Impact of direct rice-sowing technology on rice producers’ earnings: empirical evidence from Pakistan

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Using the comprehensive data set collected from 238 rice producers during 2011, this study estimates the impact of direct seeding of rice-sowing technology on rice and wheat crop yields and farmers’ earnings in Pakistan. The propensity score-matching approach was employed to correct for potential sample selection bias that may arise due to systematic differences between the adopters and non-adopters of the direct rice-sowing technology. The empirical results indicate that the adopters of the direct rice-sowing technology have higher rice and wheat crop yields as compared to non-adopters. The rice yields are high, in the range of 8–9 maunds per acre, while the wheat yields are higher, in the range of 2–3 maunds per acre, indicating that the direct rice-sowing technology also has a positive impact on the following wheat crop. Results show that the adopter households have a higher income compared to non-adopter households. Most importantly, the new technology is a water-saving technology and on average it requires four times less irrigation than the traditional rice transplanting method. With the direct rice-sowing technology, the demand for skilled labor was less compared to the traditional transplanting method. However, the new technology is associated with a weed control problem, which needs to be addressed in order to maximize the benefits from the new technology.

Keywords: adoption; direct rice sowing; impact evaluation; propensity score matching; Pakistan

1. Introduction

Rice is one of the most important cereals in the world, feeding well in excess of 4 billion people. It is the staple food of more than half of the world’s population (Sinha and Talati 2007; Vijayakumar et al. 2006). The demand for rice increases with the increasing population, and is expected to rise further by 38% within the next 30 years (Satyanarayana 2005).

Rice–wheat rotation is one of the most widely used agricultural production systems in the world, occupying 13.5 million hectares of the most productive land in the Indo-Gangetic Plains of South Asia, encompassing Northern India, Pakistan, Nepal and Bangladesh. About 1.3 billion people are dependent on the produce of this area. Rice–wheat systems cover about 32% of the total rice area and 42% of the total wheat area in these three countries and Northern India, and account for between one-quarter and one-third of total rice and wheat production.

In Pakistan, rice plays an important role in the economy as well as in rural livelihoods, and is the staple food crop, second only to wheat. Besides meeting the dietary requirements of the people, it has emerged as a major export commodity contributing to about 13% of the total foreign exchange earnings of the country (Government of Pakistan 2004). Pakistan’s share of the world rice trade is around 11%. Rice is grown in an area of 2.57 million hectares and the average rice yield in Pakistan is 2240 kg per hectare, which is very low compared to the potential yield (Economic Survey of Pakistan 2012–2013; Government of Pakistan 2013). Of the total area, 62% is under basmati, 27% under International Rice Research Institute (IRRI) coarse varieties, and 11% under other varieties. About 96% of the basmati rice is grown in the Punjab province as the environment is suitable for maintaining the quality and aroma of basmati rice. Although the yield of basmati is much lower than IRRI, the demand is high, both in the national and international markets. Therefore, the majority of farmers prefer to grow basmati rice despite the low yield, high production cost and intensive water requirement.

Rice is the crop with one of the highest water requirements in the world, which fluctuates depending on the variety and when it matures. Coarse varieties are early maturing while fine basmati varieties are late maturing. In Pakistan, it takes about 25,000 liters of water to produce 1 kg of basmati rice, while in China and India the same quantity of water produces five and 2 kg of rice respectively. In Pakistan, rice consumes 21% of the available...
fresh water. Traditionally, rice is grown by transplanting one-month old nursery seedlings into the puddled area with continuous flooded soil conditions. Puddling is done to create a hard pan below the plow zone to reduce soil permeability. High loss of water occurs through the puddling process, surface evaporation and percolation. The underground and surface water in Pakistan are shrinking and will become the most limiting factor in future (Mann et al. 2007). As well as water shortages, the limiting factors for low rice yield are weed infestation, prevalence of insects, pests and diseases, inappropriate planting methods leading to low plant populations, unbalanced use of fertilizers and scarcity of labor for transplanting and harvesting.

Looming water crises and increasing labor costs are the challenges being faced by the rice growers in the traditional transplanting system. Direct seeding could be an attractive alternative to the traditional transplanting culture (Balasubramanian and Hill 2002) but poor germination, uneven stand crops and high weed infestation are among the main constraints to the adoption of direct-seeded rice (Du and Tuong 2002).

The availability of fresh water is one of the major constraints that restrict increasing rice production in Asia (Lampayan et al. 2003). About 80% of the available water resource world-wide is used by the agricultural sector of which irrigated rice makes the highest demand. Currently, on-farm availability of fresh water is being reduced due to many reasons (Uphoff 2006). Future predictions indicate that 2 million hectares of fully irrigated and 13 million hectares of partially irrigated lands in Asia during the wet season will experience a ‘physical water scarcity’, and 22 million hectares of irrigated lands in the dry season would face ‘economic water scarcity’ by 2025. This will necessitate and encourage research on alternative measures for reducing water use and increasing the efficiency of water use in order to ensure food security.

The stagnation of rice–wheat productivity called for new resource-conserving production techniques to meet the challenge of productivity enhancement, ensure environmental safety and conserve natural resources. Since the mid-1980s, researchers, farmers, extension specialists, machinery importers and local machinery manufacturers have been working to adopt resource conservation technologies for South Asia’s rice–wheat cropping systems. Direct rice sowing is a new technology which is gaining popularity among rice producers in Pakistan.

