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Adoption of Modern Varieties and Rice Varietal Diversity on Household Farms in Bangladesh

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ABSTRACT

This paper investigates the relationship between adoption of modern rice varieties and rice varietal diversity on household farms in Bangladesh. As shown in previous studies, adoption of modern varieties depends on agroecological- and input-related factors, including the availability and use of irrigation facilities, such as tubewells. Having irrigation affects the diversity index significantly and positively, which could be due to the diffusion of more modern varieties (MVs) in areas where irrigation is available and accessible.

Farmers who acquire seeds from informal sources—i.e. from their own farm or neighboring farmers—are more likely to adopt MVs. This is because there is neither a formal seed market nor a formal seed distribution system that farmers can rely on for their seeds. Almost 70 percent of the sampled farmers grow more than one variety per season. The number of varieties planted is higher in the wet season (*aman*) than in the dry season (*boro*): in the wet season, almost 90 percent of the sampled farmers grew more than one variety. Varietal diversity is higher in unfavorable areas, such as saline-affected areas. Farmers with larger landholdings are more likely to have higher levels of on-farm varietal diversity. These factors held constant, farmers who have adopted MVs are less likely to have higher levels of on-farm varietal diversity.

This empirical evidence is consistent with the hypothesis that cultivating MVs reduces rice varietal diversity, as MV adoption reduces production risk and increases income because of higher yields. Farmers value these traits, which should be considered when breeders develop new varieties. Although farmers' education was not significant in MV adoption, education is a significant determinant in rice varietal diversity in accessing information or knowledge about the traits of MVs. Educated farmers have the ability to decide which MV to grow among a wide range of choices.

Keywords: varietal diversity, adoption, modern varieties, rice, Bangladesh

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CONTENTS

1. INTRODUCTION

A number of studies have tested the relationship of variety choice to crop diversity using microeconomic models of farmer decision making and econometric analysis. Some of these studies focused on identifying the factors that affect the levels of infraspecific (i.e., between varieties of the same crop species) diversity maintained on farms and on characterizing those farmers most likely to continue managing high levels of diversity. Others looked at both interspecific (i.e., among varieties of more than one crop species) and infraspecific diversity, and compared levels of diversity at the household and community levels. The microeconometric approaches were developed in early work on Andean potatoes, Turkish wheat landraces, maize in Mexico, and rice in Nepal (Brush, Taylor, and Bellon 1992; Meng 1997; Van Dusen 2000; Van Dusen, Gauchan, and Smale 2007). Later empirical examples are collected in the volume edited by Smale (2006).

Meng (1997) studied wheat diversity in Turkey. She analyzed the probability that a household cultivates a wheat landrace on a plot as a function of household attitudes toward risk, agroecological conditions on the farm, and market access using maximum likelihood probit estimation. The diversity among traditional varieties (TVs), calculated from measurements taken on their morphological characteristics, was specified recursively as an outcome of variety choice.

Research by Bellon (1996) emphasized that farmers consider variety characteristics in choosing which variety or varieties will suit farm-specific production conditions, consumption preferences, or marketing requirements. Thus, Smale, Bellon, and Aguirre (2001) incorporated variety characteristics into the agricultural household model and empirically showed a positive relationship between consumption characteristics and on-farm diversity of maize in Mexico. Edmeades (2003) adapted Smale, Bellon, and Aguirre's model and incorporated risk aversion and transactions costs into a household decision model for bananas in Uganda. Her empirical results showed that variety attributes and transactions costs are jointly significant across the six varieties of bananas tested, and that other explanatory variables, such as household and farm characteristics, vary in significance and explanatory power for each variety.

In the case of rice production in Bangladesh, different varieties of rice respond differently to environmental conditions (climatic, pest, and agronomic) with varying yields and production risk. Often, farmers plant more than one variety to manage yield risk and meet different production constraints, such as diversity in land and soil quality and climatic conditions. Moreover, varietal diversity is influenced by demand for variety-specific attributes, such as yield and grain quality, as shown by Bose et al. (2001).[1]

Other studies of varietal diversity on household farms find that farm household characteristics and economic factors (such as income, education, other household resources like labor), agroecological factors (such as irrigated, highland, and rainfed lowland ecosystems, soil physical quality, farm size, and land fragmentation), and use of new technology (such as modern varieties [MVs]) are significant determinants in influencing farmers' decision to choose to continue cultivating diverse crop variety combinations (Benin et al. 2004; Birol, Smale, and Gyovai 2004; Brush, Taylor, and Bellon 1992; Gauchan, Van Dusen, and Smale 2005; Meng 1997; Smale, Bellon, and Aguirre 2001; Van Dusen 2000; Joshi and Bauer 2006).

Our objective in this paper is to investigate the determinants of adoption of modern rice varieties and the impact of adoption on variety diversity on household farms in Bangladesh. Studies that relate adoption of MVs to varietal diversity on farms have reported contradicting results. For example, while Brush, Taylor, and Bellon (1992) showed that use of modern varieties contributes to low levels of potato diversity on farm, Benin et al. (2004) found that adoption of modern varieties of maize and wheat had no statistically significant impact on the diversity of the maize and wheat varieties grown on household farms in Ethiopia.

The conceptual approach we use to analyze on-farm diversity is motivated by the theory of farm household model developed by Singh, Squire, and Strauss (1986) and de Janvry, Fafchamps, and Sadoulet (1991) and applied to variety choice. Variety diversity indices are expressed as outcomes of variety choice (Van Dusen 2000; Benin, Smale, and Pender 2006; Smale 2006). We use data from a household survey with a sample of 14,095 rice farmers in Bangladesh, and estimate the determinants of rice variety diversity at the household level.

Information about the factors that affect farmers' variety choices and the impact of their choices on varietal diversity is important not only for programs that are aiming to introduce new modern varieties (such as biofortified varieties of rice), but also for evidence-based policy making to develop and implement support measures for targeting and improving access and use of MVs. An understanding of farmer seed preferences, by farmer

[1] In this paper, modern varieties are defined as varieties that are genetically distinct and developed by breeders and researchers at the Bangladesh Rice Research Institute, International Rice Research Institute, and other national agricultural research systems. Traditional varieties are varieties that have been locally adaptive and selected over generations of cultivation or a hybrid first-generation cross with hybrid vigor traditional varieties.

typology, can guide breeders and agricultural researchers as they work to develop modern rice varieties with high levels of micronutrients (such as zinc and vitamin A).

The next section describes the data used and the profiles of the sampled farm households, and includes an inventory of different varieties grown by farmers in *aman* and *boro* seasons. Section III discusses the methodology to determine factors that explain varietal diversification on household farms. The conceptual framework is based on the household farm utility maximization theory, whereby a household's decision on choice of variety is determined by the inputs and technology used, and the farm's agroecological characteristics and physical conditions. We establish a causal link between variety choice decisions and farm, household, and agroecological characteristics using an instrumental variable method. Section IV discusses empirical findings in detail, and section V provides conclusions and some policy implications.

2. DATA

The analysis of this paper makes use of household survey data collected by the International Rice Research Institute in collaboration with the Department of Agricultural Extension (DAE) in Bangladesh in 2005.

Sampling was done using multi-stage random sampling. In the first stage of sampling, 100 blocks were randomly selected from each of the six regions (a total of 600 blocks from six regions composed of 64 sample districts). In the second stage, three villages were randomly selected from each block (1,800 villages), and from each village eight farmers were selected by stratified random sampling. The total number of sample farm households interviewed was 14,095.

The sampled farm households are not representative of Bangladeshi rice farmers, when their land-size distribution is compared with the distribution of land size obtained from the 1996 National Agricultural Census (Table 1). This is because, unlike the 1996 National Agricultural Census, our sample frame did not include landless farm households (landless farmers are farmers cultivating other people's land); it only included owner and tenant farmers (where tenant farmers are farmers cultivating land that they leased). As a result, in our sample, the marginal farms are underrepresented and larger farms are overrepresented, as shown in Table 1. Therefore, it should be noted that findings that vary with farm size, such as sources of information of improved varieties and sources of seeds, would be biased toward large farms (>1 hectare [ha]).

Table 1. Representativeness of the sample farmers compared with the 1996 National Agricultural Census of Bangladesh

Farm size (ha)	2005 survey (%)	1996 Census (%)
Up to 0.2	5	28
0.2 to 0.4	18	21
0.4 to 1.0	37	31
1.0 to 2.0	27	13
2.0 to 3.0	10	4
3.0 and higher	3	3
Total	**100**	**100**

Source: Authors' survey

Structured questionnaires were used in conducting the survey. Among the information collected were (1) environmental and physical characteristics of the survey areas; (2) socioeconomic characteristics of the sample farmers; (3) rice varieties cultivated, sources of seeds, and sources of information about new varieties; and (4) irrigation and fertilizer use. In particular, questions related to the most preferred traits and sources of variety information were asked about two of the most popular modern varieties, BRRIdhan (BR)-29 and BR-28, and on two most popular TVs.[2]

However, this large dataset has some limitations. First, information on preferred variety traits, rate of adoption, and source of information about improved varieties was limited to the two most popular varieties. Second, information on important factors related to market access, such as distance to sources of inputs (seeds, fertilizer), rate of seed replacement, cost of production, diversification to other crops, and mapping of sources of information about a new variety, was not available. Despite these shortcomings, data collected in this study are unique, as they record farm-level information on rice varieties and on rice varietal diversification, and cover different production

[2] Information on the most popular varieties is based on a previous survey, namely the International Rice Research Institute–Bangladesh Institute of Development Studies (IRRI-BIDS) survey, conducted in 2000. This survey also collected data on specific rice varieties grown in different parcels of land operated by the sample farmers. The results of that survey show that in Bangladesh the most popular modern rice varieties grown during the wet season were BRRIdhan-11 (BR-11) (42%), Swarna (23%), and Paijam (13%). For the dry season, the most popular varieties were BR-28 (11%), BR-29 (9%), BR-14 (11%), BR-1 (7%), and BR-8 (6%).

environments and topography nationwide. The large proportion of rice producers who are also rice consumers can be targeted for adoption of new MVs improved with favorable traits, such as high-yielding and biofortified nutrient-rich varieties.

