PART 3

Late-Adopter Asian Countries

EVOLUTION OF AGRICULTURAL MECHANIZATION IN BANGLADESH: THE CASE OF TRACTORS FOR LAND PREPARATION

Mansur Ahmed and Hiroyuki Takeshima

Abstract: In Bangladesh, mechanization—particularly tractor use for land preparation—has grown, despite the country’s having one of the smallest average farm sizes in the region and a historically large rural labor force. The early period of this growth, up to the mid-2000s, was led by technological factors that significantly raised the demand for intensive farm power for land preparation. Economic transformation, including rising real wages, played a greater role in the expansion of mechanization following the mid-2000s. Recently, mechanization has become increasingly associated with growth of nonfarm income-earning activities, and household survey data show that it is increasingly substituted for labor. A considerable part of the growth of tractor use for land preparation during the last three decades has been led by the private sector, whereas the government has engaged in relatively few direct interventions in mechanization. These patterns of mechanization growth in Bangladesh have important implications for other countries that have yet to go through this process.

Introduction

In recent decades, agriculture in Bangladesh has undergone a remarkable transformation. Smallholder households in the country have adopted agricultural machinery, especially for land preparation, at an unprecedented level. Intensification of production systems along with the tightening of the rural labor market have created power bottlenecks in agricultural production, particularly in land preparation, harvesting, and threshing operations. These bottlenecks are alleviated with the adoption of labor-saving agricultural technology, which in turn raises agricultural productivity and reduces the per-unit cost of crop production (Pingali 2007). Mandal (2002) estimated that in

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Bangladesh around 150,000 power tillers have been imported annually since liberalized import policies were implemented in the mid-1990s.

The increase in market-based hiring of agricultural technology in Bangladesh brings the benefit of modern technology within reach of subsistence smallholder households. For example, in 2008 about 89 percent of farm households used tractor or power tillage for land preparation in agricultural production, yet only 4 percent of farm households owned a tractor, a power tiller, or both (Ahmed and Goodwin 2016). Smallholder households are also increasingly engaging in nonfarm economic activities, both to diversify the risks of farm income volatility from price shocks and production loss, and to smooth consumption during the lean season. This phenomenon encourages smallholder households to increasingly adopt agricultural mechanization in their farm practices.

This chapter explores the factors that play direct or indirect roles in the agricultural mechanization of smallholder farm households through the development of the custom hiring service (CHS) market for agricultural machinery in Bangladesh. The chapter examines the factors that affect the uptake of power tillers and tractors in Bangladesh. Because agricultural mechanization has evolved much more quickly for land preparation than for other farm activities, this chapter also explores and identifies constraints contributing to the slower pace of mechanization in weeding, harvesting, and threshing. Insights from the Bangladesh example of agricultural mechanization through CHS can provide insights for many developing countries in Asia, Africa, and elsewhere that are seeking sustainable ways to promote agricultural mechanization.

For the analysis of this chapter, we will rely on multiple rounds of the Household Income and Expenditure Survey (HIES), a nationally representative cross-sectional survey conducted by the Bangladesh Bureau of Statistics. We will use the three latest rounds of the HIES (2000, 2005, and 2010) to analyze the drivers of smallholder mechanization in rural Bangladesh. In addition to the use of these and other primary data, this chapter also uses secondary data from various sources to understand the evolution of smallholder agricultural mechanization in Bangladesh.

Evolution of Agricultural Mechanization and Supporting Policies in Bangladesh

The early wave of agricultural mechanization in Bangladesh occurred because of policies and programs that began in the 1970s in support of the Green

Revolution, including the release of successful high-yielding varieties (HYVs) and the spread of deep and shallow tube wells for irrigation. In countries like Bangladesh with extremely small average farm sizes, the major driver of demand for farm power comes from demand for increased intensity or frequency of tillage per plot of land, induced by the introduction of HYVs that would respond more to such intensive tillage.

Between 1972 and 1989, Bangladesh's domestic plant breeding institutes made 217 crosses of new rice varieties per year (Witcombe et al. 2013), from which approximately 1 out of 200 elite varieties were eventually selected and released. Few African countries with significant rice areas have invested in plant breeding at such intensity, even up until today.¹ By the late 1990s most of the popular rice varieties adopted by farmers had originated from these domestically crossed varieties, and by 1998 Bangladesh had spent \$3.4 million² on rice breeding activities alone (Hossain et al. 2003). Rice breeding has also focused on rainfed areas (Orr 2012), so the demand for intensive tillage rose considerably even in nonirrigated systems. By the early 1990s, right before power tillers began to be substituted for draft animals, the intensity of animal traction use had reached a substantial level—typically as high as 90 head-days per farming household per year (Mandal and Parker 1995), which is substantially higher than the intensity in African countries. For example, the average is just 6–9 head-days per farming household per year in Nigeria, as shown in the Nigeria chapter of this book. In the 1980s, though the share of rice area cultivated with tractors was still small, 98 percent of areas had been prepared by draft animals (IRRI 1986). The demand for intensive farm power for land preparation had thus risen significantly by the 1980s, and already far exceeded the levels in African countries today.