2. Comparison of direct seeding of rice and the traditional rice-planting system

By adopting the improved planting methods, the cost of rice planting and irrigation efficiency can be improved considerably in the rice–wheat area of Pakistan. The traditional rice-planting system uses the puddling method that requires 10–20 cm of standing water throughout its growing season, resulting in higher water use than is actually required. Lower plant population is also one of the main constraints in obtaining high yields under conventional planting. In Pakistan, rice is normally sown at the end of May and transplanted during the first week of July. Transplanting is a traditional method which provides a high and stable yield but it is laborious and expensive. Due to industrialization and urbanization in recent years, the shortage of labor in agriculture has aggravated the situation, resulting in an increase in labor costs in agriculture, which in turn threatens the sustainability of the traditional rice-planting system that requires large amounts of labor.

Nowadays farmers are switching toward other methods like direct seeding of rice (DSR) to minimize the labor expenses and difficulties (Mehmood et al. 2002). The exact sowing date for the DSR plays a vital role in improving its growth and increasing the yield. The sowing time of a rice crop is important for three major reasons: first, it ensures good vegetative growth during a period of satisfactory temperatures and high levels of solar radiation; second, the optimum growing time for each cultivar ensures that the cold-sensitive stage occurs when the minimum night temperatures are historically the warmest; third, sowing on time guarantees that grain filling occurs when milder autumn temperatures are more likely, hence good grain quality is achieved (Farrell et al. 2003). The sowing date also has a direct impact on the rate of establishment of rice seeding (Tashiro, Saigusa, and Shibuya 1999).

DSR refers to the process of establishing a rice crop from seeds sown in the field rather than by transplanting seedlings from the nursery. There are three principal methods of DSR: dry seeding (sowing dry seeds into dry soil), wet seeding (sowing pre-germinated seeds into dry soil) and water seeding (seeds sown into standing water). Dry seeding has been the principal method of rice establishment since the 1950s in developing countries (Pandey and Velasco 2005).

DSR is a major opportunity to change production practices to attain optimum plant density and high water productivity in water-scarce areas. Traditionally, rice is grown by transplanting one-month old seedlings into puddles and continuously flooded soil. The advantages of the traditional system include increased nutrient availability (e.g. iron, zinc, phosphorous) and weed suppression. Direct seeding is a successful method of rice cultivation in some countries, which saves labor and is more economical than transplanting and provides good stand establishment (Sharma 1995). Sometimes labor may not be available at the right time for transplanting. To minimize the labor requirement, some planting technologies/methods have been tested at different research institutes which developed technologies like direct seeding, parachute technology, mechanical transplanting, etc. The direct seeding technology of rice was found to be almost at par in yield with the conventional planted crop (Awan...
et al. 2006). The past results of many years of experimentation on direct seeding techniques revealed that this technology had great potential for adoption as a substitute for transplanting if the weeds were controlled properly with the availability of high-yield potential varieties.

Against the backdrop of declining water resources and reduced availability of labor, the conventionally flooded rice system is losing its sustainability and economic viability (Bhushan et al. 2007; Guerra et al. 1998). The decreasing water table, increasing costs of diesel and electricity and climatic changes have further aggravated the problem (Rosegrant, Cai, and Cline 2002; Vörösmarty et al. 2000). Due to these reasons there is a need to shift from conventionally flooded transplantation to the DSR in Pakistan. DSR is an alternative option to cope with the problems of water and labor scarcity associated with conventionally flooded rice (Weerakoon et al. 2011). Direct seeding is accomplished by either water seeding or wet seeding and dry seeding (Bouman et al. 2007; Farooq et al. 2011). Direct-seeded rice is being cultivated successfully in many parts of the world such as China, Australia, Malaysia, the USA, Sri Lanka.

The objective of the current paper is to study the impact of the direct rice-sowing technology on rice and wheat crop yields, water and labor requirements and, most importantly, on the problem of weeds associated with the direct rice-sowing technology. The rest of the paper is organized as follows: the conceptual framework is presented in Section 3; in section 4, empirical results are presented and the conclusion and policy recommendations are in Section 5.

3. Conceptual framework of technology adoption

3.1. Adoption of DSR technology

Let the adoption of DSR technology be a dichotomous choice, where the new technology is adopted when the net benefits from choosing the technology are greater than not adopting the technology. The difference between the net benefits from adoption and non-adoption may be denoted as $I^*$, such that $I^* > 0$ indicating that the net benefits from adoption exceeds that of non-adoption. However, $I^*$ is not observable, but can be expressed as a function of observable elements in the following latent variable model:

$$I^*_i = \beta X_i + \mu_i, \quad I_i = 1[I^*_i > 0],$$

where $I_i$ is a binary indicator variable that equals 1 for household $i$ in case of adoption and 0 otherwise, $\beta$ is a vector of parameters to be estimated, $X_i$ is a vector of household and plot-level characteristics and $\mu_i$ is an error term assumed to be normally distributed.