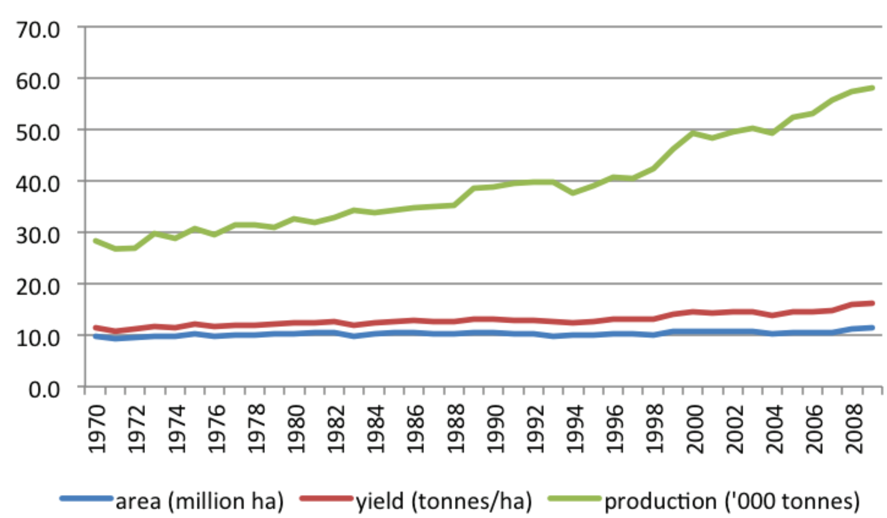
3. DESCRIPTIVE ANALYSIS

In Bangladesh, farmers started cultivating MVs as early as the 1960s with the introduction of Paijam (known as Mashuri in India) in the *aman* season and Purbachi in the *boro* season.[3] The adoption of MVs increased particularly in the mid-1980s and 1990s, due to their superior agronomic traits (higher yields, higher disease and pest resistance, shorter maturity periods, and better grain quality) compared with several of the TVs (Hossain et al. 1994). The ever-increasing MV adoption rates in the mid-1980s coincided with the changes in policies in favor of privatization in the procurement and distribution of small-scale irrigation equipment and chemical fertilizers, trade liberalization, and tariff reduction for imported agricultural equipment (Hossain 1996).

With the diffusion of modern rice varieties, it was expected that farmers would specialize in fewer varieties, whose traits would contribute to the reduction of production risk and improvement of farm income as a result of their higher yields, improved resistance to pest and diseases, and better grain quality. Consequently, TVs might be displaced as the area planted for MVs increased, and so diversity would decrease. However, despite the diffusion of MVs in Bangladesh, rice varieties at the farm level are considerably diverse (Hossain, Bose, and Mustafi 2006). This is possible if farmers attach a high value to maintaining TVs and if they keep on experimenting with new varieties. Thus, farmers are not proficient or effective in using MVs, so the diversity of varieties will remain.

3.1 Description of survey area

Bangladesh has made notable progress in increasing its rice production over the last four decades, despite its extreme scarcity of land resources. Rice area increased marginally from 9.9 million ha in 1970 to 11.4 million ha in 2009 (see Figure 1), but production almost tripled from 16,900 to 42,000 tons over this period. The progress is particularly remarkable starting in the late 1980s when the growth in the volume of rice production increased from 2.2 percent during 1970–1990 to 2.6 percent during 1991–2009. This increase in rice production was driven by increases in yield (with the yield growth rate increasing from 2.5 to 3.2 percent during the same periods, respectively) due to technological progress (i.e., rapid diffusion of high-yielding MVs fueled by private-sector investment in irrigation) (Hossain and Deb 2010).



Source: FAOSTAT 2011

Figure 1. Trends in area, production, and yield of rice (paddy) in Bangladesh, 1971–2009

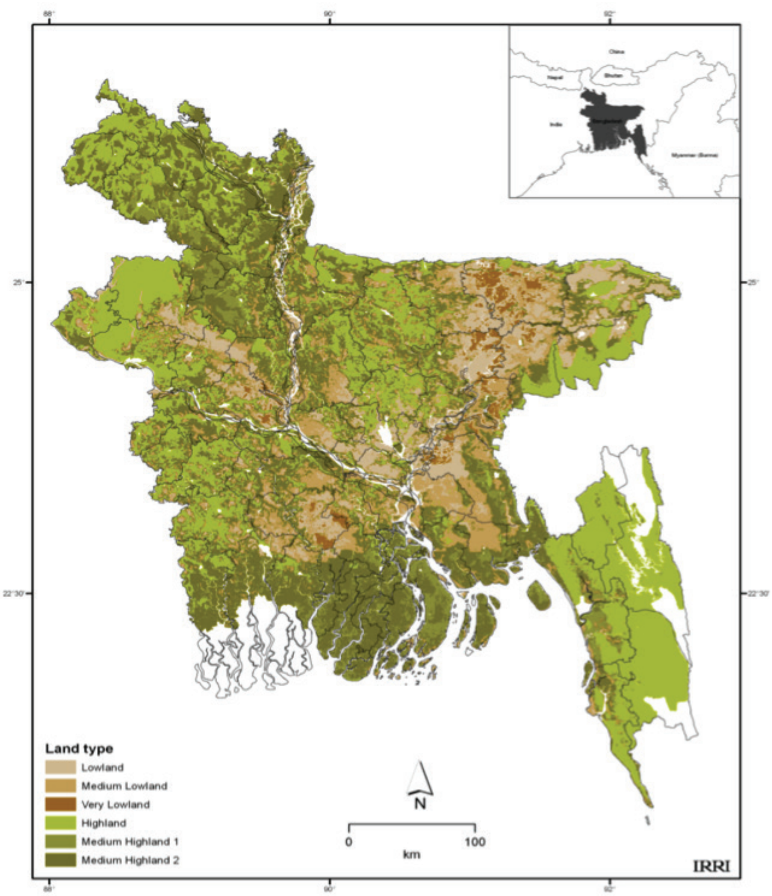
[3] *Aman* is monsoon rice that is usually planted in April–May and harvested in November–December. *Boro* is irrigated rice that is usually planted in December-February and harvested in April-May. *Aman* is also the name for the wet season, and *boro* is the name for the dry season.

In terms of physical characteristics of the regions covered in this study, 19 percent of the total sample farm area is in the lowland areas (land flooded from 30 to 90 centimeters [cm] deep), where crop (rice) damage due to excessive rainfall occasionally occurs (Figure 2). About 75 percent of the study area is in medium-elevation land areas (land flooded up to 30 cm deep), where crops are not normally damaged by flood (Chitaggong and Dhaka). The areas under very low elevations (land flooded more than 90 cm deep) composed about 1 percent of the sample and were most frequently affected by floods. Highlands, which are never flooded (Rajshahi), constituted about 5 percent of the study areas (Figure 2). Most of the sampled areas (59 percent) were located in environments favorable for crop production, while unfavorable production environments were located in flood-prone areas (29 percent, mostly in Sylhet and Rajshahi) and drought-prone and saline areas (11 percent, mostly in Khulna and Barisal).

There are three overlapping seasons for growing rice in Bangladesh: *aman*, *aus*, and *boro*. *Aman* is the main rice crop harvested in November–December. Two methods are commonly used in planting rice. One is labor-intensive transplanting, which involves replanting of seedlings from nurseries to puddle soils. The other one, which involves sowing seeds directly in the soil, requires less labor and a shorter duration, and thus reduces labor costs.

On shallow flooding land, *aman* is transplanted with shorter-duration varieties, but on deep-flooded land, *aman* is directly seeded as an upland crop from March to May. Then the plant grows with floodwater from June to September, and is harvested in November after the floodwater recedes. *Boro* is mostly transplanted in January–February and harvested in May–June. It used to be grown in very low land (not suitable for growing any crop during the monsoon season), transplanted in November after the floodwater recedes, and harvested in April–May. However, with the spread of groundwater irrigation, the area for *boro* has expanded to all land types. *Aus* is known as a short-duration, drought-resistant cropping season variety that is mostly directly seeded during March–April and harvested in July–August. The rice area for *aus* has declined dramatically as farmers shifted the land to vegetables or *boro*.

Since *aus* and *boro* are overlapping seasons, in this paper we have classified the seasons into two: wet (monsoon rice called *aman*) and dry (irrigated rice called *boro* and *aus*) (Hossain, Bose, and Mustafi 2006; Hossain and Deb 2010).