The surge of power tiller imports from China in the early 1990s is often attributed to the liberalization of import policies (Mottaleb, Krupnik, and Erenstein 2016; Mandal, Biggs, and Justice 2017). However, liberalization alone would not have caused this, if the demand for intensive farm power use had not risen following the improvements in varieties. Such technology-led growth in demand for farm power in the late 1980s and the 1990s is also consistent with the fact that mechanization grew in the 1990s and most of the 2000s despite flat agricultural real wages (Figure 7.1). By the time the real wage started rising in the late 2000s, 80 percent of land preparation was

1 For example, from 1961 to 2010, Nigeria, the largest rice producer in Africa, made only 10 crosses per year, 1/20 the number in Bangladesh (Takeshima and Maji 2016).

2 Dollar figures are US dollars throughout the chapter.

FIGURE 7.1 Agricultural labor, cattle/buffalo, machinery, and real wages, Bangladesh, 1992–2013

Source: Authors' own calculation using data from USDA (2018).

already done by tractors (Table 7.1). Wage increases since the late 2000s, and the declining use of draft animals and agricultural labor (Figure 7.1; Zhang et al. 2014), are likely to have induced further expansion of mechanization. The imported, fairly inexpensive power tillers—priced at around \$800–\$1,000 (Mottaleb et al. 2017)—have accounted for the majority of tractor power provided, although recently four-wheel tractors (4WTs) have started to account for an increasing share of tractor use. In 2010, 4WTs contributed 40 percent to the total 95 percent of rice area that was plowed by tractors (Table 7.1).

Mechanization of other operations in Bangladesh has remained low. The number of combine harvesters in the country is minimal; the total was just 30 in 2008, 100 in 2011 (Biggs and Justice 2013), and 160 in 2012 (CSAM 2014). Similarly, the number of transplanters was just 200 in 2011.³ Mechanization of these operations is likely to grow in the coming decades.

Although Bangladesh's agricultural mechanization lagged behind that of neighboring South Asian countries in the 1980s and 1990s, mechanization growth in the last decade has been outstanding, and the country has quickly outpaced its neighbors in terms of the intensity of agricultural machinery per 1,000 ha of agricultural land (Figure 7.2). Given the fact that average farm

3 Presentation at the Bangladesh Agricultural Research Institute on November 4, 2015.

TABLE 7.1 Evolution of economic and employment structure and mechanization in Bangladesh, 1980s–2010s

Variable	1980s	1990s	2000s	2010s
Sector share of GDP^a				
Agriculture	31	27	20	18
Manufacturing/industry	21	23	25	27
Service	46	50	55	56
Employment share (%)^a				
Agriculture	—	60	51	44
Manufacturing/industry	—	11	13	18
Service	—	21	32	35
Share (%) of rice area plowed by tractors	< 2 (1986) ^b	28 (1996) ^c	80 (2008) ^d Wheat: 75 (2002) by 2WT ^e	95 ^b (55—2WT, 40—4WT)
Share (%) of area plowed by animals	98 (1986) ^b	—	—	30 (2013) ^f
Share (%) of spare parts produced locally ^g	—	—	2 (2004/2005)	77 (2011)
Share of arable land irrigated (%) ^h	Approx. 20	Approx. 40	Approx. 60	—

Source: ^a World Bank (2018). ^b IRRI (1986). ^c Ahmed (2001). ^d Roy and Singh (2008); author's conversation with The Metal Ltd. ^e Meisner et al. (2003). ^f Ahmed (2013). ^g Alam and Khan (2017). ^h FAO (2018).

Note: — = data not available; 2WT = two-wheel tractors; 4WT = four-wheel tractors; GDP = gross domestic product.

size in Bangladesh is the smallest in the region, the major cause of the spread of agricultural mechanization is the CHS market. This is true even though the dominant machine, the power tiller, is relatively affordable when compared with 4WTs. In 2013, a nationally representative survey showed that 72 percent of farmers used power tillers, but only 2 percent of farmers actually owned them. This suggests that on average, each power tiller–owning farmer served 36 other farmers (Ahmed 2013).

