8-40% and 17-22% of the total rice area in eastern India are prone to flood and drought, respectively. Appendix Table 18 shows that on the average around 63% of the rice producers in the sample were affected by flood and drought, with mid-performance farms affected the most.

The major inputs used in rice production are seeds, labor, and fertilizer (NPK, DAP, Urea). It shows that low-performing farms apply the highest amount of seeds which reached 43 kg/ha. The use of fertilizer is highest in the mid-performing group, which reached 290 kg/ha. On the other hand, the labor used in rice production is composed of three types: family, hired, and contract labor. Family labor provided the highest day worked on the farm (32 person-day/ha) and followed by contract labor (16 person-day/ha) and hired labor (15 person-day/ha). It also shows that the participation of family labor is constant across the group. Among the farm groups, low-performing groups required the lowest labor in rice production (60 person-day/ ha) compared to the two farm groups.

Appendix Table 18 shows the nearly half of rice producers use MRV6 (mixed generation) and MRV2 (1977-1985). The farm group shows that nearly 71% of low-performing farms still use old rice varieties and local rice varieties.[41] The use of these local varieties may explain the low productivity of the group. In Bagchi et al. (2012), they found that local varieties in West Bengal generate a lower yield than modern varieties by 1.63 kg/ha. It also

[41] Old varieties as rice varieties that were released 1995 and earlier which excludes local varieties.

shows high performing groups preferred the MRV2 (rice varieties released between 1977–1985) and MRV6 (mixed). The hybrid rice varieties (MRV5) and MRV6 (mixed) are preferred in the mid-performing group. According to Behura et al. (2012), combining different varieties is one of the practices among the flood/drought-prone areas to ensure production. This is not surprising since many farmers in this group experienced flood/drought during 2015.

The household characteristics show that the average operator's age is 48 years old with an average of 6 years of education (Appendix Table 18). There is also a narrowing difference of education between husband and wife, which increases as productivity increases. However, the age difference is constant across farm groups. Most farmers belong to Other Backward castes (40%), followed by general caste and scheduled tribe/caste (30%).[42] The low and mid groups constitute primarily scheduled castes among the farm group, while the high-performing group is composed mainly of general castes. In terms of farm location, most of the rice producers are found in Odisha (32%), followed by Bihar (27%), West Bengal (23%), and Uttar Pradesh (18%). More than 60% of the household has at least one member with non-farm employment in terms of sources of income. Finally, in deciding rice varieties, Appendix Table 20 shows that nearly half of low and high-performing groups jointly participate in decision-making in determining the rice variety.

[42] Other backward caste includes castes that are marginalized sectors of the Indian society. On the other hand, general caste is a group of people who do not qualify for any of the affirmative action schemes operated by the Government of India (excludes scheduled castes and scheduled tribes, and other backward classes). This group of people does not qualify for any of the affirmative action schemes operated by the Government of India (excludes scheduled castes, scheduled tribes, and other backward classes). Lastly, the scheduled tribe/caste are considered designated groups of historically marginalized indigenous people in India and recognized by the Government of India (GoI). Since independence, the Scheduled Castes and Scheduled Tribes (SC/ST) were given reservation status, guaranteeing political representation.

4.6 Results and Discussion

Inverse relationship

Table 15 shows the results of the five specifications for testing the relationship between farm size and productivity in rice production using the yield approach: (1) naïve; (2) farm and household; (3) farm and household with joint decision-making; (4) household-specific; and (5) soil quality. Results of the naïve specification (Model 1) show that the cultivated area and rice productivity have a negative relationship but are not significant. This suggests that every percentage of the cultivated area will result in a 3% decrease in yield. Model 1 only predicted 0.1% of the variation in yield, and the estimates may be more likely to suffer from omitted variables bias.

Next, the farm and household characteristics variables are included in the estimation in Model 2 (Table 15). It shows that the relationship between farm size and productivity is negative and significant, suggesting that a percentage increase in farm area will result in a 23% (*p-value=0.000*) decrease in yield. Notice that farm area coefficient is higher compared to Model 1 and becomes significant. In addition, Model 2 predicted the yield better than Model 1 since the R-square reached 10% (Appendix Table 19). Principal inputs like total labor, use of machines, and rice variety type contribute significantly to rice productivity. In terms of the household variables, it shows that having non-rural farm employment contributes to productivity. In contrast, the respondent's age and joint participation in decision-making have a negative effect on productivity. In terms of intrahousehold effect on inverse relationship, married couple joint decision-making regarding rice variety was included to test inverse relationship. It shows that if the household follows a joint decision-making strategy, the yield will drop by 22% (*p-value=0.000*) and further weakens.

Following Barrett et al. (2010) and Guarav and Mishra (2015), two common explanations on why inverse relationship exists: household-specific market imperfections and soil quality. To address market imperfection, household-specific fixed variables are included in the estimation. Table 15 (Model 4) shows that inverse relationship still holds having an area coefficient of -0.11 (*p-value=0.060*). Testing the joint household-specific controls show significant (F-test=6.04; *p-value=0.000*), thus rejecting the null hypothesis $(H_0\colon \lambda_3 = 0)$. The magnitude of the farm area coefficient also decreased by almost half compared to Model 2. The same result was found by Barret et al. (2010), which shows that controlling for household-specific weakens the explanation of the existence of inverse relationship.

Model 5 (Table 15) also shows the results when soil quality control when included in the estimation. The proportion of medium land was used as a proxy for soil quality. The results show that the inverse relationship between farm area and productivity still holds and is significant. The inclusion of proportion of medium land decreased of the magnitude of the area cultivated coefficient (-0.110; *p-value=0.067*) by nearly half as compared to Model 2. Testing the soil quality control show significant (F-test=5.810; *p-value=0.014*), thus rejecting the null hypothesis $(H_0\colon \lambda_3 = 0)$. Similar results were found by Bhalla and Roy (1988) regarding the weakening of the relationship when controlling for land quality. The authors argued that ignoring the land quality may result in specification errors, leading to an artificial impact on productivity.

Table 15: Rice Productivity (Kg/ha) Estimation Results with Household-specific and Soil Quality Control Using Yield Approach.

	Naïve	Farm and Household	Farm and Household and Joint decision-making	Household fixed	Soil quality fixed
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*
Total area (ha), log	-0.034	-0.232***	-0.221***	-0.113*	-0.110*
	(0.026)	(0.061)	(0.061)	(0.060)	(0.060)
Joint - participation[5](=1 if yes; 0 otherwise)			-0.104**	-0.041	-0.031
			(0.048)	(0.052)	(0.052)
Household and farm characteristics *Controls*	No	Yes	Yes	Yes	Yes
Caste and village	No	No	No	Yes	Yes
Proportion of medium land					-0.138***
					(0.046)
Constant	7.101***	6.855***	6.910***	6.597***	6.791***
	(0.039)	(0.451)	(0.451)	(0.454)	(0.457)
$\delta_1 = -0.034$		19.300***	17.610***	6.040**	5.810**
Observations	1,931	1,931	1,931	1,931	1,931
R-squared	0.001	0.099	0.102	0.162	0.166

[1] Total chemical fertilizer used in rice production: NPK- nitrogen, phosphorus and potassium (15-15-15); DAP - diammonium phosphate (18-44-0); and Urea (46-0-0) (http:\www.yara.com).
[2] This includes family labor, hired labor, and contract labor. Person-days/ha is same as person-days/ ha in which 6 hours =1 day.
[3] The household is using at least one of the type of machines listed: tractor, transplanter, sprayer, combine harvester, thresher, diesel pumps, electric pumps.
[4] At least one household member has off-farm labor like salaried job, business, and works in service industry.
[5] Husband and spouse making farming-related decisions jointly.
[6] Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.
[7] Includes castes that are socially and educationally marginalized.
Source: 2016 Rice Monitoring Survey conducted by IRRI.
Full results are in Appendix Table 19.

Overall, the inputs used show that signs and significance are almost identical in all the models in Table 15. The occurrence of flood and drought remains to have a negative impact on productivity in the three models, and magnitude decreased once the controls were added (Appendix Table 19). The negative effects of flood and drought are consistent with Mishra et al.'s (2015), who found that abiotic stresses (drought and flood) reduced rice production among rice farmers in Bangladesh. Thus, controlling for soil quality seems to emphasize the effect of flood and drought. The seed usage shows that it has a negative effect on productivity, which increased in magnitude after controlling for household-specific and soil quality effects. In terms of caste, the coefficients of households belonging to Other Backward caste show a negative impact on rice yield when added to the model. This is similar to the result in the study of Dar et al. (2013), which shows these groups are usually located in poor water conditions prone to flooding having low productivity. The effect of non-rural employment is significant in the last three models (Model 3 to Model 5) and weakens once the controls are included. The joint participation variable negatively affected yield, which decreased in magnitude and became insignificant once the controls were added (Table 15).

Quantile regression

Table 16 presents the results inverse relationship of farm size and productivity using quantile regression. It shows that inverse the relationship disappears when analyzing farmer groups based on productivity. The estimates for a cultivated area, though not significant, the magnitude of the total area coefficient decreases as the farmer productivity increases. It is noticeable that the sign of the area coefficient starts to change from negative to positive starting in the 80th quantile, or a return to scale switch. The change suggests that increasing farm area would not benefit farmers who belong in the 70th quantile and below. However, farmers in the upper quantile will experience gains in rice productivity in increasing farm size. Similar findings were found by Savastano and Scandizzo (2017) in Ethiopia, wherein the relationship between gross income and farm size changed from inverted U-shape (lower performers) to U-shape (high performers). The authors pointed out that the change can be associated with the different management styles among farmers. Major inputs used in rice production also show different patterns across the quantiles. For instance, seed quantity use indicates a negative effect on rice productivity in all the farm groups. The seed parameter estimates show a mixed pattern with a significant yield among the 50^{th} quantile (-0.108; *p-value=0.018*). Total labor and machine use show a positive effect among the high-performing groups (70th and 80th quantile). Still, in terms of the magnitude of the coefficient, the effect of using the machine on yield is higher than the total labor on rice yields. This is not surprising since Otsuka et al. (2016) found that efficient farms switched for labor-saving machines to use in rice production in Asia to avoid the cost of hiring labor. The effect of rice variety use also varies per quantile. It shows that older varieties (MRV1 and MRV3) significantly affect low performers than high performers. Recall in Appendix 18 that more than 50% of farmers from this group adopt old MRV (released 1995 and earlier except MRV2) and local rice varieties. Hybrid (MRV5) adoption has a positive and significant effect on yield only among the low and mid-performing groups. On the other

Table 16: Quantile Analysis of Rice Production in Eastern India. Dependent Variable: Yield (Kg/ha), Log.

	Q 0.1	Q 0.3	Q 0.5	Q 0.7	Q 0.8
Total area (ha), log	-0.293	-0.087	-0.077	-0.021	0.026
	(0.191)	(0.102)	(0.070)	(0.049)	(0.044)
Non-rural farm major source of income[1] (=1 if yes; 0 otherwise)	0.095	0.118	0.047	0.078*	0.063*
	(0.159)	(0.085)	(0.058)	(0.041)	(0.036)
Joint -participation[2] (=1 if yes; 0 otherwise)	-0.119	-0.041	-0.068	-0.054	-0.070*
	(0.165)	(0.088)	(0.060)	(0.042)	(0.038)
Constant	442.60	364.80	397.50	1,172.00***	2,103.00***
	(296.00)	(293.70)	(324.10)	(335.0)	(382.90)
Observations	1,931	1,931	1,931	1,931	1,931

[1]At least one household member has off-farm labor like salaried job, business, and works in service industry.

[2] Husband and spouse making farming-related decisions jointly.

Source: 2016 Rice Monitoring Survey conducted by IRRI.

Full coefficients are in Appendix Table 20.

hand, rice variety MRV2 and MRV6 estimates are significant among all the quantiles. In terms of MRV4, it shows that there is a significant and negative effect in yield among the low performing group while a positive and significant effect among high performing groups.

Regarding choosing the rice varieties, results show that joint decision-making is negative and significant among farmers in the 80th quantile. The result suggests that the household belongs to the 80th quantile, the yield will decrease by 7% (*p-value=0.061*). A decrease in yield when there is a joint-participation strategy may be due to the variety chosen that satisfies the couple's individual preferences but does not provide a high yield. The study of Paris et al. (2008) shows that women farmers prefer rice characteristics that pertain to taste and cooking quality while men farmers prefer production qualities (such as resistance to pests or responsiveness to fertilizer). Similar findings were found by Anja et al. (2017) in analyzing the gender-differentiated varietal trait preferences of several crops in Asia, Sub-Saharan Africa, and Latin America. It shows that women prefer post-harvest, processing, and food use traits while men prefer production-related traits. The couple should combine rice varieties' desired traits to choose a rice variety, which may sometimes penalize the yield characteristics.[43] Additionally, Mottaleb et al. (2017) and Mottaleb and Mishra (2016) found that with increasing income and urbanization, consumers were increasingly consuming fine-grain (i.e., long-and-slender-grain) rice by replacing ordinary-grain (i.e.,

[43] The specific traits mentioned by men and women: post-harvest traits (tall height, ease of threshing and dehulling); processing (quantity of useable flour); food use (cooking time, taste, grain color); and production-related (pest resistance, resistance to water logging, high yield).

short-and-bold-grain) rice. Perhaps, spouses of farmers in the 80^{th} quantile are aware of and prefer rice varieties with cooking qualities—aroma, slender grain, long-grain, and less starch content. This result is supported by a study by Subir et al. (2019) in the major cities in South and Southeast Asia. It shows that women who are mainly the sole decision-maker when doing the groceries are more concerned about aroma and cooking characteristics than taste, appearance, and nutritional benefits compared to other shoppers.

