Economic and Resource Conservation Perspectives of Direct Seeded Rice Planting Methods: Evidence from India

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Abstract

Over the past decade, several parts of rice-growing regions in Asia and South Asia have shifted from the puddled transplanted rice (PTR) establishment method to the direct-seeded rice (DSR) establishment method. Unlike the PTR establishment method, the DSR establishment method can reduce soil erosion, slow the loss of organic matter, and lessen the degradation of soil's physical properties. The DSR method also can improve land productivity and labor efficiency while taking into account the soil and hydrologic conditions of the field, the availability of appropriate land preparation equipment, and irrigation-drainage systems. Using plot- and household-level data, we analyze the impacts of DSR adoption in two rice-growing states of India. We account for observed and unobserved heterogeneity using endogenous switching regression. In addition to yield, we analyze the costs and household income effects of DSR adoption. Our study shows a small but significant effect of DSR adoption on yield and costs. We find a 2.13% reduction in total costs for DSR adopters; DSR farmers can significantly reduce their irrigation and land preparation costs. However, we find that adoption of the DSR method can increase household income of smallholder households by as much as 16%; non-adopting households would benefit with about a 17% increase if they switched to the DSR method. Hence, the decision not to adopt DSR may be irrational and perhaps hurt non-adopting households financially. Policy incentives that encourage adoption of DSR method could increase economic well-being of resource-poor farmers and encourage resource conservation.

Keywords: Rice establishment method, impact assessment, puddled transplant rice (PTR), direct-seeded rice (DSR), smallholders, switching regression, India

JEL codes: D24, D20, D13

1.   Introduction

Rice, a staple food for more than half of the world's population, is one of the most important food crops in terms of area, production, and consumer preference (Farooq et al., 2011; Kumar and Ladha, 2011).[1] More than 90 percent of the world's rice is produced and consumed in the Asia-Pacific region, including India. India is the second-largest producer and consumer of

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[1] The term 'rice is life' is most appropriate for India as this crop plays a vital role in the country's food security and is the backbone of livelihood for millions of rural households.

rice in the world[2]; in 2013-14 India was the biggest exporter of rice followed by Thailand, Vietnam, and the United States of America. Rice, an important staple food crop and primary source of calories, is key to food security in India (Naresh et al., 2013). However, due to urbanization, industrialization, and crop diversification, the total area devoted to rice production is declining not only in India but in the entire rice-producing region of the world. Similarly, the number of rice farmers is declining rapidly in most countries. The possibility of expanding the area under rice production to meet the domestic and global demand for rice[3] in the near future is limited. Additionally, erratic rainfall (drought in some regions and flooding in others), labor, and resource inputs[4] constraints (Rice Alamance, 2013) are pushing producers toward sustainable rice production methods, especially when it comes to water. Take the example of India, where the *Green Revolution* brought substantial gains in rice and wheat yields[5] with a significant use of improved seeds (high-yielding varieties), irrigation, chemical fertilizer, fertilizer, and pesticides.

Five decades later, farmers in India face several problems, and the need for resource conservation is paramount. With falling yields, increasing energy prices, and increasing fertilizer and input costs, agriculture in India and in South Asia is becoming a costly proposition. This would have an adverse impact on the income of smallholders and would pose a greater threat to the food security of smallholder and marginal farmers. Food security for a growing population in

[2] Rice production in India for 2013-14 was 107 million MT while world rice production was about 476 million MT. India exported about 10 million MT of rice in 2013-14 http://agricoop.nic.in/imagedefault/trade/Ricenew.pdf

[3] 114 million tons of additional milled rice needs to be produced by 2035 (Khush 2004).

[4] Includes pesticides, fertilizer, and herbicides.

[5] Adequate water supply is one of the most important factors in rice production. In India, and perhaps in Asia, the rice crop suffers either from too little water (drought) or too much of it (flooding, submergence). Most studies on constraints to high rice yield indicate water as the main factor for yield gaps and yield variability from experiment stations to farms (Barker et al., 1998).

India and most South Asian countries — while sustaining agricultural systems under the current

scenario of depleting natural resources, increasing input costs, and climate variability — calls for

a paradigm shift in farming practices.[6] This requires eliminating unsustainable parts of

conventional agriculture (plowing/tilling the soil, removing all organic material, monoculture)

and adopting agricultural systems that conserve resources for productive agriculture.

Additionally, the International Water Management Institute estimates that by 2020 one-third of

the Asian population will face water shortages. In a recent study, Suryavanshi et al., (2013) argue

that interest in maintaining the sustainability of rice farming is increasing with the scarcity of

water and the competition for water resources, coupled with stagnant or declining yield levels.

Therefore, improved water usage at the systems level and plot level are important

considerations. In Asia and Southeast Asia, rice is widely established by transplanting. Called the

puddled transplant rice (PTR) establishment method, it involves growing seedlings in a nursery

bed and later transplanting them in the main field. An alternative way of growing rice is the

direct-seeded rice (DSR) establishment method, a low-cost establishment technology that

provides an opportunity to improve water and environmental sustainability (Joshi et al. 2013). In

the DSR establishment method, seeds are broadcast, drilled, or dribbled into dry or moist soils

(Chauhan et al., 2015).[7] In this way, the DSR establishment method not only reduces the use of

water but, as Khush (1995) notes, that a new plant type of rice is amenable to direct seeding and

dense planting and therefore would increase land productivity. Figure 1 shows a significant shift

toward the DSR method in a survey of Indian farmers in the state of Uttar Pradesh. Finally, Joshi

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[6] Integrating concerns of productivity, resource conservation and soil quality and the environment is now fundamental to sustained productivity growth.

[7] Rice establishment in the United States is largely done by direct seeded method (Kumar and Ladha, 2011).

et al. (2013) note that the DSR method could be considered a natural resource management technology because it reduces crop water requirements and emission of greenhouse gasses.[8]

The DSR establishment method was practiced only in areas with low population density and/or severe climatic constraints that prevented the intensification of rice systems (Pandey and Velasco, 2002; Kumar and Ladha, 2011; Singh et al., 2013). Rice farmers in Asia and other developing countries are trying to substitute the PTR establishment method with the low-cost DSR establishment method (Johnkutty et al., 2002). DSR can reduce soil erosion, slow the loss of organic matter, and lessen the degradation of soil's physical properties. Finally, Can and Xuan (2002) note that DSR can improve land productivity and labor efficiency while taking into account a field's soil and hydrologic conditions, the availability of appropriate land preparation equipment, and irrigation-drainage systems. Finally, Marenya and Barrett (2007) argue that for smallholder agriculture, as in our case of Indian farmers, resource endowments and farm management options are highly diverse and tend to complicate the adoption and dissemination of resource management technologies like DSR establishment technology. Similarly, the impacts of rice establishment techniques (DSR versus PTR) may vary, and excluding context-specific factors may lead to biased estimates. Controlling for sample heterogeneity and selection bias is therefore important in impact analysis.