The private sector in Bangladesh played a key role in the overall agricultural mechanization process. Agricultural machinery importers and suppliers in Bangladesh have extensive service and sales networks, and often provide credit support and free servicing offers to support the sale of agricultural machines. Since the mid-2000s, about 100 importers in the country have been responsible for the total of approximately 50,000 power tillers imported per year, which mostly come from China (Mottaleb et al. 2017). Over time, the numbers of tractor dealers and retailers in the country have increased to 500 and 2,000–2,500, respectively (Bhattarai et al. 2017). It is important to note that the power tiller import market is still quite concentrated; for example,

FIGURE 7.2 Agricultural machinery use in South Asian countries

Source: Authors' own calculation using data from USDA (2018).

Note: The total stock of farm machinery in "40 CV tractor equivalents" aggregates the number of two-wheel tractors (2WTs), four-wheel tractors (4WTs), and combine harvesters. For weights, we assume 2WTs average 12 CV; 4WTs, 40 CV; and combine harvesters, 20 CV. Data for each category are from the Food and Agriculture Organization of the United Nations, except for the data for 2WT, which were compiled from national sources. BGD = Bangladesh; CV = *cheveaux vapeur*, or metric horsepower; IND = India; LKA = Sri Lanka; PAK = Pakistan.

in 2014 the largest importer accounted for 80 percent of the 60,000 units imported that year.⁴

Along with the continuous increase in agricultural machine imports, local manufacturing of small-scale agricultural machines and spare parts has also grown. During the 2000s and onward, substantial growth occurred in local manufacturing of agricultural machinery, attachments, and spare parts. As the overall market for spare parts for power tillers, diesel engines, and centrifugal pumps grew from \$89.2 million in 2004/2005 to \$309.3 million in 2011, the share of locally manufactured products increased from about 2 percent in 2004/2005 (\$1.78 million) to 77 percent in 2011 (\$237.9 million) (Alam 2005; Alam and Khan 2017). Much of this growth has been spatially concentrated; in 2011, 80 percent of the local spare parts were produced in Bogra district, with Dhaka and Jessore districts accounting for the remaining 20 percent (Alam and Khan 2017). Such high spatial concentration may reflect the role of clusters in the growth of the manufacturing industry, as well

⁴ Furthermore, Bhattarai and others (2017) have suggested that the number of importers with substantial import quantities could be as low as 8–10.

as high spatial mobility of spare parts. Aside from spare parts for centrifugal pumps, the manufacturing of centrifugal pumps themselves also grew; by 2010, about 560,000 units of centrifugal pumps had been supplied for shallow tube wells and low-lift pumps in the country, almost all of which were produced locally (Alam and Khan 2017). Again, Bogra district accounted for 90 percent of centrifugal pumps produced in Bangladesh. In the mid-2010s, meetings with agricultural machinery firms revealed that local manufacturing of small power tillers had begun for the first time in the country, produced by Alim Industries Ltd. in Sylhet district (Animaw et al. 2016). This local manufacturing has been enabled by the spread of local workshops and artisans; by 2012, there were 550 agrimachinery manufacturing workshops, 250 spare parts manufacturing workshops, 10,000 repair and maintenance workshops, and 100,000 village artisans (CSAM 2014).

Though the government in Bangladesh has not been directly involved in the importation and supply of agricultural machinery, it has provided key supports through the tariff liberalization of agricultural equipment imports, and subsidies and tax exemptions to local producers of agricultural machinery and private businesses importing, manufacturing, and selling agricultural machines and tools. These supporting policies may have driven the development of the agricultural machinery hiring service market in Bangladesh. Generally, over the last two decades, successive governments have adopted agricultural policies that were conducive to agricultural mechanization.

Several government agencies worked together to achieve the goal of increased agricultural mechanization. The major agencies include the Bangladesh Agricultural Development Corporation, the Bangladesh Rural Development Board, the Department of Agricultural Extension, the Bangladesh Rice Research Institute, the Bangladesh Agricultural Research Institute, and the Bangladesh Agricultural Research Council. Furthermore, the Department of Agricultural Extension has 26,000 staff across the country, amounting to a high ratio of extension staff to farmers and creating a strong extension system in the country.

Demand-Side and Supply-Side Factors in the Growth of CHS: Descriptive Evidence

There are many factors that affect agricultural mechanization directly and indirectly through CHS. This section explores why smallholders are accessing mechanization through CHS, instead of through individual ownership of machines. The use of longitudinal data that track the behavioral changes

of the smallholder farm households in rural Bangladesh may be the best strategy to identify the major factors behind smallholders' adoption of mechanized processes in land preparation, harvesting, and threshing. For the analysis in this chapter, we will rely on multiple rounds of a nationally representative cross-sectional survey, the HIES. The Bangladesh Bureau of Statistics, a wing of the Ministry of Planning of the government of Bangladesh, has conducted this survey periodically since 1973/1974, and it has undergone many transformations in terms of methodology and coverage over the decades. We will use the three latest rounds of the HIES (2000, 2005, and 2010) for analyzing the drivers of smallholder mechanization in rural Bangladesh. This chapter also complements the HIES analysis with some results from three rounds of a unique panel survey (Ahmed and Goodwin 2016).⁵