In terms of sources of income, non-rural employment shows a positive effect on yield among high-performing groups. For example, when the household has a non-rural income source, the yield in the 70th and 80th quantile will increase by 8% and 6%, respectively. Employment to the non-rural sector will enable the household to diversify the income sources that serve as coping strategies due to income risk (such as flood and drought). Recall that in 2015 rice production, more than 60% of farmers were affected by flood and drought. Similar results were found by Webb and Reardon (1992) that households in Burkina Faso who diversified to non-farm activities were more able to cope with droughts. In addition, the male household members in India usually work in the non-rural sector, leaving the women to take all farm responsibilities by increasing their participation in decision-making (Paris et al., 2005). Thus, having a non-rural farm income among high performers may also reinforce women's participation in rice variety decision-making.

4.7 Conclusion and Policy Implications

Smallholders are one of the major players in the Indian rice sector. With the continuously increasing number of small and fragmented land, inevitably, this sector will remain.

However, with the slow growth in rice production for the past decades in India, understanding the relationship between smallholders and rice productivity is essential in identifying the major constraints. The existence of an inverse relationship in farm size and productivity is a common justification for implementing land reform programs that promote efficiency and equity among poor farmers. Hence, this paper analyzed the farm size and productivity relationship among rice farmers in eastern India. Specifically, how intrahousehold issues such as joint decision-making in choosing rice variety may affect rice productivity.

Using the 2016 Rice Monitoring Survey by the International Rice Research Institute (IRRI) shows two significant findings. First, there is an inverse relationship between farm size and productivity and weakens when controlling household fixed and soil quality. In addition, the inverse relationship eventually disappears when analyzing the relationship by farm productivity. Second, to address intrahousehold issues that affect productivity, the inclusion of joint participation in decision-making was included found to be significant when the controls are not included. However, when analyzing the effect of joint decision-making using quantile regression, it shows a negative and significant in high-performing households (80^{th} quantile).

There are two major implications of this study. First, the study shows the existence of an inverse productivity relationship among the smallholder. Thus, land reform programs advocating large farms may be disregarded by policymakers. Instead of focusing land reform programs since inverse relationship weakens when controlling for house-specific variables and land quality. Instead of focusing on land fragmentation programs, policies should focus on farming practices regarding the application of inputs. The focus should be on rice variety and other technologies that pertain to the sustainable application of input. For instance, fertilizer usage has an insignificant effect on yield among low and mid-performing farmers despite the high application. (Appendix Table 18). Thus, farmers should be aware of the required fertilizer application since excessive use of fertilizer may lead to lower yield and may cause environmental problems (soil acidification, greenhouse gas emission (Peng et al., 2006; Guo et al., 2010; Cassman et al., 2003; Smil, 2004). Farmers can explore site-specific nutrient management (SSNM), a natural technique that adjusts the N, P, and K management specific in season and field condition of the plot to fill the nutrient deficit to sustain fertility (Buresh, 2009). This kind of program can help the low and mid-performing groups manage their soil nutrients and improve their yield.

Second, since the joint participation strategy in choosing the rice variety penalizes the rice productivity, enhancing the couple's knowledge regarding rice varieties should be a priority for policymakers, researchers, and extension agents. Information dissemination about rice variety characteristics (planting duration, pest resistance, and ecosystem) and consumer traits (aroma, grain length, and taste) should be clearly communicated to farming couples. In addition, the couple could also develop new rice varieties by providing rice breeders information on their preferred rice traits through Participatory Varietal Selection (PVS) (Paris et al., 2005). A PVS study by Manzanilla et al. (2013) regarding submergence tolerant varieties in Southeast Asia shows that female farmers are as knowledgeable as male farmers in evaluating the lines/variety visible characteristics. It means that the couple has their preference traits for a rice variety.

5 CONCLUSION AND IMPLICATIONS

The introduction of high-yielding rice varieties through the Green Revolution has increased rice production in India. However, there has been steady growth in rice productivity in recent years. Though India did not experience a vast production and consumption gap compared to other countries, this is still critical since smallholder production dominates the rice sector and serves as the primary source of livelihood among women. In rice production, the involvement of women is usually limited to their labor participation. Differences in gender roles within the household hinder women from accessing productive resources and services compared to their male counterparts, leading to a gender gap in rice productivity. Reducing the gender gap by providing women equal access to resources may help to increase rice productivity in eastern India. However, there is little information on how the gender gap in productivity can be addressed between married couples in a patriarchal family structure like India. The dissertation's primary objective is to analyze the potential impact on rice productivity and input use when the spouse was given access to resources (e.g., rice variety and credit) in the household. The Rice Monitoring Survey (RMS) of 2016 was used in all three chapters of the dissertation. This survey contains detailed information about rice production (rice variety, cropping practices, rice production, and input use) and gender-disaggregated data, particularly decision-making participation and access to resources of the household's major male and female decision-makers.

Chapter 2 measures the impact of the married couple's joint decision-making regarding rice variety on rice productivity. This chapter created a married couple decision-making variable and explicitly related it to rice productivity and input use if the spouse is given access to resources. The results show that households under joint decision-making tend to have higher rice yields than their counterparts. In terms of complementary inputs such as labor and total fertilizer, results show that households with the husband sole decision-maker require lower labor and higher fertilizer usage than households with joint decision-makers. This chapter provides evidence that the joint decision-making strategy of the couple results in a gender-differentiated impact on rice productivity indicators (yield, total labor, and total fertilizer). Thus, identifying the primary decision-maker is very important for implementing rice technology programs to ensure a high adoption rate.

The third chapter provides empirical evidence on spouses' access to financial resources on rice managerial and technology gaps in eastern India. Results show a significant difference in technological and managerial gaps between households with access and without access to financial resources. Families with access to financial resources have lower yields compared to a household with access. Thus, the spouses' access to credit does not necessarily lead to an increase in rice productivity. Directly linking financial access may provide misleading information. It is essential to determine the primary purpose of why households avail financial services to estimate the actual impact of productivity.

The last chapter analyzes the inverse relationship between farm size and productivity when accounting for joint decision-making in rice variety. Results show that the inverse relationship weakens when controlling household fixed and soil quality. The joint decision-making variable was significant when control variables (household-specific and soil quality) are not included in the estimation. However, when analyzing the effect of joint decision-making using quantile regression, it shows a negative and significant in high-performing households (80th quantile). Having a joint decision-making strategy, the couple combined their preferred rice traits that penalizes rice productivity, particularly among highly productive farmers. Thus, enhancing the couple's knowledge regarding rice varieties should be given focus.

The dissertation has two significant limitations. First, the joint decision-making variable only provides information about participation. It does not provide information regarding the control between husband and wife in the joint decision-making process. The degree of spouse's influence within the joint decision-making framework is worth exploring in future studies. Second, due to data limitations, the dissertation used the spouses' access to evaluate its impact on farmer's technical efficiency. It is recommended that future studies may also explore additional information regarding the major reasons for availing of loans, household's financial status and credit constraints.

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APPENDIX

TABLES 1-10

Table 1. Test on the Validity of the Instruments Used for the Selection Equation.

Variable	Yield		Total labor		Total fertilizer	
	Joint decision-making (1/0)	Husband solely deciding (kg/ha) log	Joint decision-making (1/0)	Husband solely deciding (persons-day/ha) log	Joint decision-making (1/0)	Husband solely deciding (kg/ha), log
With credit	0.309***	0.014	0.309***	-0.051	0.314***	-0.056
	(0.058)	(0.106)	(0.058)	(0.051)	(0.057)	(0.051)
Difference age	0.0216**	0.016	0.0216**	-0.007		
	(0.007)	(0.012)	(0.007)	(0.006)		
Distance to nearest market (km), log	0.004	-0.032	0.004	-0.018	0.001	-0.016
	(0.012)	(0.022)	(0.012)	(0.011)	(0.012)	(0.010)
Constant	-0.250***	6.631***	-0.250***	4.747***	-0.123***	4.709***
	(0.051)	(0.084)	(0.051)	(0.041)	(0.031)	(0.026)
Wald test χ^2/ or F-stat	39.880***	1.590	39.880***	1.620	30.030***	1.710
Number of observations	2,471	1,274	2,471	1,274	2,471	1,274

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.10

Table 2: Description of Rice Varieties by Year of Released in Eastern India, 2016.

Variety type	Year released	Characteristics	Popular rice varieties in the sample and its released year
MRV1	Before or during 1976)	higher yield than traditional varieties and responsive to fertilizer but susceptible to pest and diseases.	Mahsuri (1972) and Annapura (1976)
MRV2	1977–1985	Resistant to multiple pests and diseases, making the yield more stable.	Swarna (1979)
MRV3	1986–1995	Better grain quality and improved pest resistance	MTU-1010 (1995), Moti (1988), and Pooja (1999)
MRV4	released 1996 later except hybrid rice varieties (HRV)	Varieties for adverse environments	Swarna-Sub1 (2009)
MRV5	released after 1995	superior productivity compared to the previously discussed MRV generations	Arize 6444 (2015), PHB 71 (1997), and GK-5000 (2008)
MRV6	Mixture of rice varieties except for MRV5 and local rice varieties		

Source: Laborte et al. (2015), Launio et al. (2008) and Indian Institute of Rice Research (IIRI).

Table 3: Summary Statistics of the Variables Used in Endogenous Switching Regression Model, Eastern India, 2016.

	Joint decision-maker[1] (n=1,197)	Male decision-maker (n=1,274)	All households (n=2,471)		Difference
Dependent variables					
Yield (kg/ha)	1,545.608	1,679.701	1,614.744	$t =$	-134.093***
	(10.008)	(1,547.090)	(1,591.461)		
Explanatory variables					
Household characteristics					
Age of the respondent[2] (years), log	47.867	48.467	48.176	$t =$	-0.600
	(11.619)	(11.938)	(11.786)		
Years of education respondent (years), log	5.236	6.119	5.691	$t =$	-0.883***
	(4.228)	(4.779)	(4.541)		
Total number household members, log	3.515	3.872	3.699	$t =$	-0.357***
	(1.484)	(1.750)	(1.636)		
Scheduled caste/tribe[3] (=1 if yes; 0 otherwise)	0.355	0.221	0.286	$\chi^2 =$	54.697***
	(0.479)	(0.415)	(0.452)		
Other backward caste[4] (=1 if yes; 0 otherwise)	0.426	0.396	0.410	$\chi^2 =$	2.367
	(0.495)	(0.489)	(0.492)		
General caste (=1 if yes; 0 otherwise)	0.219	0.384	0.304	$\chi^2 =$	79.373***
	(0.414)	(0.487)	(0.460)		
Farm location, Bihar state (=1 if yes; 0 otherwise)	0.121	0.370	0.250	$\chi^2 =$	204.815
	(0.326)	(0.483)	(0.433)		
Farm location, Odisha state (=1 if yes; 0 otherwise)	0.577	0.107	0.335	$\chi^2 =$	613.616***
	(0.494)	(0.309)	(0.472)		
Farm location, West Bengal state (=1 if yes; 0 otherwise)	0.257	0.240	0.248	$\chi^2 =$	0.969
	(0.437)	(0.427)	(0.432)		
Farm location, Uttar Pradesh state (=1 if yes; 0 otherwise)	0.283	0.044	0.167	$\chi^2 =$	251.755***
	(0.450)	(0.206)	(0.373)		
With off-farm employment[5]	1.224	0.914	1.064	$t =$	0.309***
	(0.995)	(0.915)	(0.947)		
Share of assets owned by women[6]	22.200	25.755	24.033	$t =$	-3.555***
	(25.092)	(27.552)	(26.443)		

Table 3 (continued)

	Joint decision-maker1	Male decision-maker (n=1,274)	All households (n=2,471)		Difference
Share of assets owned by women[6]	22.200	25.755	24.033	$t =$	-3.555***
	(25.092)	(27.552)	(26.443)		
With migrants[7] (=1 if yes; 0 otherwise)	0.165	0.191	0.178	$\chi^2 =$	2.987
	(0.462)	(0.499)	(0.481)		
Farm characteristics					
Experienced flood/drought 2015 (=1 if yes; 0 otherwise)	0.508	0.632	0.572	$\chi^2 =$	38.714***
	(0.500)	(0.482)	(0.495)		
Uses machine (1=yes; 0 otherwise)	0.795	0.953	0.877	$\chi^2 =$	141.643***
	(0.404)	(0.212)	(0.329)		
Uses pesticide (1=yes; 0 otherwise)	0.444	0.503	0.474	$\chi^2 =$	8.772***
	(0.497)	(0.500)	(0.499)		
Transplanted rice (=1 if yes; 0 otherwise)	0.869	0.966	0.919	$\chi^2 =$	78.721***
	(0.338)	(0.181)	(0.273)		
Total number of rice plots	1.490	1.301	1.393	$t =$	0.190***
	(0.778)	(0.625)	(0.709)		
Share of irrigated area (%)	40.421	74.520	58.001	$t =$	-34.099***
	(48.095)	(41.012)	(47.723)		
Proportion of medium land[8]	0.522	0.537	0.530	$t =$	-0.015
	(0.488)	(0.492)	(0.490)		
Inputs used					
Seeds usage (kg/ha)	40.490	36.069	38.211	$t =$	4.421***
	(38.681)	(38.689)	(38.740)		
Total fertilizer (kg/ha)[9]	248.419	294.102	271.972	$t =$	-45.684***
	(164.251)	(183.184)	(175.725)		
Total active fertilizer (kg/ha)	114.883	136.382	125.968	$t =$	-21.499***
	(76.631)	(84.419)	(81.436)		
Total labor (person-days/ha) [10]	71.499	75.895	73.765	$t =$	-4.400**
	(47.139)	(48.800)	(48.043)		
Family labor (person-days/ha)	30.558	30.981	30.776	$t =$	-0.423
	(33.704)	(41.224)	(37.762)		