The probability of adoption of the new technology can be represented as

$$Pr(I_i = 1) = Pr(I^*_i > 0) = Pr(\mu_i < -\beta X_i) = 1 - F(-\beta X_i),$$

where $F$ is the cumulative distribution function for $\mu_i$.

Different models such as logit or probit normally result from the assumptions that are made on the functional form of $F$. The adoption of the DSR-sowing technology is expected to affect the demand for inputs such as pesticide, as well as productivity and net returns. To link the adoption decision with these potential outcomes of adoption, consider a risk neutral farm that maximizes net returns, $\pi$, subject to competitive input and output markets and a single-output technology that is quasi-concave in the vector of variable inputs, $W$. This may be expressed as:

$$\max \pi = PQ(W, X) - YW,$$

where $P$ is the output price and $Q$ is the expected output level; $Y$ is a column vector of input prices, whereas $W$ is a vector of input, and $X$ represents farm-level and household characteristics. The farm net returns can be expressed as a function of technology choice $I$, output price, variable inputs and household characteristics as follows:

$$\pi = \pi(I, Y, P, X).$$

The application of Hotelling’s Lemma to Equation (4) yields the reduced-form equations for input demand and output supply:

$$W = W(I, Y, P, X),$$

$$Q = Q(I, Y, P, X).$$

The specifications in Equations (4)–(6) indicate that the choice of technology, input and output prices, as well as farm and household-level characteristics tend to influence farm net returns, demand for inputs and the level of farm output.

3.2. Impact evaluation problem

The new agricultural technologies such as adoption of DSR can help to increase productivity and farm income, and as such, improve the welfare of farm households. Although several other reasons can be advanced to explain the importance of agricultural technology, improving household welfare is the crucial one. However the difference in welfare between adopters and non-adopters cannot be attributed simply to technology adoption. In cases where
experimental data is gathered through randomization, information on the counterfactual situation would normally be provided, and as such the problem of causal inference can be resolved. However, when the data available are from a cross-sectional survey, as are those employed in the current study, no information on the counterfactual situation is obtained. An effective way of addressing the problem is to resort to an investigation of the direct effect of technology adoption by looking at the differences in outcomes among farm households (Blundell and Costa Dias 2000).

Given that the decision of households to adopt or not to adopt the new technology may be associated with the net benefits of adoption, the issue of self-selection is crucial. To show the significance of self-selection, consider a reduced-form relationship between the technology choice and the outcome variable such as:

$$R_i = \alpha_0 + \alpha_1 I_i + \alpha_2 X_i + \varepsilon_i,$$

where $R_i$ represents a vector of outcome variables for household $i$, such as demand for inputs, farm output, net returns and poverty status of the household, $X_i$ represents household characteristics and $\varepsilon_i$ an error term, with $\varepsilon_i \sim N(0, \sigma)$. The issue of selection bias arises if unobservable factors influence both the error term of the technology choice, $\mu_i$, in Equation (1) and the error term of the outcome specification ($\varepsilon_i$), in Equation (7), resulting in a correlation of both error terms.

When the correlation between the two error terms is greater than zero, ordinary least square (OLS) regression techniques tend to yield biased estimates. Some authors have employed the Heckman two-step method or similar approaches to address selection bias. However, the two-step procedures are completely dependent on the strong assumption that unobservable variables are normally distributed. Another way of controlling for selection bias is to employ the instrumental variable (IV) approach. A major limitation of the approach is that it normally requires at least one variable in the treatment equation to serve as an instrument in specifying the outcome equation. Finding such instruments remains an arduous task in empirical analyses. Moreover, both OLS and IV procedures tend to impose a linear functional form assumption, implying that the coefficients on the control variables are similar for adopters and non-adopters. As indicated by Jalan and Ravallion (2003); Mendola (2007), this assumption is not likely to hold.

When panel data are available, selection bias can be addressed by the difference in the differences matching estimator. Difference-in-difference matching differs from cross-sectional matching in that it allows for temporally invariant differences in outcomes between adopters and non-adopters (Smith and Todd 2005). Crost et al. (2007) also employed a fixed effects approach to account for selection bias in their analysis of a genetically modified crop productivity estimate for Indian cotton farmers.

In the absence of panel data, this study employed statistical matching to address the problem of selection bias. This involves pairing adopters and non-adopters that are similar in terms of their observable characteristics (Dehejia and Wahba 2002).

When outcomes are independent of assignment into treatment, conditional on pre-treatment covariates, matching methods can yield an unbiased estimate of the treatment impact. A brief description of the propensity score-matching (PSM) method is presented below.

3.3. Propensity score method

It follows that the expected treatment effect for the treated population is of primary significance. This effect may be given as

$$\tau_{I=1} = E(\tau|I = 1) = E(R_1|I = 1) - E(R_0|I = 1),$$

where $\tau$ is the average treatment effect for the treated (ATT), $R_1$ denotes the value of the outcome for adopters of the new technology and $R_0$ is the value of the same variable for non-adopters. As noted above, a major problem is that we do not observe $E(R_0|I = 1)$. Although the difference $[\tau^e = E(R_1|I = 1) - E(R_0|I = 0)]$ can be estimated, it is a potentially biased estimator.

