1. Introduction

Rice is the most important staple food crop in India. It accounts for 41 percent of the food grain production, 48 percent of the food grain consumption, and 35 percent of the area under food grain crops in the country (Ministry of Agriculture, 2014). Increasing rice production is very important for food security in India. However, producing enough rice to feed India's large and growing population is a major challenge. Raising production through conventional means such as increasing area under cultivation, irrigation and fertilizer use is facing limitations. There is a need to shift to a new and higher production frontier. In this context, hybrid rice technology offers a significant promise and has been shown to be very effective in countries such as China, Philippines, Indonesia and Bangladesh.

However, so far the diffusion of hybrid rice in India is proving to be very difficult, and its use has not taken off despite higher yield and advantages such as pest and disease resistance. Adoption of hybrid rice is a challenge for food security and food policy in India. The researchers and policy makers involved in the development of hybrid rice in the public and the private sector are still trying to explain the reasons behind this. In this context, this paper attempts to identify the factors related to farm, farmer and technology which affect the level of adoption of hybrid rice – partial or complete, by the farmers. To be more precise, we attempt to find the factors which encourage or discourage the complete adoption of hybrid rice by the farmers and evaluate the reasons behind differences in the extent of adoption across farmers. Complete adoption of hybrid rice is desirable from the point of view of the state which is trying to increase the production of food grains while facing severe limitations with increasing area under cultivation. While farmers might choose to have only a part of the rice area under hybrid rice cultivation in order to diversify and mitigate their risk, the study will help in identifying factors which lead to such behaviour. This also helps to assess why farmers differ from each other in terms of the total rice area they allocate to hybrid rice. This will help in identifying potential constraints to the conversion to hybrid rice cultivation in India and the results can be instrumental in designing policies for stimulating the growth in area under hybrid rice.

This paper is divided into five sections. The first section on introduction includes the background of rice production in India and its status vis-à-vis other major rice producing countries, status of hybrid rice across major hybrid rice growing countries and in India. The second section deals with the review of literature on hybrid rice. The third section elaborates the methodology, model, data and the sample profile. The next section discusses the results of the estimated model and the final section describes the conclusion and policy implications of the study.

1.1. Rice production in India

According to the USDA, India has the largest area under rice cultivation in the world (27%) followed by China (19%). Other major rice producing countries are Bangladesh (8%), Indonesia (7%), Thailand (6%) and Vietnam (5%). However, India (22%) lags behind China (30%) in terms of total rice production. This gap can

be attributed to relatively lower yields of rice in India compared to China and several other important rice growing countries. Although the productivity of rice in India has increased over last 50 years, it is still lower than most of the rice growing countries (Figure 1).

[Insert figure 1 here]

The post-independence era, after the food crisis, witnessed unparalleled developments in the form of the Green Revolution. However, the achievements of Green Revolution have started tapering off in the recent decades (Figure 2). While the growth in production of rice in the country till 1960s was driven mostly by the increase in area under cultivation, majority of the increase in production of rice in the past few decades has come from increase in yield. Due to limitations of horizontal expansion, it is expected that majority of the future increase in production will also have to come from increase in the yield (Alexandratos and Bruinsma, 2012).

[Insert figure 2 here]

1.2. Need for a new technology

According to FAO and IRRI, the demand for rice in world is expected to increase by nearly 30% in next 20 years and majority of this gap will have to be filled by the rice growing Asian countries. The demand for food grains including rice in India is also expected to increase in the future primarily driven by increase in population - both within the country and outside, derived demand for feed, export and indirect use in the industry (Mittal, 2008; Ganesh-Kumar et al., 2012). Therefore, in order to ensure continuous supply of rice, it is important to push the yield barriers further and enhance the productivity levels especially in the states with poor yield levels.

Hybrid rice technology is seen as one of the most important tools in fulfilling rice demand of the world. A study by Durand-Morat et al. (2011) noted that hybrid rice has made significant contributions towards aggregate supply of rice in spite of the low adoption rates in several Asian countries. Hybrid rice accounts for 60% of the total rice production in China and helped produce 20 million tonnes of additional rice every year, thus saving more than 2 million hectares of agricultural land for other uses (Julfiquar et al., 2003). Similarly, hybrid rice is also being grown in other countries such as Vietnam (10%), Bangladesh (6.8%), Indonesia (4.9%) and Philippines (4.6%).

[Insert Table 1 here]

1.3. Hybrid rice in India

Realising the importance of hybrid rice technology, concentrated research efforts to develop the same in India were initiated since 1989 and the first four rice hybrids were released in the country during 1994. Since then

59 varieties, both from the public and private sector have been released for cultivation till 2012. The initial emphasis of technology development in case of hybrid rice was mostly on increasing the yield. Over time, other traits such as disease resistance, grain quality were added as technology goals in the development of hybrid rice. Despite all this, the acceptance of hybrid rice has remained poor.

In 1995, only 0.02% of the total rice area was under hybrid rice cultivation. Over the years, the area under hybrid rice increased to 1.3million ha (2010). It was expected to reach 3 million ha in 2010 and increase up to 6 million ha by 2020 (Nirmala et al., 2009). According to estimates by Spielman et al. (2012), the coverage of hybrid rice in India was 4.6% in 2010. Another estimate suggests that during 2014, 2.5 million hectare of rice area accounting for only 5.6% of the total rice area in the country was under hybrid rice cultivation (Valdamani, 2016). Government of India had planned to increase the cultivation of hybrid rice to 25% of the total rice growing area by 2015. However, the target was not achieved given the slow pace of adoption. The sluggish pace of adoption remains an issue for both the public and the private sector entities which have made significant investments in the research and development of technology as well as in production and distribution. It needs to be noted here that the data on hybrid rice cultivation in India including the area under cultivation for different states over years had not been documented properly and is very sketchy. Therefore, tracking the progress of technology in an accurate manner is difficult.

