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ADOPTION AND PRODUCTIVITY IMPACT OF MODERN RICE VARIETIES IN BANGLADESH

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Technological progress has helped Bangladesh to achieve self-sufficiency in rice production in 2001 from a heavy import-dependence, despite doubling of population and a reduction in arable land since its independence in 1971. As the adoption of modern varieties (MV) of rice is reaching a plateau, particularly for the irrigated ecosystem, an important issue is whether the research system will be able to sustain the growth of production. The present paper addresses the following questions: (i) to what extent farmers have been replacing the old MV with the new MV, and (ii) what has been the impact of the variety replacement on productivity and profitability. How crucial is the continuous research and release of improved rice varieties toward improving farm production and income for farmers comes out as a clear message to policymakers from the current paper.

Keywords: Variety replacement; Technological progress; Productive efficiency; Unit costs; Bangladesh
JEL classification: O13, O33

I. INTRODUCTION

Technological progress in rice cultivation is crucial for sustaining food security in Bangladesh. The country now supports a population of 140 million at a density of 920 persons per square kilometer and an arable land base of 0.061 hectares per person. The population growth has declined from 3.0% to 1.5% per year over the last three decades, but the nation's population is still growing by two million people every year. Since the per capita income is extremely low (US$375 in 2001), nearly 60% of the income is spent on food; 30% on rice alone (BBS 2001). Rice accounts for three-fourths of the total cropped area, and it also bears the burden of being the dominant staple food, thus having a need to increase its supply to meet the demand of the growing population.

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The area under rice cultivation will have to be reduced to accommodate crop diversification, as the demand for other food grains has been increasing rapidly from urbanization and a respectable growth in per capita incomes since the mid-1980s (BBS 2002).

Indeed, Bangladesh has made notable progress in sustaining a respectable growth in rice production over the last three decades through the adoption of modern varieties (MV), despite of the declining availability of arable land and an agrarian structure dominated by small and marginal farmers and landless agricultural laborers. Several influential rural studies in the 1970s had observed that the agrarian structure would constrain the development forces in Bangladeshi agriculture (Van Schendel 1976; Jannuzi and Peach 1980; Boyce 1987). This apprehension has now proved to be unfounded. The MV have spread to about 65% of the rice area with support from the expansion of minor irrigation through shallow tubewells and power pumps. The growth in production has originated mostly from the shift of land from low-yielding traditional to high-yielding MV when irrigation facilities were developed.

The rice research system has been producing new generations of MV. To what extent farmers have been changing from the "old" improved varieties to the "new" ones, and what has been the impact of the new generations of MV are issues that have not yet been rigorously studied in Bangladesh. Addressing these issues is important for assessing the capacity of the research system to sustain the growth in rice production in the future, as the adoption of MV are reaching their plateau, particularly for the favorable rice-growing environments. The present study makes an attempt to address these issues using available secondary data, and primary data on costs and returns of specific varieties. The main source of the primary data are national-level sample surveys conducted by the International Rice Research Institute (IRRI) in collaboration with the Bangladesh Institute of Development Studies (henceforth called IRRI-BIDS survey) in 1987 and 2000 in 62 villages (see Hossain *et al*. [1994, 2002, 2003] for the survey methodology).[1]

[1] The sample was selected in 1987 using a multistage random sampling method. In the first stage 64 unions were selected from the list of all unions in the country using a random number table. In the second stage, data on landholding, total population, and literacy rates were obtained from all the villages of the selected unions to select a representative village for the union. In the third stage, a census of all households of the villages was done to collect information on land ownership and land tenure to select 20 households from each village using the stratified random sampling method. Two sites were dropped because of the problem of the implementation of the survey. A repeat survey was done in the same villages in 2000. This time the sample was drawn using the classification of the households by wealth ranking method. To ensure that all the former sample households were covered in the present survey, a sample of 30 households were drawn from each village from four groups with regard to wealth status, using the stratified random sampling method. A new sample was drawn for the cell that was under-represented by the 1987 sample and its offshoots because of the breaking up of the family. This study uses parcel-level data on area and production of rice, and the data on costs and returns which were collected for the subsample of the plots.

The paper is organized as follows: Section II assesses both the production of MV by the Bangladesh rice research system and their traits. It also provides information on the adoption of successive generations of MV, the technological progress, and their impact on the growth of rice production. Section III uses the factor share and production function analysis with household-level data to study the effect of the successive generations of MV on productivity and profitability. The main findings are recapitulated in Section IV.

II. PRODUCTION AND ADOPTION OF MODERN VARIETIES

In Bangladesh, rice is grown in three overlapping seasons. The monsoon rice, "*aman*," harvested in November–December is the main rice crop. It occupied 5.7 million hectares in 2002/03, approximately 53% of the total rice area. On land with shallow flooding depth *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. Bangladesh receives about 400 millimeters of rain during the pre-monsoon months of March to May, which farmers use to grow a short-duration drought-resistant crop known as "*aus*," which gives an yield of about 1.8 t/ha. The crop is mostly directly seeded during March–April and harvested in July–August. In 1969/70 the crop occupied 3.4 million hectares, but the area has declined to 1.2 million hectares by 2002/03, as farmers shifted the land to vegetables or dry season irrigated rice called "*boro*." *Boro* was used to be grown in very lowing land (not suitable for growing any crop during the monsoon season), transplanted in November after the recession of the flood and harvested in April–May. However, with the spread of the ground water irrigation, the area has expanded to all land types, and is now mostly transplanted in January–February and harvested in May–June. The area has expanded from 0.5 million hectares in 1969/70 to 3.8 million hectares in 2002/3, which is 35% of the total rice area. Since *aus* and *boro* are overlapping crops, for the purpose of the current paper we have classified the seasons into two: wet (*aman*) and dry (*boro* and *aus*).