The HIES collects detailed information about households' farm production practices, such as land preparation, weeding, harvesting, and threshing. In addition to farm production practices, the survey asks for information related to households' socioeconomic status as well as constraints such as access to finance and markets. We sketch profiles for both mechanized and nonmechanized households using descriptive analysis from the survey data for the last decade, and identify the potential correlates that may drive rural smallholder farm households to adopt mechanization in their farm production practices. We also sketch a profile of the mechanized service providers to identify their role in farm mechanization and to identify the factors behind the development of this service market in rural Bangladesh.

The rural module of the HIES included 3,005 farm households in 2000 and 4,798 farm households in 2010. Although the survey does not allow us to track adoption of all kinds of agricultural machinery through the hire market, we are able to identify the adoption practices within the hire market for tractors/power tillers. The evidence shows a consistent increase in the adoption rate of tractors/power tillers over last decade, with use of tractors/power tillers increasing from 56 percent in 2000 to 67 percent in 2010 (Table 7.2).⁶ The HIES survey also elicits information about ownership of agricultural machinery; results show that the rate of agricultural machinery ownership has grown over time. For example, the number of threshers per 1,000 farmers increased

5 The first round of this panel survey took place in 1988, and the repeat rounds were conducted in 2000, 2004, 2008, and 2013. We could access the data for 2000, 2004, and 2008 only.

6 The panel survey of rural households conducted by Mahaboob Hossain showed that the adoption of tractors/power tillers for land preparation was 87 percent in 2008 (cited in Ahmed and Goodwin 2016).

TABLE 7.2 Profile of farm machines of farm households, Bangladesh, 2000–2010

Category	2000	2005	2010
Farmers	3,005	3,824	4,798
Adoption of tractors/power tillers (%)	56	62	67
Cost of tractor rental per ha (in 2010 BDT)	1,848	2,066	3,481
Tractors (per thousand farmers)	6	4	6
Power tillers (per thousand farmers)	12	17	17
Threshers (per thousand farmers)	22	35	28
Power pumps (per thousand farmers)	17	12	25
Deep tube wells (per thousand farmers)	14	10	14
Shallow tube wells (per thousand farmers)	61	66	84
Sprayers (per thousand farmers)	22	17	45
Husking machines (per thousand farmers)	9	4	8
Ginning machines (per thousand farmers)	2	0	3

Source: Authors' own calculation using data from Household Income and Expenditure Surveys for 2000–2010.

Note: BDT = Bangladeshi taka.

from 22 in 2000 to 28 in 2010. Similarly, the number of mechanized sprayers per 1,000 farmers has doubled in the last decade.

The kernel density of operating land distribution reveals a clear distinction between the households that use agricultural machines and those that own them. More than 80 percent of using, or “adopter,” households are marginal or small-scale farmers operating less than 1 ha, whereas less than 40 percent of machine-owning households are marginal or small-scale farmers (Figure 7.3). The 2008 agricultural census reported that 84 percent of rural farm holdings were actually small farm holdings—that is, less than 2.5 acres (BBS 2010)—and ownership of agricultural machinery is often beyond these farmers' reach. The high adoption rate of agricultural machinery among smallholder households is therefore an outcome of the presence of the CHS market. Evidence suggests that the majority of agricultural machinery owners are large-scale farmers who hire out their tools to non-owner farmers (who are mostly smallholders) through the CHS market (Figure 7.4).

Figure 7.5 shows that the share of agricultural machinery-owning households that hire out their machines through the CHS market has declined from 90 percent in 2000 to 65 percent in 2010. This suggests that an increasing number of farm households have purchased agricultural machinery for their own use only, most of whom are large- or medium-scale farmers. Figure 7.4 also shows that the medium-scale farmers are increasingly buying

FIGURE 7.3 Kernel density of land distribution among adopters and owners of machinery, Bangladesh, 2000–2010

Source: Authors' own calculation using data from Household Income and Expenditure Surveys for 2000–2010.

FIGURE 7.4 Landownership and adoption of agricultural machinery, Bangladesh, 2000–2010

Source: Authors' own calculation using data from Household Income and Expenditure Surveys for 2000–2010.

FIGURE 7.5 Percentage of owners hiring out their tractors/power tillers, Bangladesh, 2000–2010

Source: Authors' own calculation using data from Household Income and Expenditure Surveys for 2000–2010.

agricultural machines and thus the average amount of operating land of the owning households has declined from more than 5 ha in 2000 to less than 2 ha in 2010.