[Insert Table 2 here]

According to an estimate, during kharif 2011, nearly 39% of the total area under hybrid rice area was in Uttar Pradesh followed be Bihar (16.6%), Chhattisgarh (10.5%) and Jharkhand (10.2%) (Table 3). Rest of the states such as Haryana (5%), Madhya Pradesh (4.19%), Gujarat (4.04%) and Odisha (2.67%) also have some rice area under cultivation of hybrid rice.

[Insert Table 3 here]

At the time of introduction of hybrid rice, states such as Punjab, Haryana, Tamil Nadu, Karnataka and Andhra Pradesh where the rice is 'fertilized, irrigated and transplanted', were expected to be the early adopters. However, contrary to the expectations, rainfed regions like Jharkhand, Chhattisgarh, Uttar Pradesh and Bihar, emerged as the faster adopters of this technology. Regions comprising of Uttar Pradesh, Madhya Pradesh, Bihar, Chhattisgarh, Haryana, Gujarat, Odisha and Jharkhand account for nearly 80% of the total hybrid rice market (AICRIP, 2015). On the other hand, states such as Punjab, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu together comprise of 20% of the area under hybrid rice in the country.

The increase in area under hybrid rice in India has been very slow as compared to some other crop technologies such as Bt cotton which was introduced in 2002-03 and rapidly spread to 95 percent of area under cotton cultivation within 12 years of its introduction in the country (Choudhary and Gaur, 2015). Thus, it is important to understand the reasons behind the slow rate of adoption of hybrid rice so that appropriate

policy measures can be designed. With this background of the importance of rice in India and the need for hybrid rice technology, we now examine the literature on the adoption of agricultural technologies especially hybrid rice to identify the research gap.

2. Literature review

Adoption of a new technology is a hierarchical process (Rogers, 1962; Aker et al., 2005). The potential adopters go through the process of awareness, interest, evaluation, trial and adoption (Bohlen & Beal, 1981). At the end of these stages, an individual might chose to adopt the technology either partially or completely (Perey, 2016). A large part of literature on adoption of agricultural technologies focuses on understanding the factors which lead to adoption of technologies. The next section of the write up focusses on the studies done in the context of adoption of hybrid rice technology in India.

The existing literature on hybrid rice, especially in the Indian context, revolves around identifying the factors associated with adoption of the technology. Low and marginal yields of hybrid rice (Spielman et al., 2012; Ahmed et al., 2008; Janaiah, 2003; Ramasamy et al., 2003), poor resistance towards biotic and abiotic stresses (Pandey and Bhandari, 2009; Ahmed et al., 2008) and poor quality of the grain (Sobha Rani et al., 2012; Spielman et al., 2012; Ahmed et al., 2008; Virmani et al., 2003) have been identified as some of the reasons for slow adoption of hybrid rice in India. As far as economics of cultivation is concerned, hybrid rice was found to be giving low returns in India due to higher input cost and poor market price of the output (Nirmala B., 2012; Pandey and Bhandari, 2009; Chengappa et al., 2003; Janaiah, 2003; Ramasamy et al., 2003) and it has often been cited as one of the reasons for poor adoption. Farmers' preference for cheap seeds (Ward et al., 2013), cost of hybrid rice seed (Spielman et al., 2012; Pandey and Bhandari, 2009; Ahmed, Meera and Viraktamath, 2008), supply of hybrid rice seeds (Singh et al., 2013) and quality (Pandey and Bhandari, 2009; Xie and Hardy in Spielman et al., 2012; Spielman et al., 2012) have also been found to be important for the technology to succeed. The impact of landholding on adoption decision of hybrid rice was studied by several researchers. Sarkar and Ghosh (2013), Hossain et al. (2003) and Janaiah and Hossain (2003) found that adoption was negatively related to landholding size indicating popularity of hybrid rice amongst poorer farmers. The study by Spielman et al. (2012) did not take landholding into account but considered the income level of farmers and concluded that nearly 75% of all hybrid rice adopters were wealthy and belonged to upper-middle or middle income quintiles.

Thus, the existing literature has covered aspects ranging from the yield advantage, profitability, grain quality, seeds, and farm and farmer level factors to government policies as factors affecting the adoption of hybrid rice technology. However, none of the studies has attempted to consider the factors which determine whether the farmer is a partial adopter or complete adopter of the technology. It is important to distinguish between partial and complete adopters of hybrid rice technology as well as identify the factors which are important regarding a farmer's decision to switch to hybrid rice cultivation completely. Moreover, the analysis in most of the above mentioned works on hybrid rice in India is very simple and is mostly based on averages or frequencies.

There is a lack of studies with econometric background to establish the factors affecting hybrid rice adoption in India.

Therefore, this piece of research attempts to determine the factors which lead to partial and complete adoption of hybrid rice by the farmers in India.

3. Methodology

3.1. Model for analysis

In order to do this, we employ a Tobit model. A Tobit model is considered appropriate when the dependent variable in the study is truncated at the lower bound, upper bound or both of them (Maddala, 1992; McDonald and Moffitt, 1980; Amemiya, 1973). Khaledi et al. (2010) used a Tobit model to identify the factors that encourage or discourage complete adoption of organic farming amongst the farmers in Canada. The study assesses what makes farmers differ in terms of the area they allocate to organic farming. Alene et al. (2000) also used Tobit to understand the adoption of maize varieties in Ethiopia. Baidu-Forson (1999) also used a Tobit model to identify factors influencing adoption of land-enhancing technology in Africa. Bellon and Taylor (1993) examined the effect of soil taxonomy to explain the rationale behind the partial adoption of maize varieties. Although these studies are not in the context of rice cultivation but other agricultural technologies, such studies are a step ahead of the adoption studies and help to understand the reason behind the share of land allocated to a technology by the farmers.