In this study, we analyze the impact of DSR's and PTR establishment methods in four rice-growing states of India. In particular, we use plot-level data from Punjab, Eastern Utter Pradesh, Haryana, and Bihar. Our contribution to the literature is twofold. First, we analyze productivity, income, and costs by building on-farm survey data. Recall that most available

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[8] Reduced emissions of these gases help in climate change adaptation and mitigation, enhanced nutrient relations, organic matter turnovers and carbon sequestrations (Joshi et al., 2013).

studies are based on field trial data that may not be representative of real smallholder conditions. We account for observed and unobserved heterogeneity using endogenous switching regression (see Wollni and Brummer, 2011). Second, we go beyond yield and also analyze the impact of the DSR establishment method on smallholder household income, total costs, and fertilizer, irrigation, and land preparation costs. To our knowledge, such broader economic impact of the DSR establishment method on smallholder households has not been previously analyzed.

2.   Rice Establishment Methods

There are two principal methods of rice establishment: transplanting, known as the PTR method, and direct seeding, known as the DSR method. Transplanting involves planting rice seedlings in puddled soil. Direct seeding, on the other hand, can be done under wet (wet seeded rice) or dry (dry seeded rice) conditions. Wet seeded rice is more suited for an irrigated environment, and dry seeded rice is equally suitable for irrigated and rain-fed environments.

Historical evidence of rice cultivation in Asia indicates that dry seeding is the oldest method of crop establishment. Dry seeding consists of sowing dry seeds on dry soils. The seeds are generally broadcasted manually, while line seeding can be done with a drum seeder. In the case of the dry seeded rice establishment method, dry seeds are either broadcasted, or line seeded with a country plow or seed drill and is considered as one of resource conservation technologies.[9] In the case of wet seeded rice sprouted rice seeds are broadcast or line-seeded on puddled soil just after drainage (Farooq et al., 2011; Naresh et al., 2013).[10]

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[9] Direct seeding avoids three basic operations, namely, puddling (a process where soil is compacted to reduce water seepage), transplanting and maintaining standing water.

[10] A drawback of wet seeded rice is that too much standing water creates anaerobic conditions and inhibits germination of seeds because of reduction in oxygen.

Though DSR is merely an alternative method of crop establishment but with optimum water management, it has potential to save irrigation water (primarily because of avoiding the water requirement for puddling) in irrigated environments (Yadav et al., 2011). DSR can further reduce water input by shortening the period of land preparation (Tabbal et al., 2002). In addition, high-yielding, short-duration rice varieties and chemical weed control methods made it economically profitable to substitute the PTR system with DSR. The PTR method[11] is preferred in areas with lower wages and adequate water supply. Finally, short-duration rice varieties and cost-effective selective herbicides have encouraged Asian farmers to adopt the DSR method of establishing rice (Balasubramanian and Hill, 2002). DSR may not be feasible in lowlands where poor drainage conditions make transplanting the only viable method. However, Tabbal et al., 2002, in a study in the Philippines, conclude that direct wet-seeded rice (a method within DSR) resulted in higher yields than traditional transplanted rice by 3% to 17% and used 19% less water during the crop growth period; the direct dry-seeded DSR method resulted in the same yields as transplanted and wet-seeded rice, but made more efficient use of rainfall early in the wet season and saved irrigation water for the subsequent dry period.

The DSR establishment method has several advantages: (1) DSR saves labor, water, and production costs. Compared to the PTR method, DSR can reduce labor requirements by as much as 50%; (2) DSR may help reduce production risks in possible drought situations and when rainfall at planting time is variably high (Kumar and Ladha, 2011); (3) DSR can facilitate crop intensification. For example, the spread of direct seeding has led to double rice cropping in Iloilo, Philippines (Pandey and Velasco, 2002); (4) DSR is fruitful in water-scarce areas,

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[11] Puddled transplanting rice (PTR) method of cultivation became the dominant method of rice establishment in most of Asia in the 1950s.

especially in uplands. DSR has a shorter crop duration, requires less water, and therefore has higher water-use efficiency than the PTR method (Ali et al., 2006); (5) total farm income has increased due to double cropping of rice facilitated by the DSR method. On the other hand, DSR has some disadvantages, mainly in terms of lower yield and higher weed-control costs. Weed control in DSR is challenging primarily because of the diversity and severity of weed infestation caused by the absence of a standing water layer at the time of rice emergence (Chauhan et al., 2015).

However, Kumar and Ladha (2011) found that rice yields are very similar in both methods. Using meta-analysis of 77 published research papers, the authors found that DSR reduced the cost of production by about $9 to $125 per hectare compared with the PTR system. They argue that major reasons for farmers' interest in DSR are the rising costs of cultivation and the decreasing profits associated with conventional transplanting methods such as PTR. Further, they concluded that DSR is either more profitable than PTR or is equally as profitable as PTR. Some of the previous studies (Pandey and Velasco, 1999) found that the technical efficiency of rice production in a DSR system is lower and more variable than in a PTR system. A greater variability in the technical efficiency of DSR is mainly due to the use of varieties specifically developed for transplanted culture.

In the context of rice establishment systems, Chauhan et al., (2015) studied the effect of crop establishment methods and weed control treatment on weed management and rice yield. The authors used experimental data from the International Rice Research Institute, Philippines, and noted that without any control measure, weed pressure was higher in DSR than in PTR. Additionally, Chauhan et al., (2015) note that in both seasons, herbicide efficacy was better in DSR than in PTR. In an earlier study, Pandey et al., (2012) studied the patterns of spread and the

economics of DSR in northeast Thailand in the 1996-2009 period. The authors concluded that

the rate of DSR adoption was increasing and covered 38% of the rice area in northern Thailand.

It should be pointed out that both studies, related to rice and our area of interests, fail to address

the impacts of DSR on yield, costs, and income.