Agroecological Conditions and Agricultural Mechanization

The literature on farm mechanization often suggests that adoption of agricultural machinery is significantly related to the agroecological conditions and cropping patterns in a country. Despite minimal variation in agroecological conditions and cropping patterns across Bangladesh, we observe significant variation in adoption behaviors across the agroecological distribution of farm households. Although the longitudinal data show that mechanical adoption is increasing across agroclimatic conditions, these data also show that the share of adopter households is comparatively low in coastal regions, especially in the saline coast region.⁷ For example, in 2008 the adoption rate of tractors/power tillers for land preparation in the saline coast was 76 percent, whereas

⁷ Mahaboob Hossain, the principal investigator of the survey, categorized sample villages into five different groups based on their agroclimatic conditions. The five agroclimatic conditions are flood-prone, drought-prone, saline coast, non-saline coast, and favorable (cited in Ahmed and Goodwin 2016).

it was 89 percent in favorable and flood-prone regions (Figure 7.6). Farmers in drought-prone and non-saline coast regions are catching up quickly in terms of agricultural machinery adoption, with the shares of adopter farm households increasing much faster in these regions from 2000 to 2008 than in other regions. For example, the share of agricultural households that used tractors/power tillers for land preparation in drought-prone zones increased from 51 percent in 2000 to 84 percent in 2008. We see some variation in the adoption rates across administrative divisions, with rates ranging from 83 percent to 91 percent in 2008 (Figure 7.7). Sylhet division, especially, lagged in terms of adoption in early 2000 but caught up quickly with the rest of the country and increased its adoption rate from 43 percent in 2004 to 91 percent in 2008.

Table 7.3 reveals various characteristics of adopter (non-owner), owner, and non-adopter farm households across rural Bangladesh. The rate of adoption of agricultural machinery for land preparation increased consistently over the 2000s, from 56 percent in 2000 to 67 percent in 2010. The intensity of ownership also increased from 1.6 percent in 2000 to 2 percent in 2010. The adoption rate of 67 percent, with the ownership rate of 2 percent, suggests a large role for the CHS market in the spread of agricultural mechanization in Bangladesh. More than 95 percent of farm households, most of which are smallholders, rely on CHS to get the necessary services for their farm production process.

The variation in demographic characteristics between adopter households and non-adopter households is also evident. The average age of adopter household heads is slightly lower compared with the non-adopter household heads, implying a tendency for agricultural machinery adoption to be higher among younger farmers. The adoption rate is lower among female-headed households, and access to the CHS market may be a constraining factor for these households. There is systematic variation in household sizes between the adopter and non-adopter households. Finally, non-Muslim farm households were initially slow to adopt agricultural machinery, but they caught up quickly.

Labor–land ratios have important implications for the growth of agricultural mechanization. Table 7.3 also reveals that labor shortage is, in fact, a key factor for agricultural mechanization in Bangladesh. The shortage highlights the need for agricultural mechanization and explains why smallholders rely on the CHS markets for the services of agricultural machines. Average labor endowment is much lower among adopter households compared with non-adopter households. For example, in 2010, adopter households had about 14,000 labor hours per hectare available, whereas non-adopter households had more than 31,000. Average labor endowment is even lower among owner

FIGURE 7.6 Mean adoption rate of tractors/power tillers by ecology, Bangladesh, 2000–2008

Source: Authors' own calculation using data from Ahmed and Goodwin (2016).

FIGURE 7.7 Mean adoption rate of tractors/power tillers by division, Bangladesh, 2000–2008

Source: Authors' own calculation using data from Ahmed and Goodwin (2016).

households, and these severe labor shortages may have driven them to own agricultural machines. This is consistent with the hypothesis that low labor endowment is one of the key factors that can explain the rise in smallholder mechanization demand.

There is no variation in terms of literacy among the heads of adopter and non-adopter households. Also, there is minimal variation in enterprise ownership, electricity access, and mobile phone use. The agricultural machinery

TABLE 7.3 Characteristics of tractor/power tiller adopter and owner households, Bangladesh, 2000–2010