In this study we are employing upper –limit Tobit model to examine the probability of complete versus partial adoption as well as the extent of hybrid rice adoption by the farmers. The model used in the study is as follows:

$$y^* = x'\beta + \sigma\epsilon$$

Where, E (ϵ) =0

$$y = \min(y^*, 1)$$

Here, y* is the extent of adoption given as the percentage of rice area allocated to hybrid rice cultivation., *x'* is a vector of factors which affect farmer's decision to adoption the hybrid rice technology either partially or completely and β are the coefficients to be estimated. ϵ is the error term and captures the factors that are beyond this study.

Similar approach has been used by Khaledi et al. (2010), Akpoko (2007), Oladele (2005), Adesina and Zinnah (1993), Norris and Batie (1987), Smith and Blundell (1986) and Akinola and Young (1985). We extend the model further to calculate the impact of each of the independent variables on partial and complete adopters separately. The complete derivation of these expectations has been given in annexure.

3.2. Data

This study is based on a cross-sectional data which was collected from farmer surveys conducted during December 2012 – February 2013. Such micro level analysis of cross-sectional data can provide information

on farmers' preferences and thus, helps in understanding the adoption patterns (Doss, 2006). Farm level primary data was collected in three main hybrid rice growing states - Uttar Pradesh, Chhattisgarh and Gujarat, which account for more than half of the hybrid rice area of the country. The selection of the states was done carefully after a thorough analysis of the secondary data and opinion of experts in the public as well as private sector (Table 4).

These three states represent different agro-ecologies of rice cultivation in India. The states also differ in terms of yield levels of rice, cropping pattern, major crops, average landholdings, time of introduction of hybrid rice as well as response to it. Uttar Pradesh is the largest rice producing state in the country and was the first state where hybrid rice was introduced followed by Chhattisgarh and Gujarat. While rice cultivation in Uttar Pradesh and Gujarat is mostly irrigated, rice in Chhattisgarh is mainly rainfed. As a result, the farmers in the first two states cultivate two or more crops per year whereas those in Chhattisgarh are able to cultivate only one crop. The average landholding size in Uttar Pradesh is 0.75 ha compared to 1.36 ha in Chhattisgarh and 2.11 ha in Gujarat. These states also differ in terms of agro-climatic zones and major crops.

[Insert Table 4 here]

As explained previously in Table 3, approximately 39% of rice area in Uttar Pradesh, 10.45% in Chhattisgarh and 4.04% in Gujarat was under hybrid rice cultivation in 2011. The first two states – Uttar Pradesh and Chhattisgarh have traditionally been the focus of government policies including recent ones such as Bringing Green Revolution to Eastern India (BREI) which involved technology demonstration, input subsidies, post-harvest management etc. as well as the private sector marketing initiatives with respect to hybrid rice cultivation. On the other hand, Gujarat was not a part of such initiation and only the private sector seed companies started focussing on Gujarat in the recent past.

The sampling frame for the current study consists of farmers who had grown hybrid rice in at least one of the last four rice growing seasons, 2009 to 2012. A multi-stage stratified sampling was used to select 441 hybrid rice growing farmers. A total of 18 districts were sampled across the three states. On an average, 2-3 villages were selected from each district and 12-15 farmers were surveyed from each village. The selection of districts and villages was done based on the inputs from the field assistants working in those regions.

Farmers were interviewed with a structured and pre-tested questionnaire. The survey tool was translated into the local language for each state and was proof read by a rice expert of the native language. While interviewing, we requested that the survey instrument be completed by the person of the household who was responsible for carrying out activities related to hybrid rice cultivation. 4 interviewers were recruited for the purpose of data collection – 2 of them were females and 2 others were males. They along with the author collected the data for the study. The 4 recruited interviewers were graduates in different fields and were working as free lancers. Previously they had worked on data collection for projects from different universities and institutes in and outside India. All of them had prior experience of administering such questionnaires in

rural India on studies related to Bt Cotton, weather insurance etc. They were further trained for the data collection of the current study.

3.3. Sample profile

A total of 441 hybrid rice growing farmers were sampled across 3 states. 158 farmers were sampled from Uttar Pradesh, 149 from Chhattisgarh and 134 from Gujarat. There were two clearly identifiable groups of hybrid rice growing farmers in the sample: *Complete adopters* - those who cultivated hybrid rice on the entire rice area they had and *partial adopters* – those who cultivated hybrid rice only on a part of the rice area at the time of the survey. We were able to sample complete as well as partial adopters from all the three states. The state and adoption status wise split of farmers is given in Table 5.

[Insert Table 5 here]

Table 6 presents the descriptive statistics of the socio-economic characteristics of the complete and partial adopters in the sample. T-tests have been conducted to determine whether there is a significant difference between the means of the two groups for the given socio-economic characteristics.

The data shows difference between complete and partial adopters in terms of age, education, family size, experience of rice and hybrid rice cultivation, machinery ownership and landholding. On an average, complete adopters are younger and more educated than partial adopters. Also, farmers who adopted hybrid rice completely had smaller families, lesser cattle and machinery ownership compared to partial adopters. It can also be noted that the complete adopters had prior knowledge of the technology for a longer time and were using hybrid rice technology for longer duration than partial adopters. To check whether means for the two groups are significantly different from each other, we conducted t-tests and chi-square tests. The test results indicate that the family size for complete adopters is significantly lower than partial adopters. At the same time, the duration for which famers have known about hybrid rice as well as the number of years they have been growing it is significantly higher for complete adopter vis-à-vis partial adopters.

[Insert Table 6 here]

Table 6 also presents landholding and allocation pattern amongst the farmers categorised by their adoption status. The average landholding size and average rice area is higher for partial adopters as compared to complete adopters. Similarly, percentage of landholding allocated to rice is higher for partial adopters compared to complete adopters indicating that probably complete adopters are not primarily rice growers and have diversified into other crops. The test for difference of means indicates that partial adopters of hybrid rice have significantly higher average landholding, average area under rice, percentage of area under rice and percentage of rice area under hybrid rice as compared to complete adopters. These results give an indication that there are some inherent differences between the complete and partial adopters and there might be reasons behind the pattern that is observed in terms of the extent of technology adoption by them. We explore more of this in the next few sections.