3.   Econometric Specification

Recall that we want to analyze the impact of the DSR and of the conventional PTR establishment

methods on productivity, income, and costs using cross-sectional plot and household data. Note

that in such exercise, and in our study as well, the treatment and control groups are not randomly

allocated Greene (2012). In particular, smallholder households may self-select into the treatment

group (to adopt DSR), a case self-selection and a source of endogeneity. A second issue is how

to assess the impact of adoption in the empirical model.[12] However, in our case we expect that

household and farm attributes may influence DSR's impact on outcome variables, namely yields,

income, and costs. Cameron and Trivedi (2005) suggest the endogenous switching regression

(ESR) framework to estimate our empirical model, in which adoption is treated as a regime

shifter. Additionally, ESR accounts for observed and unobserved differences between

smallholders in the two adoption schemes. The ESR regime consists of two steps. The first step

is a selection equation, a binary choice criterion function. In this case, the smallholder will assess

whether or not to adopt DSR on the basis of available resources and management options.

Specifically, the smallholder compares the expected utility of the adoption of DSR, $A^*_{i,DSR}$, to the

expected utility of PTR ($A^*_{i,PTR,}$ or conventional technology). Smallholders will adopt if

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[12] Standard way would be using a dummy variable as an explanatory variable. However, in this case we are assuming a homogenous impact that is independent of plot and household-level attributes (Cameron and Trivedi, 2005).

$A^*_{i,DSR} > A^*_{i,PTR}$ and will not adopt if $A^*_{i,DSR} < A^*_{i,PTR}$. A^*_i is the adoption dummy variable that is

unobservable, but we do observe A_i. In the first step, we estimate with probit

$$A^*_i = \mathbf{Z}_i \alpha + \zeta_i \quad \text{with } A_i = \begin{cases} 1 \text{ if } A^*_{i,DSR} > A^*_{i,PTR} \\ 0 \text{ if } A^*_{i,DSR} < A^*_{i,PTR} \end{cases} \tag{1}$$

The vectors $\mathbf{Z}_i$ include farm, household and village attributes. α is a vector of parameters to be

estimated, ζ_i is a random error $\zeta \sim N(0, \sigma^2)$. In the second step, based on the results of the

criterion function—selection function, two regime equations are specified explaining the

outcome of interest (yield, income, and costs, in our case). The relationship between a vector of

explanatory variables X and the outcome R can be represented by $R = f(X)$. Specifically, the

two regimes are:

Regime 1: $R_{i,DSR} = X_i ' \beta + \psi_{i,DSR}$ if $A_i = 1$,

Regime 2: $R_{i,PTR} = X_i ' \gamma + \psi_{i,PTR}$ if $A_i = 0$, $\tag{2}$

where β and γ are a parameter to be estimated. Additionally, as noted by Fuglie and Bosch

(1995), variable in $\mathbf{Z}_i$, and X_i are allowed to overlap; errors terms $\zeta_i, \psi_{i,DSR}$, and $\psi_{i,PTR}$ have tri-

variate normal distribution with zero mean and non-singular covariance matrix (see Fuglie and

Bosch, 1995, for details). Greene (2012) noted that since Regime 1 and Regime 2 are not

observed simultaneously, the covariance between $\psi_{i,DSR}$, and $\psi_{i,PTR}$ is not defined; since the

correlation between the error term of the selection equation (1), the expected values of

$\psi_{i,DSR}$, and $\psi_{i,PTR}$ conditional on selection are non-zero. We assume that $\sigma^2_\zeta = 1$ (α is estimable

only up to a scalar). For additional assumptions on the disturbance terms, see Maddala (1986).

σ^2_1 and σ^2_2 are variance terms of the disturbance terms in the continuous equation; σ_{21} is a

covariance of ζ_i and-and σ_{21} is a covariance of ζ_i and $\psi_{i,PTR}$. Finally, Fuglie and Bosch (1995)

note that expected values of the error terms in equation (2) are non-zero because of the

correlation between the error terms in the selection equation (1) and regime equations (2), which

are evaluated as truncated error terms. In such a case, Greene (2012) and Fuglie and Bosch

(1995) conclude that the expected value is a product of the variance and Inverse Mills Ratios

(IMRs) evaluated at $Z_i\alpha$.

The ESR model can be applied using the two-stage procedure and IMRs are included in

the regime equations. Following Lokshin and Sajaia (2004), we use the full information

maximum likelihood method in our study. For the ESR model to be correctly specified, the

factors affecting the selection equation (1) should contain at least one instrument in addition to

the factors affecting outcome variables in equation (2) that are correlated with the adoption of

DSR but uncorrelated directly with outcome variables. In our study we use the ESR model to

compare the expected outcome variables (yield, costs, income) of DSR adopters and non-

adopters (conventional PTR)[13]; and to assess the expected outcomes in the hypothetical

counterfactual cases that adopter smallholders had not adopted, and that non-adopter

smallholders had adopted DSR. Specifically, the conditional expectations in these four cases are

defined as follows:

DSR plots/smallholder households with adoption (observed):

$$E\left(R_{DSR} \mid A = 1\right) = X'\beta + \sigma_{\zeta\psi DSR}\lambda_{\psi DSR} \tag{3a}$$

DSR plots/smallholder households without adoption (or counterfactual):

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[13] Several studies have used ESR framework in their study, including Di Flaco, Veronesi and Yesuf, 2011; Doss, 2011; Lapple and van Rensburg, 2011; Alene and Manyong, 2007.

$$E\left(R_{PTR} \mid A=1\right) = X'\gamma + \sigma_{\zeta PTR}\lambda_{\psi DSR} \tag{3b}$$

PTR plots/smallholder households without adoption (observed):

$$E\left(R_{PTR} \mid A=0\right) = X'\gamma + \sigma_{\zeta\psi PTR}\lambda_{\psi PTR} \tag{3c}$$

PTR plots/smallholder households with adoption (counterfactual):

$$E\left(R_{DSR} \mid A=0\right) = X'\beta + \sigma_{\zeta\psi DSR}\lambda_{\psi PTR} \tag{3d}$$

Besides the marginal effects of X on yield, income, and costs, we are interested in estimating the treatment effects of DSR adoption. Following Fuglie, Bosch (1995), Greene (2012), and Alene and Manyong (2007), equations 3(a) to 3(d) can be used to estimate the net impact of adoption for adopters of DSR (average treatment effect on the treated, or ATT) and average treatment effects on the untreated (ATU). Specifically, we can derive ATT and ATU from:

$$\text{ATT} = E\left(R_{DSR} \mid A=1\right) - E\left(R_{PTR} \mid A=1\right) \tag{4}$$

$$\text{ATU} = E\left(R_{DSR} \mid A=0\right) - E\left(R_{PTR} \mid A=0\right) \tag{5}$$

4.   Data

The data used in this study is from farmer household surveys conducted in two major rice-producing states in India—Punjab and Eastern Utter Pradesh[14] — during the 2011 and 2012 period. Farmers in these two states practice the DSR establishment method in a suitable ecosystem. Additionally, land in these states is generally dry, unbounded, and appropriate for the DSR establishment method (Joshi et al., 2013). Incidentally, farmers in these states were part of the Green Revolution—for instance Punjab was in the forefront of the Green Revolution, while Eastern UP was the last to adopt rice and wheat varieties of the green revolution. Major rice growing states in India are West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Tamil Nadu,

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[14] For more details on rice production in India visit http://agricoop.nic.in/imagedefault/trade/Rice%20profile.pdf

Orissa, Bihar, and Chhattisgarh—comprising 72 percent of the total rice area and 75 percent of

total rice production (Rice Almanac, 2013). The DSR method can be suitable and applicable in

Punjab, where labor wages are higher than those in other states (Kumar and Ladha, 2011).

