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Factors influencing hybrid rice adoption: a Bangladesh case

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As rice constitutes the major share in cereal consumption in South and East Asian countries that ranges from as low as 40 per cent in India to 97 per cent in Myanmar, to ensure food security, governments in these countries are encouraging farmers to adopt hybrid rice. This is mainly because hybrid rice provides a yield gain of 15–20 per cent over conventionally bred varieties in general. Yet, despite strenuous government efforts, farmers' adoption rates have remained low in India, Bangladesh and Vietnam compared with China. Although studies often claim that higher seed costs and inferior grain quality are the major factors limiting hybrid rice adoption, very few studies examine the importance of socio-economic factors and infrastructure in the adoption of hybrid rice. Using Bangladesh as a case, a comparative analysis has been made on the adoption of hybrid and modern varieties relative to traditional rice varieties and land allocation to these varieties. Econometric results indicate that general land characteristics, loan facilities and general infrastructure, such as roads, irrigation facilities and the availability of government-approved seed dealers, significantly influence the adoption of hybrid and modern rice varieties and land allocation to these varieties compared with traditional varieties.

Key words: adoption, farm households, hybrid rice, infrastructure, modern variety.

1. Introduction

Rice is the staple food of half of the world population (Zeigler and Barclay 2008), and it is the primary source of income of one-fifth of the total world population. Alarmingly, because of increases in population and income in many Asian and African countries, demand for rice has been steadily increasing over the years (Mohanty 2009). For example, by 2035, rice consumption will be 555 million tonnes globally compared with 439 million tonnes in 2010, which means that, in less than 25 years, an extra 116 million tonnes of rice need to be produced to meet global demand (GRiSP 2010). Therefore, sustainable growth in rice production worldwide is needed to ensure rice food security and the income of millions of people. Ironically, there is no or little scope to extend the land frontier to produce more rice,

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particularly in Asian countries, where 90 per cent of the total rice is produced and consumed (Miah and Sarma 2000). Also, the productivity gains derived from the green revolution in the 1970s that started with the development of short-duration fertiliser-responsive semi-dwarf modern high-yielding rice varieties are near exhaustion (Pingali *et al*. 1997). In this critical backdrop, a sharp vertical shift in rice yield is necessary to meet the growing demand for rice in many Asian countries.

The development of hybrid rice and the success of some countries, such as China, in achieving rice food security by expanding hybrid rice adoption generated a new enthusiasm for increasing rice yield after the green revolution (e.g., Spielman *et al*. 2012). This is mainly because hybrid rice provides a yield gain of 15–20 per cent over the conventionally bred best varieties in general (Miah and Sarma 2000; Husain *et al*. 2001; Azad *et al*. 2008). However, there is a critical contrast between hybrid rice and conventionally bred rice varieties. Hybrid rice is a first-generation (F_1) crop developed by crossing two distantly related rice varieties, one of which is sterile (male). Hybrid vigour, or heterosis, is the foundation for the yield advantage of hybrids over inbred rice varieties. One critical aspect of hybrid rice is that yield gains achieved through heterosis decline significantly after the first generation of seeds (F_1). As a result, unlike conventionally bred rice varieties that farmers can store and use their harvested grains as seeds in the following year, hybrid rice compels farmers to purchase new seeds in each season if they want to achieve higher yield continuously.

Because of the yield advantage, governments in South and South-East Asian countries, where rice constitutes the major share in cereal consumption that ranges from as low as 40 per cent in India to 97 per cent in Myanmar (Janaiah and Xie 2010), are encouraging farmers to adopt hybrid rice (e.g., Chowdhury 2002; FAO 2002; David 2006). Yet, despite strenuous government efforts, farmers' adoption rates have remained low in India, Bangladesh and Vietnam compared with China (FAO 2002; Spielman *et al*. 2012). In 2010, around 52 per cent of the total rice farmland in China was under hybrid rice, whereas it was only 6.8 per cent in Bangladesh, 4.6 per cent in India and the Philippines, 4.9 per cent in Indonesia and 10 per cent in Vietnam (Spielman *et al*. 2012). Questions arise: Why is the rate of adoption of hybrid rice in general low in Asian countries except China? What factors affect the adoption of hybrid rice?