In the absence of experimental data, the PSM model can be employed to account for this sample selection bias (Dehejia and Wahba 2002). The PSM is defined as the conditional probability that a farmer adopts the new technology, given pre-adoption characteristics (Rosenbaum and Rubin 1983). To create the condition of a randomized experiment, the PSM employs the unconfoundedness assumption also known as conditional independence assumption, which implies that once $Z$ is controlled for, technology adoption is random and uncorrelated with the outcome variables. The PSM can be expressed as,

$$p(Z) = \Pr[I = 1|Z] = E[I|Z].$$

where $I = \{0,1\}$ is the indicator for adoption and $Z$ is the vector of pre-adoption characteristics. The conditional distribution of $Z$, given $p(Z)$ is similar in both groups of adopters and non-adopters.

Unlike the parametric methods mentioned above, PSM requires no assumption about the functional form in specifying the relationship between outcomes and predictors of outcome. The drawback of the approach is the strong assumption of unconfoundedness. As argued by Smith and Todd (2005), there may be systematic differences between outcomes of adopters and non-adopters even after conditioning because selection is based on
unmeasured characteristics. However, Jalan and Ravallion (2003) point out that the assumption is no more restrictive than those of the IV approach employed in cross-sectional data analysis. In a study by Michalopoulos, Bloom, and Hill (2004) to assess which non-experimental method provides the most accurate estimates in the absence of random assignment, they conclude that propensity score methods provided a specification check that tended to eliminate biases that were larger than average. On the other hand, the fixed effects model did not consistently improve the results.

3.3.1. Average treatment effects
After estimating the propensity scores, the ATT can then be estimated as:

\[ \tau = E[R_1 - R_0 | I = 1] = E[E[R_1 - R_0 | I = 1, p(Z)] - E[R_0 | I = 0] \]

Several techniques have been developed to match adopters with non-adopters of similar propensity scores. In the current paper the nearest neighbor matching (NNM) and the kernel-based matching (KBM) approaches are employed. The nearest neighbor matches with the similar neighbors in the adopters and non-adopters group while the KBM takes the weighted average of all the non-adopters and then matches with the adopters.\(^5\)

4. Data and variables
The current study was carried out in the rice–wheat area of the Pakistani Punjab. Comprehensive data sets for 238 rice growers were collected in 2011 from the three main rice growing districts, i.e. Sheikhupura, Hafizabad and Gujranwala. Of the 238 rice growers interviewed, 42% were from Hafizabad district, 24% from Sheikhupura and 34% from Gujranwala district. These three districts were purposely selected for the current study as the direct rice-sowing technology has been widely adopted there. The number of farmers interviewed from each district was proportional to the area under rice. In Pakistan the technology is still in its initial stages, hence data were collected from both categories of farmers, i.e. those farmers who have adopted the direct rice-sowing technology and those who have not adopted it. A comprehensive questionnaire covering different aspects of rice production was requested to collect the data from the farmers. Information on farmers’ socioeconomic characteristics, household assets and cropping pattern was also collected.

Table 1 presents the descriptive statistics (mean and standard deviation) of the important variables used in the empirical analysis. The descriptive statistics show that the average age of the farmers is 47 years with an average of 25 years’ experience and average of 10 years of education, indicating that the farmers are middle-aged with substantial experience and a good level of education. In the study area, the average household size is 9.2 and 46% are children, 35% are adults and 11% are elderly.

Land assets are the most important endowment for farmers; the average land holding in the study area is about 18.72 hectares, which is quite substantial. The data show the existence of the rental market; the average land rented and rented out are 7.19 and 2.90 hectares, respectively. Of the operational land of 23 hectares per household, 16 hectares is under wheat and rice, which highlights the importance of the wheat and rice-sowing technology in the study area.

Technology adoption and productivity are influenced by several factors like irrigation, farm mechanization, credit facilities, extension services, and so on. In the study area, we find that 27% of the households own tube wells, 31% own tractors, 41% have access to extension services and 15% have availed themselves of credit. In the study sites, the average household income is 13,400 Pak rupees and 36% of the households live below the poverty line.\(^6\)

5. Results and discussion
5.1. Descriptive analysis
Table 2 shows the difference in key characteristics of the households that adopted the direct rice-sowing technology and those that did not adopt. The mean area allocated to conventional and DSR was 10.18 and 7.88 hectares. The DSR entails 11 kg more seed as compared to conventional rice sowing, and is significant at 1%. The results show that the DSR on average requires much less irrigation compared to conventional rice sowing. The transplanting cost is high for conventional rice sowing and, by adopting the DSR, the farmers can save up to Pak rupees 1716 per acre. The labor demand is less for the DSR compared to conventional rice sowing and the results are significant at 5%. The diammonium phosphate (DAP) and the urea fertilizer requirements are also high for the DSR-sowing technology compared to the conventional rice-planting method. Weeds are a major problem associated with direct sowing; as a result herbicide application costs are also high for the dry rice-sowing technology and farmers have to bear about Pak rupees1100 for herbicide application.\(^7\)

The most notable finding is that the yield of the farmers who have adopted the direct rice-sowing technology is about 9 maunds higher compared to that with traditional rice sowing. The difference in income is negative and significant, indicating that households practicing the direct rice-sowing technology earn Pak rupees 2456 per month more than the households practicing the traditional
methods of rice cultivation. The head count index was employed to estimate the poverty level of households. The difference in poverty level is positive and significant, hence indicating that households practicing the conventional methods have higher poverty levels compared to households which have adopted the DSR-sowing technology.