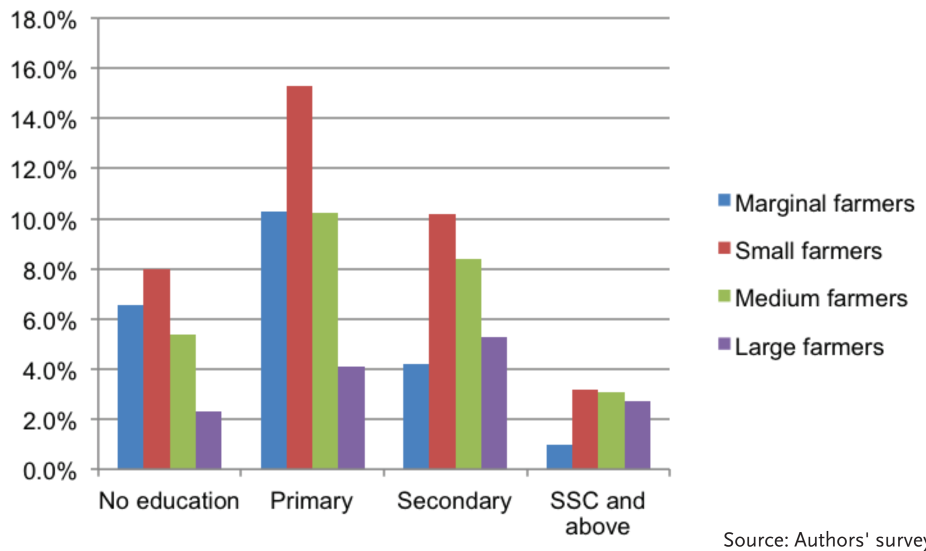
Source: Geographic Information System, International Rice Research Institute

Figure 2. Regional differences by land elevation, Bangladesh

3.2 Socioeconomic characteristics of sample farmers

3.2.1 Educational attainment of the sample farmers

In terms of educational attainment, about 40 percent of the sample farmers completed primary education, 28 percent finished secondary level, and 10 percent completed vocational, higher secondary, and tertiary education (Figure 3). Farmers with large farms attained higher levels of education (56 percent have reached the secondary and higher levels), compared with small-scale and marginal farmers (78 percent and 96 percent have finished the primary level, respectively).



Source: Authors' survey

Figure 3. Distribution of level of educational attainment by size of farmers

3.2.2 Farm Size

In terms of landholding size, about 64 percent of the sampled farm households were small-scale farmers (with 0.4–1.0 ha of land) and medium-scale farmers (with 1–2 ha of land), 22 percent were marginal farmers (with less than 0.4 ha of land), and 14 percent were large-scale farmers (with more than 2 ha of land). Table 2 shows the distribution of area owned by sampled farmers for each region. Across regions, farmers from Sylhet seem to own more land than farmers from other regions for each farm size group, except the marginal group, where Dhaka farmers own more land (mean differences are highly significant across regions based on t-tests). Marginal farmers own land averaging 0.23 ha, ranging from 0.19 to 0.28 ha on average. Small and marginal farmers are either subsistence farmers or deficit farmers who consume 75 percent of their harvest, while large farmers consume only 4 percent of their harvest. Therefore, a large proportion of households can be targeted for biofortified rice produced on their own farms.

Table 2. Landholdings related to crop/rice production activities, by region

Region	Marginal (<0.4 ha) (N=3,096)		Small (0.4–1.0 ha) (N=5,155)		Medium(1–2 ha) (N=3,817)		Large (>2 ha) (N=2,027)		All (N=14,095)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std dev.	Mean	Std dev.	Mean	Std. dev.
Rajshahi	0.24	0.22	0.53	0.36	1.17	0.57	3.01	1.67	1.21	1.31
Dhaka	0.28	0.43	0.55	0.41	1.13	0.70	3.08	2.52	1.08	1.43
Khulna	0.19	0.19	0.51	0.39	1.09	0.82	2.83	2.02	1.10	1.37
Barisal	0.19	0.13	0.49	0.34	1.06	1.48	2.66	1.78	1.13	1.50
Chittagong	0.23	0.17	0.53	0.38	1.13	0.65	2.64	1.82	1.00	1.16
All	0.23	0.25	0.54	0.41	1.13	0.89	2.95	2.31	1.13	1.47

Table 3 shows the percentage of farmers adopting MVs and TVs. The proportion of marginal and small farmers adopting MVs is significantly higher compared with large farmers in both *boro* and *aman* seasons (with t-test values ranging between 3.63 and 6.13).

Table 3. Proportion of farmers cultivating MVs and TVs by size of farms

Landholding	*Aman*		*Boro*	
	MV	TV	MV	TV
Marginal (<0.4 ha)	74.4%	25.6%	84.3%	11.6%
Small (0.4–1.0 ha)	70.9%	28.9%	82.9%	12.3%
Medium (1–2 ha)	68.2%	31.5%	79.7%	14.6%
Large (>2 ha)	66.0%	33.7%	77.4%	17.9%
Total	**70.1%**	**29.7%**	**81.5%**	**13.6%**

Source: Author's survey.

3.2.3 Tenancy

The average farm size of rented land per household is 0.3 ha (Table 4). Rented land is about 32 percent of the cultivated area, and the average incidence of tenancy is 49 percent, composed mostly of farmers with marginal and small land areas.

Table 4. Percentage of area under ownership and tenancy status by size of farms

Farm sizes	Tenant (share-cropped) (%)	Average area under tenancy (ha)	Owner (%)	Average area owned (ha)
Marginal (<0.4 ha)	15%	0.15	17%	0.22
Small (0.4–1.0 ha)	18%	0.23	33%	0.56
Medium (1–2 ha)	13%	0.43	25%	1.18
Large (>2 ha)	3%	0.47	14%	2.73
Total	49%	0.30	89%	0.98

Source: Author's survey.

3.2.4 Number of Rice Varieties Grown

Based on the household survey, 670 unique rice varieties were reported by the sample farmers, which indicates a considerable diversity of rice varieties within the six regions surveyed. During the dry (*boro*) season, 417 varieties are grown, covering 52 percent of cultivated rice land per crop year (Table 5). The most popular variety during this season is BRRIdhan 29 (BR-29), accounting for 37 percent of the *boro* area. BR-29 is heavily concentrated in the middle part of Bangladesh, which is mostly planted in irrigated and favorable rainfed areas.[4] Released in 1994, BR-29 belongs to the third generation of MVs, developed in the 1990s by the Bangladesh Rice Research Institute (BRRI). Third-generation MVs produced plants that are shorter in height than previous generations of MVs and have higher yield potential than the first-generation MVs (Hossain, Bose, and Mustafi 2006). The sampled households indicated an average yield of 6.1 tons/ha for BR-29, which is the highest yielding of all MVs reported. According to farmers, the top three reasons for choosing BR-29 are high yield (46 percent), good taste (24 percent), and lodging resistance (23 percent).[5]

[4] Data on the percentage of area cultivated with a rice variety, such as BR-29, were taken from the parcel-level data on area of rice reported by farmers. To get the district-level data on the proportion of area under a specific variety, for both *aman* and *boro* the total area cultivated with a certain variety across sample households is calculated and then divided by the total area cultivated with rice by district (the total number of sample districts is 64, which covered all 64 districts in Bangladesh). For example, in district 1 in Rajshahi, the total area cultivated with rice is 341 ha. The total area planted with BR-29 in district 1 is 15 ha; hence, the proportion of area planted with BR-29 in district 1 is 4.4 percent.

[5] The percentages in parentheses represent the proportion of sample households that stated their most preferred traits for BR-29. For example, 46 percent of the total sample stated that they prefer BR-29 because of its high yield.

Table 5. Number of varieties named by sample farmers by season

Season	No. of rice varieties	Top 3 most popular MVs (yield/ha)	Share of area (%)	Share of production (%)
Wet: *Aman* (July–December)	523	BR-11 (4.4 tons/ha) Swarna (4.0 tons/ha) Paijam (3.5 tons/ha)	48	38
Dry: *Boro* (November–May) *Aus* (March–August)	417	BR-29 (6.7 tons/ha) BR-28 (5.3 tons/ha) BR-14 (5.6 tons/ha) BR-16 (5.8 tons/ha)	52	62
All	**674**	**BR-29, BR-28, BR-11**	**100**	**100**

Source: Author's survey.

The second-most popular variety in the *boro* season is BR-28, also released in 1994, accounting for 23 percent of the *boro* area. Yielding 5.1 tons per ha on average, BR-28 is concentrated in highland areas (particularly in the northwestern and southeastern regions) and also in drought-prone environments (coastal districts in the southwestern regions). BR-28 is also popular among farmers because of its high yield (28 percent), good taste (20 percent), and early maturation (13 percent).[6]

These two popular varieties accounted for 49 percent of the area planted in the dry season. Hybrids are also grown during the dry season, yielding as high as 7.0–7.5 tons per ha. The most popular hybrids are Hira and Hagoron, which cover only 2.6 percent of the *boro* rice area. A list of the top 50 varieties grown during the *boro* season is found in Appendix Table A.1.

About 523 TVs (40 percent) and MVs (60 percent) were reported to be grown in the wet season (*aman* monsoon rice), covering 48 percent of area cultivated with rice (Table 5). The most dominant varieties grown in the *aman* season reported by farmers are BR-11 and Swarna. (The top 50 varieties is listed in Appendix Table A.2.) About 27 percent of the *aman* area is planted with BR-11, mostly in highland and drought-prone areas, and some in flood-prone and medium lowland areas, and is highly concentrated in the northwestern regions of Bangladesh. BR-11 was first released in 1980 by BRRI, and became the highest-yielding variety in the *aman* season, averaging 3.9 tons/ha.

MVs developed in the 1980s had improved resistance to pests and diseases and better grain quality compared with the first generation of MVs, released in the 1970s. The first generation of MVs was high yielding, but had low pest resistance (Hossain, Bose, and Mustafi 2006). Several MVs were released after 1980, but none of them surpassed BR-11's yield potential in the *aman* season (Bose, and Mustafi 2006). Swarna, which was developed in 1982 in Andhra Pradesh, India, is concentrated in Rajshahi and in the highlands near the borders of the eastern part of West Bengal, India. Swarna is early maturing and produces good-quality grain, but it is highly susceptible to the sheath blight disease (Hossain Bose, and Mustafi 2006). About 12 percent of the *aman* area is planted with Swarna, which yields an average of 3.8 tons/ha.