Although the issue is important for its implications for rice food security, only a few studies focus on it (e.g., Husain *et al*. 2001; Hazra 2002; Azad *et al*. 2008). Using large national data sets from Bangladesh, an attempt has been made in this article to identify the factors facilitating and limiting hybrid rice adoption in comparison with the adoption of modern and traditional rice varieties. This paper empirically demonstrates that, although the availability of loan and irrigation facilities significantly and positively affects both hybrid and MV rice adoption, the presence of trusted seed dealers affects only the

adoption of hybrid rice compared with traditional varieties. Policies are drawn up based on the findings.

Bangladesh is one of the most successful countries in achieving higher rice yield by expanding irrigation facilities along with adopting modern high-yielding varieties in the boro, dry rice season (e.g., Hossain *et al.* 2007). The country was able to produce 31.97 million tonnes of rice in 2009–10 compared with 13.63 million tonnes in 1981–82 (BBS 2011). However, self-sufficiency in rice has yet to be achieved in Bangladesh. For example, during 1972–73 to 2010–11, on average, the country imported 516,000 tonnes of rice annually. To increase rice production to meet the growing demand, the government of Bangladesh has been encouraging the adoption of hybrid rice since the 1990s (Chowdhury 2002).

2. Literature review and major objectives

Although there is a rich literature studying the process of the adoption of modern high-yielding rice varieties (MVs) following the success of the green revolution in Asia (e.g. Bera and Kelley 1990; Husain *et al.* 2001; Hossain *et al.* 2007; Hossain and Jaim 2012), only a limited number of studies focus on the adoption of hybrid rice in South and East Asia, where the rice green revolution was a great success. It is found that, although before the 1980s, only 27 per cent of the rice-growing area in Bangladesh was occupied by MVs (Bera and Kelley 1990), by the late 1980s MV coverage in the country's total rice area reached 60 per cent, and, by 1995, it increased to 82 per cent (Islam *et al.*, 2012) . MV rice has expanded rapidly mainly in input-intensive and irrigation-based dry-season boro rice cultivation. As MV rice adoption highly depends on irrigation, 92 per cent of the total rice area in Bangladesh is now under MV rice as the boro season uses mostly irrigation and modern input-based rice varieties. In connection with this, Hossain *et al.* (1994) indicated that the liberalisation of input markets, such as the chemical fertiliser market, and a reduction in the tariff on imported irrigation engines also fuelled the development of a private water market as well as the adoption of MV rice in Bangladesh.

Several studies have also been carried out on the adoption of MV rice, especially with regard to factors such as farm size, human capital, household size and the availability of labour and capital (Asaduzzaman 1979; Mandal 1980; Ahmed 1981; Hossain 1988; Parikh and Andrew 1988). Contrary to the findings that small farmers have inherent disadvantages in adopting input-intensive modern varieties (Pearse 1980; Lipton and Longhurst 1989), these studies confirmed that the average farm size of Bangladesh, which was 0.61 hectare on average in 2000–01, does not have any negative influence on the adoption of modern varieties.

To achieve rice food security in Bangladesh in the long run in the face of the declining land/person ratio and near exhaustion of productivity gains derived from the green revolution (Pingali *et al.* 1997), the government of Bangladesh

considered that the widespread adoption of hybrid rice can be a useful strategy for increasing rice production (Chowdhury 2002). To continue that effort, from 1998 to 2010, a total of 75 hybrid rice varieties were released in Bangladesh with government approval, of which 60 were imported from China, five from India and one from the Philippines; four were developed by BRRI (Bangladesh Rice Research Institute); and 5 were developed by private companies (Islam *et al*., 2012; Masuduzzaman 2011). To ensure the availability of hybrid rice seeds, the government also provides assistance to NGOs and private organisations to start hybrid seed production locally. Despite the strong efforts of the government and private companies, the adoption rate of hybrid rice in Bangladesh is low. In 2005–06, nearly 4.5 per cent of the total rice area was covered by hybrid rice (Masuduzzaman 2011) and recently that increased to 6.8 per cent of the total rice area (Spielman *et al*. 2012).

Existing studies often claim that higher seed costs, a lack of management skills and inferior grain quality are the major factors limiting hybrid rice adoption (e.g., Hazra 2002; Azad *et al*. 2008; Husain *et al*. 2001; and relevant references in Spielman *et al*. 2012). These studies, however, often overlook the importance of socio-economic and agro-ecological factors and infrastructure, such as land topography, the availability of trusted seed dealers and local weather, in the adoption of hybrid rice. To ascertain the importance of socio-economic factors and infrastructure in the adoption of hybrid rice in South Asia, this study uses Bangladesh as a case.