The descriptive statistics of some other important variables and the results of test of difference of means are presented in Table 7. Significant difference exists between complete and partial adopters in terms of the availability of information and perception of adequacy of irrigation, good demand of hybrid rice, availability of good price in the market, procurement of the output by the government, availability of seed subsidy, availability of good quality seeds and credit facility from the seed dealer. On the other hand, no difference observed between the two types of farmers in terms of their perception of their risk taking ability, awareness of package of practices, availability of seeds through government outlets and availability of seeds at a reasonable price.

[Insert Table 7 here]

4. Results and discussion

We use TOBIT analysis in order to understand the factors that make a farmer adopt the technology completely vis-à-vis partially. The dependent variable *extent of adoption* is defined as the proportion of total rice area under hybrid rice cultivation and ranges from 0 to 1 where 1 represents complete adoption and values below that represent partial adoption. In the upper bound TOBIT model, the proportion of land under hybrid rice cultivation was regressed against various factors hypothesized to influence the adoption decision. The list of independent variables used in the analysis is given in Table 8. The independent variables used in the model can be broadly divided into three categories (i) farm and farmer related variables (ii) farmer's perception of technology and (iii) dummy variables.

[Insert Table 8 here]

The farm related variables include landholding size, distance from the city, availability of adequate water for irrigation, cattle and number of kharif crops. The farmer related variables include farmer's age, education, experience of hybrid rice cultivation, availability of information, family size etc. Availability of information has been captured as an index. Farmers were asked about the various sources of information available to them and their ratings in terms of quality. We have taken an average to represent the extent of information available to the farmers. Farmers' perceptions of the various aspects of hybrid rice technology and its cultivation were also captured. Similar approach has been suggested by Coughenour and Swanson (1992), Fliegel and Kivlin (1966) and Rogers (1962). Aspects such as relative yield of hybrid rice, demand in the market, price available to the farmers, government procurement of hybrid rice output, availability of seed subsidy, farmer's willingness to take risk of trying new technologies, pricing of hybrid rice seeds, availability of good quality seeds and availability of credit for purchasing hybrid rice seeds were captured and have been used as explanatory variables. These variables were presented as statements to the farmers and responses were captured on a scale of 5 to 1 where 5 meant strongly agree and 1 meant strongly disagree. Apart from these, dummy variables were used for 3 states in the study, cattle ownership, machinery ownership and number of crops grown in kharif season (single or multiple).

The results of the TOBIT model have been shown in table 9 and 10. The results from hybrid rice share estimation include the estimates of the coefficients, standard errors and marginal effects. The dependent variable in this estimation is the extent of adoption which varies from 0 to 1 with 0 indicating no adoption, 1 indicating complete adoption and the values in between indicating partial adoption of hybrid rice by the farmers.

Model statistics:

The measures of fit for the Tobit model have been given in Table 9. Higher likelihood of full model compared to null or intercept only model as well as the LR value and its probability indicate that the specified model is significant. The table also reports R-square values for the model. However, we are not interpreting it as it is not equivalent to the R-square of OLS regression. The sigma which is the estimated standard error is 0.3629. The assumption of normality of errors was also tested for the given model. The residuals were calculated and a p-p plot was made which showed that the error terms were normally distributed. This also indicates the robustness of the specified model.

[Insert Table 9 Here]

The result of the model including the coefficients and marginal effects is given in Table 10. The independent variables used in the model are given in Column 1. Column 2 and 3 report the Tobit coefficients and their t-statistics respectively. Column 4 values show the impact of change in independent variables on the dependent variable for all the observations (partial as well as complete adopters). Column 5 reports the effect of change in the independent variables on the adoption of hybrid rice for the farmers who had adopted hybrid rice partially at the time of the survey. Column 6 presents the effect of changes in the independent variables on adoption for farmers who were complete adopters at the time of the survey. Column 7 reports the effect of the change in each one of the independent variable on the probability of a farmer of having less than the maximum area under organic practice. That is, it shows the impact of the independent variables on the probability of a farmer being a partial adopter. All the marginal effects have been captured at the means of the variables.

[Insert Table 10 here]

The coefficients of the independent variables used in the model have been reported in column 2 of table 10. Farmer's *experience* of hybrid rice cultivation and *education* level of the farmer are positively related to the share allocated to hybrid rice cultivation at 1% and 5% significance respectively. Thus, farmers with more experience of hybrid rice and higher education are more likely to allocate higher area under rice for hybrid rice cultivation. The estimated parameters for *age, family size*, *city distance* and *information* are statistically insignificant. On the other hand, *landholding* and having *multiple kharif* crops are negatively related to the percentage of area under hybrid rice cultivation at 1% respectively. It shows that smaller farmers and farmers who grow single crop (rice) during kharif season are more likely to have higher percentage of rice area under

hybrid rice cultivation. Among the variables related to hybrid rice, *good demand* of the hybrid rice in the market and *availability of seed subsidy* are positively related to the share of hybrid rice cultivation at 1% and 5% *Adequate irrigation* significance respectively. *Good price* of the hybrid rice output and the availability of hybrid rice seeds in *government outlets* are negatively and significantly related to the allocation of rice area to hybrid rice cultivation. Variables such as *better yield* of hybrid rice, *reasonable price* of seeds, *good quality* seeds and *credit* from dealer have positive coefficients as per the expectation but they are statistically insignificant. *government procurement, risk taking ability* and *package awareness* are negatively related to adoption but are insignificant. The dummies for the state of *Uttar Pradesh* and *Chhattisgarh* are significant and have a negative relationship with the percentage of rice area under hybrid rice cultivation indicating lower adoption levels in these states compared to Gujarat. Cattle and machinery ownership have a positive but insignificant impact on adoption levels.