It was also found that farmers grow a higher number of different MVs than TVs for both seasons and across regions, except during the dry season in Barisal (Table 6). The difference in the number of MVs versus TVs also depends on the ecosystem. For example, in favorable areas, farmers grow a higher number of MVs, which have been developed for these areas. In unfavorable areas—for example, in the saline-affected areas—fewer numbers of MVs are grown, since salinity in soil is still a constraint to MV adoption, and an MV suitable for such areas is yet to be developed.

The average number of rice varieties grown by farmers sampled is four. As shown in Table 7, two-thirds (66 percent) of the sampled farmers grow more than one variety, with the number of varieties ranging from two to four (a maximum of ten varieties per household per season), which indicates considerable diversity at the household farm level.

In the process of deciding whether to adopt new varieties,

[6] The percentages in parentheses are the proportion of sample households that stated their most preferred traits for BR-28. For example, 28 percent of the total sample stated a preference for BR-28 because of its high yield.

Table 6. Average number of traditional varieties (TVs) and modern varieties (MVs) cultivated by sample farmers for each season, by region and by ecosystem

Variable	Type of measure	Wet season (*aman*)		T-test	Dry season (*boro*)		T-test
		MV	TV		MV	TV	
Region							
Rajshahi	Mean	3.9	1.6	5.54***	3.8	1.8	28.77***
	Std. dev.	1.5	1.2		1.5	1.4	
Dhaka	Mean	3.9	2.1	5.80***	3.2	2.5	9.52***
	Std. dev.	1.4	1.4		1.6	1.7	
Sylhet	Mean	4.4	2.6	2.74***	3.6	2.7	13.55***
	Std. dev.	2.2	1.4		2.1	1.5	
Khulna	Mean	3.6	2.5	9.07***	3.6	1.7	19.71***
	Std. dev.	1.6	1.3		1.6	1.1	
Barisal	Mean	3.6	4.0	14.21	3.0	3.8	18.30***
	Std. dev.	1.7	1.8		1.7	1.9	
Chittagong	Mean	4.1	2.7	3.45	4.0	2.7	15.49***
	Std. dev.	1.8	1.5		1.8	1.6	
Bangladesh	Mean	3.9	3.1	12.77	3.5	2.9	11.71***
	Std. dev.	1.7	1.8		1.8	1.8	
Ecosystem							
Flood prone	Mean	1.8	1.9	2.71***	2.3	2.2	4.88***
	Std. dev.	0.9	1.2		1.1	1.3	
Drought prone	Mean	1.8	2.0	3.63***	2.2	2.1	3.00***
	Std. dev.	0.9	1.2		1.0	1.3	
Salt affected	Mean	2.4	2.7	3.87***	2.3	2.4	0.67
	Std. dev.	1.1	1.3		1.3	1.0	
Favorable	Mean	2.9	2.2	10.23***	2.3	2.2	10.77***
	Std. dev.	0.9	1.3		1.0	1.3	
Bangladesh	Mean	1.9	2.2	12.77***	2.3	2.2	11.71***
	Std. dev.	0.9	1.3		1.0	1.3	

Source: Authors' calculation.

Table 7. Proportion (%) of household farms cultivating one or more varieties by season in Bangladesh

Number of varieties	*Aman*	*Boro*	All
One	12.0%	17.5%	14.8%
Two	28.3%	35.6%	32.0%
Three	25.5%	26.4%	26.0%
Four	16.4%	13.2%	14.8%
More than four	17.8%	7.3%	12.5%
Total	**100.0%**	**100.0%**	**100.0%**

Source: Authors' calculation.

the source of information about the variety is important (Hossain et al. 1994). Taking the case of BR-29, the main source of information is the DAE field staff. However, as shown in Table 8, the field staff is biased in favor of large farmers. Other farmers are also an important source of information, particularly on the performance of a new variety (Hossain et al. 2003b). Other farmers include neighbors or extended family members who first experiment with a new variety and pass the information on to their social networks. Interestingly, the role of radio and television in spreading information about a new variety remains limited. Similarly, fertilizer dealers (where 97.6 percent of the sampled farmers use fertilizer) are not cited as an important source of information about new varieties.

Table 8. Sources of information about a modern variety (% of households)

Information source	Small farmer	Medium farmer	Large farmer	All cases
Dept. of Agricultural Extension staff	58.1	57.8	69.6	57.8
Other farmers	28.4	26.1	16.6	27.6
Radio	1.5	1.9	1.2	1.6
Television	2	1.6	2.1	1.9
Fertilizer dealer	2.5	3.8	3.2	3.2
Relatives and friends	5.6	7.6	5.6	6.2
Others	1.8	1.2	1.8	1.6

Source: Authors' survey.

4. METHODOLOGY

As stated in the introduction, this paper attempts to investigate the determinants of adoption of modern rice varieties and the impact of adoption of MVs on variety diversity on household farms in Bangladesh. The decision to adopt may be determined by unobservable variables that may also affect variety diversity, and that the choice of adopting MVs is not voluntary and may be based on individual self-selection. Unobservable characteristics of farmers and their farms may affect both the adoption decision and variety choices, resulting in inconsistent estimates of adoption.

To account for this endogeneity problem, we can use either the control function approach (Smale and Mason 2012), or an instrumental regression technique that assumes a joint normal error distribution (Di Falco et al. 2011). The control function approach is not applicable, since binary regressors are specified in the model. Hence, we use the instrumental regression approach, which is applied in two stages.

In the first stage, the model for adoption of MVs is estimated (where MV adoption is binary and suspected as an endogenous variable). In the second stage, we use the predicted MV adoption values to estimate the impact of adoption of MVs on variety diversity index using quantile regression to account for censoring of the diversity index. We use the quantile regression approach to see whether the variables have significantly different effects at other points of the distribution of the variety diversity index than at the mean of the distribution of the index. It takes into account censoring and endogeneity problems and heterogeneity effects across the distribution of the variety diversity index.

4.1 Estimating the determinants of varietal diversity

The conceptual approach to a farmer's choice is based on the theory of the household farm (Singh, Squire, and Strauss 1986; de Janvry, Fafchamps, and Sadoulet 1991). In terms of estimating the determinants of diversity, we follow the general approach on crop diversity developed by Brush, Taylor, and Bellon (1992); Meng (1997); Van Dusen and Taylor (2005); Birol, Smale, and Gyovai (2004); Benin et al. (2004); and Smale (2006).

We assume that household decisions on consumption and production are made jointly when markets for labor and other inputs or product markets are imperfect (or missing). The main basis of this assumption is that the majority of the sample farms are marginal and small farms, whose production decisions about inputs and labor depend on household preferences and income. Households face shadow prices for inputs that lie somewhere between the consumption and production price, and are influenced by access to markets and by the household characteristics that affect access to markets. Farm productivity depends also on agroecological conditions. Variety choices are derived from the household's optimal choice over the levels of goods produced and consumed on the farm. Varietal diversity indices are metrics constructed over the outcomes of variety choices.

The farmer's choice of rice variety may be determined by production, which is determined by the quantity of inputs applied; technology (e.g., adoption of MV, irrigation); transaction costs in seed markets; farmer characteristics; and agroecological characteristics of the farm (or physical environment of the farm—e.g., soil type, land elevation). For this study, the data that were collected did not contain information on market characteristics, such as price of seeds and distance to seed markets; however, the data collected on sources of seeds can be used as indicators of different transactions costs and seed prices in the markets.

4.2 Estimation Procedures

4.2.1 Diversity Index

We use two diversity indices, the Simpson and Shannon indices, as quantitative indicators of varietal diversity in different production systems. These two indices are the most common indices used to explain variations in spatial diversity (see introduction in Smale (2006) for detailed explanation of these indices). The Simpson and Shannon indices combine the richness of species with a measure of their relative abundance. They are called non-parametric indices because they account for the distributions of varieties without making assumptions about their shape.

Also known as the Varietal Diversity Index (VDI), the **Simpson index** measures the number of varieties cultivated over the sample area (or the richness). It is defined as 1 minus the sum of squares of the proportional area planted to each variety. It is calculated as:

$$VDI = 1 - \sum_j (\alpha_{ij}/A_i)^2 \quad (1)$$

where α_{ij} is the area planted to the j[th] variety by the i[th] farmer and A_i is the total rice area planted by the i[th] farmer. The value of the index is between 0 and 1—i.e., it is 0 if a farmer grows only one variety, and approaches 1 as the level of diversity increases (which means the area shares decrease). So if there are j varieties, the VDI falls between 0 and 1—1/j.

Area share planted to variety j, $\frac{\alpha_{ij}}{A_i}$, is treated as a single observation, which represents the proportion of land area that a household allocates to a variety. Large-area shares imply fewer rice varieties and less varietal diversity, while small-area shares imply more varieties grown.

The **Shannon index** measures the richness and abundance of the supply of characteristics that distinguish each rice variety from one another (or the relative uniformity of the frequency distribution across varieties).

$$SI = -\sum\left(\frac{\alpha_{ij}}{A_i}\right) ln\left(\frac{\alpha_{ij}}{A_i}\right) \quad (2)$$

Following Van Dusen and Taylor (2005), Benin et al. (2004), and Gebremedhin, Smale, and Pender (2006), we estimate varietal diversity indices (denoted as D^k) as a function of household and farm characteristics (as listed in Table 3), including the farmer's education, the rice farm area cultivated, irrigation, and the physical environment in which rice is grown (denoted as x_{ij}); dummy variable for adoption of modern varieties (denoted by z_{ij}, = 1 if adopting MV, = 0 otherwise); district fixed effects (ξ_k^i); and the unobserved error term (ϵ). The fixed effects control for unobserved differences among districts in agroecological conditions and the overall state of farming technology. The β is a vector of parameters to be estimated, and γ is an MV effect parameter also to be estimated.