The surveys were carried out under the *Cereals System Initiative for South Asia* (CSISA)

project that was established in 2009 to promote long-term rice production practices in South

Asia's cereal-based cropping systems. A multi-stage sampling procedure (from state to district-

to-village-to-farmers) was followed in the above survey. A total of 537 farms were surveyed

during the 2011-2012 period. Some of the farmers surveyed practiced DSR and PTR on separate

plots, while others practiced DSR only or PTR only on their plots. Moreover, some of the

farmers were surveyed in both years while others appeared either in 2011 or 2012. For the

analysis performed in the paper, we consider that each farm/plot represent a separate

establishment.

Descriptive statistics

Table 1 shows that about 48 percent of farm households cultivate rice using the PTR

method, and about 52 percent grow rice using the DSR method. Table 1 illustrates the

comparison between DSR and PTR establishment methods. The average age of the head of

household (HH) is higher (51 years) for farms using the DSR method compared to the average

age (49 years) for those using the PTR method. Additionally, the average educational attainment

of HH and the average household size are higher for farmers using the DSR method than for

those using the PTR method. Similarly, the average plot size is greater (1.26 acres) for those

using the DSR method compared to the average plot size (1.13 acres) of those using the PTR

method.

Finally, Table 1 shows the distribution of male- and female-headed smallholder

households for the two rice establishment methods. About 53% of smallholder households headed by males established rice using the DSR method, and 43% of smallholder households headed by females established rice using that method. This finding is consistent with anecdotal evidence that India's extension system is male-dominated and tends to ignore female farmers in the promotion of new technologies and practices like the DSR method. Additionally, the extension system tends to target only men, perhaps because women in the family traditionally have very little say in the purchase, adoption, or use of farm equipment and less control over decisions to hire farm laborers. On the other hand, a higher percentage of smallholder households headed by females (about 9% percentage points higher) established rice using the PTR method than did households headed by males. We can conclude that male-headed households are more likely to use the DSR establishment method, and female-headed households are more apt to use the PTR establishment method.

As noted above, farmers like the DSR method because of the lower costs associated with the method. For example, land preparation cost, which is mainly due to a lower number of tillage operations on a plot[15], is significantly lower, 45%, the DSR method (*Rs*. 1,081/acre) compared to the PTR method (*Rs*. 1,954/acre). A big difference between the groups has to do with crop establishment costs. Crop establishment costs for the DSR method are about half those of the PTR method (*Rs*. 1,099/acre versus *Rs*. 2,325/acre.). The DSR method saves on tillage, puddling, and irrigation water; Table 1 shows that irrigation costs are about *Rs*. 604/acre for the DSR method compared to *Rs*. 836/acre under the PTR method. Table 1 reveals that the amount of seed used and the total weeding cost are higher in the DSR establishment method than in the

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[15] We found average number of tillage operation on DSR plot was about 4 while on PTR plot it was about 7. Rice harvested from PTR system (5.9 tons/hectares) is higher compared to DSR system (5.2 tons/hectares).

PTR establishment method. Weeding costs are about 2.5 times greater in the DSR method than in the PTR crop establishment method (*Rs.* 1,264/acre vs. *Rs.* 497/acre, respectively). Table 1 also shows that the amount of seed used on DSR plots (about 12 kg./acre)is statistically significant and different from the amount of seed used on PTR plots (about 11 kg./acre). On the issue of labor requirements under the two crop establishment methods, Table 1 reveals that family labor days are significantly lower for DSR plots (29 days/acre) compared to family labor days on PTR plots (42 days/acre). On the other hand, hired labor costs are twice more on PTR plots than on DSR plots.

Finally, the lower panel of Table 1 shows the total cost, rice income, and rice yields under the two rice establishment methods. Total production costs are significantly lower under the DSR method (*Rs.* 6,236/acre) than under the PTR method (*Rs.* 7,747/acre). As seen above, most of the cost savings under the DSR method originates from labor (both family and hired labor), irrigation, land preparation and crop establishment items. Rice yield is one of the most important characteristics that farmers consider when deciding to adopt a new technology or variety. Table 1 reveals that, on average, rice yield is significantly lower on DSR plots (12,694 Kg/acre) than on PTR plots (14,510 Kg/acre). This finding is in contrast to Ali, Erenstein and Rahut (2014) and Singh et al. (2008). Plausible explanations include that farmers in eastern UP may be adopting the DSR method on lands with lower productivity potential, that DSR may not be suitable for farmers in eastern UP, and/or that farmers in eastern UP lack and capacity and experience in DSR.

5.   Result and Discussions

We estimate three different ESR models, two at the plot level to explain factors affecting rice yields and costs of production in DSR and conventional PTR regimes, and the other at the household level to explain incomes in the two regimes.

5.1.   Rice Yield Effects

Table 2 presents parameter estimates for yield effects of adoption of DSR method on a double-log specification of the production function. The Wald test in the lower panel of Table 2 suggests that the Cobb-Douglas specification could not be rejected. The bottom part of Table 2 also presents the estimated covariance terms, and statistics confirm that there is heterogeneity, which could lead to biased estimates without correcting for them. In addition to inputs used in rice cultivation and to control for differences in human capital, a number of other explanatory variables (e.g., human capital, experience, and irrigation facility) are included in our empirical model. Note that in the ESR procedure, in order for an observation to fall into a regime, the criterion function (selection equation in the above model) and the regime equations are estimated jointly. Further, based on Lokshin and Sajaia (2004), the criterion equation should contain all explanatory variables plus at least one instrumental variable. In our case, we use a farmer's membership in community organizations, a form of social networking, as an instrumental variable. This variable is correlated with individual farmer behavior. Empirical evidence (Bandiera and Rasul, 2006) suggests that farmers tend to learn and acquire technologies through farmer networks like membership in community organizations (e.g., cooperatives or farmer unions). On the other hand, a farm operator's membership in organizations is not correlated with rice yields.