Table 1. Socioeconomic characteristics of the surveyed household.

| Variable                  | Description                                      | Mean   | SD    |
|---------------------------|--------------------------------------------------|--------|-------|
| Age                       | Age of the rice producers in number of years      | 46.80  | 2.17  |
| Education                 | Education of the sample respondents in years      | 10.09  | 0.74  |
| Experience                | Experience of the sample respondents in years     | 24.67  | 2.58  |
| Male child                | Number of male children in the household          | 1.967  | 0.326 |
| Female child              | Number of female children in the household        | 2.29   | 0.41  |
| Adult males               | Number of adult males in the household            | 1.612  | 0.29  |
| Female adults             | Number of female adults in the household          | 1.614  | 0.210 |
| Old age males             | Number of old age males in the household          | 0.612  | 0.078 |
| Old age females           | Number of old age females in the household        | 0.387  | 0.082 |
| Family size               | Number of total family members in the household   | 9.19   | 0.88  |
| Male worker               | Number of male workers working on the farm        | 1.580  | 0.206 |
| Female worker             | Number of female workers working on farm          | 0.483  | 0.121 |
| Highest education         | Years of highest education in the family          | 11.25  | 0.66  |
| Own area                  | Number of hectares owned by the household         | 18.72  | 3.77  |
| Rented in                 | Area rented in by the household                   | 7.12   | 3.94  |
| Rented out                | Area rented out by the household                  | 2.90   | 2.13  |
| Shared in                 | Area shared in by the household                   | 0.064  | 0.06  |
| Shared out                | Area shared out by the household                  | 0.057  | 0.003 |
| Operational land          | Operational land holding of the farmer in hectares| 22.53  | 4.32  |
| Wheat area                | Area under wheat crop in hectares                | 16.22  | 2.40  |
| Rice area                 | Area under rice crop in hectares                 | 16.26  | 2.79  |
| Tube well                 | 1 if household have tube well ownership, 0 otherwise | 0.27  | 0.22  |
| Tractor                   | 1 if household have tractor ownership, 0 otherwise | 0.31  | 0.26  |
| Extension                 | 1 if household have extension contact, 0 otherwise | 0.41  | 0.28  |
| Credit facility           | 1 if household have availed credit facility, 0 otherwise | 0.15  | 0.31  |
| Road access               | 1 if household have road access, 0 otherwise      | 0.68   | 0.24  |
| Market distance           | Distance of market in kilometers                  | 7.26   | 2.83  |
| Income                    | Average monthly income of the household in rupees| 13,400 | 598   |
| Poverty                   | Head count index of poverty                       | 0.36   | 0.31  |

Source: Survey results, 2011.

Table 2. Difference in key characteristics of DSR and conventional rice sowing.

| Variable                  | Conventional rice | Direct rice | Difference  | t-Value |
|---------------------------|-------------------|-------------|-------------|---------|
| Area (hectares)           | 10.182            | 7.882       | 2.601       | 0.92    |
| Seed rate (kg)            | 2.921             | 13.906      | −10.984***  | −18.76  |
| Irrigation (number)       | 21.64             | 17.55       | 4.09*       | 1.73    |
| Transplanting cost (rupees)| 2147.02          | 430.55      | 1716.47***  | 7.85    |
| Labor demand (number)     | 4.05              | 1.13        | 2.92***     | 2.77    |
| DAP application (bags)    | 0.046             | 0.482       | −0.437***   | −4.26   |
| Urea application (bags)   | 1.075             | 1.992       | −0.898***   | −4.31   |
| Herbicide cost (rupees)   | 187.7             | 1283.2      | −1095.4***  | −7.97   |
| Rice yield (maunds)       | 35.93             | 45.07       | −9.140**    | −2.24   |
| Income (rupees)           | 12,762            | 15,218      | −2456*      | −1.69   |
| Family size (number)      | 9.36              | 8.93        | 0.43        | 0.12    |
| Poverty (Head Count Index)| 0.42              | 0.33        | 0.09**      | 2.05    |
| Tube well                 | 0.23              | 0.29        | −0.06       | −1.24   |
| Tractor                   | 0.35              | 0.24        | 0.11**      | 1.97    |
| Extension                 | 0.34              | 0.47        | −0.13*      | −1.81   |
| Credit facility           | 0.17              | 0.12        | 0.05        | 1.32    |
| Road access               | 0.57              | 0.74        | −0.17*      | −1.94   |
| Market distance           | 7.93              | 6.55        | 1.38*       | 1.75    |

*Significantly different from zero at 10% level.
**Significantly different from zero at 5% level.
***Significantly different from zero at 1% level.
The difference in tractor ownership is positive and significant at 5% signifying that the households practicing the traditional methods of rice sowing have higher tractor ownership. The difference in extension services is negative and significant at 10%, denoting that the farmers practicing the DSR-sowing technology have higher contact with the extension services and vice versa. The difference in credit facilities used is positive and non-significant. The difference in road access is negative and significant at 10%. Similarly the difference in market distance is positive and significant at the 10% level of significance, indicating that conventional rice farmers are farther away from markets compared to those farmers who have adopted the DSR-sowing technology.