The general structure of the regression equations to be estimated is given by:

$$D_i^k = \alpha_i + \beta^k x_{ij} + \gamma_i^k z_{ij} + \xi_i^k + \epsilon_i^k \quad (3)$$

However, the variable for adoption of modern varieties (denoted by z_{ij}, = 1 if adopting MV) is endogenous, so estimating equation (3) by a standard ordinary least squares (OLS) resulted in biased and inconsistent estimates (Greene 2003; Wooldridge 2003).

We estimate equation (3) using a two-stage instrumental variable model that accounts and tests for endogeneity or self-selection bias when the suspected endogenous variable is binary, such as adoption of MVs (Smith and Blundell 1986; Newey 1987).

Equation (4) represents the first-stage probit regression or adoption equation, and is estimated with robust standard errors (Huber-White):

$$z_{ij}^k = \beta_0 + \beta_i^k x_{ij} + \mu_{ij}^k \quad (4)$$

The residual from the first stage is used as an explanatory variable in the second stage of the model.

The endogeneity test is the statistical significance of the coefficient of the residual, with bootstrapped standard errors. The quality of our instrumental variables is tested using an F-test and a weak instrument robust test. In the case of the former, if the F-test is greater than 10, we reject the weak instrument hypothesis (Stock and Staiger 1997). For the weak instrument robust test, we test for exogeneity, estimate confidence sets, compare the test with the Wald test, and perform an over-identification test of the model.

In the second stage, the censored variable for rice varietal diversity is regressed against the same set of explanatory variables, excluding the binary variable, and adoption of MVs. The second stage is estimated using quantile regression (bsqreg command in Stata), Tobit, and bootstrapped standard errors (up to 50 iterations). Marginal effects are also computed for all equations.

4.2.2 Variables used to instrument the choice of modern variety

We hypothesize that farmers owning larger landholdings (landfarm4 [>2 ha]) are positively associated with the likelihood of adopting modern varieties to ensure high yield. Large-scale farmers may be able to dedicate some proportion of land to testing new varieties, or may face lower information costs relative to small-scale farmers due to economies of scale (Feder, Just, and Zilberman 1985; Lipton and Longhurst 1989).

Educational attainment of farmers (edu; edu2), measured as the number of years of completed schooling, reduces uncertainty regarding information about new technology, such that more educated farmers may choose to adopt MVs than less educated farmers (Leathers and Smale 1991; Feder and Umali 1993). During the latter phase of MV diffusion, education is not an important determinant of MV adoption (Otsuka and Gascon 1990; David and Otsuka 1990; Ramasamy, Paramisivam, and Otsuka 1992; Hossain et al. 1994).

The land tenure status of the farmer is used as a proxy for socioeconomic status—i.e., farmers cultivating rented land will have less access to financial resources to finance new technology. We hypothesize that tenant status (measured as the proportion of rented land cultivated to total cultivated land) (tenure_shri=share cropped in; tenure_morti=mortgaged in) is not an impediment in the adoption of MVs, and could have either a positive or a negative effect on MV adoption (Hossain et al.1994; Hossain, Janaiah, and Husain 2003a; Knox McCulloch, Meinzen-Dick, and Hazell 1998).[7]

We also include land types as variables that would affect the choice of adopting MVs. Elevation of land (high land [dumhland], medium [base], low land [dumlland], and very low land [dumvlland]), is represented by dummy variables. For *boro* and *aman* taken together, adoption of MVs is expected to be highest on medium-high land, followed by high land and very low land. During *boro*, MV adoption is highest on very low and medium-high land, because of the availability of surface water and groundwater irrigation. During *aman*, MV adoption varies directly with the elevation of land (Hossain et al. 1994).

Environmental characteristics are also represented by dummy variables for flood-prone (floodpro), drought-prone (droughtp), saline (dumsln), and favorable (base) conditions. It is hypothesized that greater heterogeneity in farm conditions will increase adoption of MVs (Marshall and Brown 1975; Van Dusen 2000). The most unfavorable environment for MVs is drought-prone areas, while a favorable environment (with better soil and water availability) increases the expected utility of income from MV production, and thus increases the probability that a farmer will adopt MVs (Feder, Just, and Zilberman 1985).

Irrigation is likely to influence the probability of adoption, since it is one of the necessary inputs to grow MVs. The proportion of area irrigated (with low-lift pumps [irhired4] and shallow and deep tubewells [irhired3]) to total cultivated land is likely to increase adoption of MVs. Irrigation allows farmers to overcome environmental constraints, such as inadequate rainfall in high elevated lands, and hence has a positive effect on MV adoption. Irrigation may decrease diversity, since yield variability is reduced through uniform moisture conditions

Sources of seeds, such as farmers' own harvests (seedmvbras1), government agencies (Bangladesh Agricultural Development Corporation [BADC]/DAE) as the base, other farmers (seedmvbras2=neighbors), and seed traders (seedmvbras3), are used as a proxy for market access and are represented by dummy variables. There is still an absence of good seed markets in Bangladesh. The seeds planted are obtained from farmers' own harvests or are exchanged among neighbors.

Administrative locations, such as districts, are included as district dummy variables to capture the physical environment or the spatial heterogeneity and the unobserved technological progress in rice production across districts.

4.2.3 Variables used to estimate the determinants of varietal diversity

We hypothesize that farmers with larger landholdings

[7] Sharecropping is a common tenancy arrangement in Bangladesh, where the tenant pays 50 percent of the gross produce as rent to the landowner; the landowner may share 50 percent of the cost of fertilizer and irrigation, but the tenant bears much of the input costs (Hossain 1988). Mortgage-in, on the other hand, is a formal tenancy arrangement, where the tenant pays a fixed rent to the landowner.

(>2ha) own and cultivate the land (same as if tenure status is owned). While these farmers are wealthy and have the ability to partition a single land area into different cropping systems to grow both MVs and TVs (Brush, Taylor, and Bellon 1992), they may be less risk averse and thus may lack incentives to grow more varieties to reduce the risk of poor harvests.

The educational attainment of farmers, measured as the number of years of completed schooling, is expected to affect varietal diversity. Higher education may increase farmers' ability to process information and test a number of varieties, or may be associated with specific MVs or TVs.

Environmental characteristics are also represented by dummy variables for flood-prone, drought-prone, saline, and favorable (base) conditions. It is hypothesized that greater heterogeneity in farm conditions or unfavorable conditions (such as saline-affected and drought-prone areas) will increase diversity. Land elevation, such as high land, low land, and very low land, will affect diversity.

Access to irrigation, including low-lift pumps shallow and deep tubewells, may decrease diversity, since yield variability is reduced through uniform moisture conditions.

Sources of seeds may represent different prices and transaction costs. It is hypothesized that dependency on formal seed sources (BADC/DAE) reduces varietal diversity, while dependency on informal sources (own harvest, other farmers) will increase diversity.

Cultivation of MV rice varieties represented by a dummy variable (= 1 if cultivating MV, = 0 otherwise) is expected to decrease varietal diversity, since MVs have higher yields than TVs.

District dummies are again included to capture the physical and cultural environments of the districts.

5. RESULTS

5.1 Patterns of Rice Varietal Riversification

Table 9 shows the diversity indices by region for each season. The Simpson index is higher in the *boro* than the *aman* season, because of a considerable number of modern varieties that farmers can choose from in the *boro* season. Diversity indices are high in regions with higher agroecological diversity, such as in Barisal and Chittagong, as shown in Figure 2.1 and Table 9.

Further, diversity is highest in marginal agroecologies, such as saline-affected areas where the salt content varies by season (very low during *aman* and high during *boro*, so land becomes unsuitable for growing rice). Diversity is also high for larger-scale farmers (with more than 2 ha), since they are in a more favorable position to try new varieties on their farms (Hossain et al. 1994; Bose et al. 2001). Diversity is consistently higher in the *boro* season, whether grouped by landholding or agroecological conditions (Table 10). The Simpson index is significantly different in each season, with a t-test value of 15.6; likewise, the Shannon index is significantly different in each season, with a t-test value of 10.1.

5.2 Regression Results

5.2.1 Determinants of adoption of modern varieties

Equations (3) and (4) are estimated using a median regression of diversity index (bsqreg) on the explanatory variables, and a two-stage instrumental variable regression (ivtobit) command in Statistics/Data Analysis software (Stata). For the median regression, we ran a probit regression in the first stage, with the decision to adopt MVs as the dependent variable, and the following variables and predictors: level of education, size of land owned (larger farm size), irrigation type (pump or tubewell), ecosystem, land elevation, sources of seeds, and tenancy (Table 11). The residuals from the fitted probit model are then used as a predictor in the median regression (bsqreg). The same variables were used in the ivtobit to instrument the adoption of MVs, which takes a value of 1 if the farmer adopts MVs, and 0 otherwise. For ivtobit, the first stage is a linear regression analysis (ordinary least squares estimation).

The first stage was estimated separately for the *aman* and *boro* seasons. The main reason for estimating the model by season is the seasonal differences in terms of land preparation and labor use. In the *boro* season, irrigation is required to be able to puddle and transplant seedlings; in the *aman* season, rainfall is abundant, so all land is cultivated, which could lead to labor shortage. In all three equations, we control for district fixed effects to control for district-level unobservables.

The maximum likelihood estimates of adoption of MVs are presented in Table 11. Several factors emerged from the regression results to significantly affect the decision of farmers to adopt MVs. The following discussion pertains to probit results.

Irrigation facilities by tubewell in the *boro* (deep) and *aman* (both shallow and deep) seasons increases the likelihood of MV adoption. This result is supported by previous studies that have shown that irrigation is a major factor that contributed to the diffusion of MVs (David and Otsuka 1990).