The second column of Table 2 shows parameter estimates of the criterion function. The important factors affecting adoption of the DSR method at the plot level are seed quantity, total

labor (hired and family) costs, and land preparation costs. The two regime equations are shown in columns 3 and 4 of Table 2. Looking at various factors, we see some notable differences between the coefficients in the DSR and PTR methods. For example, in the DSR method, total labor has the biggest elasticity: A 1% increase in total labor (hired and family) increases rice yield by about 0.08%. Given that the DSR method is in its infancy in India, labor productivity may increase in the future as many other farmers adopt DSR technology[16]. This finding suggests that it is prudent to allocate more labor to rice production. In the case of the PTR method, education has the highest effect, albeit negative. Results in Column 4 of Table 2 indicate that an additional year of schooling for a farm operator decreases rice yield by 0.7%. An explanation (Huffman, 1980; Dewbre and Mishra, 2007) is that educated farmers are more likely to allocate hours to off-farm work, to earn more and steady income, at the expense of farming time. Further, these educated farmers tend to own their own irrigation pumps. Cross-checks of our data reveal a positive correlation between education and irrigation pump ownership.

Further, in the PTR method, seed quantity and land preparation costs have the negative effect on rice yield. For instance, a 1% increase in land preparation costs increases rice yields by about 0.12%. Results in Table 2 reveal that weed control costs have a negative, albeit small, impact on rice yield for both the DSR and the PTR method—a 1% increase in weed control costs decreases rice yield by 0.01% and 0.04%, respectively. Perhaps higher weed control costs indicate a higher weed infestation and intense competition with rice plants. Our finding is consistent with Antralina et al. (2015), who found that weed competition reduces rice yield. The authors suggest farmers control weeds with chemicals or manual labor in order to increase rice yields.

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[16] Note that water and labor shortage may push farmers to hasten the adoption of DSR method.

Finally, compared to farmers who use public pumps for irrigation, farmers who own their irrigation pumps tend to have lower rice yields. A first glance at these results may not make sense, but we argue that ownership of an irrigation pump may be a proxy for wealth (Mottaleb, Krupnik, and Erenstein, 2016) for two reasons. First, for a smallholder in India to purchase an irrigation pump requires significant capital; most farmers buy these pumps without credit and have outright ownership. This is consistent with Mottaleb, Krupnik and Erenstein (2016), who found a positive correlation between machinery ownership and household assets in rural Bangladesh. Second, irrigation pump owners tend to rent their pumps to other rice farmers, thereby earning rental income — focusing more on rental and off-farm income. Hence, relatively wealthy smallholder rice farms have lower rice yield.

We calculate the average treatment effects of DSR adoption on rice yields—see equations 4 and 5. Results are presented in Table 3 and report the net impacts; that is, they control for negative DSR effects and other confounding factors. Findings in Table 3 show that DSR farmers would have significantly, albeit smaller, lower rice yields had they not adopted DSR—an ATT of about 1.1%. Note that a little positive ATT of DSR adoption by a sample of farmers in India combined with the significant rice yield difference in Table 1 may point toward negative selection. For smallholders in India, perhaps DSR has been adopted on plots and by farms that would have had below-average rice yield regardless of adoption. Finally, Table 3 also shows a positive and significant ATU, meaning that mean rice yields on PTR plots could be 1.66% higher if the DSR method were adopted on these parcels.

5.2   *Total Costs Effects*

Let us turn our attention to the ESR model of total costs at the plot level, differentiating between DSR and PTR plots. Again, in this case, we experimented with different possible functional

forms. The double-log specification, with the logarithm of total costs as the dependent variable and independent logarithm variables, especially factors affecting costs function, showed the best fit.[17] The estimated results are presented in Table 4. The lower part of Table 4 also presents the estimated covariance terms, and statistics confirm that there is heterogeneity, which could lead to biased estimates in the absence of such corrections. Several factors, such as seed quantity, total labor, land preparation costs, and weed control costs, have a positive and significant effect on DSR adoption. Findings here suggest that a 1% increase in seed quantity, total labor costs, land preparation costs, and weed control costs increase adoption of DSR by 0.5%, 0.6%, 0.6%, and 0.95%, respectively. However, an additional household member decreases adoption of DSR by about 7%—by far the biggest factor in determining the adoption of DSR. A plausible explanation is that household members can supply their labor to the production of rice, and the labor-intensive PTR method can easily absorb additional labor in the family.

The two regime equations are shown in columns 3 and 4 of Table 4. Looking at various factors, we see some notable differences between the coefficients in DSR and PTR plots. Fertilizer costs have the highest elasticity in both regimes. Increasing fertilizer input by 1% would increase total costs by about 0.4% on a DSR plot and about 0.25% on a PTR plot. Secondly, land preparation costs significantly affect total expenses in both the DSR and PTR methods. For instance, a 1% increase in land preparation costs increases total costs by 0.21% and 0.25% on DSR and PTR plots, respectively. For some of the coefficients, there are notable differences between DSR and PTR plots, confirming that the switching regression framework is more appropriate than pooling data in one cost function. For instance, the estimate for total labor

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[17] This is based on Akaike Information criterion (AIC). AIC of 4.76 was lower than the linear AIC of 15.65. Further, farmer's membership in community organization(s) served as instrument for DSR adoption in the criterion function.

costs is significant in the PTR regime but insignificant in the DSR regime. Conversely, the estimate for total weed control costs is significant in the DSR regime but insignificant in the PTR regime. Recall that weeds spread more quickly in the DSR method, which is a non-flooded condition. Agronomists recommend regular weeding with the DSR method, but if it is not followed, chemical control can become more expensive and can increase total production costs. Finally, two other factors that have a significant effect on DSR costs are the educational attainment of the head of households and irrigation pump ownership. Findings in Table 4 reveal that an additional year of schooling increases total costs on DSR plots by 0.5%.