3. Materials and methods

3.1. Data sources

This study relied on different data sets made available by the Bureau of Statistics (BBS) and Bangladesh Agricultural Research Council, under the Ministry of Agriculture of the government of Bangladesh. The household-level data on the absolute size of land owned by households, land under rice cultivation and the size of rice land under traditional and modern varieties and hybrid rice, family members, members in the family engaged in agriculture, sex of the household head, household heads depending on agricultural labour and informal loan information are taken from the Agriculture Census 2008 data sets made available by BBS.

Sub-district-level data on population density, literacy rate, percentage of population aged 7 years and above who are not attending school but are engaged in agriculture and percentage of households that are connected to electricity have been extracted from the Population and Housing Census 2011 data sets made available by BBS. Note that the use of 2011 census data to determine the adoption of hybrid and modern rice varieties in 2008 may generate a data-matching problem. However, the Population and Housing Census was actually conducted in 2010, but the data of the census started to be released only recently. Thus, within 2 years' difference, one cannot expect

a big change in electrification, population growth and literacy rate in a developing country such as Bangladesh, where, because of shortages of electricity and natural gas, the government has almost stopped electrification. These best available data are used to control for sub-district-level influences on the adoption of different rice varieties.

Sub-district-level data on the proportion of irrigated agricultural land and the total length of paved roads are collected from District Profile 2007, an online data source made available by BBS. The information on the number of government-approved seed dealers at the subdistrict level is collected from the directory of registered seed dealers, an online database made available by the Ministry of Agriculture. Data on land area at the subdistrict level that is characterised by high land and very low land are collected from Land Resources Inventory (LRI) data, an online source made available by the Bangladesh Agricultural Research Council (BARC), Ministry of Agriculture. The station-level data on total rainfall and monthly average maximum and minimum temperature in 2005 were initially collected from 33 weather stations from an online data source made available by BARC.

Importantly, although the Agriculture Census 2008 covered all of Bangladesh, BBS provides access to only 5 per cent of the entire census data sets that included 531,676 households from 200 subdistricts in 26 districts in Khulna, Rajshahi, Rangpur and Sylhet divisions. Ironically, for a number of subdistricts, however, information on irrigated agricultural land and the length of paved roads was not available in the online district profile of BBS. This paper tried to supplement the information on irrigated land and the length of paved roads by collecting data from *Banglapedia*, an online data source. Unfortunately, even in, for a number of subdistricts, there is no information on irrigated land and the length of paved roads (*Banglapedia* 2013). Therefore, we had to drop those subdistricts from our sample. Our study is thus based on 384,337 sampled households from 135 subdistricts in 25 districts in Bangladesh.

3.2. Characteristics of the sampled households by division

The first three rows of Table 1 present the distribution of the sampled 25 districts, 135 subdistricts and 384,337 households by division, and the rest of the rows show demographic and other information on the sampled households. The largest shares of the sampled subdistricts and households come from Rajshahi and Rangpur divisions. These two divisions are located in the northwest part of Bangladesh, characterised by relatively dry area compared with that of other divisions. Table 1 also shows that at least 6 per cent of the sampled households received an informal loan in 2008, when the census was conducted. As farmers need to buy seeds and inputs at the beginning of a season, later it is shown that informal loans significantly and positively affect the adoption of both hybrid and MV rice compared with traditional varieties.

Table 1 Number of districts and subdistricts sampled and demographic information on the sampled households by division

Variables	Divisions			
	Kulna	Rajshahi	Rangpur	Sylhet
No. of districts	6	8	7	4
No. of subdistricts	28	44	35	28
No. of households (000)	77.45	142.87	110.03	53.99
% Male household heads	96.5	96.5	96.0	94.5
No. of members in the family	2.81	2.72	2.83	4.01
No. of persons engaged in agriculture	0.93	0.87	0.96	0.93
% household heads depending on agricultural labour	42.0	36.5	43.0	31.6
% Received informal loan	8.1	6.5	6.7	13.8

Source: Bangladesh Bureau of Statistics. *Agriculture Census 2008*.