Table 9. Measures of rice varietal diversification across households by season and by region

Region	Type of Measure	*Aman* Simpson index	*Aman* Shannon index	t-test value (Simpson)	*Boro* Simpson index	*Boro* Shannon index	t-test value (Shannon)
Rajshahi	Mean	0.32	0.20	-0.726	0.326	0.20	-0.0191
	Std. dev.	0.254	0.149		0.266	0.154	
Dhaka	Mean	0.342	0.202	7.452***	0.278	0.176	5.278***
	Std. dev.	0.273	0.152		0.258	0.155	
Sylhet	Mean	0.364	0.213	-0.701	0.371	0.219	-1.302
	Std. dev.	0.273	0.15		0.268	0.148	
Khulna	Mean	0.212	0.181	8.181***	0.287	0.179	6.840***
	Std. dev.	0.151	0.157		0.267	0.158	
Barisal	Mean	0.49	0.248	18.053***	0.337	0.205	9.764***
	Std. dev.	0.266	0.123		0.267	0.152	
Chittagong	Mean	0.42	0.238	6.161***	0.368	0.218	4.402***
	Std. dev.	0.261	0.137		0.275	0.153	
Bangladesh	Mean	0.383	0.219	15.626***	0.328	0.199	10.150***
	Std. dev.	0.272	0.145		0.269	0.154	
	Coefficient of variation	62.2%	57.5%		74.6%	70.3%	

Source: Authors' calculation; Note: * significant at 10%; ** significant at 5%; *** significant at 1%

Table 10. Measures of rice varietal diversification across ecosystems and landholdings

Variable	Type of measure	*Aman* Simpson index	*Aman* Shannon index	*Boro* Simpson index	*Boro* Shannon index
Ecosystem					
Flood prone	Mean	0.375	0.214	0.45	0.251
	Std. dev.	0.274	0.146	0.25	0.125
Drought prone	Mean	0.383	0.219	0.4	0.243
	Std. dev.	0.272	0.144	0.248	0.14
Salt affected	Mean	0.52	0.266	0.339	0.192
	Std. dev.	0.241	0.111	0.297	0.158
Favorable	Mean	0.399	0.227	0.444	0.255
	Std. dev.	0.267	0.141	0.248	0.128
Bangladesh	Mean	0.402	0.227	0.439	0.252
	Std. dev.	0.27	0.141	0.251	0.13
	Coefficient of Variation	67%	64.4%	71%	67.1%
Landholding					
Marginal (<0.4 ha)	Mean	0.245	0.16	0.316	0.199
	Std. dev.	0.257	0.163	0.268	0.161
Small (0.4–1.0 ha)	Mean	0.376	0.226	0.409	0.245
	Std. dev.	0.261	0.146	0.251	0.138
Medium (1-2 ha)	Mean	0.471	0.255	0.476	0.268
	Std. dev.	0.248	0.118	0.233	0.114
Large (>2 ha)	Mean	0.53	0.262	0.51	0.271
	Std. dev.	0.233	0.1	0.227	0.103
Bangladesh	Mean	0.402	0.227	0.439	0.252
	Std. dev.	0.27	0.141	0.251	0.13
	Coefficient of Variation	67%	64%	71%	67%

Source: Authors' calculation; Note: Numbers in parentheses are standard errors. * significant at 10%; ** significant at 5%; *** significant at 1%

In the *boro* and *aman* seasons, the most important sources of MV seeds are farmers' own harvests and other farmers' harvests. Seed traders are another important source of seeds in the *aman* season. As hypothesized, MV seeds planted come from farmers' own harvests or are exchanged among neighbors.

In the *boro* season, farmers located in the highlands are less likely to adopt MVs. In contrast, in the *aman* season, farmers located in highlands are more likely to adopt MVs, but and farmers located in low lands are less likely to do so.

Interestingly, the socioeconomic characteristics represented by education and farm tenancy did not significantly affect adoption of MVs in both seasons. The education variable is a proxy for farmers' ability to access and process information about MVs. Thus, we expect farmers with higher education levels to be more likely to adopt MV (Leathers and Smale 1991; Feder and Umali 1993). Our results show that education is a positive, though not a significant, determinant of MV adoption. This result is consistent with the findings of several adoption studies, which showed that education was not an important determinant of MV adoption, particularly in the final phases of MV diffusion—i.e., when paddy area has been covered by high-yielding MVs, as is the case in India and the Philippines (Otsuka and Gascon 1990; David and Otsuka 1990; Ramasamy, Paramisivam, and Otsuka 1992; Hossain et al. 1994). In the case of BR-28 and BR-29, the majority of the farmers (60 percent and 64 percent, respectively) reported that it took them up to four years to fully adopt these MVs to all suitable areas (Hossain and Jaim 2012).

On tenancy status, mortgaged-in land for cultivating rice is a positive, but not significant, determinant of MV adoption, while sharecropped land is a negative, but not significant, determinant. This result is consistent with our hypothesis that farmers cultivating sharecropped land may have less access to financing for new technology, as they bear more of the input costs (labor, fertilizer, and irrigation costs), but this may not be an impediment in the adoption of MVs.

In the case of the first-stage regression results of ivtobit, the results are consistent with the probit regression results, except for deep tubewell irrigation in the *boro* season, which significantly negatively affects the decision to adopt MVs. This could be the case, considering that deep tubewells are costlier than shallow tubewells. Having large farms decreases the adoption of MVs.

When farmers were asked which MVs they prefer and why they adopt them, they answered BR-28 and BR-29, which are the most popular varieties in the *boro* season. These varieties have high yield, good grain quality, and resistance to pests. High yield means more grains for small farms, good grain quality means higher price for higher quality, and pest resistance means good harvest and reduced yield loss—all leading to the increased productivity and profitability of growing rice. So if new varieties are introduced that can further increase yield, then farmers will be more attracted to grow those varieties.

5.2.2 Determinants of rice varietal diversity

In choosing the instruments, we first performed a pairwise correlation analysis between instruments and MV adoption variables. If there was no correlation, then the instrument (or variable) was rejected. The significance of the instruments (i.e., F-value >10) used was tested, and results are shown in the last row of Table 12, where the F-test value is greater than 10 (Stock and Staiger 1997). Further, for *boro*, the weak instrument hypothesis is rejected at a 5 percent level of confidence. (The Wald test of exogeneity is rejected, and the estimated confidence sets produced from the weak instrument tests are significantly larger than the Wald confidence interval, indicating that the instruments are not strong, and the point estimates are biased [Finlay and Magnuson 2009]). On the other hand, for *aman*, the weak instrument hypothesis is rejected. The results of the second-stage instrumental variables and bsqreg are shown in Table 12.

A combination of household characteristics and agroecological conditions explains the variation in diversity of rice varieties (measured by the Simpson and Shannon indices). The factors that are significantly positive in explaining the richness of rice varieties grown in all seasons (Simpson index) are higher levels of education but at a diminishing rate, larger farmer size, and land irrigated with tubewells. Factors that significantly reduce diversity are adoption of MVs, environmental conditions (saline-affected areas), and agroecological factors (high land, very low land). High lands contain adequate moisture for growing rice for a shorter duration; thus, farmers specialize on short-duration varieties, although they might be low yielding.

Irrigation affects the diversity index significantly and positively in *boro* but not in *aman*, which is mainly rainfed/deepwater cultivation. This finding is contrary to the popular view that expansion of irrigation reduces diversity by enabling farmers to grow MVs that dominate in irrigated areas. However, with the spread of irrigation facilities, including shallow and deep tubewells, area planted with MVs has expanded to all land types, except for drought-prone and high land areas. It is possible, therefore, that with the rapid expansion of irrigation, the diffusion of MVs at the early stage of adoption provided farmers with

Table 11. Factors affecting farmers' decision to adopt modern varieties by season (average partial effects)

Characteristics	Probit		First-stage ivtobit	
	Boro	*Aman*	*Boro*	*Aman*
Dependent variable: varcodtemp1=1 if cultivating modern variety				
Socioeconomic characteristics				
Farmer's level of education	0.016	0.002	0.004	0.001
	(-0.011)	(-0.012)	(-0.003)	(-0.003)
Education squared	0.0004	0.0002	0	0
	(-0.001)	(-0.001)	(0)	(0)
Large farmer (>2ha)	-0.172***	-0.139***	-0.042***	-0.031**
	(-0.039)	(-0.041)	(-0.01)	(-0.012)
Sharecropping	0.0002	-0.003	0	-0.001
	(-0.012)	(-0.015)	(-0.004)	(-0.004)
Mortgaged-in	0.033	0.023	0.005	0.005
	(-0.05)	(-0.03)	(-0.009)	(-0.008)
Farm/production characteristics				
Shallow tubewells	-0.035	0.116**	-0.003	0.036***
	(-0.044)	(-0.045)	(-0.01)	(-0.011)
Deep tubewells	-0.327***	0.165***	-0.064***	0.049***
	(-0.06)	(-0.063)	(-0.011)	(-0.015)
Seed source==own	0.370***	0.744***	0.078***	0.229***
	(-0.034)	(-0.033)	(-0.009)	(-0.01)
Seed source==other farmer	0.408***	0.774***	0.070***	0.228***
	(-0.05)	(-0.05)	(-0.013)	(-0.014)
Seed source==traders	0.065	0.851***	-0.016	0.242***
	(-0.047)	(-0.062)	(-0.01)	(-0.017)
Agroecological conditions				
Dummy of ecosystem: saline	0.053	0.098	0.01	0.021
	(-0.092)	(-0.077)	(-0.03)	(-0.025)
dummy of land elevation: high land	-0.133**	0.244***	-0.035**	0.052***
	(-0.066)	(-0.077)	(-0.016)	(-0.018)
Dummy of land elevation: low land	0.041	-0.297***	0.013	-0.092***
	(-0.039)	(-0.043)	(-0.008)	(-0.012)
Dummy of land elevation: very low land	0.239*	0.104	0.051*	0.04
	(-0.144)	(1.526***)	(-0.026)	(-0.09)
Constant	1.169***	-0.252	0.870***	0.764***
	(-0.143)	(-0.25)	(-0.029)	(-0.017)
District-level effects	Yes	Yes	Yes	Yes
Observations	12892	11079	13105	11088
Pseudo-]R-squared	0.119	0.246		
Wald chi2(72)	1282***	2634 ***		

Source: Authors'calculation.
Note: Numbers in parentheses are standard errors. * significant at 10%; ** significant at 5%; *** significant at 1%

more varieties to grow where irrigation is available and accessible. Studies on adoption of MVs in Bangladesh show that farmers tend to replace MVs as new varieties are introduced, particularly, if they perform better than the previous MVs, in terms of shorter maturity and higher yields (Miah 1989; Bose et al. 2001; Hossain, Bose, and Mustafi 2006).