Variable	HIES 2000			HIES 2005			HIES 2010		
	Non-adopter	Adopter	Owner	Non-adopter	Adopter	Owner	Non-adopter	Adopter	Owner
Percentage of households	44.43	55.57	1.57	38.02	61.98	1.97	32.76	67.24	2.04
Age of head	47	45	50.51	48	47	53.52	49	47	50.01
Female head (yes = 1)	0.06	0.03	0.02	0.14	0.05	0.01	0.20	0.07	0.04
Household size	5.65	5.43	7.98	4.43	4.69	6.11	4.49	4.85	5.50
Religion (non-Muslim = 1)	0.11	0.06	0.04	0.13	0.12	0.08	0.13	0.12	0.07
Employed workers per ha	14.75	4.72	2.06	14.26	5.43	2.12	12.46	5.91	3.11
Ag. labor per ha	6.59	1.92	0.17	3.76	1.86	0.11	2.94	1.94	0.54
Ag. farmers per ha	11.14	3.63	1.61	1.39	2.48	1.68	1.50	2.55	2.50
Non-ag. labor per ha	4.69	1.21	0.22	4.44	0.88	0.08	3.95	1.19	0.10
Annual work hours per ha	39,687	11,888	4,985	35,293	12,535	3,972	31,382	13,694	6,675
Literacy of head (yes = 1)	0.42	0.42	0.63	0.48	0.42	0.59	0.52	0.43	0.55
Enterprise (yes = 1)	0.22	0.26	0.28	0.23	0.22	0.31	0.24	0.24	0.26
Electricity (yes = 1)	0.19	0.20	0.26	0.36	0.34	0.45	0.50	0.44	0.57
Mobile phone (yes = 1)	0.00	0.00	0.00	0.10	0.06	0.15	0.66	0.62	0.90
Aus (yes = 1)	0.21	0.22	0.19	0.13	0.17	0.28	0.09	0.15	0.22
Aman (yes = 1)	0.50	0.68	0.83	0.32	0.63	0.68	0.20	0.64	0.73
Boro (yes = 1)	0.48	0.78	0.74	0.32	0.80	0.81	0.20	0.79	0.79
Wheat (yes = 1)	0.15	0.17	0.33	0.05	0.10	0.26	0.04	0.11	0.20
Jute (yes = 1)	0.09	0.16	0.20	0.07	0.18	0.28	0.06	0.23	0.38
Other (yes = 1)	0.54	0.59	0.79	0.35	0.52	0.76	0.50	0.94	0.93
Forest (yes = 1)	0.70	0.69	0.78	0.23	0.37	0.47	0.42	0.52	0.72
Fish (yes = 1)	0.23	0.22	0.45	0.11	0.22	0.25	0.17	0.24	0.28
Livestock (yes = 1)	0.88	0.87	0.98	0.25	0.43	0.46	0.75	0.90	0.93
Cattle/buffalo per ha	5.49	2.92	1.54	4.81	3.91	2.61	4.58	4.76	5.97
Own cultivated land (decimals)	153	132	740	129	123	410	109	105	345
Total operating land (decimals)	288	237	1,384	234	192	535	213	171	501

Source: Authors' own calculation using data from Household Income and Expenditure Surveys for 2000–2010.

Note: HIES = Household Income and Expenditure Survey.

adoption rate is generally very high among boro (spring rice) and aman (rainy-season rice) producers, but quite low among aus (dry-season rice) producers; adoption of agricultural machines is also low among the farm households that produce wheat and jute. The farm households that are involved in forestry, fisheries, and livestock are more likely to adopt agricultural machinery in their farm production processes. Cattle and buffalo are generally used for traditional cultivation processes, and [Table 7.3](#) reveals that, especially in 2000 and 2005, the farm households that adopt agricultural machinery own fewer of these animals than the farm households that do not adopt agricultural machinery.

In this section, we have seen that farm households hiring agricultural machinery own and operate a smaller area of cultivable land than the machine-owning households. [Table 7.3](#) also shows that machinery-using farm households own or operate less land than the non-adopter farm households, implying a fast rate of adoption among smallholders.

Drivers of Mechanization Adoption

This section discusses the empirical evidence on the factors playing an important role in agricultural mechanization growth in Bangladesh ([Appendix 7A](#) describes the econometric models used).

[Table 7.4](#) presents the results on the adoption and ownership of tractors, power tillers, or both, using equation (1) in the appendix. The first six columns present results on adoption decisions from each of three rounds (HIES 2000, 2005, and 2010), and the last six columns present results on ownership decisions of farm households from the same three rounds. In general, youths are more inclined to adopt new technologies than their elder counterparts, and the age of household heads is negatively correlated with adoption in 2000 and 2010. However, age is generally not an important factor in explaining the ownership of agricultural technologies. Among other demographic variables, household size is an important determinant of adoption and ownership of agricultural machinery. A large household often implies a joint family with large land and financial endowments, which make such a family more likely to own and adopt agricultural technologies, compared with single-family farm households. Gender also plays an important role in the adoption of agricultural technologies. Female-headed households are less likely to adopt agricultural machinery, which may be due to a lack of gender-friendly social norms—especially toward female workers in agricultural activities—and a lack of management skills.