5.2. Empirical analysis

5.2.1. Determinants to the adoption of the direct rice-sowing technology

The determinants of adoption of direct rice technology were estimated using probit regression analysis, and the results are presented in Table 3. Analysis shows a negative relation between age and the adoption of direct rice-sowing technology, and is significant at 10%, indicating that young farmers are most likely to adopt the direct rice-sowing technology compared to older farmers. This may be because young farmers are eager to try new technologies while the older farmers are accustomed to the conventional method of sowing rice and are reluctant to come out of their comfort zone and try new technologies.

Education plays a fundamental role in technology adoption; the result shows a positive and significant association between education and the adoption of the direct rice-sowing technology. Educated farm households are aware of the new technology and its potential impact on yield and new returns; therefore the level of education attained by the household head tends to have a positive influence on the choice of a new technology like direct rice sowing.

The number of male and female family workers was included in the model. The number of male family workers showed a positive and significant association at 10%, while the number of female farm workers was negatively associated with the direct rice-sowing technology, indicating that, if the household has more male workers, the chances that farmers will adopt the direct rice-sowing technology is higher. The coefficient for total family size is positive and significant at the 1% level of significance, indicating that the larger the family size the higher the chances are of adopting the direct rice-sowing technology. Land ownership measured in hectares is also positive and significant at 1%, indicating that the prospect of adopting the direct rice-sowing technology is higher if the agricultural land owned by the household is larger. The coefficient for tube well ownership is positive and significant at 5%, while the coefficient for tractor ownership, extension contact and road access is positive but not significant.

The coefficient for credit facility is positive and significant at 10% while the coefficient for market distance is negative and significant at 5%, demonstrating that those farm households with credit facilities are more likely to adopt the direct rice-sowing technology and those households which are further away from the market are less likely to adopt it.

Table 3. Determinants of area under DSR technology (poisson regression).

| Variable                      | Coefficient | z-Value | Significant level |
|-------------------------------|-------------|---------|------------------|
| Age (years)                   | −0.017      | −1.92   | *                |
| Education (years)             | 0.135       | 2.54    | ***              |
| Male family worker (number)   | 0.023       | 1.73    | *                |
| Female family worker (number) | −0.175      | −2.18   | **               |
| Total family size (number)    | 0.067       | 3.48    | ***              |
| Own area (hectares)           | 0.038       | 11.38   | ***              |
| Tube well ownership (number)  | 0.024       | 2.05    | **               |
| Tractor (dummy)               | 0.010       | 1.25    |                  |
| Extension (dummy)             | 0.038       | 1.50    |                  |
| Credit facility (dummy)       | 0.025       | 1.89    | *                |
| Road access (dummy)           | 0.011       | 1.30    |                  |
| Market distance (km)          | −0.033      | −1.99   | **               |
| Non-farm Participation        | −0.041      | −1.33   |                  |
| Number of observations        | 238         |         |                  |
| LR $\chi^2$                   | 146.44      |         |                  |
| Prob $> \chi^2$               | 0.000       |         |                  |
| Pseudo $R^2$                  | 0.4054      |         |                  |

***Significant at 1% level.
**Significant at 5% level.
*Significant at 10% level.
The LR $\chi^2$ value is significant, indicating the robustness of variables included in the model. The $R^2$ value is 0.405, which signifies that the 41% variation in the dependent variable is due to independent variables included in the model.

### 5.2.2. Impact of direct rice-sowing technology

The impact of the DSR technology is estimated by employing the PSM approach, and the results are presented in Table 4. The PSM approach is employed to correct for potential sample selection bias that may arise due to systematic differences between the adopters and non-adopters of DSR technology. Two different matching algorithms, i.e. NNM and KBM are employed. The most important results are the ATT, i.e. the difference in the outcome of the technology adopters and non-adopters. The impact on wheat yield is positive and significant both in the case of NNM and KBM, indicating that adopters of DSR technology are getting higher wheat yields in the range of 2.35–2.67 maunds per acre. The results for rice yields are also positive and highly significant at the 1% level of significance, indicating that adopters of DSR technology are able to obtain higher rice yields in the range of 7.46–9.15 maunds per acre compared to non-adopters. The results for seed rates are also positive and highly significant at 1%, signifying that adopters of DSR technology have to apply a higher seed rate in the range of 7.94–8.11 kg per acre. The results for labor demand are negative and significant at the 5% level of significance, indicating that adopters of the DSR technology require less labor in the range of 2.18–2.73 laborers per day. The results for herbicide demand are positive and significant in the case of NNM, while they are positive and non-significant in the case of KBM indicating that adopters of the DSR technology require more application of herbicide due to higher weed intensity. The overall cost of production for DSR technology is also less, indicating that adopters of the DSR technology have fewer production costs – in the range of 2253–2543 Pak rupees – mainly due to fewer water requirements. The results for household income are positive and significant indicating that households that adopted the DSR technology were achieving higher incomes in the range of Pak rupees 2736–2840. The increase in household income is a huge incentive for the farming community. Similarly, the poverty levels are less in the range of 16–24% indicating that adopter households have a lower incidence of poverty compared to non-adopters or, in other words, the adoption of the DSR technology can help reduce poverty levels.