Bangladesh Rice Research Institute (BRRI) is the main organization responsible for rice research. The Bangladesh Institute of Nuclear Agriculture (BINA), the Bangladesh Agricultural University (BAU), Mymensingh, and the botany and biochemistry departments of various universities do basic and strategic research, but their contribution to developing improved varieties has remained marginal.

A. *Production of Varieties*

The major achievement of the rice research system in Bangladesh, as in other Asian countries, has been the development of improved varieties. By 2001, BRRI had released 40 rice varieties for different agroecological conditions, whereas BINA and BAU had released six (Miah 1989; Islam and Rabbi 2002; BRRI 2003). Table 1 reports the

TABLE 1

Characteristics of Rice Varieties Developed by Bangladesh Rice Research Institute, 1970 to 2001

Variety	Real Name	Year of Release	Target Season[a]	Plant Height (cm)	Growth Duration (Days)	Grain Quality	Source of Breeding[b]	Yield[c] (t/ha)
BR1	Chardina	1970	*Boro*	88	150	Coarse	IRRI	5.5
BR2	Mala	1971	*Boro*	120	160	Medium	IRRI	5.0
BR3	Biplob	1973	*Boro*	95	170	Coarse	BRRI	6.5
BR4	Brrishail	1975	*Aman*	125	145	Coarse	BRRI	5.0
BR5	Dulabhog	1976	*Aman*	120	150	Fine	BRRI	3.0
BR6	No local name	1977	*Boro*	100	140	Fine	IRRI	4.5
BR7	Brribalam	1977	*Boro*	125	155	Fine	IRRI	4.5
BR8	Asha	1978	*Boro*	125	160	Coarse	BRRI	6.0
BR9	Sufola	1978	*Boro*	125	155	Coarse	BRRI	6.0
BR10	Progoti	1980	*Aman*	115	150	Medium	BRRI	6.5
BR11	Mukta	1980	*Aman*	115	145	Coarse	BRRI	6.5
BR12	Moyna	1983	*Boro*	120	160	Coarse	BRRI	5.5
BR14	Gazi	1983	*Boro*	120	160	Coarse	BRRI	6.0
BR15	Mohini	1983	*Boro*	90	165	Medium	IRRI	5.5
BR16	Shahi Balam	1983	*Boro*	90	165	Fine	IRRI	6.0
BR17	Hashi	1985	*Boro*	125	155	Coarse	IRRI	6.0
BR18	Shahjalal	1985	*Boro*	125	155	Coarse	IRRI	6.0
BR19	Mongol	1985	*Boro*	110	170	Coarse	IRRI	6.0
BR20	Nizami	1986	*Aus*	120	115	Coarse	BRRI	3.5
BR21	Niyamot	1986	*Aus*	100	110	Coarse	BRRI	3.0
BR22	Kiron	1988	*Aman*	125	150	Coarse	BRRI	5.0
BR23[d]	Dishari	1988	*Aman*	120	150	Medium	BRRI	5.8
BR24	Rahmat	1992	*Aus*	105	105	Fine	BRRI	3.5
BR25	Noya Pajam	1992	*Aman*	138	135	Coarse	BRRI	4.5
BR26	Shraboni	1993	*Aus*	115	115	Fine	BRRI	4.0
BR27	Brridhan 27	1994	*Aus*	140	115	Coarse	BRRI	4.0
BR28	Brridhan28	1994	*Boro*	90	140	Medium	BRRI	5.0
BR29	Brridhan29	1994	*Boro*	95	160	Medium	BRRI	7.5
BR30	Brridhan30	1994	*Aman*	120	145	Medium	BRRI	5.0
BR31	Brridhan31	1994	*Aman*	115	140	Coarse	BRRI	5.0
BR32	Brridhan32	1994	*Aman*	120	130	Coarse	BRRI	5.0
BR33	Brridhan33	1994	*Aman*	100	118	Coarse	Sri Lanka	5.0
BR34	Brridhan34	1997	*Aman*	117	135	Aromatic	BRRI	3.5
BR35	Brridhan35	1998	*Boro*	105	155	Coarse	BRRI	5.0
BR36	Brridhan36	1998	*Boro*	90	140	Fine	IRRI	5.0
BR37	Brridhan37	1998	*Aman*	125	140	Aromatic	BRRI	3.5
BR38	Brridhan38	1998	*Aman*	125	140	Aromatic	BRRI	3.5
BR39	Brridhan39	1999	*Aman*	106	122	Fine	BRRI	4.5
BR40[d]	Brridhan40	2001	*Aman*	110	145	Coarse	BRRI	4.5
BR41[d]	Brridhan41	2001	*Aman*	115	148	Coarse	BRRI	4.5

Source: BRRI (2003).

[a] The varieties released for the *boro* season can also be cultivated in the *aus* season but the yield will be low.

[b] Crosses made at IRRI are evaluated in Bangladesh under the International Network for Genetic Evaluation of Rice (INGER) through multi-local trials, and is released under BR name if found suitable.