The marginal effects show that a 1% increase in the farmer's experience predicts an increase of 1.49% in the share of the hybrid rice area for all hybrid rice growing farmers. Similarly, a 1% increase variables such as education, good demand of hybrid rice and availability of subsidy on hybrid rice seeds leads to an increase in the share of the rice area under hybrid rice cultivation by 0.79%, 6.51% and 4.07% respectively. The predicted effect of a 1% increase in the experience of hybrid rice cultivation, education, good demand, and seed subsidy is 1.05%, 0.5%, 4.57% and 2.85% increase in the proportion of hybrid rice cultivation for the partial adopters. At the same time, the predicted effect of a 1% increase in the experience of hybrid rice cultivation, education, good demand and seed subsidy is 0.4%, 0.2%, 1.9% and 1.2% increase in the proportion of hybrid rice cultivation for the current complete adopters of the technology. The values in column 7 indicate that a 1% increase in the experience and education level of the farmer decreases the probability of a farmer being a partial adopter of hybrid rice by 2.40% and 1.27% respectively. If the good demand and availability of seed subsidy goes up by 1%, it decreases the probability of a farmer being a partial adopter by 10.46% and 6.52% respectively.

On the other hand, a 1% increase in variables such as landholding, good market price and availability of seeds through government outlets predict a decrease of 2.39%, 3.49% and 2.90% respectively. Also, if the farmer is having multiple kharif crops or belongs to the state of Uttar Pradesh and Chhattisgarh, results predict a decrease in the share of hybrid rice area by 6.67%, 10.19% and 8.41% respectively. Also, a 1% increase in landholding, good output price and availability of seeds through government outlets, predicts a decrease in the proportion of area under hybrid rice by 1.67%, 2.45% and 2.03% respectively for the partial adopters. Farmers growing multiple kharif crops, being from Uttar Pradesh or Chhattisgarh are expected to have a decrease in the proportion of hybrid rice by 6.67%, 7.14% and 5.89% respectively for the partial adopters. Similarly, for complete adopters, a 1% increase in landholding, good output price and availability of seeds in government outlets leads to a decline of 0.7%, 1% and 0.9% in the proportion of area under hybrid rice cultivation. In case a farmer cultivates multiple kharif crops, is from Uttar Pradesh or from Chhattisgarh, the decline in the

proportion of area under hybrid rice cultivation for the complete adopters is 2.8%, 3.1% and 2.5% respectively.

The values in column 7 suggest that if the landholding of the farmer increases by 1 %, the probability of him being a partial adopter increases by 3.84%. At the same time, 1% increase in good price and availability of seeds in government outlets increases the probability of a farmer bring a partial adopter by 5.61% and 4.66% respectively. If a farmer shifts from single kharif crops to multiple kharif crops, there is 15.26% higher probability of him being a partial adopter. Similarly, the probability of a farmer bring a partial adopter is higher by 16.35% and 13.50% if he belongs to the states of Uttar Pradesh and Chhattisgarh respectively.

Overall, the results indicate a positive relation between share of hybrid rice cultivation and experience of farmer with hybrid rice cultivation, education, good demand of hybrid rice and availability of seed subsidy. On the other hand, landholding of the farmer, good price of hybrid rice, availability of seeds in government outlets, multiple kharif crops and the dummies for the state of Uttar Pradesh and Chhattisgarh are negatively related to the share of hybrid rice. This indicates that the farmers who are educated, experienced, have smaller landholdings and grow single kharif crop i.e. rice are more likely to have higher area under hybrid rice cultivation.

Farmers are more likely to be complete adopters if they perceive that hybrid rice has good demand in the market and subsidy is available on the purchase of seeds. These are mostly the small and marginal farmers who sell the hybrid rice output in the market and depend upon government subsidies for the adoption of new technologies. Although they have smaller landholdings, they usually allocate complete rice area for hybrid rice cultivation.

On the other hand, farmers who perceive that hybrid rice gets better price in the market and is available through government outlets usually have lesser share of their rice area under hybrid rice cultivation. Given the inputs from the field survey, these are mostly large farmers who manage to get good price for the hybrid rice output. They are also the privileged ones and have access to the limited seeds available in the government outlets. However, they do not allocate the entire rice area to hybrid rice cultivation.

Thus, the results indicate that probably small and marginal farmers are the ones who are complete adopters of hybrid rice. For them, demand of output in the market and subsidy on seeds is of importance. Large farmers, however, are the partial adopters. They have more landholding but allocate relatively lesser area to hybrid rice cultivation. The inputs from the field visits indicate that these farmers prefer to grow the traditional rice varieties due to better taste. These farmers have access to government outlets and manage to get good price of the output in the market. The results point towards the inefficiencies existing in the system. Access to market, availability of good output prices and availability of seeds through government outlets seem to be an issue for the small and marginal farmers, who are the complete adopters of the technology. Also, the coefficients of state dummies show that farmers in Uttar Pradesh and Chhattisgarh have lesser percentage of their rice area under hybrid rice cultivation.

5. Conclusion and policy implications

Rice is the staple food of India and the demand for it is growing consistently. However, increasing the production of rice remains a challenge due to constraints on the horizontal expansion. A technology such as hybrid rice seems to have huge promise as it has the potential to increase the production by 15-20% without increasing the area under cultivation. However, the poor rate of adoption of hybrid rice by the Indian farmers has been a reason of concern for the policy makers and the private sector involved in the production and distribution of hybrid rice seeds.

Adoption is found to be negatively related to the extent of land owned by the farmer. This indicates that farmers with smaller landholdings are more likely to adopt the technology completely. Therefore, the focus of initiatives to encourage the adoption of new agricultural technologies should be the small and marginal farmers. Contrary to the expectations, factors such as family size, age of the farmer, distance from the city, mechanization, better yield, awareness level of the farmer, price of the hybrid rice seeds, quality of seeds etc. were not found to be significant determinants of the extent of adoption of hybrid rice by the farmers.