Table 3 (continued)

	Joint decision-maker1	Male decision-maker (n=1,274)	All households (n=2,471)		Difference
Hired labor (person-days/ha)	16.614	15.631	16.107	t=	-0.982
	(20.517)	(21.252)	(20.901)		
Contract labor (person-days/ha)	10.828	17.981	14.516	$t =$	7.154***
	(23.677)	(26.899)	(25.635)		
Total cultivated rice area (ha)	0.455	0.411	0.432	$t =$	-0.044**
	(0.411)	(0.524)	(0.473)		
Contract labor (person-days/ha)	10.828	17.981	14.516	$t =$	7.154***
Rice varieties					
Traditional varieties (TV)	0.129	0.130	0.130	$t =$	-0.015
	(0.335)	(0.337)	(0.336)		
MRV1 (before 1977) (=1 if yes; 0 otherwise)	0.077	0.126	0.102	$t =$	-16.002***
	(0.266)	(0.332)	(0.303)		
MRV2 (1977-85) (=1 if yes; 0 otherwise)	0.236	0.219	0.227	$t =$	0.968
	(0.425)	(0.414)	(0.419)		
MRV3 (1986-1995) (=1 if yes; 0 otherwise)	0.077	0.113	0.096	$t =$	-9.347***
	(0.266)	(0.317)	(0.294)		
MRV4(1996 or later) (=1 if yes; 0 otherwise)	0.104	0.061	0.082	$t =$	15.277***
	(0.306)	(0.240)	(0.275)		
MRV5 (hybrid rice 1995 and later) (=1 if yes; 0 otherwise)	0.028	0.120	0.075	$t =$	-75.903***
	(0.164)	(0.325)	(0.264)		
MRV6 (mixed generation) (=1 if yes; 0 otherwise)	0.350	0.231	0.289	$t =$	42.767***
	(0.477)	(0.421)	(0.453)		

Table 3 (continued)

	Joint decision-maker1	Male decision-maker (n=1,274)	All households (n=2,471)		Difference
Instrumental variables					
With credit[11]	0.297	0.203	0.248	$t =$	0.094***
	(0.457)	(0.402)	(0.432)		
Proportion of farm credit	0.605	0.532	0.574	$t =$	0.073*
	(0.026)	(0.031)	(0.491)		
Difference age (Husband-wife)	6.045	5.555	5.792	$t =$	0.490***
	(3.420)	(3.802)	(3.630)		
Distance to nearest market (km), log	4.403	4.117	4.255	$t =$	0.286
	(4.341)	(4.060)	(4.200)		

Standard deviations in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

[1] Husband and wife are making farming-related decisions jointly.

[2] Respondents are husband.

[3] Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.

[4] Includes castes that are socially and educationally marginalized.

[5] Number of household members with off-farm labor like salaried job, business, and works in service industry.

[6] Share productive assets solely owned by women.

[7] At least of one the member is a migrant.

[8] Mediumland are term used to land that is in between lowland and upland.

[9]Total chemical fertilizer used in rice production: NPK- nitrogen, phosphorus and potassium (15-15-15); DAP - diammonium phosphate (18-44-0); and Urea (46-0-0) (http:\www.yara.com).

[10]This includes family labor, hired labor, and contract labor. Person-days/ha is same as person-days/ ha in which 6 hours =1 day.

[11]Credit availed by the household in the past 12 months.

Source: 2016 Rice Monitoring Survey conducted by IRRI.

Table 4: Definition of Variables Used in the Analysis.

Variables	Definition
Joint decision-making (1 = yes, 0 otherwise)	The participation of men and women: (1) husband and wife jointly participate in deciding the rice variety; (0) husband solely decides the rice variety in the presence of the wife.
Wife/spouse	The term wife and spouse are interchangeably used in the study.
Operator	The term operator and husband are interchangeably used in the study.
Age (years)	The age of husband (years).
Education level (years)	The years of education of the husband (years).
Household size	Number of adults in the house (16 years and above).
Caste	These are designated groups of historically marginalized indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.
State where the household is located	There are four easter Indian states included: Bihar, Odisha, Uttar Pradesh, and West Bengal.
With off-farm employment	Number of the household members with off-farm labor like salaried job, business, and works in service industry.
Share of productive assets solely owned by women	Share of productive assets which solely owned by women. The productive assets include: animals, farm equipment, small and large durables (e.g. TV, refrigerator, and radio).
With migrant (1 = yes, 0 otherwise)	At least of one the member is a migrant.

Table 4 (continued)

Variables	Definition
Experienced flood/drought 2015 (1 = yes, 0 otherwise)	This indicates if the farmer experienced flood, drought, or both in cropping the year 2015.
Uses machines (1 = yes, 0 otherwise)	The household uses machine in rice production which includes tractor, seeder, sprayer, harvester, thresher, and diesel and electric pump.
Uses pesticides (1 = yes, 0 otherwise)	The household applied pesticides during the cropping season.
Share of irrigated area	Share of irrigated rice area to the total rice area.
Proportion of mediumland	This is the proportion of area that a farmer considered to be a mediumland to the total rice area. Medium land is a land that is intermediate between lowland and upland.
Transplanted the rice (1 = yes, 0 otherwise)	Uses rice transplanting as the method of crop establishment.
Total plots	Total rice plots the household is currently cultivating.
Seeds use (kg/ha)	Seeds use (kg/ha).
Labor	Labor use can be classified as hired labor (person-days/ha); family labor (person-days/ha); and contract labor (person-days/ha). 1 day = 6 hours.
Fertilizer use (kg/ha)	Total chemical fertilizer used in rice production: NPK- nitrogen, phosphorus and potassium (15-15-15); DAP - diammonium phosphate (18-44-0); and Urea (46-0-0).
With credit (1 = yes, 0 otherwise)	Household loans that were availed in the past 24 months for farm and nonfarm purposes.
Difference of years of age and education of the husband and wife	This the difference between the husband and wife age/education.
Distance (km)	Distance to the nearest market (km).

Source: 2016 Rice Monitoring Survey conducted by IRRI.

Table 5: Parameter Estimates of Couples' Decision-making Strategies and Yield (kg/ha) log, Endogenous Switching Regression (ESR) Approach.

Variables	OLS[12]	ESR		
			Regime 1 (Joint decision-making =1)	Regime 2 (Joint decision-making =0)
	Total yield (kg/ha), log	Joint decision-making (1/0)	Total yield (kg/ha), log among joint decision-making couple	Total yield (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Joint decision-making (=1 if yes; 0 otherwise)[1]	-0.028			
	(0.076)			
Age of the respondent[2] (years), log	0.121	0.050	0.192	0.005
	(0.142)	(0.360)	(0.920)	(0.030)
Years of education respondent[2] (years), log	0.002	-0.002	0.001	0.003
	(0.005)	(-0.40)	(0.120)	(0.490)
Total number household members, log	-0.269**	-0.051	-0.133	-0.304**
	(0.091)	(-0.58)	(-0.95)	(-2.59)
Scheduled caste/tribe[3] (=1 if yes; 0 otherwise)	-0.005	0.147*	0.0766	0.040
	(0.089)	(1.810)	(0.530)	(0.330)
Other backward caste[4] (=1 if yes; 0 otherwise)	-0.003	0.394***	0.315**	-0.076
	(0.081)	(4.990)	(2.270)	(-0.75)
Farm location, Bihar state (=1 if yes; 0 otherwise)	0.575***	0.657***	-0.127	0.696***
	(0.109)	(5.330)	(-0.46)	(5.310)

Table 5 (continued)

Variables	OLS[12]	ESR		
	Total yield (kg/ha), log	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total yield (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total yield (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Farm location, Bihar state (=1 if yes; 0 otherwise)	0.575***	0.657***	-0.127	0.696***
	(0.109)	(5.330)	(-0.46)	(5.310)
Farm location, Odisha state (=1 if yes; 0 otherwise)	-0.268	2.520***	1.177**	-0.668**
	(0.164)	(15.820)	(2.390)	(-2.53)
Farm location, West Bengal state (=1 if yes; 0 otherwise)	0.855***	1.651***	2.022***	0.424**
	(0.152)	(11.040)	(4.830)	(2.150)
With off-farm employment[5]	0.048	0.025	0.075	0.011
	(0.039)	(0.670)	(1.300)	(0.230)
Share of women ownership in productive assets[6]	-0.004**	0.005***	0.003	-0.010***
	(0.001)	(4.390)	(1.380)	(-3.970)
With migrants[7] (=1 if yes; 0 otherwise)	0.166**	0.199***	0.212**	0.159**
	(0.061)	(3.190)	(2.100)	(2.270)
Experienced flood/drought 2015 (=1 if yes; 0 otherwise)	0.021	-0.167**	0.067	-0.108
	(0.071)	(-2.56)	(0.620)	(-1.150)
Uses machine (1=yes; 0 otherwise)	-0.121	-0.167	-0.269**	-0.059
	(0.113)	(-1.50)	(-1.96)	(-0.290)
Uses pesticide (1=yes; 0 otherwise)	0.175*	-0.159**	0.372***	-0.086
	(0.069)	(-2.33)	(3.320)	(-0.960)

Table 5 (continued)

Variables	OLS[12]	ESR		
	Total yield (kg/ha), log	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total yield (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total yield (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Share of irrigated area (%)	-0.0003	0.001	0.002	-0.002
	(0.001)	(0.830)	(1.420)	(-1.510)
Proportion of medium land[8]	-0.232***	0.194***	0.072	-0.433***
	(0.070)	(3.030)	(0.680)	(-4.50)
Transplanted rice (=1 if yes; 0 otherwise)	-0.448***	0.208*	-0.341**	-0.380
	(0.129)	(1.660)	(-2.25)	(-1.40)
Total number of rice plots	-0.100	-0.017	-0.063	-0.077
	(0.092)	(0.084)	(0.119)	(0.131)
Seeds usage (kg/ha), log	-0.170**	0.017	-0.087	-0.165**
	(0.052)	(0.330)	(-1.02)	(-2.41)
Total family labor (persons day/ha)[9], log	0.080***	-0.021	0.013	0.079***
	(0.016)	(-1.38)	(0.380)	(4.700)
Total hired labor (persons day/ha), log	-0.020**	0.001	-0.029**	-0.009
	(0.007)	(0.160)	(-2.50)	(-0.99)
Total contract labor (persons day/ha), log	0.008	-0.023***	-0.0201*	0.020**
	(0.007)	(-3.22)	(-1.68)	(2.130)

Table 5 (continued)

Variables	OLS[12]	ESR		
		Joint decision-making (1/0)	Regime 1 (Joint decision-making =1)	Regime 2 (Joint decision-making =0)
	Total yield (kg/ha), log		Total yield (kg/ha), log among joint decision-making couple	Total yield (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Total fertilizer (kg/ha)[10], log	0.151*	-0.046	0.152	0.096
	(0.063)	(-0.72)	(1.440)	(1.260)
MRV1 (before 1977) (=1 if yes; 0 otherwise)	0.334**	0.099	0.497***	0.357**
	(0.119)	(0.820)	(2.760)	(2.480)
MRV2 (1977-85) (=1 if yes; 0 otherwise)	-0.138	-0.036	-0.180	-0.239
	(0.113)	(-0.36)	(-1.14)	(-1.57)
MRV3 (1986-1995) (=1 if yes; 0 otherwise)	0.537***	0.024	0.467***	0.464***
	(0.117)	(0.180)	(2.620)	(3.070)
MRV4 (1996 or later) (=1 if yes; 0 otherwise)	-0.375*	-0.143	-0.571***	-0.388
	(0.166)	(-1.04)	(-2.60)	(-1.61)
MRV5 (hybrid rice 1995 and later) (=1 if yes; 0 otherwise)	0.809***	-0.086	0.971***	0.566***
	(0.113)	(-0.58)	(3.730)	(4.210)
MRV6 (mixed generation) (=1 if yes; 0 otherwise)	0.763***	-0.100	0.448**	0.824***
	(0.153)	(-0.67)	(2.120)	(3.700)
Constant	6.147***	-1.762***	3.286***	7.544***
	(0.624)	(-2.79)	(2.980)	(9.190)

Table 5 (continued)

Variables	OLS[12]	ESR		
		Joint decision-making (1/0)	Regime 1 (Joint decision-making =1)	Regime 2 (Joint decision-making =0)
	Total yield (kg/ha), log		Total yield (kg/ha), log among joint decision-making couple	Total yield (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Instruments				
With credit[11] (=1 if yes; 0 otherwise)		0.227***		
		(3.340)		
Difference age (Husband-wife)		-0.019*		
		(-1.89)		
Distance to nearest market (km), log		0.0258*		
		(1.740)		
σ_i			1.635***	1.365
			(0.060)	(0.027)
ρ_i			0.535***	0.014
			(0.096)	(0.118)
Total number of observations	2,471		1,197	1,274
R-square	0.175			
Log Likelihood		-5, 613.46	Log Likelihood	
Wald chi2 (29)		302.02***	Wald chi2 (29)	

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

[1] Husband and spouse making farming-related decisions jointly.