[c] Average yield obtained under multi-location trials. For some varieties such as BR28, the farmer-level yield is found higher.

[d] The varieties have moderate tolerance to salinity and are released for coastal areas.

characteristics of the rice varieties produced by BRRI. The production of improved varieties has been continuing. The number of varieties released in the 1990s was 16, compared with 13 in the 1980s, and nine in the 1970s. The following major points about the production of MV in Bangladesh can be noted from the table.

Almost half of the varieties released by BRRI for the dry season are advanced lines developed at IRRI or other national agricultural research systems and found suitable for Bangladesh when tested under the International Network for Genetic Evaluation of Rice (INGER). However, the crosses for most of the varieties for the wet season were made by BRRI. It shows that for the irrigated ecosystem, the countries can depend on an international spillover of technologies (Evenson and Gollin 1997) as good water control makes them widely adaptable. However, for the less favorable rainfed ecosystem, breeding needs to be done locally to take care of the location-specific agroecological and climatic conditions.

Breeders looked for traits other than yield, such as resistance to insects and diseases, grain quality, plant height, and growth duration when deciding to release a new variety (Miah 1989). Varieties released in the 1970s had medium resistance to the tungro virus, but were susceptible to most other diseases and insects. The varieties released in the 1980s had better resistance to yellow stemborer, leaf blight, and blast, along with a mild resistance to brown plant hopper and sheath blight (Miah 1989; Shahjahan 1993; BRRI 2003). In the 1990s, the traits of variable growth duration and plant height were given higher priority in the variety release decisions in order to suit parcels of land located in different elevations (which determine duration of moisture availability and flooding depth). Many varieties released in the 1990s have shorter plant height, better grain quality, and a shorter maturity period than the varieties released in the 1970s. The shorter maturity varieties helped farmers to fit non-rice crops in the rice-based farming systems, enabling farmers to both improve cropping intensity and increase yield in subsequent non-rice crops, such as wheat.

A new variety is often released to replace an old variety that became susceptible to insects and diseases. It does not necessarily have higher yield. The highest-yielding early variety for the dry season was Brridhan (BR)3 released in 1973. The yield potential of this variety was surpassed only in 1994 with the release of BR29 that showed an average yield of 7.5 t/ha in multi-location trials. The highest-yielding variety for the *aman* season is BR11 released in 1980. Many new varieties have been released for the season since then but none with a higher yield potential than that for BR11.

We will classify the MV into three groups:

MV1: The first generation varieties released in the 1970s, which has high yield but low resistance to insects and diseases.

MV2: The second generation varieties released during the 1980s, which has improved resistance to pest and diseases and better grain quality, but no yield advantages compared with the first generation.

MV3: The third generation varieties released since 1990, which produced plants shorter in height with a few higher yield potentials than the first generation MV; with a few exceptions they also had improved grain quality (Table 1).

B. *Adoption of Varieties and Technological Progress*

Farmers started cultivating MV in the early 1960s when the Bangladesh Academy of Rural Development introduced through cooperatives cultivation of Paijam (known as Mashuri in India) for the wet season and Purbachi for the dry season. These varieties were developed under an Food and Agriculture Organization (FAO) international rice improvement program and seeds were imported into Bangladesh (Miah 1989). The first IRRI varieties cultivated in Bangladesh are IR8 for the dry season in 1967, and IR20 for the wet season in 1970.

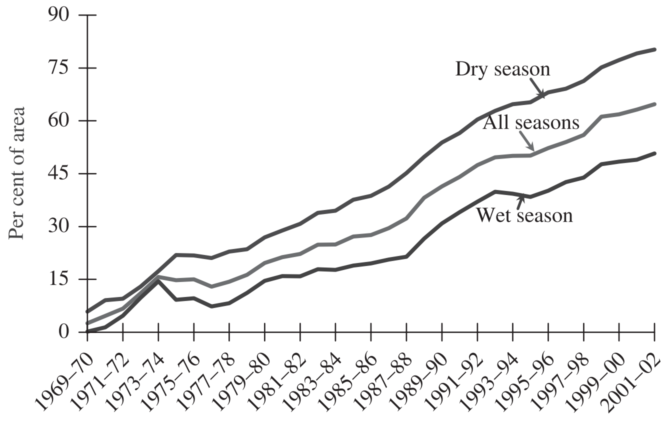
Studies on factors affecting the adoption of MV in Bangladesh (Asaduzzaman 1979; Mandal 1980; Hossain 1988; Hossain *et al*. 1994; Alauddin and Tisdell 1996; Hossain *et al*. 2003) have noted that socioeconomic factors, such as the predominance of small and marginal farmers and tenancy cultivation in the agrarian structure, did not impede the adoption of MV in Bangladesh. All studies, in fact, noted that the rate of adoption was higher in the small and tenant farms, contrary to the observations made for other countries (Griffin 1974; Pearse 1980; Lipton and Longhurst 1989). The major constraints to adoption were in fact technical factors, such as nonavailability of irrigation facilities for the dry season, and the location of the parcel in the topography, which affects the depth of flooding in the wet season.[2] Another constraint to the adoption of MV in the dry season in the coastal region is the salinity of the soil.