The evaluation of hybrid rice cultivation with censored data indicates that the partial and complete adopters of the technology differ from each other with respect to their intensity of response towards certain perceptions related to hybrid rice cultivation. The calculation of separate effects for partial and complete adopters using the upper bound Tobit model allows us to identify the factors that affect partial and complete adopters differently along with how the different technology, farm and farmer related factors can potentially affect the degree of adoption, that is, the share of hybrid rice cultivation out of total rice cultivated by the farmer. Insight into these effects can be very helpful in designing policies for encouraging the adoption of hybrid rice technology in the country.

The results from this study can be of help in policy making aimed at encouraging the adoption of hybrid rice technology or other similar agricultural technologies in India or other developing economies. Overall, factors related to the farmer, the farm as well as the perception of the technology is seen to be related to the share of rice area under hybrid rice cultivation. The results indicate that education, experience, landholding, demand, price, subsidy, seed availability and cropping pattern are of importance in determining the status of adoption of hybrid rice by the farmers. Therefore, it may be possible to encourage hybrid rice adoption by the farmers in India by:

- Targeting the educated but small and marginal farmers.
- Target regions where single kharif crop is being grown.
- Ensuring the availability of good output price
- Making hybrid rice seeds available through government outlet to all.
- Facilitating the marketing of the hybrid rice output so as to ensure good demand.

Based on the above results and discussion, it can be inferred that the decision regarding extent of adoption of a technology – partial or complete is influenced by a variety of factors. While some factors such as good demand, availability of good quality and subsidized seeds can be influenced by government policies, other factors can be taken into account by appropriate targeting of the technology towards smaller farmers and in areas which are not traditionally rice growing regions such as Gujarat where larger percentage of rice area is allocated to hybrid rice cultivation compared to the traditional rice growing regions.

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Figure 1. Rice yield in important rice growing countries (MT/Ha)
(2015-2016)

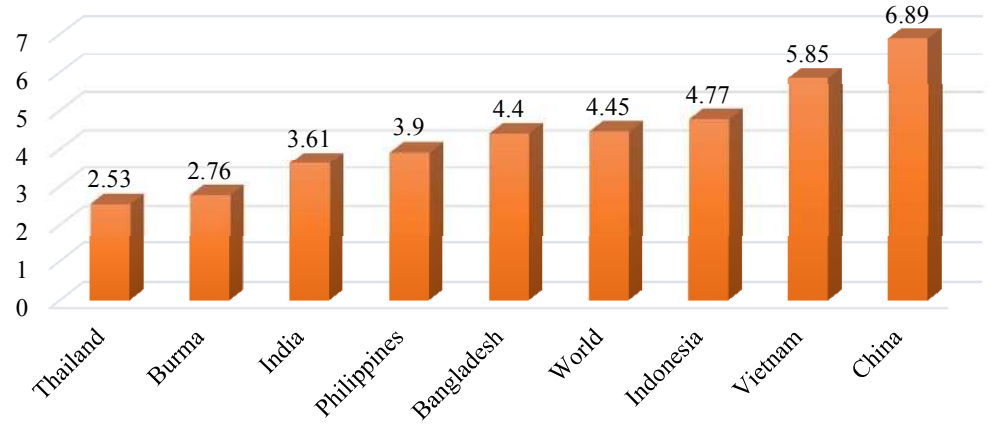

Figure 2. Growth rate of area under rice and rice yield in India
(1960 to 2015)

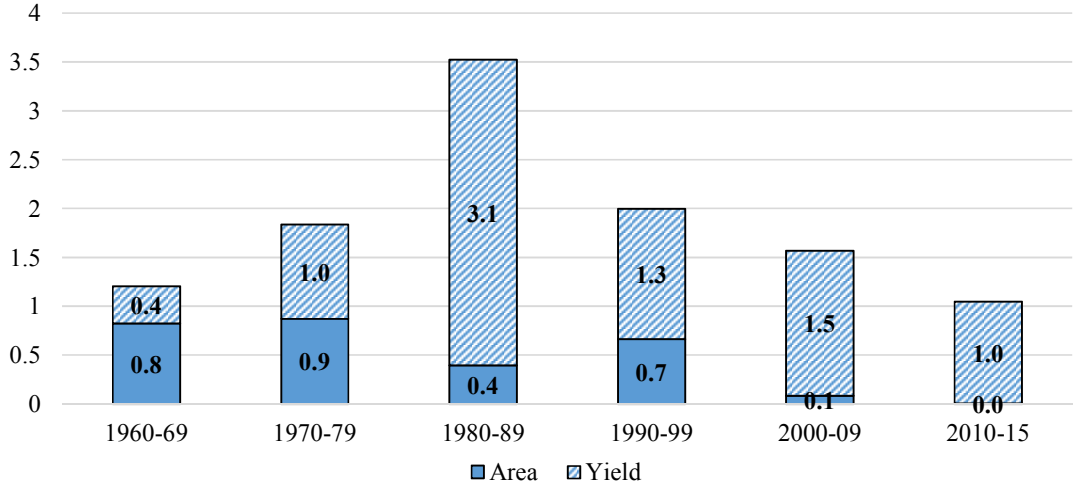

Table 1. Area under hybrid rice as a percent of rice area in selected countries (1995–2010)				
Year	**China**	**Bangladesh**	**India**	**Vietnam**
1995	43.3	0.0	0.1	1.1
2000	45.2	0.0	0.4	5.7
2005	51.4	1.9	1.8	9.0
2010	51.8	6.8	4.6	10.0

Source: Spielman et al. (2012)

Table 2. Area planted to hybrid rice cultivation in India (1995-2011)			
Year	**Gross Rice Area (mn ha)**	**Area planted to hybrid rice**	
		'000 ha	**% of gross rice area**
1995	42.84	10	0.02
2000	44.71	150	0.34
2005	43.66	750	1.72
2010	42.86	1300	3.03
2011	43.97	2000	4.55

Source: Collated from different sources

Table 3. State wise area under hybrid rice - Kharif 2011			
States	Area under hybrid rice* ('000 hectares)	% of the total rice area in the state #	% of the hybrid rice area in the country
Uttar Pradesh	770	12.9	38.88
Bihar	328	9.9	16.56
Chhattisgarh	207	5.5	10.45
Jharkhand	202	13.8	10.20
Haryana	99	8.0	5.00
Madhya Pradesh	83	5.0	4.19
Gujarat	80	9.6	4.04
Odisha	53	1.3	2.67
Others	158		7.98
Total	1980		