The critical level of hidden bias is also reported in Table 4. The critical level of hidden bias indicates the level up to which the adopters and non-adopters differ in their odds of adoption; this does not indicate that in the presence of hidden bias the results are not robust. This only indicates the level up to which the adopters and non-adopters differ in their odds of adoption. The numbers of treated and numbers of control are also reported in Table 4. The results of the direct seeding rice-sowing technology are in line with the previous studies like Singh et al. (2005) which also reported that the direct rice-sowing method has several advantages over transplanting. In addition to higher economic returns, the DSR technology involves easier planting, is less labor intensive and consumes less water (Bhushan et al. 2007; Jehangir et al. 2005).

### Table 4. ATT results for impact of DSR technology.

| Matching algorithms | Outcome        | Caliper/ bandwidth | ATT   | t-Value | Critical level of hidden bias | Number of treated | Number of control |
|---------------------|----------------|--------------------|-------|---------|------------------------------|------------------|------------------|
| **NNM**             |                 |                    |       |         |                              |                  |                  |
| Wheat yield         | 0.01            | 2.35**             | 1.89  | 1.65–1.70 | 20                           | 18               |                  |
| Rice yield          | 0.01            | 7.46****           | 4.51  | 1.20–1.25 | 19                           | 19               |                  |
| Seed rate           | 0.01            | 8.11****           | 3.07  | 1.35–1.40 | 22                           | 16               |                  |
| Labor demand        | 0.01            | -2.73**            | -2.14 | 1.15–1.20 | 18                           | 20               |                  |
| Herbicide demand    | 0.01            | 1.72**             | 2.35  | 1.55–1.60 | 20                           | 18               |                  |
| Cost of production  | 0.01            | -2543.02**         | -1.83 | 1.45–1.50 | 18                           | 20               |                  |
| Household income    | 0.01            | 2736**             | 2.07  | 1.25–1.30 | 18                           | 22               |                  |
| Poverty             | 0.01            | -0.16*             | 1.91  | 1.30–1.35 | 24                           | 20               |                  |
| **KBM**             |                 |                    |       |         |                              |                  |                  |
| Wheat yield         | 0.05            | 2.67****           | 2.53  | 1.50–1.55 | 20                           | 18               |                  |
| Rice yield          | 0.05            | 9.15****           | 3.22  | 1.35–1.40 | 20                           | 18               |                  |
| Seed rate           | 0.05            | 7.94****           | 4.16  | 1.55–1.60 | 20                           | 18               |                  |
| Labor demand        | 0.05            | -2.18**            | -2.02 | 1.20–1.25 | 20                           | 18               |                  |
| Herbicide demand    | 0.05            | 1.54               | 1.09  | —       | 20                           | 18               |                  |
| Cost of production  | 0.05            | -2253.44**         | -2.30 | 1.45–1.50 | 20                           | 18               |                  |
| Household income    | 0.05            | 2840****           | 3.46  | 1.85–1.90 | 22                           | 20               |                  |
| Poverty             | 0.05            | -0.24***           | 2.58  | 1.65–1.70 | 20                           | 18               |                  |

*Significantly different from zero at 10% level.
**Significantly different from zero at 5% level.
***Significantly different from zero at 1% level.
The main purpose of the PSM is to balance the covariates before and after matching. For that, a number of balancing tests are employed. The indicators of covariates balancing before and after matching are presented in Table 5. The balancing tests employed are the median absolute bias before and after matching; the value of pseudo $R^2$ before and after matching and the $p$-value of joint significance of covariates before and after matching are reported in Table 5. The median absolute bias is quite high before matching and is in the range of 16.74–24.72. The median absolute bias is quite low after matching and is in the range of 4.70–8.52, hence indicating that after matching a considerable amount of bias has been reduced. The results are reasonably good with bias reduction ranging from 57% to 77%. The value of pseudo $R^2$ is quite high before matching both for the NNM and for KBM. The value of pseudo $R^2$ is quite low after matching, indicating that after matching, the adopters and non-adopters are quite similar to each other. Similarly, the joint significance of covariates should always be accepted before matching and should always be rejected after matching when after matching there is no difference between adopters and non-adopters. The indicators of covariate balancing are also presented in Figure 1.