The main factor affecting the diffusion of MV in Bangladesh has been the rate of expansion of irrigation facilities. The rapid expansion of irrigation began in the early 1980s with the promotion under the private sector of small capacity shallow tubewells for ground water irrigation. Beginning in 1986, the government removed the ban on private sector imports of agricultural equipment, abolished the standardization requirement imposed for quality control and easy availability of spare parts, and reduced import duties on agricultural machinery, which led to a substantial reduction in the cost of tubewells and development of a market for irrigation services (Mandal 1980; Hossain *et al*. 2002), and contributed to the large-scale expansion of irrigation in the 1990s.[3] The area irrigated by modern methods reached 4.67 million hectares in 2000/01, approximately 58% of the cultivated area.

[2] In Bangladesh, only 32% of the cultivated land is flooded at a depth of less than 30 cm, which is favorable for growing semidwarf modern varieties. Another 40% of the land is flooded at 30–90 cm depth and would be suitable for MV of intermediate plant height. Some of this area has already been brought under MV cultivation. The remaining 31% of land is not suitable for MV (GOB 1991).

[3] A census of minor irrigation equipment done in 2001 reported operation of approximately 801,000 shallow tubewells irrigating 2.75 million hectares of land; about two-thirds of MV area cultivated in the dry season. The ground water now accounts for nearly three-fourths of total irrigated area in Bangladesh (GOB 2002).

Fig. 1. Trend in the Adoption of Modern Rice Varieties by Season, 1969–70 to 2001–02



The official statistics on the expansion of cultivation of MV in Bangladesh can be seen from Figure 1. The expansion was relatively slow during the 1970s, but by 1980, the coverage had expanded to 16% of the rice area for the wet season and 28% for the dry season. The rapid expansion that has taken place since the mid-1980s has coincided with the changes in government policies in favor of privatizing the procurement of chemical fertilizers and irrigation equipment, liberalizing trade, and the reducing of import tariffs on agricultural machinery (Hossain 1996). Another spurt in the expansion of MV took place in the late 1990s as a result of improved linkages between agricultural extension and research, and the collaboration between the public sector and nongovernmental organizations (NGO) for the production of certified seeds for the newly released varieties. By 2001–02, the coverage of MV reached 65% of rice-cropped area; 80% for the dry season, and 51% for the wet season. The green revolution in rice cultivation is, thus, not yet complete in Bangladesh.

The effect of technological progress on the growth in rice production can be assessed from Table 2. The rice-cropped area has increased only marginally from 10.3 million hectares in 1969–70 to 10.7 million hectares in 2001–02, but production has increased from 17.6 million tons to 37.7 million tons of un-husked rice. The average rice yield has increased from 1.7 to 3.5 t/ha for all rice crops, an annual rate of growth of 2.3% per year. For the dry season for which the expansion of MV has been very rapid, the yield has grown from 1.7 to 4.3 t/ha, an annual increase of 2.9% per year. This respectable growth in yield has enabled Bangladesh to maintain a favorable food-population balance despite a decline in arable land over the last three decades.

C. *Replacement of Varieties*

The macro picture on the trend in the adoption of MV in Bangladesh can be obtained from the time-series data on area covered by MV as a group published by

TABLE 2

Technological Progress in Rice Cultivation in Bangladesh, 1969–70 to 2001–02

Season	1969–70	1980–81	1990–91	2001–02
Wet season:				
Rice area (million ha)	6.01	6.04	5.78	5.65
Coverage of MV (%)	0.0	15.9	34.0	50.7
Rice yield (t/ha)	1.73	1.94	2.37	2.85
Rice production (million ton)	10.4	11.7	13.7	16.1
Dry season:				
Rice area (million ha)	4.31	4.27	4.66	5.08
Coverage of MV (%)	5.8	29.0	56.7	80.1
Rice yield (t/ha)	1.69	2.04	2.78	4.25
Rice production (million ton)	7.3	8.7	13.0	21.6

Source: BBS (2002).
MV = modern rice varieties.

the Bangladesh Bureau of Statistics (Figure 1). However, at the micro level, with the release of new varieties, an interesting question is: do farmers replace the old MV with the new ones? To answer this question, data on area covered by specific varieties are needed. Unfortunately, such data are not available from official statistics. The information on the rate of adoption of specific MV is available only from reports of sample surveys. This section reports the information on the popularity and replacement of MV over time as obtained from the large-scale national-level sample surveys.

The International Fertilizer Development Corporation did a large scale sample survey during 1979–81 to analyze the productivity and equity effects of fertilizer use (Sidhu and Baanante 1984). The survey reported that in the dry season the popular varieties as IR8 were followed by Purbachi, BR1, and BR3. IR8 was most popular in the Dhaka and Khulna Divisions, whereas Purbachi was most popular in the Rajshahi and Chittagong Divisions. In the wet season the popular varieties were Paijam and IR20.

The Agricultural Economics Division of BRRI used a multi-stage random sampling method covering seven agroecological zones, 43 *upazilas*, and 1,690 farmers to estimate the area under specific MV in 1990 (Jabber *et al.* 1991). The survey found only three varieties, BR11 (64%), Paijam (15%), and BR4 (8%), occupied 87% of the area grown with MV during the wet season. In the dry season a larger number of MV were grown, but three varieties, Purbachi (21%), BR3 (19%), and IR8 (12%), occupied nearly 52% of the MV area.