TABLE 7.4 Determinants of adoption and ownership/service provision of tractors, Bangladesh, 2000–2010

Variable	Adoption decision			Ownership and service-providing decision				
	HIES 2000	HIES 2005	HIES 2010	HIES 2000	HIES 2005	HIES 2010	HIES 2005	HIES 2010
Age of household head	-.004** (.002)	-.003* (.002)	-.004** (.002)	.002 (.006)	.010** (.005)	-.001 (.005)		
Religion (non-Muslim = 1)	-.302*** (.091)	-.052 (.069)	-.068 (.066)	-.461 (.337)	-.436* (.256)	-.119 (.223)		
Household size	.019 (.012)	.064*** (.013)	.068*** (.012)	.101*** (.027)	.080*** (.029)	.080*** (.031)		
Female head (Yes = 1)	-.315*** (.120)	-.728*** (.085)	-.690*** (.069)	-.050 (.480)	-.580 (.460)	-.431 (.363)		
Agricultural workers (per ha)	-.012*** (.002)	-.008*** (.002)	-.003** (.002)	-.193*** (.072)	.002 (.007)	.004 (.004)		
Nonagricultural workers (per ha)	-.206*** (.063)	-.266*** (.055)	-.280*** (.052)	-.300 (.215)	-.637*** (.192)	-.461** (.186)		
Schooling of household head	-.007 (.011)	-.018* (.010)	-.031*** (.009)	-.011 (.031)	.019 (.022)	.030 (.026)		
Average schooling of workers	.035 (.042)	.029 (.028)	.041 (.027)	-.015 (.104)	-.022 (.074)	-.125 (.117)		
Farmer class (base = marginal farmer)								
Small farmer	-.050 (.063)	-.012 (.054)	.141** (.062)	-.292 (.288)	.767*** (.228)	.862*** (.184)		
Medium/large farmer	-.139* (.075)	-.253*** (.065)	.133** (.060)	-.141 (.322)	.951*** (.238)	.842*** (.177)		
Number of cattle/buffalo per ha	-.022 (.015)	.063*** (.014)	.000 (.004)	.017 (.028)	.038 (.026)	.001 (.006)		
Electricity (Yes = 1)	.092 (.066)	-.035 (.051)	-.080* (.046)	-.035 (.195)	.168 (.132)	.191 (.142)		
Enterprise (Yes = 1)	.225*** (.071)	.033 (.061)	.024 (.061)	.193 (.230)	.652*** (.196)	.082 (.230)		
Forestry (Yes = 1)	.008 (.058)	-.017 (.090)	.085* (.045)	.010 (.206)	.290 (.286)	.156 (.142)		
Fishing (Yes = 1)	.007 (.061)	.201*** (.076)	.223*** (.055)	.285* (.162)	-.269 (.185)	.157 (.157)		
Livestock (Yes = 1)	-.078 (.081)	.214** (.096)	.586*** (.059)	.000 (.000)	-.190 (.297)	-.116 (.213)		
Domestic remittances (Yes = 1)	-.198** (.086)	-.044 (.080)	-.098 (.069)	.002 (.248)	-.202 (.226)	.012 (.210)		
Foreign remittances (Yes = 1)	-.248*** (.062)	-.188*** (.053)	-.063 (.061)	-.020 (.189)	-.139 (.151)	-.304 (.245)		
Log (travel time to the nearest 250,000 population city)	-.290*** (.047)	-.027 (.043)	-.122*** (.038)	.018 (.132)	.065 (.123)	.021 (.124)		

Variable	Adoption decision			Ownership and service-providing decision			
	HIES 2000	HIES 2005	HIES 2010	HIES 2000	HIES 2005	HIES 2010	
Wall materials brick/cement (Yes = 1)	-.087 (.095)	-.019 (.075)	-.089 (.063)	-.144 (.238)	.066 (.165)	-.225 (.180)	
Log (average rainfall)	.666*** (.199)	-.593*** (.148)	.233 (.265)	-.004 (.577)	-.502 (.431)	-.453 (.998)	
Std. dev. of rainfall	-.002*** (.001)	.002*** (.001)	-.002* (.001)	.000 (.002)	.001 (.002)	-.001 (.002)	
Division dummies (reference = Barisal)							
Chittagong	.586*** (.110)	.666*** (.102)	.630*** (.091)	.225 (.312)	.415 (.319)	-.442 (.339)	
Dhaka	.932*** (.104)	.716*** (.089)	.828*** (.088)	-.374 (.337)	.191 (.282)	-.286 (.293)	
Khulna	.966*** (.121)	.424*** (.133)	.923*** (.109)	.378 (.341)	.433 (.382)	.012 (.354)	
Rajshahi	1.22*** (.118)	.864*** (.123)	.973*** (.113)	.093 (.336)	.451 (.351)	-.048 (.358)	
Sylhet	n.a.	.275** (.136)	.972*** (.147)	n.a.	.033 (.134)	-.345 (.348)	
Rangpur	n.a.	n.a.	1.23*** (.110)	n.a.	n.a.	-.069 (.497)	
Observations	3,005	3,800	4,426	3,005	3,800	4,426	
			n.a.	n.a.	n.a.	n.a.	