Finally, we calculate the ATT of DSR adoption on the total costs of rice production. Results are presented in Table 5 and report the net impacts; that is, they control for negative DSR effects and other confounding factors. Findings in Table 5 show that DSR farmers would have significantly higher total costs had they not adopted DSR—an ATT of about -2.13%. Table 5 also shows a negative and significant ATU, meaning that mean total costs of rice production on PTR plots could be significantly lower, by 3.57%, if the DSR method were adopted on these parcels. Table 6 presents the ATT of the DRS method on variable cost components, using nearest neighbor matching (NNM) estimator. Findings in Table 6 suggest that adoption of the DSR establishment method in rice exerts a negative and significant impact on plot irrigation and land preparation costs per acre. Specifically, the NNM causal effect of DSR adoption on irrigation costs per acre (*Rs*. -287) suggests that irrigation costs per acre for DSR method rice plots are lower than irrigation costs per acre for PTR method rice plots by about *Rs*. 287 per acre. Similarly, the NNM causal effect of DSR adoption on land preparation costs per acre (*Rs*. -958) suggests that land preparation costs per acre for DSR method rice plots are lower than land preparation costs per acre for PTR method rice plots by about *Rs*. 958 per acre.

Findings here underscore the importance of the DSR method in cost reduction, especially in land preparation and irrigation costs. Perhaps adoption of the DSR method, while saving money, can encourage conservation tillage, water management, and better soil management for smallholder farms in the sample and, by extension, smallholder farms in India.

5.3   Household Income Effects

Finally, we estimate the ESR model for total household income at the household level, differentiating between DSR and PTR households. As in previous specifications, in this case, a double-log specification with the logarithm of total household income as dependent and key explanatory variables showed the best empirical fit.[18] Further, a farmer's membership in community organization(s), rice yield above average, and rice yield below average served as an instrument for DSR adoption in the criterion function. Recall that membership in community organizations (a proxy for farmer networks) may be correlated with individual behavior. Farmers belonging to these organizations can acquire specific technological information more easily through farmer networks. Column 2 of Table 7 shows that farmers belonging to community organizations and whose rice plots have below-average yield are more likely to adopt the DSR method than farmers not belonging to community organization with above average yield. The latter finding may reinforce earlier findings that the DSR method is being adopted on below-average farmland.

For some of the coefficients, there are notable differences between the total income of smallholder households with DSR and of those with the conventional PTR method of rice production. These findings confirm that the switching regression framework is more appropriate that data pooling in one function. Additionally, consistent with Lokshin and Sajaia (2004), the

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[18] Based on Akaike Information criterion (AIC). AIC of 3.79 was lower than the linear AIC of 19.27.

lower part of Table 7 shows the covariance terms together with the Wald test of joint independence for all three equations. Findings confirm heterogeneity and if unattended estimates could be biased. The estimation results are shown in Table 7. One additional acre increases the total household income of DSR smallholder farms by 29%. Farm size is less relevant for conventional PTR smallholder households. It is plausible that labor constraints, if realized in the four rice-growing states of India, may be pushing smallholder farms to the DSR method. In other words, labor constraints may be encouraging DSR smallholder farms to benefit more from additional farmland. In both regimes, household size has a significant positive effect on incomes, suggesting that an additional member increases the income of DSR adopters by 0.13% and by only 0.07% for non-adopters (those using conventional PTR).

Finally, Table 8 presents the ATT effects of DSR on smallholders' household income. The ATT shows that adopters benefit economically from the adoption of the DSR method. The effect is statistically significant, indicating a 16% increase in income. On the other hand, the ATU in Table 8 suggests that non-adopting households would benefit, with about a 17% increase, if they switched to the DSR method. Hence their decision of non-adoption of DSR may be irrational and perhaps hurting them financially.

6.   Conclusions

Rice is a major crop in most of the world and uses significant resources—like groundwater, fertilizer, and labor. However, variability in rainfall, labor shortages and resource input constraints are pushing producers toward sustainable methods of rice production. The direct-seeded rice, or DSR, establishment method is one production method that would preserve soil and ecosystem health. DSR could be considered a viable alternative to the puddled transplanted rice, or PTR, establishment method. In India, farmers are switching to the DSR method from the traditional PTR method. DSR can be an attractive alternative to the

transplanting of rice to minimize labor input and reduce cultivation costs. This study has

analyzed the impact of the DSR establishment method on smallholder farms in four rice-

producing states of India. Using ESR procedure, we accounted for selection bias and

heterogeneity impacts of the DSR method. Novel contributions of this study are that we account

for heterogeneous effects on the adoption of DSR technology, and, in addition to yield, we

analyzed the costs and household income effects of DSR adoption.

A simple comparison of yield, costs, and incomes between DSR adopters and non-

adopters (or users of the conventional PTR method) in four major rice-producing states of India

does not reveal a significant difference in household income, mainly because all are rice

producers. However, small gains were observed in yield and production costs. Controlling for

selection bias, we find that a significant but small yield gain of 1.09**%** for DSR adopters. On the

other hand, we find a significant reduction in production costs, about 2.13% for DSR adopters

compared to costs for non-adopters. We find that DSR farmers can significantly reduce their

irrigation and land preparation costs (*Rs*. 287/acre; *Rs*. 958/acre, respectively) compared to costs

for non-adopters. Finally, we find significant differences in the income of DSR adopters when

compared to non-adopters. It is clear that conventional PTR farmers could benefit more by

switching to the DSR method.

Finally, we found significant positive household income effects through DSR adoption.

Interestingly, ATT and ATU effects are important, and the magnitudes are almost same.

Projections from this study show that current non-adopters of DSR would realize slightly higher

yields and significantly higher income effects when they switch to the DSR establishment

method. Findings from this study confirm that impacts depend on social networks and

socioeconomic factors. The methodological approach developed in this study is advantageous

and accounts for both farm- and plot-level heterogeneity. Adoption of DSR, a form of natural resource management (NRM) technology, may prove to be helpful in managing resources (e.g., water, labor, and soil tillage) for resource-constrained smallholder farms.

The demand of rice in India to meet the food requirements of ever increasing population is increasing while on the other hand most vital inputs of agriculture such as water and labor are depleting in many part of India. Conventional puddled transplant rice establishment method is water, labor and energy intensive, adversely affecting the environment. To sustain the long-term production of rice, more efficient alternative method, like DSR, for rice productions is needed. Results from this study calls on policymakers to design policy incentives that encouraged adoption of DSR and such adoptions can help in increasing economic well-being of smallholder income and resource conservation through reduced water consumption for irrigation and conservation tillage. Adopters of DSR improve the environment through carbon sequestration (less tillage or soil turnover), prevention of soil erosion (over-irrigation or water run-off) or the encouragement of groundwater recharge (less irrigation water need). It provides ecosystem services, thus, farmers could be rewarded for such services, which have a great impact on the quality of life for rural as well as urban population. Given the evidence presented by this paper on the benefits of adopting DSR, policies aiming at promoting such resources technologies should be accompanied with measures that relax the constraints on preventing their adoption. While identifying those constraints was not the purpose of this paper, several studies have investigated those factors (farm level – socioeconomics) that still represent barriers to the adoption of DSR. Among the main constraints raised by non-DSR adopters are: weed management and the availability of DSR machines for crop establishment especially during peak planting season. With regard to the first, policies aiming to promote DSR should assist and build
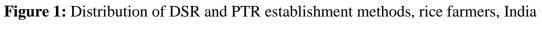
farmers capacities in weed management by teaching them best management practices. As far as the second constraint is concerned policies aiming at creating incentives for the private sector to get involved would represent entry points for sustaining business models in developing DSR machines. Business models of DSR machine services providers should be enhanced in the rural communities. Polices should be designed to allow credits access to communities who are willing to develop such business models.