The Department of Agricultural Extension conducted a large-scale survey in 1995–96 and 1996–97 on rice varieties (including traditional varieties [TV]) grown in different districts using their network of agricultural extension workers operating at the village level (Bose *et al*. 2001). The survey estimated the most popular varieties in the dry season as BR14 (24%), BR3 (19%), and BR1 (9%), together occupying 52% of the total MV area. In the wet season, four varieties, BR11 (52%), Paijam (10%), BR10 (10%), and BR23 (5%), covered the total area under MV.

The IRRI-BIDS survey conducted in 2000 also collected data on specific rice varieties grown in different parcels of land operated by the sample farmers. The estimates obtained from the survey show that the most popular MV (rice varieties) grown during the wet season were BR11 (42%), Swarna (23%), and Paijam (13%), together occupying 78% of the total MV area. For the dry season, a large number of varieties were grown; the most popular ones were Brridhan 28 (11%), Brridhan 29 (9%), BR14 (11%), BR1 (7%), and BR8 (6%).

An important point to note from the above review is that farmers still grow a number of varieties that were released more than three decades ago. Three of these varieties, Pajam, Purbachi, and IR8, which predate the development of MV in Bangladesh (Miah 1989) were highly popular until the mid-1990s. Among varieties released by BRRI, the early generation varieties BR1 and BR3 occupied a large proportion of area in the dry season, even in 2000. The type BR11 released in 1980 was still the single most dominant variety in Bangladesh in the wet season in 2000.

The low replacement of MV in Bangladesh is often the result of such factors as a weak research-extension linkage, less effective public sector extension system, and the absence of a good seed market in Bangladesh (Hossain *et al*. 2001). In 2000, only 12% of farmers got information concerning MV from public sector extension officials, and almost 90% of the seeds planted were obtained from farmers' own harvests or were exchanged with neighbors. However, a major reason for low replacement of MV is the inability of the research system to develop new varieties with traits superior to the existing ones. Farmers value traits of high yield, good grain quality, and shorter maturity, as shown by the rapid diffusion of Brridhan 28 and 29 (dry season) in the late 1990s. As mentioned earlier, Brridhan 29 is the only variety that has higher yield potential compared to those of the early generation MV (Table 1). The type BR11 still remains popular because no new variety released for the wet season after BR11 has surpassed its yield potential.

It is also worth noting that a number of varieties released in India entered into Bangladesh through informal channels and became highly popular. The 2000 IRRI-BIDS survey noted that Swarna was the second most popular variety in the wet season, and Parijat and Ratna occupied a significant proportion of land in the dry season (Table 6). Swarna is a variety developed in Andhra Pradesh in 1982 (MTU 7029) with Mashuri as one of its parents, however, it is highly susceptible to the sheath blight disease. A survey done by the Department of Agricultural Extension (Department of Agriculture Extension, pers. obs., 2001) found that farmers consider major advantages of Indian varieties over the Bangladeshi ones as early maturity and good grain quality (in that order of importance). Their major disadvantage is their susceptibility to pests. Until very recently, the rice research system in Bangladesh did not give high priority to shorter maturity and improved grain quality in the breeding strategy.

The data obtained from the IFPRI-BIDS survey show that farmers also revert back from cultivation of MV to traditional ones. In two out of 62 villages under study, MV were grown in 1987 but were discontinued in 2000. In one of the villages located in the coastal area, installation of a shallow tubewell for irrigation led to build-up of soil salinity and hence the growing of MV with irrigation was stopped. In another village, the operation of deep tubewell was ceased because of the problem of mismanagement and recovery of irrigation fees. The household-level panel data show that for farmers who adopted MV in 1987, 70% continued to adopt in 2000, 9% dropped out, and 21% quit farming to engage full-time in non-farm activities. For the non-adopter farmers in 1987, 28% continued to non-adopt, 45% became adopters, and 27% quit farm activities.

III. IMPACT OF MODERN VARIETY ADOPTION ON FACTOR PAYMENTS AND FARM EFFICIENCY

This section uses household-level data from sample surveys to estimate the effect of the adoption of different generations of MV on farm incomes and productive efficiency. First, we estimate the changes in cost structure over 1987–2000 to assess the trend in the crop management practices in the 1990s, and the effect on factor payments and unit cost of production. Second, we classify the MV adopted in 2000 by generation, and compare the factor payments for different generations. Finally, we use a production function analysis to estimate the effect of different generations of MV on productive efficiency.

A major change in the crop management practices in recent years is the rapid spread of agricultural mechanization. The IRRI-BIDS sample survey conducted in 2000 reported 60% of the farm households rented machinery for the supply of farm power. This development has contributed to a downward trend in the use of animal and human labor in land preparation and threshing operations. The spread of mechanization has reduced the unit cost of cultivation on account of power. The cost per hectare on account of machine rental and animal and human labor has declined from US$100 in 1987 to US$54 in 2000.