Table 2 presents information on landholdings and the distribution of land under different rice types at the household level by division. It shows that the size of the land allocated for total rice, high-yielding rice and hybrid rice is larger for households located in Rajshahi and Rangpur than in others, and the average size of rice farmland exceeds the average total farmland owned by households in Rangpur. This is because some part of the rice farmland in Bangladesh, particularly in Rangpur, is actually used for rice cultivation three times in a year. Consequently, the net rice area exceeds the total farmland size. The last rows of Table 2 present the percentage of households that cultivated hybrid rice in 2008. More than 15 per cent of the households in Rangpur and 13 per cent of the households in Rajshahi cultivated hybrid rice in 2008. By contrast, only 8 per cent of the households in Sylhet and 10 per cent of the households in Khulna did so. This finding supports the findings of Spielman *et al.* (2012), as they also claimed that the extent of hybrid rice cultivation is higher in Rajshahi and Rangpur than in other divisions. Spielman *et al.* (2012), however, argued that the expansion of private irrigation facilities is the major reason for the higher hybrid rice adoption rate in the northern part of Bangladesh. In this article, however, it is demonstrated that the extent of abiotic stress-prone land is also a major factor limiting the adoption of hybrid rice in other divisions, such as Sylhet and Khulna. Khulna is a coastal region, where salinity is the major abiotic stress on rice farmland in a vast area. Sylhet is a hilly division that recurrently suffers from seasonal flash floods coming from upstream India, particularly in the wet season. These abiotic stresses probably limit the adoption of hybrid rice in these areas. Table 3 supports this argument.

3.3. Some distinct features of the sampled subdistricts by division

Table 3 presents sub-district-level information on agricultural infrastructure and weather by division. It shows that Rajshahi and Rangpur have the highest proportion of irrigated rice land, the two divisions where hybrid rice

Table 2 Total land owned by the households and the distribution of land under different rice types (acres)

Variables	Divisions			
	Kulna	Rajshahi	Rangpur	Sylhet
Total land owned by the household	1.00	0.98	1.09	1.26
Land engaged in rice	0.79	0.94	1.20	1.08
% Rice land engaged in high-yielding rice	57.0	59.6	72.5	38.0
% Rice land engaged in traditional rice	32.9	27.7	17.5	50.0
% Rice land engaged in hybrid rice	10.1	12.8	10.8	11.1
% Households cultivate hybrid rice	10.0	13.0	15.1	8.0

Source: Bangladesh Bureau of Statistics. *Agriculture Census 2008*.

Table 3 Sub-district-level information on irrigation, roads and weather by division sampled

Variables	Divisions			
	Kulna	Rajshahi	Rangpur	Sylhet
% Irrigated agricultural land	47.9	72.2	73.9	43.1
Paved roads (km)	402	429	177	108
No. of registered seed dealers†	7.88	7.95	7.45	4.19
Highland (000 hectares)‡	7.75	8.20	11.09	5.97
Lowland (000 hectares)‡	0.00	0.30	0.00	2.25
Yearly total rain in 2005 (000 mm)§	1.93	2.00	2.73	3.08
Monthly average maximum temperature in 2005 (°C)§	31.43	30.91	30.04	30.56
Monthly average minimum temperature in 2005 (°C)§	21.87	21.23	20.72	20.88

Sources: Bangladesh Bureau of Statistics, BBS (2007).
†Government of Bangladesh (2013b).
‡BARC (2013b).
§BARC (2013a).

adoption is also relatively high. This demonstrates the importance of irrigation facilities for hybrid rice adoption in Bangladesh. In Sylhet, seasonal flash floods and waterlogging are the common abiotic stresses. As hybrid rice cultivation requires a substantial amount of investment in fertiliser and irrigation relative to inbred rice, farmers in the stress-prone areas might be discouraged from adopting a new technology that is costly but for which the return is risky. In the econometric estimation approach, land characteristics are included at the subdistrict level to examine how they affect the adoption of hybrid rice at the household level. The climate variables were derived from monthly data from 31 geo-referenced weather stations across Bangladesh (BARC 2013a,b). Station data were spatially interpolated to provide estimates for each subdistrict. An inverse distance weighting algorithm was used to create climate surfaces of each weather variable providing estimates on a 25-km resolution grid. These estimates were then averaged to provide climate values for each subdistrict and were then assigned to each household in its respective subdistrict. All spatial data processing and analysis were done in ArcGIS v 10.0 (Redlands, CA, USA).

Based on the assumption that farmers may make decisions on adoption and investment in a new technology based on past weather experiences, weather data for 2005 are used to explain adoption behaviour in 2008.