[2] Respondents are husband.

[3] Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.
[4] Includes castes that are socially and educationally marginalized.
[5] Number of household members with off-farm labor like salaried job, business, and works in service industry.
[6] Share productive assets solely owned by women.
[7] At least of one the member is a migrant.
[8] Mediumland are term used to land that is in between lowland and upland.
[9]This includes family labor, hired labor, and contract labor. Person-days/ha is same as person-days/ ha in which 6 hours =1 day.
[10]Total chemical fertilizer used in rice production: NPK- nitrogen, phosphorus and potassium (15-15-15); DAP - diammonium phosphate (18-44-0); and Urea (46-0-0) (http:\www.yara.com).
[11]Credit availed by the household in the past 12 months.
[12]The test for multicollinearity resulted to a VIF=2.10. In addition, using the Breusch-Pagan/ Cook-Weisberg test for constant variance shows the variance is not constant (chi2=123.36*; p-value=0.000*) which led to the use of robust standard error.
Source: 2016 Rice Monitoring Survey conducted by IRRI.

Table 6: Parameter Estimates of Couples' Decision-making Strategies and Total Labor (person-day/ha) log, Endogenous Switching Regression (ESR) Approach.

Variables	OLS	ESR		
	Total labor[1] (persons-day/ha), log	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total yield (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total yield (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Joint decision-making (=1 if yes; 0 otherwise)[2]	0.005			
	(0.024)			
Age of the respondent[3] (years), log	0.106*	-0.003	0.087	0.139*
	(0.047)	(0.004)	(0.062)	(0.072)
Years of education respondent (years), log	0.003*	0.048	0.002	0.005**
	(0.002)	(0.135)	(0.002)	(0.002)
Total number household members, log	-0.011	-0.033	0.012	-0.034
	(0.031)	(0.086)	(0.043)	(0.046)
Scheduled caste/tribe[4] (=1 if yes; 0 otherwise)	-0.089***	0.200***	-0.080	-0.098**
	(0.030)	(0.081)	(0.046)	(0.045)
Other backward caste[5] (=1 if yes; 0 otherwise)	-0.099***	0.439***	-0.110**	-0.130***
	(0.027)	(0.077)	(0.054)	(0.042)
Farm location, Bihar state (=1 if yes; 0 otherwise)	0.080**	0.671***	-0.081	0.047
	(0.040)	(0.119)	(0.109)	(0.057)

Table 6 (continued)

Variables	OLS	ESR		
	Total labor[1] (persons-day/ha), log	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total yield (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total yield (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Farm location, Odisha state (=1 if yes; 0 otherwise)	0.156***	2.424***	0.033	-0.364***
	(0.052)	(0.150)	(0.236)	(0.126)
Farm location, West Bengal state (=1 if yes; 0 otherwise)	0.129***	1.651***	0.081	-0.128
	(0.050)	(0.146)	(0.181)	(0.086)
With off-farm employment (=1 if yes; 0 otherwise)[6]	-0.017	0.015	-0.042**	-0.015
	(0.013)	(0.037)	(0.017)	(0.021)
Share of women ownership in productive assets[7]	0.001**	0.005***	-0.0005	0.001**
	(0.000)	(0.001)	(0.001)	(0.001)
With migrants[8] (=1 if yes; 0 otherwise)	0.024	0.192***	-0.004	-0.003
	(0.023)	(0.065)	(0.035)	(0.035)
Experienced flood/drought 2015 (=1 if yes; 0 otherwise)	0.0593**	-0.236***	0.026	0.111***
	(0.023)	(0.065)	(0.036)	(0.036)
Uses machine (1=yes; 0 otherwise)	0.145***	-0.187*	0.186***	0.136
	(0.036)	(0.111)	(0.043)	(0.077)
Uses pesticide (1=yes; 0 otherwise)	0.069***	-0.214***	-0.030	0.163***
	(0.023)	(0.066)	(0.038)	(0.036)
Share of irrigated area (%)	0.001**	0.0004	-0.000001	0.001**
	(0.0003)	(0.001)	(0.000)	(0.0005)

Table 6 (continued)

Variables	OLS	ESR		
	Total labor[1] (persons-day/ha), log	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total yield (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total yield (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Proportion of medium land[9]	-0.109***	0.190***	-0.059*	-0.169***
	(0.023)	(0.064)	(0.034)	(0.036)
Transplanted rice (=1 if yes; 0 otherwise)	0.232***	0.132	0.209***	0.209**
	(0.037)	(0.121)	(0.045)	(0.090)
Total number of rice plots	-0.035	0.018	-0.009	-0.043
	(0.030)	(0.085)	(0.035)	(0.051)
Seeds usage (kg/ha), log	0.111***	0.012	0.132***	0.081***
	(0.018)	(0.052)	(0.026)	(0.028)
Total fertilizer (kg/ha)[10], log	0.261***	-0.044	0.269***	0.275***
	-0.054	(0.062)	(0.032)	(0.031)
With hired labor (=1 if yes; 0 otherwise)	0.317***	0.036	0.411***	0.243***
	(0.026)	(0.069)	(0.036)	(0.035)
MRV1 (before 1977) (=1 if yes; 0 otherwise)	-0.054	0.074	-0.006	-0.086
	(0.045)	(0.123)	(0.067)	(0.064)
MRV2 (1977-85) (=1 if yes; 0 otherwise)	-0.014	-0.021	-0.032	0.00001
	(0.035)	(0.097)	(0.049)	(0.054)

Table 6 (continued)

Variables	OLS	ESR		
	Total labor[1] (persons-day/ha), log	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total yield (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total yield (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
MRV3 (1986-1995) (=1 if yes; 0 otherwise)	0.006	0.034	-0.010	0.022
	(0.045)	(0.131)	(0.064)	(0.067)
MRV4 (1996 or later) (=1 if yes; 0 otherwise)	0.004	-0.117	0.058	-0.030
	(0.045)	(0.133)	(0.060)	(0.077)
MRV5 (hybrid rice 1995 and later) (=1 if yes; 0 otherwise)	0.093*	-0.060	0.144	0.078
	(0.049)	(0.145)	(0.098)	(0.068)
MRV6 (mixed generation) (=1 if yes; 0 otherwise)	-0.029	-0.087	-0.044	0.011
	(0.052)	(0.148)	(0.067)	(0.085)
Constant	1.385***	-1.577**	1.423***	1.212***
	(0.215)	(0.614)	(0.393)	(0.325)
Instruments				
Difference age (Husband-wife)		-0.018**		
		(0.008)		
Distance to nearest market (km), log		0.021*		
		(0.012)		

Table 6 (continued)

Variables	OLS	ESR		
	Total labor[1] (persons-day/ha), log	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total yield (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total yield (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
σ_i			0.476***	0.578***
			(0.010)	(0.027)
ρ_i			0.132	-0.724***
			(0.179)	(0.090)
Total number of observations	2,471		1,197	1,274
R-square	0.258			
Log Likelihood			-2,952.63	
Wald chi2 (27)			501.30***	

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

[1] This includes family labor, hired labor, and contract labor. Person-days/ha is same as person-days/ ha in which 6 hours =1 day.

[2] Husband and spouse making farming-related decisions jointly.

[3]Respondents are husband.

[4]Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.

[5] Includes castes that are socially and educationally marginalized.

[6]Number of household members with off-farm labor like salaried job, business, and works in service industry.

[7] Share productive assets solely owned by women.

[8] At least of one the member is a migrant.
[9] Mediumland is a term used to land that is in between lowland and upland.
[10]Total chemical fertilizer used in rice production: NPK- nitrogen, phosphorus and potassium (15-15-15); DAP - diammonium phosphate (18-44-0); and Urea (46-0-0) (http:\www.yara.com).
[11]The test for multicollinearity resulted to a VIF=2.1. In addition, using the Breusch-Pagan/ Cook-Weisberg test for constant variance shows the variance is constant (chi2=2.80; *p-value= 0.100*).
Source: 2016 Rice Monitoring Survey conducted by IRRI.

Table 7: Parameter Estimates of Couples' Decision-making Strategies Total Fertilizer (kg/ha) log, Endogenous Switching Regression (ESR) approach.

Variables	OLS[12]	ESR		
	Total active fertilizer (kg/ha), log[1]	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total active fertilizer (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total active fertilizer (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Joint decision-making (=1 if yes; 0 otherwise)[2]	-0.021			
	(0.023)			
Age of the respondent[3] (years), log	-0.056	-0.067	-0.091	-0.017
	(0.044)	(0.130)	(0.060)	(0.070)
Years of education respondent[3] (years), log	-0.003*	-0.001	-0.003	-0.002
	(0.001)	(0.000)	(0.000)	(0.000)
Total number household members, log	-0.069**	-0.040	-0.110***	-0.041
	(0.029)	(0.080)	(0.040)	(0.050)
Scheduled caste/tribe[4](=1 if yes; 0 otherwise)	0.040	0.420***	0.017	0.120**
	(0.028)	(0.080)	(0.040)	(0.050)
Other backward caste[5] (=1 if yes; 0 otherwise)	0.096***	0.180**	0.150***	0.120***
	(0.028)	(0.080)	(0.040)	(0.040)
Farm location, Bihar state (=1 if yes; 0 otherwise)	-0.165***	0.690***	-0.300***	0.006
	(0.044)	(0.110)	(0.090)	(0.050)

Table 7 (continued)

Variables	OLS[12]	ESR		
	Total active fertilizer (kg/ha), log[1]	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total active fertilizer (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total active fertilizer (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Farm location, Odisha state (=1 if yes; 0 otherwise)	-0.392***	2.470***	-0.340**	0.300***
	(0.051)	(0.140)	(0.140)	(0.090)
Farm location, West Bengal state (=1 if yes; 0 otherwise)	-0.360***	1.640***	-0.350***	0.009
	(0.048)	(0.130)	(0.110)	(0.070)
With off-farm employment[6] (=1 if yes; 0 otherwise)	0.036***	0.030	0.027*	0.063***
	(0.012)	(0.040)	(0.020)	(0.020)
Share of women ownership in productive assets[7]	-0.0003	0.005***	0.002**	-0.0003
	(0.0004)	(0.000)	(0.000)	(0.000)
With migrants[8] (=1 if yes; 0 otherwise)	0.004	0.190***	0.038	0.033
	(0.022)	(0.060)	(0.030)	(0.030)
Experienced flood/drought 2015 (=1 if yes; 0 otherwise)	-0.0715***	-0.180***	-0.089***	-0.100**
	(0.022)	(0.060)	(0.030)	(0.040)
Uses machine (1=yes; 0 otherwise)	0.110***	-0.150	0.086**	-0.014
	(0.040)	(0.110)	(0.040)	(0.070)
Share of irrigated area (%)	0.00004	0.001	0.0004	0.0004
	(0.0003)	(0.0008)	(0.0004)	(0.0005)

Table 7 (continued)

Variables	OLS[12]	ESR		
	Total active fertilizer (kg/ha), log[1]	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total active fertilizer (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total active fertilizer (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
Proportion of medium land[9]	0.013	0.210***	-0.037	0.130***
	(0.021)	(0.060)	(0.030)	(0.040)
Transplanted rice (=1 if yes; 0 otherwise)	-0.142***	0.210*	-0.170***	0.019
	(0.039)	(0.120)	(0.040)	(0.090)
Total number of rice plots	-0.038	-0.007	-0.071**	-0.006
	(0.027)	(0.080)	(0.030)	(0.050)
Seeds usage (kg/ha), log	0.486***	0.110**	0.476***	0.488***
	(0.017)	(0.040)	(0.020)	(0.020)
Total labor (persons-day/ha)[10], log	0.280***	-0.129**	0.256***	0.277***
	(0.020)	(0.050)	(0.030)	(0.030)
MRV1 (before 1977) (=1 if yes; 0 otherwise)	0.095**	0.101	0.105*	0.084
	(0.043)	(0.120)	(0.060)	(0.060)
MRV2 (1977-85) (=1 if yes; 0 otherwise)	0.038	0.0002	0.048	0.035
	(0.032)	(0.100)	(0.050)	(0.050)
MRV3 (1986-1995) (=1 if yes; 0 otherwise)	0.104**	0.047	0.071	0.124*
	(0.045)	(0.130)	(0.060)	(0.070)

Table 7 (continued)

Variables	OLS[12]	ESR		
	Total active fertilizer (kg/ha), log[1]	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total active fertilizer (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total active fertilizer (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
MRV4 (1996 or later) (=1 if yes; 0 otherwise)	0.005	-0.150	0.014	-0.061
	(0.045)	(0.130)	(0.060)	(0.080)
MRV5 (hybrid rice 1995 and later) (=1 if yes; 0 otherwise)	0.372***	-0.059	0.276***	0.334***
	(0.055)	(0.140)	(0.090)	(0.070)
MRV6 (mixed generation) (=1 if yes; 0 otherwise)	0.009	-0.076	0.087	-0.105
	(0.049)	(0.140)	(0.060)	(0.090)
Constant	2.474***	-1.450***	2.710***	2.240***
	(0.192)	(0.540)	(0.280)	(0.310)
Instruments				
With credit[11] (=1 if yes; 0 otherwise)		0.135**		
		(0.050)		
Distance to nearest market (km), log		0.033***		
		(0.010)		

Table 7 (continued)

Variables	OLS[12]	ESR		
	Total active fertilizer (kg/ha), log[1]	Joint decision-making (1/0)	Regime 1 (Joint decision-making =1) Total active fertilizer (kg/ha), log among joint decision-making couple	Regime 2 (Joint decision-making =0) Total active fertilizer (kg/ha), log among male decision-making couple
	(1)	(2)	(3)	(4)
σ_i			0.442***	0.612***
			(0.011)	(0.018)
ρ_i			0.166	0.868***
			(0.167)	(0.024)
Total number of observations	2,471		1,197	1,274
R-square	0.584			
Log Likelihood			2,817.61	
Wald chi2 (26)			2,049.30***	

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

[1]Total chemical fertilizer used in rice production: NPK- nitrogen, phosphorus and potassium (15-15-15); DAP - diammonium phosphate (18-44-0); and Urea (46-0-0) (http:\www.yara.com).