Larger-scale farmers with more than 2 ha are more likely to manage higher on-farm varietal diversity. This is because farmers who own larger land areas are wealthier and, hence, are more likely to take risks, and more capable of growing more varieties. (Because wealth indicators are thought to influence output variability, risk aversion and, hence, agricultural biodiversity decrease with wealth [Meng 1997; Van Dusen 2000; Birol, Smale, and Gyovai 2004]).

Moreover, Bangladeshi farms are characterized by fragmented and scattered landholdings, so large farmers will have more scattered parcels of land. This also implies that farmers with large areas face more production uncertainties; hence, growing more varieties reduces the risk of crop failure (Di Falco and Chavas 2009). This is in line with what Bose et al. (2001) found in their study that the main reason why farmers grow several varieties is because of fragmented and scattered landholdings and the diversity of the plots in agroecological conditions.

Given the micro-agroecological (soil, irrigation, etc.) differences across different parcels, different varieties may be suited to different parcels. For example, one parcel may not be suitable for a high-yielding variety, and another parcel may not be suitable for shorter plant height. Our data show no systematic relationship between landholding size and varietal diversity of parcels in agroecological conditions at the household level, but the distribution of cultivated land according to soil type and land elevation has high varietal diversity at the block and district levels.

The adoption of MVs lowers the rice varietal diversity, even in the wet *aman* season when TVs are also dominantly produced. This finding is consistent with our hypothesis that cultivating an MV may reduce varietal diversity, since MVs contribute to reducing production risk because of their higher yields, improved resistance to pests and diseases, and better grain quality. Farmers value these traits, as demonstrated by the rapid diffusion of BR-28 and BR-29 (i.e., coverage of MVs in the dry *boro* season increased rapidly from 29 percent in the 1980s to 57 percent in the 1990s and reached 81 percent in 2000–2001 [Hossain, Bose, and Mustafi 2006]). These varieties will remain popular among farmers until breeders develop a new variety with traits superior to the existing MVs.

The education level of the household head is positively associated with the diversity index, but at a decreasing rate, which suggests that more educated farmers have better access to information about certain varieties (i.e., having information or knowledge reduces uncertainty about the productivity of that variety), and they have the ability to optimally use this information to decide which variety to grow from among a wide range of varieties.

In the *aman* season, tenure status (mortgaged-in land) and rice farms in the high lands reduce diversity. Farmers renting land for cultivation are mostly small-scale farmers or tenants, so they only grow one or two varieties, which could be MVs, as shown by a positive relationship between adoption of MVs and shared cropping tenancy. Because MVs are high yielding, adopting them could increase production from a small piece of land and augment farmers' income. Moreover, this result supports the hypothesis that farmers with larger landholdings may be less risk averse, and thus may lack incentives to grow more varieties.

Most of the factors that are significant in explaining the equitability (Shannon index) among varieties grown are consistent with those factors explaining the richness (Simpson index) among them. This implies that a program or policy intervention designed to conserve the richness of varieties is not likely to have a negative impact on the relative uniformity of the frequency distribution among varieties.

6. CONCLUSIONS & POLICY IMPLICATIONS

This paper presents evidence of rice varietal diversity on household farms in Bangladesh and investigates the impact of the adoption of modern rice varieties on varietal diversification on-farm.

In terms of factors that affect adoption of MVs, farmers who acquire seed from informal sources—i.e. from their own farms or neighboring farmers—are more likely to adopt MVs. This is because there is neither a formal seed market nor a formal seed distribution system that farmers rely on to acquire seeds. In addition, if modern and traditional seeds are available to farmers in the market, farmers will likely reduce their use of seeds from their own harvest, thereby avoiding not only lower yields but also genetic erosion. Government extension systems (such as the Department of Agricultural Extension) should be mobilized for the distribution of new seeds, focusing on small-scale and marginal farmers, since data showed that extension services are biased toward large-scale farmers. Hence, it is important to understand the seed distribution system in Bangladesh, and also the market infrastructure network, so that small-scale and marginal farmers can have better access to MVs.

Table 12. Determinants of rice varietal diversity (richness and equitability) on household farms, by season, Bangladesh

	Instrumental variable regression				Quantile regression			
	Boro		*Aman*		*Boro*		*Aman*	
Dependent variable	Simpson index (SIDs)	Shannon index (SWs)	Simpson index (SIDs)	Shannon index (SWs)	Simpson index (SIDs)	Shannon index (SWs)	Simpson index (SIDs)	Shannon index (SWs)
Education of the farmer	0.012***	0.006***	0.014***	0.007***	0.002	0	0.010***	0.005***
	(0.0030)	(0.0020)	(0.0030)	(0.0020)	(0.0010)	0.0000	(0.0030)	(0.0010)
Education squared	-0.001*	0	-0.001***	0	0	0	-0.001***	-0.000***
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Large farm (>2ha)	0.142***	0.062***	0.184***	0.077***	0.123***	0.004	0.185***	0.041***
	(0.0140)	(0.0080)	(0.0090)	(0.0060)	(0.0130)	(0.0030)	(0.0180)	(0.0070)
Sharecropping	0.009	0.005	0.016**	0.007*	0.002	0	0.012*	0.002*
	(0.0060)	(0.0030)	(0.0070)	(0.0040)	(0.0030)	0.0000	(0.0070)	(0.0010)
Mortgaged-in	0.003	0.004	-0.028	-0.013	0.005	0	-0.031**	-0.013***
	(0.0140)	(0.0080)	(0.0230)	(0.0100)	(0.0070)	(0.0040)	(0.0140)	(0.0050)
Shallow tubewell	0.044***	0.014**	-0.026*	-0.019**	0.024***	0.001	0.021***	0.006
	(0.0120)	(0.0070)	(0.0140)	(0.0080)	(0.0060)	(0.0010)	(0.0070)	(0.0040)
Deep tubewell	0.003	-0.003	0.035*	0.012	0.024***	0.001	0.076***	0.028***
	(0.0210)	(0.0110)	(0.0190)	(0.0100)	(0.0080)	(0.0010)	(0.0160)	(0.0080)
Dummy of ecosystem: saline	-0.158***	-0.089***	-0.044	-0.030**	-0.119***	-0.019*	-0.133**	-0.039*
	(0.0390)	(0.0200)	(0.0270)	(0.0130)	(0.0380)	(0.0110)	(0.0540)	(0.0240)
Dummy of land elevation: high land	-0.061***	-0.033***	-0.047**	-0.026***	-0.006	-0.001	-0.050***	-0.022***
	(0.0240)	(0.0110)	(0.0200)	(0.0100)	(0.0070)	(0.0030)	(0.0150)	(0.0070)
Dummy of land elevation: low land	-0.002	-0.003	-0.078***	-0.044***	0.004	0.001	0.009	0.005
	(0.0090)	(0.0060)	(0.0170)	(0.0080)	(0.0050)	(0.0010)	(0.0110)	(0.0040)
Dummy of land elevation: very low land	0.002	0.015	-0.134	-0.081	-0.056**	-0.030**	-0.008	-0.019
	(0.0400)	(0.0220)	(0.1260)	(0.0570)	(0.0270)	(0.0140)	(0.0440)	(0.0780)
Linear prediction								
varcodtemp==1.0000	-0.778***	-0.357***	-0.068*	-0.034				
	(0.1720)	(0.0960)	(0.0390)	(0.0230)				
IMRpredmv					-0.091	-0.022	-0.404***	-0.209***
					(0.0760)	(0.0240)	(0.0830)	(0.0490)
Constant	0.914***	0.481***	-0.068*	-0.034	0.422***	0.318***	0.451***	0.322***
	(0.1680)	(0.0830)	(0.0390)	(0.0230)	(0.0140)	(0.0030)	(0.0220)	(0.0100)
Wald test of exogeneity: chi2(1)	20.45***	13.87***	5.61**	5.10**				
F-value	23.86***	23.86***	58.23***	58.21***				

Source: Authors' calculation.
Note: Numbers in parentheses are standard errors. * significant at 10%; ** significant at 5%; *** significant at 1%

Small irrigation facilities, such as shallow and deep tubewells, increase the likelihood of MV adoption. Having irrigation affects the diversity index significantly and positively, which could be due to the diffusion of more MVs in areas where irrigation is available and accessible.

Farmers located in high land elevations are less likely to adopt MVs, which also reduces diversity index. This is possible, given that high lands contain adequate moisture for growing rice for shorter durations. Thus, farmers cultivating high land specialize in short-duration varieties, even though they might be low yielding. If new varieties are developed suitable to the high lands, they should be early-maturing and high-yielding varieties.