Table 4 presents a few other characteristics of the sampled subdistricts by division. Rajshahi and Khulna are more densely populated than others. For Rangpur and Khulna, a higher proportion of the population that is more than 7 years old and not in school is engaged in agriculture than in other divisions. The literacy rate ranges from a low of 42 per cent for Sylhet to a high of more than 50 per cent for Khulna. Less than 31 per cent of the total households at the subdistrict level in Rangpur are connected to electricity, whereas, in Rajshahi and Khulna, more than 50 per cent of the households are connected. As electricity can also be used for irrigation purposes, and as hybrid rice adoption is mainly limited within the irrigated rice ecosystem, our econometric estimation approach shows that an electricity connection significantly and positively affects hybrid rice adoption at the household level in Bangladesh.

4. Model specification and estimation

To econometrically examine how household-level characteristics and sub-district-level agricultural infrastructure and other features affect the adoption of hybrid and MV rice, the following equation is formulated and estimated:

$$Y_i = \alpha_0 + (HHC_i)\phi + (SUBDIS_j)\alpha + \sum_{d=1}^{24} \lambda_d (DD_d) + \xi \qquad (1)$$

where Y_i is a vector of dependent variables that includes a base value of 0 if a household cultivated traditional rice in 2008, a hybrid rice adoption dummy that assumes a value of 1 if a household cultivated hybrid rice in 2008 or 0 otherwise, a modern variety (MV) adoption dummy that assumes a value of 2 if a household cultivated modern high-yielding rice in 2008 or 0 otherwise, and the size of land in acres allocated to traditional, MV and hybrid rice production.

Table 4 Sub-district-level information on population density, agricultural occupation, literacy rate and electricity connection by division sampled

Variables	Divisions			
	Kulna	Rajshahi	Rangpur	Sylhet
Population density (per sq. km)	1037.53	1157.76	995.09	794.69
% Population in agriculture	77.30	74.30	78.90	73.30
Literacy rate	50.53	47.76	47.06	41.76
% Households connected to electricity	51.11	52.13	30.46	44.97

Source: Bangladesh Bureau of Statistics, BBS (2012). Population and Housing Census 2011.

Note that, according to Table 2, farmers allocate a larger share of their land to MV rice; however, they also allocate some portion of their land to traditional and hybrid rice. This means that the choice of a farmer is, therefore, which varieties to choose among different alternatives: traditional, MV and hybrid. To estimate the adoption function, the multinomial logit model is applied, for which the traditional variety is set as the base variety (0) and assigned a value of 1 if a farmer produced hybrid rice and 0 otherwise, and assigned a value of 2 if a farmer produced MV rice and 0 otherwise. A profit-maximising farmer likely decides simultaneously on how much land will be allocated to which variety. To address the simultaneity in land allocation, the seemingly unrelated regression (SUR) estimation method was applied assuming the existence of contemporaneous correlation in the error terms of equations explaining land allocation to different rice varieties. The lagrange multiplier test suggested by Breusch–Pagan was conducted to examine the validity of the application of the SUR model.

Table 5 presents the estimated functions explaining the adoption of hybrid rice (yes = 1) and MVs (yes = 2) where the base variety is traditional rice (0) and the size of land allocated to different rice varieties is in acres at the household level. Table 5 shows that, among the household-level demographic variables, the male dummy for the household head (yes = 1), number of family members, the proportion of family members engaged in agriculture, informal loan dummy (yes = 1) and the absolute size of land (acres) owned by a household positively and significantly influence the adoption of hybrid and MV rice over a traditional variety and also the allocation of land to MVs and hybrid rice. Particularly, in contrast to hybrid and MV rice, Table 5 shows that the male dummy for the household head (yes = 1) and informal loan dummy (yes = 1) negatively and significantly affect land allocation to traditional rice. This means that male-headed households and households with loan facilities allocate more land to input-intensive MVs and hybrid rice than to traditional varieties and allocate less land to low-yielding traditional rice. As the hybrid and MV seed cost is high compared with that of traditional rice seeds, and also as hybrid and MV rice are more fertiliser and irrigation dependent than traditional rice, hybrid and MV rice cultivation therefore requires more cash capital than traditional rice. As informal loan facilities can reduce a household's liquidity constraint, households with more access to informal loans are more likely to adopt hybrid and MV rice than traditional rice and also allocate a larger proportion of rice land to hybrid and MV rice. Contrasting with previous findings that state that farm size has no significant influence on the adoption of modern varieties in Bangladesh (e.g., Hossain *et al.* 2007), Table 5 shows that the total land size owned by a household significantly and positively affects the adoption of hybrid and MV rice in Bangladesh compared with traditional varieties.