[2] Husband and spouse making farming-related decisions jointly.

[3] Respondents are husband.

[4] Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.

[5] Includes castes that are socially and educationally marginalized

[6] Number of household members with off-farm labor like salaried job, business, and works in service industry.

[7] Share productive assets solely owned by women.

[8]At least of one the member is a migrant.
[9] Mediumland are term used to land that is in between lowland and upland.
[10]This includes family labor, hired labor, and contract labor. Person-days/ha is same as person-days/ ha in which 6 hours =1 day.
[11] Credit availed by the household in the past 12 months.
[12]The test for multicollinearity resulted to a VIF=2.1. In addition, using the Breusch-Pagan/ Cook-Weisberg test for constant variance shows the variance is not constant (chi2=29.23; *p-value= 0.000*) which led to the use of robust standard error.
Source: 2016 Rice Monitoring Survey conducted by IRRI.

Table 8: Average Treatment Effect on Treated/Untreated and Heterogeneity Effects for Rice Yield (kg/ha), by Rice Variety.

Rice seed variety/ Generation		Joint decision-making yield (kg/ha)	Husband solely deciding yield (kg/ha)	ATE/ATU	
				Change	%
(1)	(2)	(3)	(4)		
Local varieties	Joint	767.82	603.33	164.49***	27.26
		(50.89)	(23.10)	(55.88)	
	Husband	218.40	839.63	-621.22***	-73.99
		(14.75)	(34.18)	(37.22)	
	Heterogeneity	549.42***	-236.30***	785.72***	
		(51.34)	(41.89)	(54.68)	
MRV1 (before 1977)	Joint	581.24	852.12	-270.88***	-31.79
		(70.34)	(44.16)	(83.05)	
	Husband	149.04	1179.56	-1,030.52***	-87.36
		(11.81)	(47.42)	(48.87)	
	Heterogeneity	149.04***	1,179.56***	-1,030.52***	
		(11.81)	(47.42)	(48.87)	
MRV2 (1977-85)	Joint	826.56	509.10	317.45***	62.36
		(36.31)	(18.15)	(40.60)	
	Husband	175.34	599.51	-424.17***	-70.75
		(8.73)	(19.94)	(21.77)	
	Heterogeneity	651.21	-90.41	741.62***	
		(37.53)	(26.95)	(39.71)	
MRV3 (1986-1995)	Joint	1,013.84	757.71	256.13***	33.80
		(86.08)	(50.99)	(100.04)	
	Husband	191.17	871.88	-680.71***	-78.07
		(11.55)	(52.88)	(54.13)	
	Heterogeneity	822.67***	-114.18***	936.84***	
		(70.22)	(77.72)	(85.56)	
MRV4 (1996 or later)	Joint	269.15	270.99	-1.84	-0.68
		(17.21)	(13.99)	(22.18)	
	Husband	72.54	461.83	-389.28***	-84.29
		(9.43)	(30.30)	(31.74)	
	Heterogeneity	196.60***	-190.84***	387.44***	
		23.04	29.76	31.26	

Table 8 (continued)

Rice seed variety/ Generation (1)	(2)	Joint decision-making yield (kg/ ha) (3)	Husband solely deciding yield (kg/ ha) (4)	ATE/ATU Change	%
MRV5 (hybrid rice 1995 and later)	Joint	1,246.33	1,149.91	96.42	8.39
		(108.47)	(152.97)	(187.52)	
	Husband	204.00	1,920.29	-1,716.28***	-89.38
		(5.70)	(75.12)	(75.34)	
	Heterogeneity	1,042.32***	-770.38***	1,812.71***	
		(51.37)	(176.70)	(181.09)	
MRV6 (mixed generation)	Joint	1,043.82	963.51	80.31	8.34
		(43.54)	(30.33)	(53.06)	
	Husband	262.49	1,312.86	-1,050.37***	-80.01
		(13.64)	(46.53)	(48.49)	
	Heterogeneity	781.33	-349.35	1,130.68	
		(53.22)	(53.19)	(55.13)	

Standard errors in parentheses: *** p < 0.01, ** p < 0.05, * p < 0.1.
Note: [A] and [B] represents expected yield (kg/ha) observed in the sample while [C] and [D] represents expected yield (kg/ha) in the counterfactual case. (1 tonne=1000 kg).

Table 9: Average Treatment Effect on Treated/Untreated and Heterogeneity Effects to Total Labor Use (person day/ha), by Rice Variety.

Rice seed variety/ Generation (1)	(2)	Joint decision-making labor (persons-day/ha) (3)	Husband solely deciding labor (persons-day/ha) (4)	ATE/ATU Change	ATE/ATU %
Local varieties	Joint	65.94	32.46	33.49***	103.18
		(1.83)	(0.92)	(2.05)	
	Husband	76.66	69.24	7.42***	10.72
		(1.88)	(1.50)	(2.40)	
	Heterogeneity	-10.71***	-36.78***	26.07***	
		(2.63)	(1.80)	(1.50)	
MRV1 (before 1977)	Joint	64.51	30.48	34.02***	111.62
		(1.79)	(0.73)	(1.93)	
	Husband	72.69	61.58	11.10***	18.03
		(1.45)	(1.10)	(1.82)	
	Heterogeneity	-8.18***	-31.10***	22.92***	
		(2.35)	(1.55)	(1.64)	
MRV2 (1977-85)	Joint	64.84	32.18	32.66***	101.47
		(1.10)	(0.53)	(1.22)	
	Husband	76.05	69.90	6.15***	8.80
		(1.28)	(1.10)	(1.69)	
	Heterogeneity	-11.21***	-37.72***	26.50***	
		(1.68)	(1.22)	(1.02)	
MRV3 (1986-1995)	Joint	62.15	30.13	32.02***	106.26
		(1.87)	(0.84)	(2.05)	
	Husband	72.56	65.16	7.41***	11.37
		(1.74)	(1.47)	(2.28)	
	Heterogeneity	-10.41***	-35.02***	24.61***	
		(2.64)	(1.96)	(1.62)	
MRV4 (1996 or later)	Joint	68.61	28.52	40.09***	140.57
		(1.89)	(0.76)	(2.04)	
	Husband	75.72	60.52	15.19***	25.10
		(2.67)	(1.96)	(3.31)	

Table 9 (continued)

Rice seed variety/ Generation (1)	(2)	Joint decision-making labor (persons-day/ha) (3)	Husband solely deciding labor (persons-day/ha) (4)	ATE/ATU Change	%
	Heterogeneity	-7.11**	-32.01***	24.90***	
		(3.19)	(1.82)	(2.09)	
MRV5 (hybrid rice 1995 and later)	Joint	73.67	33.78	39.88***	118.05
		(3.92)	(1.73)	(4.28)	
	Husband	80.65	74.64	6.01**	8.05
		(1.65)	(1.64)	(2.33)	
	Heterogeneity	-6.98*	-40.86***	33.87***	
		(4.00)	(3.62)	(2.86)	
MRV6 (mixed generation)	Joint	58.34	28.86	29.48***	102.18
		(0.91)	(0.41)	(1.00)	
	Husband	68.25	61.21	7.03***	11.49
		(1.36)	(1.12)	(1.76)	
	Heterogeneity	-9.91***	-32.36***	22.45***	
		(1.57)	(1.06)	(0.88)	

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Note: ^{A} and ^{B} represents expected total labor (persons day/ha) observed in the sample while ^{C} and ^{D} represents expected total labor (persons day/ha) in the counterfactual case.

Table 10: Average Treatment Effect on Treated/Untreated and Heterogeneity Effects to Total Fertilizer (kg/ha), by Rice Variety.

Rice seed variety/ Generation		Joint decision-making Total fertilizer use (kg/ ha)	Husband solely deciding Total fertilizer use (kg/ ha)	ATE/ATU	
				Change	%
(1)	(2)	(3)	(4)		
Local varieties	Joint	106.16	123.93	-17.77***	-14.34
		(1.77)	(1.98)	(2.66)	
	Husband	124.3	316.10	-191.80***	-60.69
		(5.76)	(13.55)	(14.73)	
	Heterogeneity	16.60**	186.60***	-186.00***	
		(7.35)	(14.23)	(8.26)	
MRV1 (before 1977)	Joint	115.12	289.07	-173.95***	-60.17
		(5.63)	(14.29)	(15.36)	
	Husband	116.4	139.40	-23.00***	-16.50
		(6.56)	(6.61)	(9.31)***	
	Heterogeneity	-1.20	149.70***	-171.80***	
		(9.65)	(13.89)	(7.13)	
MRV2 (1977-85)	Joint	114.13	292.48	-178.35	-60.98
		(3.42)	(8.71)	(9.36)	
	Husband	117.94	136.76	-18.81	-13.76
		(3.97)	(4.77)	(6.21)	
	Heterogeneity	-3.82	155.72	-174.08	
		(5.24)	(9.96)	(5.83)	
MRV3 (1986-1995)	Joint	126.41	358.18	-231.76***	-64.71
		(6.79)	(20.08)	(21.20)	
	Husband	126.01	143.19	-17.18***	-12.00
		(5.53)	(5.99)	(8.15)	
	Heterogeneity	0.40	214.99****	-231.54***	
		(8.80)	(17.70)	(11.89)	
MRV4 (1996 or later)	Joint	108.20	284.95	-176.75***	-62.03
		(5.73)	(16.64)	(17.60)	
	Husband	90.69	104.34	-13.64*	-13.08
		(5.51)	(5.79)	(8.00)	

Table 10 (continued)

Rice seed variety/ Generation (1)	(2)	Joint decision-making Total fertilizer use (kg/ ha) (3)	Husband solely deciding Total fertilizer use (kg/ ha) (4)	ATE/ATU Change	%
	Heterogeneity	17.51*	180.61***	-173.96***	
		(8.46)	(21.58)	(13.93)	
MRV5 (hybrid rice 1995 and later)	Joint	148.56	425.07	-276.52***	-65.05
		(13.99)	(36.47)	(39.06)	
	Husband	97.71	134.47	-36.76***	-27.34
		(2.81)	(3.61)	(4.58)	
	Heterogeneity	50.85***	290.61***	-252.22***	
		(8.85)	(18.49)	(11.03)	
MRV6 (mixed generation)	Joint	85.75	196.00	-110.24***	-56.25
		(2.68)	(5.99)	(6.57)	
	Husband	87.33	90.50	-3.16	-3.50
		(3.30)	(3.28)	(4.66)	
	Heterogeneity	-1.58	105.50***	-117.09***	
		(4.23)	(7.67)	(4.38)	

Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Note: [A] and [B] represents expected total fertilizer (kg/ha) observed in the sample while [C] and [D] represents expected total fertilizer (kg/ha) in the counterfactual case.

APPENDIX B

TABLES 11-16

Table 11: Definition of Variables and Descriptive Statistics, Eastern India 2016.