Empirical evidence suggests that adoption of MVs lowers varietal diversity at the farm level. This finding is consistent with the hypothesis that cultivating MVs reduces crop diversity, since their adoption reduces production risk because of their superior agronomic characteristics, such as higher yields and improved resistance to pests and diseases. Farmers value these traits, which must considered when breeders develop new varieties.

Although farmers' education was not significant in MV adoption, education is a significant determinant of rice varietal diversity in accessing information or knowledge about the traits of MVs. Educated farmers have the ability to decide which MV to grow among a wide range of choices. This finding is important in formulating information campaigns for new seed varieties (for example, a nutrient-dense rice variety), to accelerate their adoption rate.

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APPENDIX TABLES

Appendix Table A.1. Area and yield of popular varieties (top 50) planted in the dry season in Bangladesh, 2005

Variety	Sample size (ha)	Total area (ha)	Average production (kg)	Average yield (kg)
BR-29	6,531	5,205.8	2,795.5	6,705.0
BR-28	6,061	4,934.0	1,729.4	5,326.7
BR-14/Gazi	850	845.7	1,531.9	5,610.4
BR-16/Shahi Balam	846	759.4	1,631.9	5,805.4
BR-1/Chandina/Chaina	795	644.8	1,505.3	4,309.7
BR-3/Biplob	787	702.8	1,687.4	5,084.5
Bhajan	694	444.4	2,036.9	5,841.6
Rotna	677	462.2	1,775.4	4,865.2
Haitta	605	361.1	658.8	2,976.6
BR-2/Mala IRRI	548	380.9	1,373.6	3,734.2
Hira	542	637.1	2,475.5	7,632.0
Purbachi	424	308.3	1,475.3	4,552.8
Parijat	400	308.4	1,461.8	4,226.5
BR-26/Shraboni	342	305.4	1,338.2	4,414.8
Iriton	289	240.0	1,440.0	5,318.2
Paizam	286	291.8	1,239.5	4,096.9
IR-50	269	148.6	1,055.3	3,675.7
BR-27	222	153.2	825.4	4,955.4
IRRI-8	204	171.2	1,537.6	6,187.2
Nayanmoni	201	123.1	1,296.7	4,906.3
Mota Miniket	198	200.1	2,289.8	5,003.9
BR-11/Mukta	197	176.2	1,567.2	4,232.4
Kali Buro	177	131.0	776.5	2,436.3
BR-12	171	105.6	1,180.7	4,133.1
G,S-1	168	136.6	2,198.5	6,156.2
BR-20	167	115.0	1,032.6	4,020.1
BR-19	161	197.0	1,768.4	4,585.3
Jagoron	157	218.6	2,295.7	7,579.3
Porangi	155	81.2	425.4	1,480.6
BR-21	155	99.5	1,412.7	3,946.4
Joya	134	100.2	1,467.9	6,965.0
Kajol Lota	119	90.7	1,527.4	4,928.1
BR-8/Asha	118	76.9	2,000.0	5,424.3
BR-33	113	63.8	1,362.7	4,698.1
Tyfa	110	101.4	1,017.8	4,170.8
Belombori	104	84.8	1,775.6	5,311.5
Kazla	102	97.8	2,694.9	6,047.6
Binni/Kashia Binni	99	86.2	693.4	3,246.6
Benama	90	66.9	1,330.8	4,475.4
Sonarbangla	86	106.0	2,567.5	7,529.9
Abdul Hai	85	73.6	1,578.4	4,118.1
IT	81	44.5	1,511.4	5,641.3

Variety	Sample size (ha)	Total area (ha)	Average production (kg)	Average yield (kg)
BR-36	79	72.4	1,835.4	5,747.0
Bina-6	73	53.6	1,343.6	4,592.9
Muralee	71	69.7	878.6	2,218.1
Sileti Iri	66	49.4	847.4	3,289.5
BR-50	65	51.8	1,299.1	3,612.5
BAU - 63	64	60.9	1,508.4	3,513.1
Hasi Kalmi	64	48.4	804.4	1,865.9
Daw-IRRI	62	46.4	1,173.1	7,263.4
Mala Shail	60	44.9	1,479.3	9,445.1

Source: Authors' compilation.
Note: The total number of rice varieties in the dry *boro* season identified was 417.

Appendix Table A.2. Area and yield of popular *aman* varieties (top 50) in Bangladesh, 2004

Variety	Sample size (ha)	Total area (ha)	Average Production (kg)	Average yield (kg)
BR-11/Mukta	6,029	5,919.6	1,629.6	4,350.7
Swarna	2,626	2,492.7	1,630.9	4,014.0
Paizam	2,140	2,417.6	995.5	3,528.8
BR-22/Kiron	1127	1,062.6	1,283.7	3,639.0
BR-32	1020	1,263.5	1,138.7	3,958.9
BR-30	811	849.2	1,387.8	4,143.4
BR-10	661	692.7	1,508.6	4,250.2
Sada Mota	619	801.4	1,087.4	2,413.8
BR-23/Disharee	465	596.6	1,306.3	3,542.8
Kala Shail	417	569.4	864.7	2,681.2
BR-41	344	445.7	1,423.8	5,759.4
Kali Zira	330	466.6	271.5	2,901.6
BR-40	320	444.8	1,157.8	4,236.8
Chikon	295	364.7	596.4	2,676.9
BR-39	291	342.1	1,136.2	4,039.8
BR-33	248	304.1	936.8	3,819.4
Binni/Kashia Binni	245	318.9	346.4	2,922.7
Dudsar	228	318.4	613.1	2,647.1
Mowlata	221	300.0	609.1	2,627.9
Mota Dhan	220	314.7	1,517.8	2,702.5
Balam	215	287.3	571.2	2,418.1
Lalmota	204	305.6	991.9	2,592.9
Nazir Shail	178	195.3	819.9	4,217.0
Mota Mota	177	281.7	820.9	2,626.2
Birui	174	234.7	645.6	2,585.7
Raja Shail	149	182.6	542.6	2,037.8

Variety	Sample size (ha)	Total area (ha)	Average Production (kg)	Average yield (kg)
BR-28	143	140.5	1,202.0	4,001.6
BR-31	132	155.1	959.3	4,345.4
Maloti	124	142.0	708.8	2,399.5
Chini Atob	114	153.7	577.7	2,668.8
Gaindha	111	90.4	700.2	2,765.4
Joyna	110	89.0	748.2	3,401.5
Shishumoti	109	76.5	490.1	2,021.7
Khama	106	80.1	491.1	1,649.8
BR-29	103	107.5	2,620.5	5,079.3
Bajal	92	89.1	726.8	1,846.6
Chapillya	92	93.7	802.3	2,735.1
Sakkhor Khora	89	150.7	211.2	2,256.1
BR-34	85	121.3	873.6	3,024.3
Zabra	82	83.9	847.1	2,186.3
Gigaj	78	98.6	604.4	3,728.2
BR-3/Biplob	76	90.5	1815.5	4,392.2
Kartik Shail	75	89.0	471.5	1,967.2
Kuri Agrahonee	75	107.3	519.8	2,367.2
Moyna Shail	74	115.1	946.2	2,188.1
BR-14/Gazi	70	91.7	1,365.1	4,223.2
Vushi Hara	70	66.8	808.1	2,468.9
Tulsimala	69	103.6	479.4	2,351.5
BR-2/Mala IRRI	69	104.6	698.0	3,214.2
Dingamoni	68	100.9	496.6	2,203.6
Anam	67	74.9	1,822.1	2,491.0

Source: Authors' compilation.
Note: The total number of rice varieties in the wet *aman* season identified was 523.

Appendix Table A.3. Descriptive statistics of variables used in the multivariate regression analysis (all seasons)

Variable	Obs	Mean	Std. dev.
Boro			
Diversity index (Simpson index)	13105	0.345	0.274
Diversity index (Shannon index)	13105	0.205	0.152
Farmer's education	13105	4.521	3.757
Education squared	13105	34.556	42.483
Large farm	13105	0.144	0.351
Sharecropping	13105	0.299	0.907
Mortgage-in	13105	0.045	0.331
Irrigation facility: deep tubewell	13105	0.098	0.498
Irrigation facility: shallow tubewell	13105	0.456	0.498
Dummy of ecosystem: saline	13105	0.020	0.141
Dummy of land elevation: high land	13105	0.0499	0.218
Dummy of land elevation: low land	13105	0.0103	0.396
Dummy of land elevation: very low land	13105	0.195	0.102
MV dummy=1 if cultivating modern variety	13105	0.817	0.386
Seed source==own	13105	0.331	0.471
Seed source==Other farmers	13105	0.114	0.317
Seed source==traders	13105	0.113	0.317
Aman			
Diversity index (Simpson index)	11088	0.330	0.278
Diversity index (Shannon index)	11088	0.195	0.155
Farmer's education	11088	4.616	3.768
Education squared	11088	35.502	42.893
Large farm	11088	0.152	0.359
Sharecropping	11088	0.308	0.851
Mortgage-in	11088	0.046	0.412
Irrigation facility: deep tubewell	11088	0.435	0.496
Irrigation facility: shallow tubewell	11088	0.103	0.304
Dummy of ecosystem: saline	11088	0.046	0.209
Dummy of land elevation: high land	11088	0.054	0.225
Dummy of land elevation: low land	11088	0.112	0.316
Dummy of land elevation: very low land	11088	0.002	0.039
MV dummy=1 if cultivating modern variety	11088	0.698	0.453
Seed source==own	11088	0.311	0.463
Seed source==Other farmers	11088	0.099	0.299
Seed source==traders	11088	0.094	0.292

Source: Authors' calculation.