Among other household-level variables, Table 5 demonstrates that household heads depending on agricultural labour are less likely to adopt hybrid and MV rice than traditional rice. This is mainly because household heads

Table 5 Estimated functions using multinomial logit and seemingly unrelated regression estimation methods to explain the probability of adoption of hybrid rice and MVs, and land allocation to traditional, modern and hybrid varieties at the household level

Estimation methods	Multinomial logit (base = grow traditional variety(0))		Seemingly unrelated regression (SUR)		
			Land size in acres		
Dependent variables	Grow hybrid rice (yes=1)	Grow modern variety (yes=2)	Traditional variety	Modern variety	Hybrid rice
A dummy for male household (yes = 1)	0.91*** (3.63)	0.34*** (14.98)	−0.02*** (−2.65)	0.24*** (20.40)	0.03*** (7.46)
No. of family members	0.11*** (10.39)	0.09*** (28.12)	0.03*** (13.19)	0.01*** (5.82)	0.003*** (4.60)
Family members in agriculture/number of family members	1.12*** (41.32)	1.06*** (63.79)	0.11*** (21.37)	0.20*** (26.29)	0.06*** (17.54)
Dummy for informal loan (yes = 1)	0.33*** (4.09)	0.23*** (16.06)	−0.02*** (−2.83)	0.06*** (7.47)	0.03*** (10.90)
Dummy for household heads depending on agricultural labour (yes = 1)	−1.02*** (−16.29)	−0.68*** (−45.05)	−0.05*** (−12.27)	−0.23*** (−32.00)	−0.05*** (−21.69)
Dummy for household heads depending on agricultural labour (yes = 1) X land size owned by household (acres)	0.01*** (25.01)	0.01*** (24.73)	0.13*** (35.93)	−0.003 (−0.74)	0.02*** (13.93)
Farmland owned by household (acres)	0.01*** (50.04)	0.01*** (59.69)	0.44*** (153.82)	0.69*** (399.40)	0.15*** (205.73)
% Agricultural land under irrigation	0.64*** (5.18)	1.08*** (52.26)	−0.07*** (−8.41)	0.41*** (40.41)	0.11*** (23.38)
Paved roads (length in kilometres)	0.01*** (5.51)	0.003*** (7.52)	−0.001*** (−3.02)	0.002*** (9.78)	0.002*** (22.93)
Population density (000 persons per sq. km)	−1.04*** (−6.18)	−0.09*** (−5.33)	0.03*** (3.88)	−0.31*** (−26.00)	−0.03*** (−7.58)
Literacy rate%	−0.02*** (−3.60)	0.02*** (27.89)	−0.003*** (−11.02)	0.01*** (12.36)	0.002*** (14.32)
% Households connected to electricity	0.003 (0.90)	−0.01*** (−9.05)	0.002*** (7.38)	0.004*** (15.05)	0.002***(14.89)
% Population engaged in agriculture	1.99*** (4.42)	1.54*** (24.33)	0.07*** (2.80)	0.69*** (20.89)	0.49*** (35.64)
No. of government-approved seed dealers	0.03*** (5.33)	−0.0001 (−0.07)	0.00001 (0.02)	0.002*** (4.95)	0.003***(15.15)
Area characterised as very high land (hectares)	−0.03*** (−5.86)	0.01*** (14.76)	0.00003 (0.13)	0.002*** (5.64)	−0.01*** (−38.00)
Area characterised as very low land (hectares)	−0.07*** (−5.36)	−0.05*** (−15.53)	−0.01*** (−12.93)	−0.02*** (−19.03)	−0.01*** (−16.38)
Yearly total rainfall in 2005 (000 mm)	−0.59*** (−5.45)	−0.92*** (−51.55)	0.12*** (19.88)	−0.28*** (−35.38)	−0.09*** (−24.11)
Monthly average maximum temperature in 2005°C	−0.91*** (−5.31)	−1.10*** (−42.97)	0.04*** (3.77)	−0.65*** (−49.83)	−0.19*** (−32.48)

Table 5 (*Continued*)

Estimation methods	Multinomial logit (base = grow traditional variety(0))		Seemingly unrelated regression (SUR)		
			Land size in acres		
Dependent variables	Grow hybrid rice (yes=1)	Grow modern variety (yes=2)	Traditional variety	Modern variety	Hybrid rice
Monthly average minimum temperature in 2005°C	1.06*** (7.43)	0.26*** (14.35)	0.03*** (4.91)	0.35*** (31.27)	0.07*** (16.86)
Inverse Mills Ratio			0.07*** (35.62)	−0.07*** (−28.53)	−0.03*** (-30.08)
Constant	−0.25 (−0.07)	25.89*** (43.71)	−2.07*** (−9.31)	10.68*** (37.10)	3.83*** (29.31)
No. of observations	384337	384337	384337	384337	384337
Pseudo R^2/R^2	0.19		0.30	0.47	0.18