The estimates of the use of three major inputs, i.e., labor, draft power, and chemical fertilizers in the cultivation of rice in different seasons obtained from the 1987 and 2000 surveys are reported in Table 3. The numbers show almost 78% reduction in the use of animal power, 25% reduction in the use of human labor, but 10% increase in the use of chemical fertilizers. The increase in the use of chemical fertilizers is, however, caused by the large expansion in the coverage of fertilizer-intensive MV in 2000 compared with 1987. Although the use of chemical fertilizers has marginally

TABLE 3

Changes in the Use of Major Inputs in Rice Cultivation, 1987 to 2000

Season/Varieties	Labor (Days/ha)		Draft Power (Days/ha)		Chemical Fertilizer (NPK/ha)	
	1987	2000	1987	2000	1987	2000
Modern varieties	206	133	46	10	176	135
Wet season	183	125	42	10	156	101
Dry season	218	139	49	10	187	158
Traditional varieties	146	107	43	10	42	46
Wet season	142	106	39	9	47	49
Dry season	155	112	51	12	31	37
Total	165	123	44	10	92	102

Sources: IRRI-BIDS sample surveys, 1987 and 2000. NPK = nitrogen, phosphorous, and potassium.

TABLE 4

Factor Payments, Factor Shares, and Unit Costs in the Cultivation of Modern Varieties (MV) and Traditional Varieties (TV), Dry Season, 1987 and 2000

	1987			2000		
	TV	MV	Difference	TV	MV	Difference
Gross value of output (US$/ha)	251 (100)	678 (100)	427 (100)	269 (100)	707 (100)	432 (100)
Current inputs (US$/ha)	38 (15)	105 (15)	67 (16)	31 (15)	94 (13)	63 (13)
Capital services (US$/ha)	82 (33)	194 (29)	112 (26)	32 (15)	144 (21)	112 (23)
Labor payments (US$/ha)	137 (55)	211 (31)	74 (17)	109 (52)	155 (22)	46 (9)
Total cost (US$/ha)	257 (102)	510 (75)	253 (59)	172 (82)	393 (56)	221 (45)
Residual payments (US$/ha)	−6 (−2)	168 (25)	174 (41)	38 (18)	308 (44)	270 (55)
Rice yield (t/ha)	1.46	3.89	2.43	1.71	4.98	3.27
Unit cost (US$/t)	176	131	−45	101	79	−22
Price (US$/t)	156	163	−7	144	134	−10

Sources: IRRI-BIDS sample surveys, 1987 and 2000.
Note: Figures in parentheses are percentage of the gross value of production.

increased in the cultivation of TV, the rate of use has declined in the cultivation of MV by 16% for the dry season and 35% for the wet season.

The estimates of the change in factor payments and unit cost of rice production during 1987–2000 are reported in Tables 4 and 5 for the dry and wet seasons, respectively. Despite of the increase in yield, the gross value of production per hectare has declined because of a downward trend in the price of paddy, measured in US dollars at current exchange rates. However, the cost of cultivation has also declined on account of all categories of inputs, current inputs, capital services, and labor costs.

TABLE 5

Factor Payments, Factor Shares, and Unit Costs in the Cultivation of Modern Varieties (MV) and Traditional Varieties (TV), Wet Season, 1987 and 2000

Items	1987			2000		
	TV	MV	Difference	TV	MV	Difference
Gross value of output (US$/ha)	368 (100)	570 (100)	202 (100)	326 (100)	519(100)	193 (100)
Current inputs (US$/ha)	38 (10)	96 (10)	58 (29)	33 (10)	65 (13)	32 (17)
Capital services (US$/ha)	64 (17)	73 (13)	9 (5)	34 (10)	36 (7)	2 (1)
Labor payments (US$/ha)	136 (37)	178 (31)	42 (21)	105 (32)	128 (25)	23 (12)
Total costs (US$/ha)	238 (65)	347 (61)	109 (54)	172 (53)	229 (44)	57 (30)
Residual payments (US$/ha)	130 (35)	223 (39)	93 (46)	154 (47)	290 (56)	136 (70)
Rice yield (t/ha)	1.79	3.04	1.25	2.01	3.33	1.32
Unit cost (US$/t)	132	114	−18	86	69	−17
Price (US$/t)	183	175	−8	148	144	−4

Sources: IRRI-BIDS sample surveys, 1987 and 2000.
Note: Figures in parentheses are percentages of the gross value of production.

The returns to the farmer for land and organization is measured in residual payments after deducting the cost of current inputs, capital services, and human labor (including the imputed value of family supplied inputs). The residual in the cultivation of MV has increased by 30% during 1987–2000 for the wet season and 83% for the dry season, despite of the decline in the price of output.

The difference of the residual payments in the cultivation of MV over that of TV measure the net return to the farmer from the adoption of MV, as the increase in cost associated with the adoption of MV has been deducted from the increase in gross revenue. The net return from the adoption was US$93 for the wet season and US$174 for the dry season in 1987. The return has increased substantially to US$136 and US$270, respectively, for the wet and dry seasons in 2000.

The impact of technological progress is often measured by the reduction in the unit cost of production. The cost of production per ton of output (excluding the imputed value of land rent and the interest charges on working capital) in the cultivation of MV was estimated at US$114 for the wet season and US$131 for the dry season in 1987. It has declined substantially to US$69 and US$79 respectively for the wet and dry seasons in 2000. A part of the decline is due to an increase in yields, but more substantially due to a reduction in cost per hectare due mainly to the spread of mechanization.