Source: Siddiq (2012) * - Based on the F1 seeds sold, # - calculated based on data from MoA, GoI

Table 4. Characteristics of sampled states			
	Uttar Pradesh	Chhattisgarh	Gujarat
Total area under rice (000 ha)	5842.0	3808.5	755.0
Total rice production (000 tonne)	12092.9	6322.1	1733.0
Average rice productivity (kg/ha)	2070	1660	2297
% of net sown area under irrigation	84.1%	31.0%	41.1%
% of rice area under irrigation	48-50%	28-30%	59-60%
Average landholding (ha)	0.75	1.36	2.11
No. of agro-climatic zones in state	9	3	8
No. of agro-climatic zones in the sample	3	2	3
No. of districts in the sample	7	6	5
Major crops	Wheat, rice, sugarcane, pulses	Rice, coarse grains, maize	Tobacco, cotton, groundnut, rice

Data Source: www.indiastat.com and www.rkmp.com

Table 5. Sampling details			
	All	Complete adopters	Partial adopters
Uttar Pradesh	158	70	88
Chhattisgarh	149	49	100
Gujarat	134	78	56
Total	441	197	244

Table 6. Socio-economic characteristics of farmers by adoption status				
	All	Complete adopters	Partial adopters	Test of difference of means
Mean age (years)	43.79 (.583)	43.26 (.819)	44.21 (.821)	-.812
Education (years)	9.25 (.229)	9.55 (.333)	9.00 (.315)	1.187
Family members (no.)	7.66 (.176)	7.21 (.269)	8.02 (.230)	-2.287**
Avg distance from city (km)	12.60 (.522)	12.64 (.752)	12.57 (.718)	.074
Rice Experience (years)	21.01 (.548)	20.63 (.812)	21.31 (.743)	-.619
Hybrid Knowledge (years)	7.06 (.157)	7.42 (.234)	6.77 (.211)	2.084**
Hybrid Experience (years)	5.43 (.143)	5.96 (.202)	4.99 (.197)	3.442***
Cattle Ownership	90.7% (.014)	88.8% (.022)	92.2% (.017)	1.214
Machinery Ownership	39.7% (.023)	34.5% (.034)	43.8% (.032)	-1.996**
Average landholding (ha)	2.59 (.159)	1.79 (.132)	3.23 (.259)	-4.603***
Average leased in land (ha)	0.42 (.078)	0.26 (0.072)	0.53 (.129)	1.603
Average area under rice (ha)	2.29	1.43	2.99	-5.847***

	(.137)	(.105)	(.224)	
% of area cultivated to rice	77.18% (1.181)	71.69% (1.795)	81.58% (1.512)	-4.244**
% of rice area cultivated to hybrid rice	73.74% (1.367)	100.0% (.000)	52.54% (1.405)	30.327***
Note: The figures in parenthesis are the standard errors. *, ** and *** are significance levels at 10, 5 and 1% respectively.				

Table 7. Descriptive statistics of other important variables

	All	Complete adopters	Partial adopters	Test of difference of means
Information	3.466 (.439)	3.551 (.443)	3.399 (.424)	-3.5794***
Adequate irrigation	4.05 (1.066)	3.903 (1.047)	4.168 (1.068)	2.611***
Good demand	3.510 (1.105)	3.831 (1.006)	3.251 (1.116)	-5.658***
Good price	3.009 (.994)	3.112 (1.054)	2.926 (.937)	-1.961*
Government procurement	2.922 (1.550)	2.663 (1.481)	3.133 (1.576)	3.182***
Seed subsidy	1.653 (.995)	1.796 (1.051)	1.539 (.935)	-2.693***
Risk taking ability	3.713 (1.005)	3.695 (.978)	3.728 (1.028)	0.341
Package awareness	3.917 (.809)	3.877 (.787)	3.950 (.826)	0.940
Government outlets	1.708 (1.041)	1.736 (1.000)	1.685 (1.074)	-0.501
Reasonable price of seeds	3.917 (1.065)	3.928 (1.032)	3.909 (1.093)	-0.193
Good quality seeds	3.938 (.783)	4.010 (.755)	3.880 (.801)	-1.728*
Credit from dealer	2.982 (1.320)	3.123 (1.266)	2.769 (1.344)	-2.793***
Note: The figures in parenthesis are the standard errors. *, ** and *** are significance levels at 10, 5 and 1% respectively.				

Table 8. Description of variables included in the model	
Variable	**Description of the variable**
Experience	Farmer's experience of hybrid rice cultivation in years
Education	Number of years of education
Age	Age in years
Family size	Family size of the farmer
City distance	Distance from the city in kilometers
Landholding	Total land owned by the farmer in hectares
Information	Quality of information available (5 to1)
Adequate irrigation	Availability of sufficient water for irrigation (5 to 1)
Better yield	Hybrid rice yields better than OPVs (5 to 1)
Good demand	Hybrid rice has good market demand (5 to 1)
Good price	Good market price of hybrid rice output (5 to 1)
Government procurement	Government procurement of hybrid rice output (5 to 1)
Seed subsidy	Availability of subsidy on hybrid rice seed (5 to 1)
Risk taking ability	Willingness to try new technology (5 to 1)
Package awareness	Awareness of correct package of practices (5 to 1)
Government outlets	Availability of hybrid rice seeds in govt. outlets (5 to1)
Reasonable price of seeds	Reasonable pricing of hybrid rice seeds (5 to 1)
Good quality seeds	Availability of good quality seeds (5 to 1)
Credit from dealer	Availability of credit from the seed dealer (5 to 1)
Kharif crops	Dummy: 1 = 1 crop, 2 = multiple crops
Cattle ownership	Dummy: 1 = No cattle owned, 2 = Cattle owned
Machinery ownership	Dummy: 1 = No machinery, 2 = Machinery owned
State	Dummy: 1= UP, 2 = CG, 3 = GJ