This study has two limitations. First, due to a lack of panel data, we cannot assess the impacts of farmers' increasing experience over time with the DSR method. Second, the impact of the adoption of technology also depends on access to useful information and advice. The present study did not account for this. Future research could focus on linkages between rural economies, extension approaches, and social networks. Perhaps these factors could play a stronger role in the spread of NRM technologies like the DSR establishment method. Finally, while we went beyond yield, costs, and household income effects of DSR, future research also could focus on environmental outcomes, which benefit societies at large.

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Figure 1: Distribution of DSR and PTR establishment methods, rice farmers, India

Source: Authors calculation from CSISA data, 2011-2012.

Table 1. Summary statistics and mean comparison of DSR and conventional PTR, rice farmers, India

Variables	DSR		Conventional PTR		t/z score[a]
	Mean	Std. Dev.	Mean	Std. Dev.	
Household level	52.00		48.00		1.99[*]
Age of household head (*years*)	50.66	13.68	48.84	13.67	-1.54
Educational level (*years*)	10.21	4.98	9.75	5.07	-1.06
Household size	5.43	2.02	5.27	1.93	-0.94
Household head community Organization(s) member (%)	40.00	3.00	34	3.00	1.16
Farm household owning irrigation pump (%)	49.46	2.99	47.28	3.11	0.50
Male headed households (%)	52.57		47.43		
Female headed households (%)	43.35		56.65		
Plot level					
Plot size (*acre*)	1.26	1.15	1.13	1.05	-1.33
Land preparation cost[a] (*Rs./acre*)	1,080.66	702.94	1,954.08	1,576.75	8.16[**]
Crop establishment cost[b] (*Rs./acre*)	1,099.38	914.72	2,325.17	1,213.21	13.13[**]
Total fertilizer cost (*Rs./acre*)	1,823.06	762.94	1,872.90	1195.84	0.56
Irrigation cost (*Rs./acre*)	604.02	945.88	836.10	1107.76	2.28[**]
Total labor[c] (*days/acre*)	47.38	69.07	91.16	95.53	6.04[**]
Seed (*kg/acre*)	11.82	6.65	10.70	9.49	-1.65[*]
Total weed control cost[d] (*Rs./acre*)	1,263.74	1,159.13	496.70	578.53	-9.81[**]
Family labor (*days/acre*)	28.58	3.29	41.74	3.25	2.83[**]
Total costs and returns					
Total cost (*Rs./acre*)	6,235.93	2663.03	7,747.22	3,498.07	5.59[**]
Income from rice (*Rs.*)	30,944.55	34,524.15	28,958.54	31,204.63	-0.70
Rice yield (kg/acre)	2080.71	744.40	2378.35	640.03	4.98[**]

Notes: ***** and ****** denotes variables are significant at 10 percent and 5 percent level of significance.

[a] The differences in means are obtained by subtracting means for plots with conventional PTR with DSR system of rice establishment.

For a continuous variable, *t*- test is used, and *t* statistics is reported; test on the equality of proportions is used to compare the differences for binary variables, and *z*-score is reported.

[a] Includes harrowing, leveling, plowing; puddling in the case of PTR.

[b] Includes transplanting costs, maintaining standing water.

[c] Includes family and hired labor.

[d] Includes herbicide and labor costs to remove weeds.

Table 2: Endogenous switching regression results for rice yield, rice farmers, India

Variables	Criterion function	Regime equation	
		DSR	Conventional PTR
Seed quantity (*kg/acre*), *log*	0.8177**	-0.096	0.122**
	(0.210)	(0.066)	(0.0468)
Total labor[a] (*man days/acre*), *log*	-0.849**	0.082**	0.004
	(0.104)	(0.026)	(0.031)
Fertilizer cost (Rs./acre), *log*	0.312**	0.064	-0.079
	(0.255)	(0.067)	(0.053)
Land preparation cost[b] (*Rs./acre*), *log*	-0.549**	0.040	0.120**
	(0.173)	(0.046)	(0.040)
Weed control cost[c] (*Rs./acre*), *log*	0.841**	-0.097**	-0.042*
	(0.154)	(0.048)	(0.023)
Household Size	-0.037	-0.007	-0.013
	(0.050)	(0.013)	(0.012)
Age of household head	-0.007	-0.002	-0.002
	(0.007)	(0.002)	(0.002)
Education of household head	-0.019	-0.003	-0.007*
	(0.022)	(0.005)	(0.004)
Own irrigation pump	-0.073	-0.119**	-0.122**
	(0.230)	(0.061)	(0.054)
Membership with community organization(s)[d]	0.591**		
	(0.269)		
Constant	-2.070	9.436	9.991**
	(1.839)	(9.050)	(0.355)
Number of observations			344
LR (Wald test) for independent equations χ^2			71.24**
			(*p*-value < 0.000)
$\ln \sigma_{DSR}$, $\ln \sigma_{PTR}$		-1.028**	-1.232**
		(0.0531)	(0.068)
$\rho_{\zeta\psi DSR} \rho_{\zeta\psi PTR}$		-0.259	-0.552**
		(0.315)	(0.263)

The dependent variable is rice yield (kg/acre), in the log.
* denotes variables are significant at 10 percent; ****** denotes variables are significant at 5 percent or higher level.
[a] Includes both family and hired labor.
[b] Includes harrowing, leveling, plowing; puddling in the case of PTR.
[c] Includes herbicide and labor costs to remove weeds.
[d] Includes cooperatives, farmer union.