The 2000 IRRI-BIDS survey collected information on specific rice varieties grown in different parcels operated by the sample farm households. The estimates of the area covered by different generations of MV and their average yields obtained from the survey are reported in Table 6. The numbers show that the majority of the

TABLE 6

Area Covered and Yield of Different Generations of Modern Varieties (MV) Grown in 2000

Generations of Modern Varieties	Wet Season			Dry Season		
	Variety	% of Area	Yield (t/ha)	Variety	% of Area	Yield (t/ha)
First generation MV		11.0	2.91		23.1	4.82
	Paizam	7.4	3.14	BR1	6.8	4.74
				BR8	6.0	4.93
				BR3	3.3	4.46
Second generation MV		25.8	3.71		21.9	4.24
	BR11	24.3	3.82	BR14	10.0	4.83
Third generation MV		7.0	3.11		23.9	5.34
	BR32	1.6	3.53	BR28	9.8	5.02
				BR29	8.4	5.57
MV of Indian origin		14.3	2.92		20.0	5.50
	Swarna	13.4	3.06	Rotna	6.1	5.58
				Nayanmoni	3.7	5.04
				Parijat	1.2	5.21
Traditional varieties		41.9	2.12		11.1	2.11
All varieties		100.0	2.80		100.0	4.65

Source: IRRI-BIDS sample survey, 2000.

land is still cultivated by MV released in the 1970s and 1980s. The MV released by BRRI in the 1990s covered 24% of the land in the dry season and only 7% in the wet season. Approximately 20% of the land in the dry season and 14% in the wet seasons were covered by MV of Indian origin most of which were developed in the 1980s.

A technique frequently used to analyze productivity and efficiency of resource is the Cobb-Douglas production function. The different generations of rice varieties can be incorporated in the production function as dummy variables (with TV as control) to estimate the efficiency effect of different generations. The following production function was estimated with the parcel-level data:

$$\begin{aligned}\ln PRDN = {} & \ln a_0 + a_1 MV_1 + a_2 MV_2 + a_3 MV_3 + a_4 MVI + a_5 Aus + a_6 Boro \\ & + (b_1 + b_2 + b_3 + b_4)\ln Land + b_2 \ln(CI/Land) + b_3 \ln(CS/Land) \\ & + b_4 \ln(Labor/Land) + \sum c_i H_i + \sum d_i E_i,\end{aligned}$$

where *PRDN* is the gross value of production in the parcel, *Land* is the area of the parcel, *CI* is the cost on account of current inputs, *CS* is the cost on account of capital services, and *Labor* is the cost of labor including the imputed value of family labor. *Aus* and *Boro* are dummy variables used to represent different rice-growing seasons with the *aman* season used as control. MV_1, MV_2, and MV_3 are dummy variables to represent MV produced in the 1970s, 1980s, and 1990s, and *MVI* to represent Indian MV. The TV are used as the control. The H_i are the household-level socioeconomic variables. The variables used are farm size, tenancy ratio, age, occupation of the household head, and education of the household head. The variable E_i's are a set of environmental and technical factors that might affect productivity of the land. The factors considered are sources of irrigation for the parcel of land (with rainfed as control), the composition of different levels of land in the land portfolio of the farm (with medium-level land as control), and whether the village was affected by soil salinity.

Since the parcel-level cross section data are used to estimate the function, one expects the amount of different inputs used to be highly correlated with the amount of land for the parcel. This creates the well-known problem of multicollinearity in estimating the parameters of the function. To avoid this problem, the inputs have been measured per unit of land, which breaks the high degree of correlation in the variables. This produces a modified version of the Cobb-Douglas production function in which the coefficient of the logarithm of the *Land* variable becomes the sum of the elasticity of all production inputs. Since the MV adoption variables and input use variables are endogenous, it is desirable to estimate the regression coefficients by using the two-stage least square method using a set of instrumental variables (IV). Unfortunately, from the present datasets we could not find valid IV. Therefore, the coefficients are estimated using the ordinary least squares (OLS) method and are presented in Table 7. The OLS results need to be interpreted with caution because of the possible endogeneity bias. The coefficient of land area is the sum of the coefficients of all input variables. The value of the coefficient (0.97) is not significantly different from unity. These findings indicate the presence of constant returns to scale in rice production. The elasticity of output with regard to inputs is estimated at 0.13 for labor, 0.13 for capital, 0.10 for current inputs, and 0.61 for land.

Among socioeconomic variables, only the coefficient of education was found statistically significant, indicating positive effect of education on productive efficiency. The coefficient of farm size is negative, but statistically insignificant. The coefficient of the tenancy variable is positive indicating higher efficiency on tenant farms, but the coefficient is not statistically significant. The age and occupation of the farm manager also does not seem to influence productive efficiency.

The coefficient for the dummy variables representing seasons show lower efficiency in the *aus* season but equal efficiency in the *boro* season, compared with the *aman* season. The result might explain the downward trend in the area under *aus* rice in Bangladesh to accommodate the expansion of *boro* rice. The yield of *boro* rice is approximately 1.5 tons higher in *boro* than in the *aman* season. However, the difference is mainly because of the use of irrigation and higher application of chemical fertilizers.