Variable	Description	With Access (n=884)	Without access (n=813)	Pooled (n=1,697)
Probit model				
Spouse age	Age of the spouse in years	42.00	42.19	42.09
Spouse education: less than primary level	Spouse completed class 5/primary or class below (=1 if yes; 0 otherwise)	0.19	0.20	0.19
Spouse education: more than primary level	Spouse completed class 5 or primary or degree above. (=1 if yes; 0 otherwise)	0.27	0.26	0.27
Spouse: illiterate	Spouse who are illiterate	0.54	0.55	0.54
Household size	Total adult members (Age>15 years old)	3.81	3.51	3.67
With Kids under nine years old and below	Household with kids whose age is 9 years old and below (1=yes; 0=otherwise)	0.47	0.48	0.48
Below Poverty card	Household with Below Poverty card (1=yes; 0=otherwise)	0.55	0.58	0.56
Number of livestock	Total number of livestock the household owned (e.g., buffalo, dairy cattle, goats, sheep, chicken, ducks, and pigs)	1.48	1.50	1.49
Off-farm source of income	At least one of the couples has off-farm employment (such as service, business, or government).	0.44	0.54	0.48
Ground irrigation	Household uses groundwater irrigation source such as shallow and deep water tubewell.	0.17	0.16	0.16
Owned a mobile phone	Spouse own personal mobile phone (1=yes; 0=otherwise)	0.31	0.16	0.24
Scheduled caste/tribe	Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.	0.26	0.32	0.29
Other backward caste	Includes castes that are socially and educationally marginalized.	0.45	0.35	0.40
General caste	Household belonging to general caste (1=yes; 0=otherwise)	0.29	0.32	0.30
Farm located in Bihar	Farm located in Bihar (1=yes; 0=otherwise)	0.28	0.27	0.28

Table 11 (continued)

Variable	Description	With Access (n=884)	Without access (n=813)	Pooled (n=1,697)
Farm located Odisha	Farm located in Odisha (1=yes; 0=otherwise)	0.24	0.41	0.32
Farm located in West Bengal	Farm located in West Bengal (1=yes; 0=otherwise)	0.18	0.27	0.22
Farm located in Uttar Pradesh	Farm located in West Bengal (Based)	0.29	0.05	0.18
SPF				
Yield	Rice yield (kg/ha)	1,784.34	2,060.85	1,916.81
Seed	Total seed (kg/ha)	33.53	35.70	34.57
Fertilizer	Total fertilizer (kg/ha) used composed of NPK (Nitrogen, Phosphorus and Potassium), Urea, and DAP (diammonium phosphate)	297.33	259.65	279.28
Total labor	Total labor used (persons day/ha)	61.50	63.24	62.33
Total cultivated rice area	Total area (ha)	0.41	0.41	0.41
Flood/drought 2015	Flood and drought occurrence in 2015	0.65	0.64	0.65
Supplemental irrigation	Uses supplemental irrigation like deep (1=yes; 0 otherwise)	0.69	0.49	0.59
Proportion of medium land	These are land that is intermediate between lowland and upland	0.56	0.42	0.49
Uses machine	Uses machine in rice production (1=yes; 0 otherwise)	0.89	0.82	0.86
Owns large farm equipment	Own large agricultural equipment (land leveler, tiller, thresher).	0.14	0.12	0.13
Hired labor	If the household hired labor (1=yes; 0=otherwise)	0.60	0.66	0.63
Local varieties	Varieties without released information from the government (1=yes; 0=otherwise)	0.13	0.12	0.13
MV1	Varieties released before 1977 (=1 if yes; 0 otherwise)	0.12	0.10	0.11
MV2	Varieties released 1977-85 (=1 if yes; 0 otherwise)	0.17	0.20	0.18
MV3	Varieties released 1986-199) (=1 if yes; 0 otherwise)	0.12	0.10	0.11
MV4	Varieties released 1996 or later (=1 if yes; 0 otherwise)	0.07	0.07	0.07
MV5	Hybrid varieties released 1995 and later (=1 if yes; 0 otherwise)	0.12	0.09	0.10
MV6	Mixed modern varieties except Hybrid (=1 if yes; 0 otherwise)	0.27	0.32	0.30

Source: 2016 Rice Monitoring Survey conducted by IRRI.

Table 12: Standardized Percentage Balance, Pseudo R2, and Final Sample Size Using Different Matching.

Type of matching	Standardized percentage bias[a]		Pseudo R^{2} [b]		LR-test		Final sample (units dropped)	
	Before matching	After matching	Before matching	After matching	Before matching	After matching	Treatment	Controlled
NN (5)	12.3%	2.2%	0.107	0.098	3.99**	3.59*	879 (5)	777 (36)
Kernel (0.04)	12.3%	2.0%	0.107	0.106	3.99**	4.20**	879 (5)	813 (0)
Radius	12.3%	2.4%	0.107	0.857	3.99**	2.35	879 (5)	702 (111)

*** p<0.01, ** p<0.05, *0.10

[a] Standardized percentage balance – mean of the treated (with access) minus the mean of the control (without access) divided by the average of the square root of the variance of the treated and control samples. Matching is sufficient if standardized bias is below 3% or 5%.

[b] Lower Pseudo R^2 after the matching and there is no systematic difference.

Table 13: Means Before and After Matching.

	Before matching			After matching			
	With access	Withou t access	*t-stats*	With access	Without access	*t-stats*	% R bias
Sample selection							
Spouse age (years)	42.00	42.19	-0.35	42.02	42.34	-0.60	-64.10
Spouse education: < primary (=1 if yes; 0 otherwise)[1]	0.19	0.20	-0.29	0.19	0.21	-1.23	-324.00
Spouse education: > primary (=1 if yes; 0 otherwise)[2]	0.27	0.26	0.89	0.28	0.27	0.30	66.50
Household size[3]	3.81	3.51	3.74***	3.81	3.82	-0.15	95.80
With kids under 9 years old (1=yes; 0=otherwise)	0.47	0.48	-0.48	0.47	0.48	-0.47	3.70
Below Poverty card (1=yes; 0=otherwise)	0.55	0.58	-1.26	0.55	0.51	1.61	-25.30
Number of livestock[4]	1.48	1.50	-0.23	1.48	1.50	-0.25	-3.80
Off-farm source of income (=1 if yes; 0 otherwise)[5]	0.44	0.54	-4.27***	0.44	0.44	0.08	98.20
Spouse owns phone (1 if yes; 0 otherwise)	0.31	0.16	7.27***	0.31	0.32	-0.72	89.30
Ground water irrigation (1 if yes; 0 otherwise) [6]	0.17	0.16	0.16	0.17	0.18	-0.66	-323.00
Scheduled caste/tribe (=1 if yes; 0 otherwise)[7]	0.26	0.32	-2.77**	0.27	0.26	0.18	93.70
Other backward caste (=1 if yes; 0 otherwise)[8]	0.45	0.35	4.04***	0.45	0.45	0.07	98.30
Farm located in Bihar (1=yes; 0=otherwise)	0.28	0.27	0.56	0.29	0.29	-0.24	56.80
Farm located in Odisha (1=yes; 0=otherwise)	0.24	0.41	-7.33***	0.24	0.25	-0.04	99.40
Farm located in West Bengal (1=yes; 0=otherwise)	0.18	0.27	-4.33***	0.18	0.18	0.24	95.00
SPF							
Yield (kg/ha)	1,784.3	2,060.8	-5.23	1,787.0	1,867.9	-1.59	70.80
Seed (kg/ha)	33.53	35.70	-1.60	33.63	29.97	2.93***	-68.80
Total fertilizer (kg/ha)	297.33	259.65	4.35	298.01	274.15	2.76**	36.70
Total labor (person-day/ha)	61.50	63.25	-0.80	61.57	60.68	0.44	49.20
Total cultivated rice area (ha)	0.41	0.41	-0.14	0.41	0.41	0.04	73.4
Experienced flood/drought 2015 (=1 if yes; 0 otherwise)	0.65	0.64	0.67	0.65	0.68	-1.21	-75.40
Use supplemental irrigation (1=yes; 0 otherwise)	0.69	0.49	8.47	0.68	0.66	1.02	88.50
Proportion of medium land	0.56	0.42	6.14	0.56	0.48	3.49***	43.80
Use farm machine (1=yes; 0=otherwise)	0.89	0.82	3.85	0.89	0.89	-0.02	99.70

Table 13 (continued)

	Before matching			After matching			
	With access	Without access	*t-stats*	With access	Without access	*t-stats*	% R bias
Owns large farming equipment (=1 if yes; 0 otherwise)[9]	0.14	0.12	1.33	0.14	0.10	3.18***	-124.50
Hired labor (1=yes; 0=otherwise)	0.60	0.66	-2.44	0.60	0.62	-1.09	55.90
MRV1 (before 1977) (=1 if yes; 0 otherwise)	0.12	0.10	1.03	0.12	0.10	1.32	-25.00
MRV2 (1977-85) (=1 if yes; 0 otherwise)	0.17	0.20	-1.38	0.17	0.15	0.97	34.30
MRV3 (1986-1995) (=1 if yes; 0 otherwise)	0.12	0.10	1.63	0.12	0.22	-5.38***	-282.80
MRV4 (1996 or later) (=1 if yes; 0 otherwise)	0.07	0.07	-0.07	0.07	0.05	1.14	-1327.40
MRV5 (hybrid rice 1995 and later =1 if yes; 0 otherwise)	0.12	0.09	1.80	0.12	0.11	0.68	61.70
MRV6 (mixed generation) (=1 if yes; 0 otherwise)	0.27	0.32	-2.13	0.27	0.26	0.65	71.20

[1] Spouse completed class 5/primary or class below.
[2] Spouse completed class 5/primary or degree above.
[3] Adult (>15 years old) members of the household.
[4] Livestock includes the following: buffalo, dairy cattle, goats, sheep, chicken, ducks, and pigs.
[5] At least one of the couples has off-farm employment (such as service, business, or government).
[6] Household uses groundwater irrigation source such as shallow and deep water tubewell.
[7] Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.
[8] Includes castes that are socially and educationally marginalized.
[9] Large agricultural equipment (such as land leveler, tiller, and thresher).
Source: 2016 Rice Monitoring Survey conducted by IRRI.

Table 14: Hypothesis Tests.

Test	Test statistics	P-value	Outcome
Frontier test (Ho: No inefficiency component)	LR = 176.513	0.000	Frontier not OLS
Test for constant returns to scale (Ho: CRS)	χ^2= 1076.154	0.000	Returns to Scale is not constant
Pooing test (Ho: pooled sample)	χ^2= 92.589	0.000	Sperate two groups
Cobb-Douglas or Translog (Ho: Cobb-Douglas)	LR = 17.11	0.060	Translog function

Table 15: Estimates of the Conventional and Sample Selection SPF: Unmatched Sample.

		Pooled	Conventional		Sample Selection	
			With access	Without access	With access	Without access
Constant	β_0	7.688***	7.672***	7.814***	7.736***	7.767***
		(0.078)	(0.115)	(0.111)	(0.133)	(0.212)
Seed	β_1	-0.059**	-0.096***	0.020	-0.095**	-0.004
		(0.023)	(0.032)	(0.032)	(0.034)	(0.040)
Fertilizer	β_2	0.125***	0.094	0.142***	0.073	0.136**
		(0.040)	(0.062)	(0.049)	(0.067)	(0.056)
Labor	β_3	0.051*	0.080**	0.005	0.077*	0.006
		(0.027)	(0.037)	(0.033)	(0.042)	(0.042)
Area	β_4	0.121**	0.098	0.154**	0.073	0.118*
		(0.047)	(0.070)	(0.059)	(0.075)	(0.069)
Seed^2	β_{11}	0.129**	0.166**	0.041	0.166*	0.027
		(0.056)	(0.075)	(0.076)	(0.086)	(0.097)
Fertilizer^2	β_{22}	0.044	-0.078	0.312**	-0.089	0.371*
		(0.126)	(0.205)	(0.159)	(0.237)	(0.199)
Labor^2	β_{33}	0.074	0.006	0.199**	-0.004	0.182**
		(0.066)	(0.093)	(0.080)	(0.131)	(0.091)
Area^2	β_{44}	0.017	0.019	0.020	-0.015	-0.046
		(0.100)	(0.138)	(0.147)	(0.153)	(0.189)
Seed*Fertilizer	β_{12}	0.039	0.039	0.079	0.045	0.101
		(0.054)	(0.079)	(0.069)	(0.094)	(0.078)
Seed*Labor	β_{13}	0.004	0.035	-0.042	0.038	-0.028
		(0.041)	(0.056)	(0.054)	(0.075)	(0.068)
Seed*Area	β_{14}	0.089	0.144*	0.025	0.150	0.020
		(0.058)	(0.084)	(0.074)	(0.093)	(0.097)
Fertilizer*Labor	β_{23}	-0.073	-0.007	-0.170*	-0.027	-0.221*
		(0.061)	(0.087)	(0.094)	(0.107)	(0.116)
Fertilizer*Area	β_{24}	-0.018	-0.089	0.137	-0.113	0.148
		(0.095)	(0.148)	(0.118)	(0.179)	(0.158)
Labor*Area	β_{34}	-0.015	0.030	-0.071	0.015	-0.104
		(0.068)	(0.096)	(0.108)	(0.121)	(0.129)
Medium land	Med	-0.064**	-0.104**	0.010	-0.100	0.019
		(0.025)	(0.038)	(0.031)	(0.039)	(0.035)
Bihar	D_1	0.406***	0.356***	0.296***	0.406***	0.353**
		(0.044)	(0.052)	(0.084)	(0.084)	(0.126)
Odisha	D_2	0.318***	0.402***	0.092	0.485***	0.104
		(0.049)	(0.067)	(0.082)	(0.112)	(0.155)

Table 15 (continued)