### Table 5. Indicators of covariates balancing before and after matching.

| Matching algorithm | Outcome            | Median absolute bias (before matching) | Median absolute bias (after matching) | (Total) % bias reduction | Pseudo $R^2$ (unmatched) | Pseudo $R^2$ (matched) | $p$-Value of LR (unmatched) | $p$-Value of LR (matched) |
|-------------------|--------------------|----------------------------------------|---------------------------------------|--------------------------|--------------------------|--------------------------|-----------------------------|-----------------------------|
| NNM               | Wheat yield        | 20.55                                  | 4.70                                  | 77.12                    | 0.326                    | 0.005                    | 0.046                       | 0.822                       |
| NNM               | Rice yield         | 22.63                                  | 5.89                                  | 73.97                    | 0.311                    | 0.003                    | 0.025                       | 0.653                       |
| NNM               | Seed rate          | 16.74                                  | 7.25                                  | 56.69                    | 0.509                    | 0.001                    | 0.058                       | 0.519                       |
| NNM               | Labor demand       | 20.65                                  | 6.84                                  | 66.87                    | 0.461                    | 0.005                    | 0.025                       | 0.723                       |
| NNM               | Herbicide demand   | 18.51                                  | 7.99                                  | 56.92                    | 0.270                    | 0.003                    | 0.064                       | 0.755                       |
| NNM               | Cost of production | 20.56                                  | 5.81                                  | 71.71                    | 0.263                    | 0.006                    | 0.037                       | 0.532                       |
| NNM               | Household income   | 17.30                                  | 6.92                                  | 69.45                    | 0.326                    | 0.004                    | 0.045                       | 0.627                       |
| NNM               | Poverty            | 19.24                                  | 6.52                                  | 70.51                    | 0.257                    | 0.006                    | 0.052                       | 0.569                       |
| KBM               | Wheat yield        | 21.09                                  | 6.41                                  | 69.60                    | 0.274                    | 0.006                    | 0.055                       | 0.765                       |
| KBM               | Rice yield         | 20.53                                  | 5.43                                  | 73.55                    | 0.270                    | 0.004                    | 0.052                       | 0.841                       |
| KBM               | Seed rate          | 18.62                                  | 6.38                                  | 65.73                    | 0.364                    | 0.005                    | 0.045                       | 0.703                       |
| KBM               | Labor demand       | 23.66                                  | 8.52                                  | 63.98                    | 0.566                    | 0.004                    | 0.041                       | 0.721                       |
| KBM               | Herbicide demand   | 24.72                                  | 6.57                                  | 73.42                    | 0.462                    | 0.002                    | 0.054                       | 0.672                       |
| KBM               | Cost of production | 22.04                                  | 5.37                                  | 75.63                    | 0.410                    | 0.005                    | 0.051                       | 0.583                       |
| KBM               | Household income   | 19.58                                  | 6.23                                  | 69.40                    | 0.251                    | 0.004                    | 0.043                       | 0.502                       |
| KBM               | Poverty            | 20.61                                  | 5.31                                  | 58.81                    | 0.360                    | 0.005                    | 0.058                       | 0.614                       |

Notes: ATT, average treatment effect for the treated; NNM, nearest neighbor matching; KBM, kernel-based matching.

*Significantly different from zero at 10% level.
**Significantly different from zero at 5% level.
***Significantly different from zero at 1% level.

6. Conclusions

In the rice–wheat area of Pakistani Punjab, the DSR is an emerging technology, where the problem of water scarcity is increasing. Since the DSR is a water-saving technology, it is becoming popular among rice farmers in the study area. The DSR-sowing technology on average requires 4–5 fewer irrigations than the conventional rice sowing. Conventional rice planting requires more labor than the DSR. Besides the less water and labor requirement, the DSR-sowing technology provides higher yields compared to the conventional sowing of rice. The rice yield for DSR is 45 maunds per acre while it is only 36 maunds per acre for the conventional sowing of rice.

The cost of production is higher for the DSR, but the gross profit is higher for the DSR technology because the farmers are getting significantly higher yields by adopting...
The results indicate that direct rice sowing technology also has a positive impact on the following wheat crop. However the main problem associated with the adoption of the DSR technology is weed control.

The key factors contributing to the adoption of the DSR technology are the farmers’ age, education level, composition of family labor, land ownership and the availability of credit facilities. Due to awareness, younger farmers are more likely to adopt the direct rice-sowing technology while older farmers are more accustomed to the conventional method of rice sowing and are less likely to switch to a new technology. The importance of education on technology cannot be over-emphasized. The results show a strong linkage between the education level and the adoption of the direct rice-sowing technology. Similarly, the land owned in hectares, and contact with the extension and credit availability also have a positive influence in DSR technology adoption. Access to markets has a positive impact on DSR technology: farm households located closer to markets are more likely to adopt DSR technology compared to those households located far from markets.

Although DSR technology has a positive impact on yield and demands less water and labor, it is still a new experience for the farmers who have been practicing conventional methods of sowing for centuries. DSR technology has great potential because it requires less labor and irrigation and produces higher yields and net returns.

Notes
1. About 20% of the world population.
2. With respect to yield, both direct seeding (viz. wet, dry or water seeding) and transplanting has similar results.
3. Propensity score matching is the most robust method to correct for the sample selection bias.
4. The unconfoundedness assumption assumes that once the observable factors are controlled for technology adoption is random and uncorrelated with the outcome variables.
5. It’s always important to employ more than one matching algorithm to check the robustness of the results.
6. The head count index of poverty was estimated.
7. In case of direct seeding of rice the farmers have to sometimes plough their fields due to having serious weed problems.
8. One maund is equal to 40 kg of rice.
9. The nearest neighbor matching method matches the participants with the similar non-participant and this can be employed with replacement or without replacement while the KBM takes the weighted average of all the non-participants.
10. The results indicate that direct rice sowing technology also benefit the following wheat crop.

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