The production efficiency is significantly higher if the land is irrigated by tubewells, but not by surface water irrigation compared with the rainfed conditions. The

TABLE 7

Estimates of Production Function for Rice, 2000

Factors	Unit	Mean	Std. Dev.	Coefficient	*t*-value
Log of land area for the parcel	ha	−2.05	0.65	0.968	58.40*
Log of current inputs used	Taka	8.06	0.80	0.102	6.49*
Log of capital services used	Taka	8.08	0.84	0.130	5.32*
Log of labor payments	Taka	9.00	0.33	0.124	3.78*
Ground water irrigation	Yes = 1	0.38	0.49	0.127	2.77*
Surface water irrigation	Yes = 1	0.08	0.27	0.056	1.14
Dummy for crop season:					
Aus (pre-monsoon)	Yes = 1	0.06	0.23	−0.243	−5.99*
Boro (dry season)	Yes = 1	0.45	0.50	−0.009	−0.20
Dummy for variety type:					
First generation MV	Yes = 1	0.21	0.40	0.221	6.29*
Second generation MV	Yes = 1	0.27	0.45	0.289	9.18*
Third generation MV	Yes = 1	0.16	0.37	0.287	7.63*
MV of Indian origin	Yes = 1	0.17	0.38	0.328	8.91*
Land portfolio of the farm:					
High land	ratio	0.38	0.44	0.0004	0.02
Low land	ratio	0.14	0.28	−0.069	−1.89
Very low land	ratio	0.13	0.30	−0.117	−3.18*
Dummy if village salt-affected	Yes = 1	0.06	0.23	−0.012	−0.31
Household characteristics:					
Farm size	ha	0.67	0.80	−0.006	−0.45
Rented in land	ratio	0.38	0.42	0.025	1.03
Education of head	Year of schooling	4.1	4.3	0.008	3.21*
Age of head	Year	46	12.6	0.0001	0.50
Occupation of head	Farm = 0, Non-farm = 1	0.24	0.43	−0.025	−1.05
Constant term				6.69	20.5*
Adj. *R*-square, *F*-value				0.78	257.2

Notes: The sample size (n) is 1,525. The dependent variable is measured in logarithm of the gross value of production that includes the value of by-products. The *aman* season is used as control in the dummy for season; traditional varieties are used as control in the dummy for variety type; and rainfed area is used as control in the dummy for source of irrigation.
* Denotes that the coefficient is statistically significant at the 5% level. MV = modern rice varieties.

productive efficiency is lower for farmers with a larger proportion of low and very low land compared to medium-level and high-level land. The negative coefficient of the soil salinity variable indicates that productive efficiency is lower in salt-affected areas, but the value of the coefficient is not statistically significant.

The coefficients of the dummy variables representing MV generations show substantially higher productive efficiency in the cultivation of MV compared with that in TV. The shift of land from TV to MV1 increases efficiency by 22%, whereas the shift of land from MV1 to MV2 increases efficiency by another 7%. These differences are highly statistically significant. There is no difference in the contribution of the third generation MV with that of the second generation. The third generation MV released in the 1990s is of shorter maturity compared with the earlier generations. They give farmers options to go for higher cropping intensity and avoid late season drought for the wet season and early flash floods for the dry season. These benefits are not, however, indicated in the value of rice production. The MV of Indian origin (Swarna for the wet season and Ratna and Parijat in the dry season) have the highest productive efficiency; about one-third higher compared with TV, and 4% higher compared with the second and the third generation MV in Bangladesh. This result might explain the popularity of Indian varieties among Bangladeshi farmers. The difference in the value of the coefficient for the MV of Indian origin with those for second and third generation MV of Bangladesh are not, however, statistically significant.

IV. CONCLUSIONS

The Bangladesh rice research system has been continuing to release improved varieties. The number of varieties released in the 1990s was higher than those released in the previous two decades. However, the priority for incorporating improved traits shifted to pest resistance, plant heights, and growth duration, to suit ecological variations in different parts of the country. The yield potential of the first generation MV was broken for the dry season only in 1994, and that achieved in 1980 for the wet season (BR11) has not yet been broken.

The cultivation of MV reached 65% of the rice area in 2001–02; 81% for the dry season and 51% for the wet season. The spread of MV has contributed to a growth in rice yield at 2.3% per year over the last three decades, which has helped Bangladesh achieve a favorable food security situation despite high growth of population and decline in arable land. The increase in yield, however, came mostly from gradual replacement of land from low-yielding TV to high-yielding MV. The yield in season-specific MV did not increase at all during the 1970–90 period, and had marginal increase in the 1990s. The profitability in the cultivation of MV has increased substantially in the 1990s mainly because of the spread of agricultural mechanization.

Bangladeshi farmers have been replacing MV, particularly, if they are of shorter maturity and the yield is higher compared with the existing ones. A production function analysis confirms higher productive efficiency in the first and second generations MV, but the increase is small compared with that from the initial shift from the TV to MV. The productive efficiency is higher for the MV of Indian origin but the difference is not statistically significant for the MV produced in Bangladesh.

The results of the present paper have important policy implications for national and international agricultural research, particularly for rice, which is a main staple in Asia and also gaining popularity in Africa recently. The important findings that MV2, MV3, and MV-Indian are all more or less equally productive, but are more productive than TV and MV1 clearly highlight the important contribution that the national rice research institution, BRRI, has made toward improving rice yields in Bangladesh. How crucial is the continuous research and release of improved rice varieties toward improving farm production and income for farmers comes out as a clear message to policymakers from the current paper. Farmers' enthusiasm in shifting of MV with the release of improved varieties at the field level is a sign of encouragement for research institutions to keep up their intensified research on varietal improvement of crops. Further, the finding that Indian MV with shorter maturity and superior grain quality are finding their way to Bangladeshi fields and yielding more or less equally to Bangladeshi MV at the farm level underlines the importance of regional and international cooperation in agricultural research.

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