		Pooled	Conventional		Sample Selection	
			With access	Without access	With access	Without access
West Bengal	D_3	0.658***	0.702***	0.478***	0.745***	0.511***
		(0.051)	(0.071)	(0.085)	(0.109)	(0.148)
Caste: ST	D_4	-0.103***	-0.084*	-0.095**	-0.087	-0.090
		(0.032)	(0.048)	(0.036)	(0.055)	(0.048)
Caste: OBC	D_5	-0.031	-0.104**	0.045	-0.097*	0.045
		(0.030)	(0.044)	(0.039)	(0.050)	(0.051)
Stress	D_6	-0.179***	-0.151***	-0.164***	-0.154***	-0.188***
		(0.027)	(0.041)	(0.034)	(0.045)	(0.042)
Irrigation	D_7	0.050	0.093*	-0.003	0.086*	0.012
		(0.032)	(0.049)	(0.036)	(0.048)	(0.049)
Machine	D_8	0.134***	0.158**	0.130***	0.178**	0.147***
		(0.038)	(0.068)	(0.040)	(0.069)	(0.045)
Equipment	D_9	-0.140***	-0.166***	-0.065	-0.170***	-0.074
		(0.035)	(0.051)	(0.041)	(0.054)	(0.046)
Hired labor	D_{10}	-0.102***	-0.176***	-0.069*	-0.175***	-0.080*
		(0.028)	(0.040)	(0.039)	(0.042)	(0.047)
MV1	D_{11}	-0.005	-0.111	0.059	-0.125*	0.072
		(0.046)	(0.068)	(0.055)	(0.066)	(0.063)
MV2	D_{12}	0.248***	0.259***	0.162***	0.228***	0.177***
		(0.042)	(0.061)	(0.046)	(0.058)	(0.056)
MV3	D_{13}	0.073	-0.011	0.124*	-0.043	0.144*
		(0.049)	(0.069)	(0.065)	(0.065)	(0.075)
MV4	D_{14}	0.253***	0.276***	0.176***	0.258***	0.203***
		(0.053)	(0.077)	(0.062)	(0.076)	(0.066)
MV5	D_{15}	0.059	0.048	0.022	0.009	0.044
		(0.051)	(0.071)	(0.066)	(0.076)	(0.096)
MV6	D_{16}	0.192***	0.146**	0.194***	0.107**	0.233***
		(0.041)	(0.058)	(0.047)	(0.054)	(0.053)
Financial access	FA	-0.042*				
		(0.024)				
Lambda (λ)		4.533***	3.869***	8.712***		
		(0.362)	(0.388)	(1.370)		
Variance (σ^2)		0.926***	0.909***	0.939***		
		(0.000)	(0.001)	(0.001)		

Table 15 (continued)

	Pooled	Conventional		Sample Selection	
		With access	Without access	With access	Without access
Sigma -u (σ_u)				0.917***	0.904***
				(0.030)	(0.021)
Sigma – v (σ_v)				0.213***	0.145***
				(0.036)	(0.025)
Rho (ρ)				-0.431	-0.185
				(0.486)	(0.827)
Log likelihood function	-1,362.85	-714.74	-604.99	-1,235.00	-1,136.51

*p<0.10, **p<0.05,***p<0.001.

Table 16: Estimates of the Conventional and Sample selection SPF: Matched Sample.

		Pooled	Conventional		Sample Selection	
			With access	Without access	With access	Without access
Constant	β_0	7.688***	7.672***	7.837***	7.781***	7.766***
		(0.079)	(0.115)	(0.103)	(0.134)	(0.078)
Seed	β_1	-0.067***	-0.096***	0.004	-0.090**	-0.006
		(0.023)	(0.032)	(0.030)	(0.033)	(0.022)
Fertilizer	β_2	0.126***	0.092	0.138**	0.093	0.097***
		(0.041)	(0.062)	(0.049)	(0.070)	(0.034)
Labor	β_3	0.048*	0.081**	-0.010	0.064	-0.010
		(0.027)	(0.037)	(0.032)	(0.042)	(0.026)
Area	β_4	0.114**	0.097	0.120**	0.081	0.068*
		(0.048)	(0.070)	(0.057)	(0.076)	(0.039)
Seed^2	β_{11}	0.120**	0.166**	-0.002	0.110	-0.035
		(0.056)	(0.075)	(0.072)	(0.070)	(0.055)
Fertilizer^2	β_{22}	0.067	-0.087	0.379**	-0.082	0.384***
		(0.128)	(0.206)	(0.161)	(0.248)	(0.118)
Labor^2	β_{33}	0.076	0.005	0.187**	-0.015	0.156**
		(0.067)	(0.094)	(0.078)	(0.131)	(0.058)
Area^2	β_{44}	0.044	0.018	0.093	-0.061	-0.039
		(0.103)	(0.139)	(0.145)	(0.154)	(0.124)
Seed*Fertilizer	β_{12}	0.056	0.040	0.118*	0.035	0.125**
		(0.055)	(0.080)	(0.064)	(0.094)	(0.051)
Seed*Labor	β_{13}	0.001	0.035	-0.061	0.015	-0.056
		(0.041)	(0.056)	(0.050)	(0.070)	(0.045)
Seed*Area	β_{14}	0.096	0.145*	0.019	0.107	0.016
		(0.059)	(0.085)	(0.072)	(0.087)	(0.064)
Fertilizer*Labor	β_{23}	-0.061	-0.007	-0.121	-0.060	-0.200***
		(0.062)	(0.087)	(0.096)	(0.110)	(0.068)
Fertilizer*Area	β_{24}	0.008	-0.094	0.219*	-0.134	0.163*
		(0.097)	(0.148)	(0.117)	(0.185)	(0.093)
Labor*Area	β_{34}	-0.001	0.030	-0.029	-0.028	-0.115
		(0.069)	(0.097)	(0.108)	(0.123)	(0.074)
Medium land	Med	-0.063**	-0.103**	0.025	-0.103**	0.039*
		(0.026)	(0.026)	(0.026)	(0.041)	(0.022)
Bihar	D_1	0.410***	0.356***	0.300***	0.437***	0.411***
		(0.044)	(0.052)	(0.077)	(0.084)	(0.052)
Odisha	D_2	0.320***	0.404***	0.095	0.534***	0.237***
		(0.050)	(0.067)	(0.077)	(0.109)	(0.048)

Table 16 (continued)

		Pooled	Conventional		Sample Selection	
			With access	Without access	With access	Without access
West Bengal	D_3	0.663***	0.703***	0.464***	0.815***	0.592***
		(0.053)	(0.071)	(0.079)	(0.111)	(0.048)
Caste: ST	D_4	-0.112***	-0.083*	-0.117***	-0.104*	-0.163***
		(0.032)	(0.048)	(0.035)	(0.056)	(0.027)
Caste: OBC	D_5	-0.034	-0.102**	0.035	-0.104**	-0.014
		(0.031)	(0.044)	(0.039)	(0.052)	(0.031)
Stress	D_6	-0.183***	-0.150***	-0.170***	-0.157***	-0.192***
		(0.028)	(0.041)	(0.034)	(0.046)	(0.023)
Irrigation	D_7	0.051	0.094*	0.001	0.083*	-0.028
		(0.032)	(0.049)	(0.036)	(0.049)	(0.031)
Machine	D_8	0.122***	0.159**	0.106**	0.157**	0.097***
		(0.039)	(0.068)	(0.039)	(0.075)	(0.029)
Equipment	D_9	-0.141***	-0.167***	-0.052	-0.179***	-0.044
		(0.036)	(0.051)	(0.039)	(0.057)	(0.031)
Hired labor	D_{10}	-0.102***	-0.175***	-0.081**	-0.168***	-0.084***
		(0.029)	(0.040)	(0.037)	(0.043)	(0.024)
MV1	D_{11}	0.0003	-0.112	0.097*	-0.118*	0.136***
		(0.047)	(0.068)	(0.055)	(0.068)	(0.035)
MV2	D_{12}	0.255***	0.258***	0.163***	0.208***	0.129***
		(0.043)	(0.061)	(0.044)	(0.059)	(0.029)
MV3	D_{13}	0.093**	-0.007	0.168***	-0.045	0.251***
		(0.050)	(0.069)	(0.061)	(0.067)	(0.051)
MV4	D_{14}	0.260***	0.276***	0.202**	0.231***	0.214***
		(0.054)	(0.077)	(0.060)	(0.072)	(0.039)
MV5	D_{15}	0.068	0.046	0.026	0.016	0.049
		(0.051)	(0.071)	(0.062)	(0.078)	(0.055)
MV6	D_{16}	0.209***	0.144**	0.238***	0.107*	0.244***
		(0.042)	(0.058)	(0.045)	(0.055)	(0.033)
Financial access	FA	-0.038				
		(0.024)				
Lambda (λ)		4.510***	3.915***	10.576***		
		(0.369)	(0.398)	(1.960)		
Variance (σ^2)		0.929***	0.912***	0.951***		
		(0.000)	(0.001)	(0.001)		

Table 16 (continued)

	Pooled	Conventional		Sample Selection	
		With access	Without access	With access	Without access
Sigma -u (σ_u)				0.919***	0.937***
				(0.033)	(0.012)
Sigma – v (σ_v)				0.241***	0.074***
				(0.049)	(0.018)
Rho (ρ)				-0.657**	0.838***
				(0.323)	(0.244)
Log likelihood function	-1,336.75	-714.74	-577.63	-1,224.64	-1,094.81

*p<0.10, **p<0.05,***p<0.001.

APPENDIX C

TABLES 17-20

Table 17: Variable definition used in the analysis.

Variables	Definition of terms
Age (years)	The age of respondent (years).
Education level (years)	The years of education of the husband (years).
Household size	Number of adults in the house (16 years and above).
Wife/spouse	The term wife and spouse are interchangeably used in the study.
Joint decision-making (1 = yes, 0 otherwise)	The participation of men and women: (1) husband and wife jointly participate in deciding the rice variety; (0) husband solely decides the rice variety in the presence of the wife.
Land title (1 = yes, 0 otherwise)	Ownership of land based on the name in the land title (certificate).
Caste	These are designated groups of historically marginalized indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.
Non-rural farm employment	Non-rural farm employment: salaried job, business, and works in service industry.
Share of irrigated area	Share of irrigated rice area to the total rice area.
Proportion of mediumland	This is the proportion of area that a farmer considered to be a mediumland to the total rice area.
Experienced flood/drought 2015 (1 = yes, 0 otherwise)	This indicates if the farmer experienced flood, drought, or both in cropping the year 2015.
Seeds use (kg/ha)	Seeds use (kg/ha).
Fertilizer use (kg/ha)	Total chemical fertilizer used in rice production: NPK- nitrogen, phosphorus and potassium (15-15-15); DAP diammonium phosphate (18-44-0); and Urea (46-0-0).

Table 17 (continued)

Variables	Definition of terms
Labor use	Labor use can be classified as hired labor (person-days/ha); family labor (person-days/ha); and contract labor (person-days/ha). 1 day = 6 hours

Source: 2016 Rice Monitoring Survey conducted by IRRI.

Table 18: Summary statistics of the variables used in the estimation, Eastern India, 2016.

	Low (n=773)	Mid (n=163)	High (n=995)	All Farms[1] (n=1,931)
Dependent variable: Yield (kg/ha)	625.23	1,471.47	2,743.77	1,788.30
Farm characteristics				
Total area (ha)	0.37	0.41	0.45	0.42
Experienced flood/drought 2015 (=1 if yes; 0 otherwise)	0.65	0.71	0.60	0.63
Share of irrigated land to the total land area (%)	47.97	41.24	36.03	41.25
Proportion of medium land	0.63	0.41	0.43	0.51
Land with title (1=yes; 0 otherwise)	0.75	0.74	0.76	0.76
Inputs				
Seed (kg/ha)	43.32	35.05	34.75	38.21
Total fertilizer (kg/ha)[2]	286.59	290.49	264.23	275.40
Total labor (person-days/ha)[3]	30.22	34.09	32.43	31.68
Family labor (person-days/ha)	16.93	16.98	14.96	15.92
Hired labor (person-days/ha)	11.82	12.37	16.98	14.53
Contract labor (person-days/ha)	58.97	63.44	64.37	62.13
Machine (1=yes; 0 otherwise)[4]	0.83	0.89	0.88	0.86
Local rice varieties (=1 if yes; 0 otherwise)	0.18	0.10	0.09	0.12
MRV1 (before 1977) (=1 if yes; 0 otherwise)	0.16	0.04	0.07	0.10
MRV2 (1977-85) (=1 if yes; 0 otherwise)	0.19	0.09	0.24	0.21
MRV3 (1986-1995) (=1 if yes; 0 otherwise)	0.17	0.06	0.06	0.10
MRV4(1996 or later) (=1 if yes; 0 otherwise)	0.11	0.04	0.07	0.08
MRV5 (hybrid rice 1995 and later) (=1 if yes; 0 otherwise)	0.05	0.36	0.09	0.10
MRV6 (mixed generation) (=1 if yes; 0 otherwise)	0.14	0.31	0.40	0.28
Household characteristics				
Age respondent	47.44	49.01	48.27	48.00

Table 18 (continued)

	Low (n=773)	Mid (n=163)	High (n=995)	All Farms[1] (n=1,931)
Education respondent	5.57	6.08	5.50	5.58
Household size	3.73	3.69	3.63	3.68
Non-rural farm major source of income[5] (=1 if yes; 0 otherwise)	0.62	0.66	0.74	0.62
Joint -participation[6] (=1 if yes; 0 otherwise)	0.48	0.39	0.45	0.46
Scheduled caste/tribe[7] (=1 if yes; 0 otherwise)	0.31	0.23	0.29	0.30
Other backward caste[8] (=1 if yes; 0 otherwise)	0.48	0.40	0.34	0.40
General caste (=1 if yes; 0 otherwise)	0.21	0.37	0.36	0.30
Farm located in Bihar (1=yes; 0=otherwise)	0.20	0.41	0.29	0.27
Farm located Odisha (1=yes; 0=otherwise)	0.36	0.26	0.31	0.32
Farm located in Uttar Pradesh (1=yes; 0=otherwise)	0.30	0.17	0.09	0.18
Farm located in West Bengal (1=yes; 0=otherwise)	0.14	0.17	0.31	0.23

[1]Low performing farms (yield less than 1,297.28 kg/ha); Mid performing farms (yields between 1,297.28 to 1,662.09 kg/ha); and High performing farms (yield greater than 1,662.09 kg/ha)

[2] Total chemical fertilizer used in rice production: NPK- nitrogen, phosphorus and potassium (15-15-15); DAP - diammonium phosphate (18-44-0); and Urea (46-0-0) (http:\www.yara.com).