Notes: Numbers in parentheses are t statistics based on standard error that allow for intragroup correlation at the household level. *Significant at the 10% level. **Significant at the 5% level. ***Significant at the 1% level. For brevity, district dummies are not included.

depending on agricultural labour are less likely to have their own land to cultivate rice and to adopt a rice variety. However, the multiplicative dummy, which is an agricultural labour household dummy multiplied by the land size owned by households, is highly positive and significant in equations explaining the adoption of hybrid and MV rice and in estimated functions explaining land allocation to traditional and hybrid rice. Thus, household heads depending on agricultural labour and with their own land are more likely to adopt both hybrid and MV rice than traditional rice. As family members are a major source of high-quality and free labour and as rice farming is a labour-intensive activity, the number of family members and the proportion of family members in agricultural activities positively and significantly affect the adoption of MV and hybrid rice compared with traditional varieties, and also land allocation to all types of rice varieties.

Among the sub-district-level variables, the length of paved roads, percentage of agricultural land under irrigation, population density per square kilometre (in thousand persons), percentage of the population engaged in agriculture and the number of government-approved registered seed dealers significantly and positively affect both the adoption of and land allocation to hybrid and MV rice. As hybrid rice is suitable only for favourable land with artificial water control through irrigation, the proportion of irrigated agricultural land and the extent of electricity facilities, which are a relatively cheap input of irrigation, positively and significantly affect the adoption and intensity of hybrid rice cultivation. As a higher proportion of people engaged in agriculture indicate more availability of agricultural labour, the percentage of the population engaged in agriculture therefore significantly and positively affects hybrid and MV rice adoption compared with traditional rice and the allocation of land to all rice varieties. Table 5 clearly demonstrates that, although the length of paved roads significantly and positively affects the adoption of hybrid and MV rice compared with traditional varieties, and land allocation to hybrid and MV rice, the length of paved roads significantly and negatively affects land allocation to traditional rice. An improved transportation system can contribute to hybrid rice adoption in two ways. First, the transportation costs of carrying seeds, inputs and products to and from the farm and nearest markets and cities tend to be lower in the presence of improved roads and highways. Second, roads and highways also enhance the flow of useful information, as farmers can easily visit government extension offices in the cities and agricultural extension workers can easily travel to and from the office to the farm. Thus, the length of paved roads at the subdistrict level positively and significantly influences the adoption of and land allocation to both hybrid and MV rice, but it negatively and significantly affects the allocation of land to traditional rice, which usually provides lower yield for households.

Table 5 also presents a contrasting but interesting finding in the case of the influence of the number of government-approved seed dealers. Table 5 shows that, although the number of government-approved registered seed dealers

significantly and positively influences the adoption of hybrid rice compared with traditional rice, and the allocation of land to both MV and hybrid rice, it does not have any significant effect on the adoption of MV rice. A supply of reliable seeds in time is critically important to hybrid rice cultivation, as households need to buy hybrid rice seeds every season. By contrast, in the case of traditional and MV rice, households can store seed grains from past years' harvests and can also purchase from neighbours and local markets. As government-approved registered seed dealers are more trustworthy than private seed dealers, the presence of government-approved registered seed dealers can influence the adoption of hybrid rice compared with traditional rice and the allocation of land to hybrid rice by a household. The positive and statistically significant coefficients of the number of government-approved registered seed dealers at the subdistrict level in the estimated functions in Table 5 reflect this fact. This supports the view of Xie and Hardy (2009), who found that the production and supply of hybrid rice seed at significant levels of quality and quantity are a challenge in the diffusion of hybrid rice.

Among the sub-district-level variables, literacy rate and the extent of very high land and very low land negatively and statistically significantly affect the adoption of and the allocation of land to hybrid rice cultivation by households compared with other varieties. It is found that people in urban areas in Bangladesh prefer long and slender, nonsticky rice grain. As the grain of hybrid rice is usually short and bold in size, it does not match middle-class, educated and urban consumers' preferences, and the adoption of hybrid rice is lower in areas where the literacy rate is higher.