Table 3: Average treatment effects of DSR on rice yield, rice farmers, India

Method	Observations	With DSR		Without DSR		Treatment Effects	ln %
		Mean yield§	SD	Mean yield§	SD		
DSR plots	183	9.346	0.172	9.245	0.132	ATT: 0.101**	1.09
Conventional PTR plots	161	9.610	0.130	9.453	0.148	ATU: 0.157**	1.66

* denotes variables are significant at 10 percent; ** denotes variables are significant at 5 percent or higher level; § the yield shown are predictions based on the coefficients estimated with the endogenous switching regression model. As the dependent variables in the model are the logarithms of yields in kg per acre, the predictions are also given in the logarithmic form. Converting the mean back to tons would lead to inaccuracies due to the inequality of arithmetic and geometric means.

Table 4: Endogenous Switching Regression Results for total cost, rice farmers, India

Variables	Criterion function	Regime equation	
		DSR	Conventional PTR
Seed quantity (*kg/acre*), *log*	0.508**	0.047	0.020
	(0.182)	(0.034)	(0.039)
Labor[a] (*man days/acre*), *log*	0.643**	0.027	0.117**
	(0.083)	(0.018)	(0.024)
Fertilizer cost (*Rs./acre*), *log*	0.182	0.364**	0.254**
	(0.213)	(0.034)	(0.038)
Land preparation cost[b] (*Rs./acre*), *log*	0.592**	0.208**	0.252**
	(0.155)	(0.026)	(0.033)
Weed control cost[c] (*Rs./acre*), *log*	0.950**	0.215**	0.017
	(0.134)	(0.029)	(0.021)
Household Size	-0.071**	0.015**	0.019**
	(0.042)	(0.007)	(0.008)
Age of household head	-0.005	0.000	-0.001
	(0.007)	(0.001)	(0.001)
Education of household head	-0.025	0.005*	0.002
	(0.019)	(0.003)	(0.004)
Own irrigation pump	-0.149	0.071**	-0.004
	(0.199)	(0.032)	(0.039)
Membership in community organization(s)[d]	-0.655		
	(0.237)		
Constant	-1.064	2.697**	4.410**
	(1.542)	(0.257)	(0.266)
Number of observations			344
LR (Wald test) for independent equations χ^2			60.84** (*p*-value < 0.000)
$\ln \sigma_{DSR}$, $\ln \sigma_{PTR}$		-1.716**	-1.491**
		(0.060)	(0.095)
$\rho_{\zeta\psi DSR}\rho_{\zeta\psi PTR}$		0.206	-0.862**
		(0.398)	(0.123)

The dependent variable is total cost in rice production (Rs.), in the log; * denotes variables are significant at 10 percent; ** denotes variables are significant at 5 percent or higher level.

[a] Includes both family and hired labor.
[b] Includes harrowing, leveling, plowing; puddling in the case of PTR.
[c] Includes herbicide and labor costs to remove weeds.
[d] Includes cooperatives, farmer union.

Table 5: Average treatment effects of DSR on the total cost of rice production, rice farmers, India.

Method	Observations	With DSR		Without DSR		Treatment Effects	ln %
		Mean cost§	SD	Mean cost§	SD		
DSR plots	183	8.533	0.286	8.719	0.359	ATT: -0.186**	-2.13
Conventional PTR plots	161	8.637	0.514	8.957	0.365	ATU: -0.320**	-3.57

* denotes variables are significant at 10 percent; ** denotes variables are significant at 5 percent or higher level; § the costs shown are predictions based on the coefficients estimated with the endogenous switching regression model. As the dependent variables in the model are the logarithms of total costs in Rs., the predictions are also given in the logarithmic form. Converting the mean back non-logarithmic form would lead to inaccuracies due to the inequality of arithmetic and geometric means.

Table 6: Average treatment effects of DSR on various costs component using matching estimator, rice farmers, India

Outcome	Treatment Effect (ATT)	Standard Error	t-statistic
Fertilizer cost[1] (Rs./acre)	-142.231	135.869	-1.047
Irrigation cost[1] (Rs./acre)	-287.201**	116.426	-2.467
Land preparation cost[1] (Rs./acre)	-957.737**	156.263	-6.129

* denotes variables are significant at 10 percent; ** denotes variables are significant at 5 percent or higher level
[1] covariates used in propensity score matching were: age and education of the household head, household size, membership to organization (s), source of information about rice establishment methods, whether household owns pump; this set of covariates were tested for and satisfied the common support and balancing property assumption of matching estimators

Table 7: Endogenous Switching regression results for total household income, rice farmers, India

Variables	Criterion function	Regime equation	
		DSR	Conventional PTR
Farm size (acre), log	0.113**	0.291**	0.046
	(0.073)	(0.097)	(0.104)
Household size	-0.002	0.126**	0.071*
	(0.031)	(0.042)	(0.042)
Age of the household head	0.007	0.006	-0.006
	(0.005)	(0.006)	(0.005)
Education of the household head	0.011	0.020	-0.017
	(0.014)	(0.019)	(0.019)
Male household head	-0.258	0.333	0.672
	(0.362)	(0.467)	(0.511)
Married household head	-0.165	0.027	0.829**
	(0.317)	(0.416)	(0.437)
Household owns pump	-0.233**	0.374*	0.393*
	(0.135)	(0.212)	(0.229)
Membership with community organization(s)[a]	0.511**		
	(0.121)		
Rice yield is above average	-0.177		
	(0.129)		
Rice yield is below average	0.2571**		
	(0.117)		
Constant	-0.458	10.204	9.287
	(0.446)	(0.585)	(0.597)
Number of observations			403
LR (Wald test) for independent equations χ^2			273.98** (p-value < 0.000)
$\ln \sigma_{DSR}$, $\ln \sigma_{PTR}$		0.335**	0.269**
		(0.073)	(0.124)
$\rho_{\zeta\psi DSR}\rho_{\zeta\psi PTR}$		-1.419**	-1.039**
		(0.186)	(0.357

The Dependent variable is total household income (Rs.), in log;

* denotes variables are significant at the 10 percent; ****** denotes variables are significant at the 5 percent or higher level.

[a] Includes cooperatives, farmer union.

Table 8: Average treatment effects of DSR on total household income, rice farmers, India

Method	Observations	With DSR		Without DSR		Treatment Effects	ln %
		Mean income§	SD	Mean income§	SD		
DSR households	215	11.273	0.597	9.708	0.367	ATT: 1.566**	16.13
Conventional PTR households	203	13.172	0.582	11.298	0.356	ATU: 1.873**	16.58

§ The income shown are predictions based on the coefficients estimated with the endogenous switching regression model. As the dependent variables in the model is logarithms of household income in Rs.
The predictions are also given in the logarithmic form. Converting the mean back to non-logarithmic form would lead to inaccuracies due to the inequality of arithmetic and geometric means.