[3]This includes family labor, hired labor, and contract labor. Person-days/ha is same as person-days/ ha in which 6 hours =1 day.

[4] The household is using at least one of the type of machines listed: tractor, transplanter, sprayer, combine harvester, thresher, diesel pumps, electric pumps.

[5] At least one household member has off-farm labor like salaried job, business, and works in the service industry.

[6] Husband and spouse are making farming-related decisions jointly.

[7] Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.

[8] Includes castes that are socially and educationally marginalized.

Source: Rice Monitoring Survey 2016.

Table 19: Rice Productivity (kg/ha) Estimation Results with Household-Specific and Soil Quality Control using Yield Approach.

	Naïve	Farm and Household	Farm and Household and Joint decision-making	Household fixed	Soil quality fixed
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*
Total area (ha), log	-0.034	-0.232***	-0.221***	-0.113*	-0.110*
	(0.026)	(0.061)	(0.061)	(0.060)	(0.060)
Experienced flood/drought 2015 (=1 if yes; 0 otherwise)		-0.246***	-0.257***	-0.156***	-0.171***
		(0.045)	(0.046)	(0.046)	(0.0462)
Share of irrigated land to the total land area (%)		-0.002***	-0.002***	-0.001	-0.001
		(0.0005)	(0.001)	(0.001)	(0.001)
Inputs					
Land with title (1=yes; 0 otherwise)		0.032	0.028	-0.018	-0.025
		(0.051)	(0.051)	(0.049)	(0.049)
Seed (kg/ha)		-0.102***	-0.092**	-0.118***	-0.118***
		(0.039)	(0.039)	(0.039)	(0.039)
Total fertilizer[1],log		-0.040	-0.040	0.050	0.044
		(0.060)	(0.060)	(0.059)	(0.059)
Total labor[2],log		0.105**	0.105**	0.0289	0.0123
		(0.042)	(0.042)	(0.042)	(0.042)
Use machine (1=yes; 0 otherwise)[3]		0.262***	0.237***	0.103	0.119*
		(0.068)	(0.069)	(0.070)	(0.070)
MRV1 (before 1977) (=1 if yes; 0 otherwise)		0.228**	0.230**	0.207**	0.222**
		(0.091)	(0.091)	(0.089)	(0.089)

Table 19 (continued)

	Naïve	Farm and Household	Farm and Household and Joint decision-making	Household fixed	Soil quality fixed
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*
MRV2 (1977-85) (=1 if yes; 0 otherwise)		0.263***	0.266***	0.245***	0.255***
		(0.077)	(0.077)	(0.074)	(0.074)
MRV3 (1986-1995) (=1 if yes; 0 otherwise)		0.278***	0.282***	0.478***	0.477***
		(0.091)	(0.091)	(0.089)	(0.089)
MRV4(1996 or later) (=1 if yes; 0 otherwise)		-0.115	-0.106	0.013	0.018
		(0.100)	(0.095)	(0.094)	(0.094)
MRV5 (hybrid rice 1995 and later) (=1 if yes; 0 otherwise)		0.513***	0.505***	0.456***	0.454***
		(0.096)	(0.096)	(0.095)	(0.095)
MRV6 (mixed generation) (=1 if yes; 0 otherwise)		0.595***	0.605***	0.626***	0.615***
		(0.075)	(0.075)	(0.073)	(0.073)
Household characteristics					
Age respondent, log		-0.006**	-0.006**	-0.004	-0.004
		(0.003)	(0.003)	(0.003)	(0.003)
Years of education respondent, log		-0.022	-0.019	-0.071	-0.072
		(0.096)	(0.096)	(0.094)	(0.094)

Table 19 (continued)

	Naïve	Farm and Household	Farm and Household and Joint decision-making	Household fixed	Soil quality fixed
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*
Household size, log		-0.085	-0.092	-0.031	-0.032
		(0.059)	(0.059)	(0.059)	(0.059)
Non-rural farm major source of income[4] (=1 if yes; 0 otherwise)		0.168***	0.179***	0.142***	0.130***
		(0.050)	(0.050)	(0.050)	(0.050)
Joint -participation[5](=1 if yes; 0 otherwise)			-0.104**	-0.041	-0.031
			(0.048)	(0.052)	(0.052)
Controls					
Scheduled caste/tribe[6](=1 if yes; 0 otherwise)				-0.056	-0.045
				(0.056)	(0.056)
Other backward caste[7] (=1 if yes; 0 otherwise)				-0.150**	-0.143**
				(0.059)	(0.059)
Farm located in Bihar (1=yes; 0=otherwise)				0.589***	0.539***
				(0.074)	(0.076)
Farm located Odisha (1=yes; 0=otherwise)				0.307***	0.259***
				(0.097)	(0.099)
Farm located in West Bengal (1=yes; 0=otherwise)				0.782***	0.731***
				(0.097)	(0.098)

Table 19 (continued)

	Naïve	Farm and Household	Farm and Household and Joint decision-making	Household fixed	Soil quality fixed
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*
Proportion of medium land					-0.138***
					(0.046)
Constant	7.101***	6.855***	6.910***	6.597***	6.791***
	(0.039)	(0.451)	(0.451)	(0.454)	(0.457)
$\delta_1 = -0.034$		19.300***	17.610***	6.040**	5.810**
Observations	1,931	1,931	1,931	1,931	1,931
R-squared	0.001	0.099	0.102	0.162	0.166

[1] Total chemical fertilizer used in rice production: NPK- nitrogen, phosphorus and potassium (15-15-15); DAP - diammonium phosphate (18-44-0); and Urea (46-0-0) (http:\www.yara.com).

[2] This includes family labor, hired labor, and contract labor. Person-days/ha is same as person-days/ ha in which 6 hours =1 day.

[3] The household is using at least one of the type of machines listed: tractor, transplanter, sprayer, combine harvester, thresher, diesel pumps, electric pumps.

[4] At least one household member has off-farm labor like salaried job, business, and works in service industry.

[5] Husband and spouse making farming-related decisions jointly.

[6] Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.

[7] Includes castes that are socially and educationally marginalized.

Source: 2016 Rice Monitoring Survey conducted by IRRI.

Table 20: Quantile Analysis of Rice Production in Eastern India. Dependent variable: Yield (kg/ha), log.

	Q 0.1	Q 0.3	Q 0.5	Q 0.7	Q 0.8
Total area (ha), log	-0.293	-0.087	-0.077	-0.021	0.026
	(0.191)	(0.102)	(0.070)	(0.049)	(0.044)
Experienced flood/drought 2015 (=1 if yes; 0 otherwise)	0.059	-0.146*	-0.128**	-0.166***	-0.194***
	(0.147)	(0.078)	(0.054)	(0.038)	(0.034)
Share of irrigated land to the total land area (%)	-0.002	-0.0005	-0.0004	-0.0003	-0.0002
	(0.002)	(0.001)	(0.001)	(0.0005)	(0.0004)
Land with title (1=yes; 0 otherwise)	0.046	0.0001	-0.015	-0.024	0.001
	(0.157)	(0.084)	(0.057)	(0.040)	(0.036)
Inputs					
Seed, log	-0.156	-0.071	-0.108**	-0.031	-0.033
	(0.125)	(0.066)	(0.046)	(0.032)	(0.029)
Total fertilizer[1],log	-0.113	0.020	0.055	0.067	0.096**
	(0.187)	(0.099)	(0.068)	(0.048)	(0.043)
Total labor[2],log	0.008	0.012	0.070	0.072**	0.051*
	(0.135)	(0.072)	(0.049)	(0.035)	(0.031)
Use machine (1=yes; 0 otherwise)[3]	0.044	0.019	0.046	0.119**	0.194***
	(0.224)	(0.119)	(0.082)	(0.058)	(0.051)
MRV1 (before 1977) (=1 if yes; 0 otherwise)	0.487*	0.543***	0.109	-0.068	-0.045
	(0.285)	(0.152)	(0.104)	(0.073)	(0.065)
MRV2 (1977-85) (=1 if yes; 0 otherwise)	-0.496**	0.463***	0.656***	0.249***	0.153***
	(0.236)	(0.126)	(0.086)	(0.061)	(0.054)
MRV3 (1986-95) (=1 if yes; 0 otherwise)	0.775***	0.863***	0.386***	-0.064	-0.013
	(0.284)	(0.151)	(0.104)	(0.073)	(0.065)
MRV4(1996 or later) (=1 if yes; 0 otherwise)	-0.669**	-0.306*	-0.003	0.275***	0.161**
	(0.299)	(0.159)	(0.109)	(0.077)	(0.068)

Table 20 (continued)

	Q 0.1	Q 0.3	Q 0.5	Q 0.7	Q 0.8
MRV5 (hybrid rice 1995 and later) (=1 if yes; 0 otherwise)	0.715**	0.858***	0.449***	0.076	0.030
	(0.303)	(0.161)	(0.111)	(0.078)	(0.069)
MRV6 (mixed generation) (=1 if yes; 0 otherwise)	0.770***	1.175***	0.707***	0.219***	0.096*
	(0.233)	(0.124)	(0.085)	(0.060)	(0.053)
Household characteristics					
Age respondent, log	-0.009	-0.003	0.001	0.0004	-0.001
	(0.010)	(0.005)	(0.004)	(0.003)	(0.002)
Years of education respondent, log	-0.146	-0.013	-0.045	-0.026	-0.023
	(0.300)	(0.159)	(0.109)	(0.077)	(0.069)
Household size, log	-0.165	0.027	0.030	0.002	-0.006
	(0.187)	(0.099)	(0.068)	(0.048)	(0.043)
Non-rural farm major source of income[4] (=1 if yes; 0 otherwise)	0.095	0.118	0.047	0.078*	0.063*
	(0.159)	(0.085)	(0.058)	(0.041)	(0.036)
Joint -participation[5](=1 if yes; 0 otherwise)	-0.119	-0.041	-0.068	-0.054	-0.070*
	(0.165)	(0.088)	(0.060)	(0.042)	(0.038)
Controls					
Scheduled caste/tribe[6] (=1 if yes; 0 otherwise)	-0.104	-0.146	-0.102	-0.089*	-0.087**
	(0.189)	(0.100)	(0.069)	(0.049)	(0.043)
Other backward caste[7] (=1 if yes; 0 otherwise)	-0.140	-0.112	-0.050	0.017	0.005
	(0.178)	(0.095)	(0.065)	(0.046)	(0.041)
Farm located in Bihar (1=yes; 0=otherwise)	0.745***	0.394***	0.404***	0.500***	0.477***
	(0.241)	(0.128)	(0.088)	(0.062)	(0.055)
Farm located Odisha (1=yes; 0=otherwise)	0.525*	0.186	0.114	0.182**	0.344***
	(0.314)	(0.167)	(0.115)	(0.081)	(0.072)

Table 20 (continued)

	Q 0.1	Q 0.3	Q 0.5	Q 0.7	Q 0.8
Farm located in West Bengal (1=yes; 0=otherwise)	0.391	0.502***	0.736***	0.751***	0.749***
	(150.00)	(148.80)	(164.20)	(169.80)	(194.00)
Proportion of medium land	-0.224	-0.072	-0.078	-0.070*	-0.039
	(0.146)	(0.078)	(0.054)	(0.038)	(0.034)
Constant	442.60	364.80	397.50	1,172.00***	2,103.00***
	(296.00)	(293.70)	(324.10)	(335.0)	(382.90)
Observations	1,931	1,931	1,931	1,931	1,931

[1]Total chemical fertilizer used in rice production: NPK- nitrogen, phosphorus and potassium (15-15-15); DAP - diammonium phosphate (18-44-0); and Urea (46-0-0) (http:\www.yara.com).
[2] This includes family labor, hired labor, and contract labor. Person-days/ha is same as person-days/ ha in which 6 hours =1 day.
[3] The household is using at least one of the type of machines listed: tractor, transplanter, sprayer, combine harvester, thresher, diesel pumps, electric pumps.
[4] At least one household member has off-farm labor like salaried job, business, and works in service industry.
[5] Husband and spouse making farming-related decisions jointly.
[6] Includes designated groups of historically disadvantaged indigenous people in India. The terms are recognized in the Constitution of India (GoI), and the various groups are designated in one of the categories. Since independence, the scheduled castes and scheduled tribes were given reservation status, guaranteeing political representation.
[7] Includes castes that are socially and educationally marginalized.
Source: 2016 Rice Monitoring Survey conducted by IRRI.