The estimated functions in Table 5 demonstrate that the extent of less favoured area characterised by very high or very low land at the subdistrict level negatively and statistically significantly affects the adoption of and the allocation of land to hybrid rice compared with MVs and traditional rice varieties. Hybrid rice in Bangladesh is so far adopted only in the boro rice season, which is mostly irrigated. Artificial water control through irrigation is difficult in the case of very high land and low land. Moreover, these less favoured areas tend to be stress-prone areas, where abiotic stresses such as drought, submergence and salinity are severe. As hybrid rice is a relatively costly technology that involves a substantial amount of investment compared with inbred rice, farmers in stress-prone areas are less likely to adopt hybrid rice.

The estimated functions in Table 5 show that sub-district-level yearly total rainfall and monthly average maximum temperature (°C) in 2005 negatively and statistically significantly affected the adoption of hybrid and MV rice and the allocation of land to these varieties compared with traditional varieties. As hybrid and MV rice yield is sensitive to solar radiation and as high temperature reduces yield significantly, households in 2008 were less likely to adopt and cultivate hybrid and MV rice, whereas there was more rainfall (less sunshine) and higher temperature in 2005.

The Inverse Mills Ratio (IMR) indicates the correlation between the unobservable characteristics in the adoption of different rice varieties and the allocation of land to those varieties in outcome equations. The significant and positive IMR in the estimated functions explaining land allocation to traditional rice indicates that unobserved variables increase the probability of allocation of land to traditional varieties, and the significant and negative IMR in the estimated functions explaining land allocation to hybrid and MV rice indicates that unobserved variables decrease the probability of allocation of land to hybrid and MV rice. Table 6, on the other hand, presents the correlation matrix of residuals and the Breusch–Pagan test of independence of residuals that indicate the validity of the application of the SUR model.

5. Conclusions and policy implications

As rice is the major crop and staple food in most South and East Asian countries, to ensure rice food security and viable income for farmers, governments in these countries are encouraging farmers to adopt hybrid rice. Yet, despite strenuous government efforts, farmers' adoption rates have remained low in most of the countries except China. Although studies often claim that higher seed costs, lack of management skills and inferior grain quality are the major factors limiting hybrid rice adoption, existing studies often overlook the importance of socio-economic factors and infrastructure, such as the availability of trusted seed dealers and roads in the adoption of hybrid and MV rice. Using Bangladesh as a case, this article identifies the facilitating and limiting factors that affect hybrid and MV rice adoption and land allocation to these varieties in Bangladesh.

This article demonstrates that informal loan and irrigation facilities significantly and positively affect the adoption and allocation of rice land to hybrid and MV rice compared with traditional varieties. Most importantly, this article clearly demonstrates that a reliable source of seed supply and the extent of basic infrastructure such as paved roads positively and significantly affect a household's decision to adopt hybrid rice compared with traditional varieties and allocate land to hybrid rice cultivation. This article also demonstrates that the extent of less favoured land (represented by very high and very low land) hinders the adoption of hybrid rice; however, it has mixed effects on the adoption of and land allocation to MV rice.

Table 6 Correlation matrix of residuals

Variety	Traditional	Hybrid	Modern
Traditional	1.0000		
Hybrid	−0.1065	1.0000	
Modern	−0.4585	−0.1662	1.0000

Breusch–Pagan test of independence: $\chi^2(3) = 95760.0$, Pr = 0.

Based on the findings, this paper suggests clear policy implications for facilitating hybrid rice adoption in Bangladesh. First, it is suggested to extend more seasonal loan facilities to rice farmers to reduce the liquidity constraint at the beginning of the season, when farmers need to buy costly rice seed. It is also suggested to expand irrigation facilities in favourable areas to harness the potential of hybrid and MV rice production and to develop basic infrastructure such as roads. It is further suggested to increase trusted channels in rural areas for the timely dissemination of high-quality hybrid rice seed. A trustworthy public–private partnership might be useful in the timely dissemination of this seed to farmers in rural areas.

Finally, based on the findings, this paper suggests investing in research and development for hybrid rice, targeting less favoured stress-prone areas. The development of hybrid rice targeting these areas will not only increase yield and production from the stress-prone areas but will also directly affect the economic conditions of rice farmers, as stress-prone areas are also characterised by higher incidence of extreme poverty. International agricultural research centres should strengthen collaboration among major rice research institutes on aspects of the development of hybrid rice for stress-prone areas. Policymakers and donors are also strongly encouraged to fund the research, development and dissemination of new hybrid rice with high-quality grain, particularly suitable for the less favoured stress-prone regions.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Data S1. Description of variables included in the model.