Table 9. Measures of Fit for Tobit model	
Log-Lik Intercept Only: -246.618	Log-Lik Full Model: -187.776
Prob > LR: 0.000	LR(25): 117.684
McFadden's R^2: 0.239	McFadden's Adj R^2: 0.129
ML (Cox-Snell) R^2: 0.281	Cragg-Uhler (Nagelkerke) R^2: 0.375
Sigma (σ) : .3629	Standard Error of sigma : .0199

Table 10. Results of Tobit analysis

1	2	3	4	5	6	7
Independent Variables	Tobit coefficient	t-statistic	Effect on dependent variable for all observations (adopters)	Effect on dependent variable for observations below the limit (partial adopters)	Effect on dependent variable for observations at the limit (complete adopters)	Effect on probability of being below the limit (probability of being partial adopters)
Experience	.0232	2.91***	.0149	.0105	0.004	-.0240
Education	.0123	2.29**	.0079	.0055	0.002	-.0127
Age	-.0023	-1.28	-.0015	-.0010	-0.001	.0024
Family size	-.0049	-0.77	-.0031	-.0022	-0.001	.0050
City distance	-.0022	-1.01	-.0014	-.0009	-0.001	.0021
Landholding	-.0372	-4.14***	-.0239	-.0167	-0.007	.0383
Information	.0217	0.43	.0139	.0097	0.004	-.0223
Adequate irrigation	-.029	-1.28	-.0186	-.0130	-0.006	.0298
Better yield	.021	0.66	.0137	.0096	0.004	-.0220
Good demand	.101	4.06***	.0651	.0457	0.019	-.1046
Good price	-.0544	-1.80*	-.0349	-.0245	-0.010	.0561
Government procurement	-.0262	-1.46	-.0168	.0118	-0.029	.0270
Seed subsidy	.0634	2.28**	.0407	.0285	0.012	-.0652
Risk taking ability	-.0116	-.052	-.0074	-.0052	-0.002	.0119
Package awareness	-.0475	-1.63	-.0305	-.0214	-0.009	.0489
Government outlets	-.0452	-1.87*	-.0290	-.0203	-0.009	.0466
Reasonable price of seeds	.0231	1.04	.0148	.0104	0.004	-.0238
Good quality seeds	.0301	1.00	.0193	.0135	0.006	-.0310
Credit from dealer	.0262	1.59	.0168	.0135	0.003	-.0270
Kharif_dummy	-.148	-2.98***	-.0950	-.0667	-0.028	.1526
Cattle_dummy	.1203	1.49	.0771	.0540	0.023	-.1238
Machinery_dummy	.0064	0.12	.0041	.0029	0.001	-.0067
State_dummy_1	-.1588	-2.02**	-.1019	-.0714	-0.031	.1635
State_dummy_2	-.1311	-1.99**	-.0841	-.0589	-0.025	.1349
Constant	.635					

1 Deriving the Expectation in a Censored Regression Model

The censored regression model is written in the generic form :

$$\begin{aligned} y^* = x'\beta + \sigma\epsilon \quad where \quad E[\epsilon] = 0 \\ y = min(y^*, 100) \\ Prob(\epsilon \leq a) = F(a) \quad where \quad -\infty < \epsilon < \infty \\ f(\epsilon) = F'(\epsilon) = dF(\epsilon)/d\epsilon \end{aligned}$$

$$E[y|x] = Prob(y^* < 100|x) * E[y^*|x, y^* < 100] + Prob(y^* \geq 100|x) * 100$$

$$Prob(y^* < 100|x) = Prob(x'\beta + \sigma\epsilon < 100|x) = Prob\Big(\epsilon < (100 - x'\beta)/\sigma|x\Big) = F\Big((100 - x'\beta)/\sigma\Big)$$

Similarly,

$$Prob(y^* \geq 100|x) = 1 - F\Big((100 - x'\beta)/\sigma\Big)$$

Now,

$$E[y^*|x, y^* < 100] = x'\beta + \sigma E[\epsilon|y^* < 100] = x'\beta + \sigma E[\epsilon|\epsilon < (100 - x'\beta)/\sigma]$$

Now,

$$E[\epsilon|\epsilon < (100 - x'\beta)/\sigma] = \int_{-\infty}^{(100-x'\beta)/\sigma} \epsilon f(\epsilon|\epsilon < (100 - x'\beta)/\sigma)d\epsilon$$

Also,

$$f(\epsilon|\epsilon < (100 - x'\beta)/\sigma) = f(\epsilon)/Prob(\epsilon < (100 - x'\beta)/\sigma) = f(\epsilon)/F\Big((100 - x'\beta)/\sigma\Big)$$

Hence, plugging in the values

$$E[y|x] = F\Big((100 - x'\beta)/\sigma\Big)[x'\beta + \int_{-\infty}^{(100-x'\beta)/\sigma} \epsilon f(\epsilon)/F\Big((100 - x'\beta)/\sigma\Big)d\epsilon] + [1 - F\Big((100 - x'\beta)/\sigma\Big)] * 10$$

Also,

$$\int_{-\infty}^{(100-x'\beta)/\sigma} \epsilon f(\epsilon)d\epsilon = -f(\epsilon)|_{-\infty}^{(100-x'\beta)/\sigma} = -f\Big((100 - x'\beta)/\sigma\Big)$$

Hence,

$$E[y|x] = F\Big((100 - x'\beta)/\sigma\Big)[x'\beta - \lambda\Big((100 - x'\beta)/\sigma\Big)] + [1 - F\Big((100 - x'\beta)/\sigma\Big)] * 100$$

where

$$\lambda\Big((100 - x'\beta)/\sigma\Big) = f\Big((100 - x'\beta)/\sigma\Big)/F\Big((100 - x'\beta)/\sigma\Big)$$