Source: Authors' estimations using data from Household Income and Expenditure Surveys for 2000–2010.

Note: Standard errors are in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. HIES = Household Income and Expenditure Survey; n.a. = not applicable.

Households with high labor endowments of both farm and nonfarm workers are less likely to adopt and own agricultural machinery. Agricultural machines in Bangladesh are generally labor-saving technologies, and thus households with an excess labor endowment do not have a strong need to adopt mechanized agricultural processes unless there are high opportunity costs from engaging labor in farm activities. The results suggest that schooling, especially overall education levels of all household workers, plays a limited role in the adoption of agricultural machinery. Supporting this result, Ahmed and Goodwin (2016) found that the education of working household members was not an important driver of technology adoption in rural farm households.

Effects of farm size on adoption are somewhat ambiguous, reflecting the possibility that some smallholders may be more productive than larger farmers, if returns on machine use intensity per unit of land are sufficiently high. Households with large farms are still more likely to be the owners of farming machinery, compared with smallholder households, and it is the CHS market that brings the services of agricultural machinery to the doorsteps of smallholder farm households. The role of households' orientation toward high-value crop production (for example, livestock or fisheries) in the adoption of agricultural machinery has also become more significant over time. The receipt of remittances, both foreign and domestic, has not come out as an important driver of either adoption or ownership of agricultural machinery, even in later years; indeed, in earlier years the effects were negative. This might indicate that liquidity constraints were not binding on machine adoption, and remittances would even substitute for higher agricultural incomes from intensification. The role of rainfall and its variability has changed over the years, possibly because, over the years, the frontier of machine-use adoption moved from favorable areas to more marginal areas with very different hydrological conditions and thus farming systems.

The clear demarcation between the advanced urban economy and the rural farm economy has been disappearing rapidly due to infrastructure development in recent decades. Therefore, the overall business climate in rural areas has improved significantly. Improved connectivity has been an important driver of the adoption of agricultural machinery in rural areas. The results indicate that distance (measured by travel time) to a big city (with a population of 250,000 or more) is negatively associated with the rate of machine adoption. Across regions, our regression results show minimal variation in machinery ownership but significant variation in overall machinery adoption. Barisal division has the lowest rate of agricultural machinery adoption,

whereas the adoption rate is quite high in the Rajshahi, Rangpur, and Sylhet divisions.

Table 7.5 shows the results from equation (2) in the appendix. Most of the results from the panel survey regressions are in line with our findings from the HIES data. Higher dependency ratios among the rural households induce households to adopt agricultural machinery. Education (particularly higher levels), as in the earlier results, does not stand out as an important driver of agricultural machinery use. High intensity of nonagricultural workers among rural households induces them to adopt labor-saving agricultural technologies. Agricultural mechanization is also strongly positively associated with the share of irrigated land of rural farm households. Crop diversification generally supports agricultural mechanization among rural farm households. The results also confirm that connectivity, measured as distance from Dhaka in kilometers, and access to electricity are important for the rural farm households in their machine adoption decisions.

The panel regressions provide some new insights because of new determinants available in the data. Soil type and village ecological conditions come out as important factors in the adoption of agricultural machinery among rural farm households. Adoption rates are high among households with a higher amount of clay loam, loam, and sandy loam land; farm households with sandy land are less likely to adopt agricultural machinery. Farm households in flood-prone areas are most likely to adopt labor-saving agricultural technologies, followed by the farm households in favorable zones and drought-prone zones. The adoption rate is much lower in both saline and non-saline coastal zones.

Impact of Agricultural Mechanization on Nonfarm Labor Supply and Agricultural Productivity

Policymakers and development economists have long been cautious about promoting agricultural mechanization in densely populated countries with surplus labor, due to its potential displacement of labor and tenant farmers. However, existing evidence suggests minimal labor displacement effects occur from power-intensive agricultural operations such as tillage, water lifting, and milling (Pingali 2007). Therefore, agricultural mechanization has been a focus in many densely populated countries such as Bangladesh and India.

Agricultural mechanization can enhance agricultural productivity in three ways: (1) improvement in crop yields, (2) cultivation area expansion, and (3) agricultural labor savings. Early literature on agricultural mechanization

TABLE 7.5 Determinants of adoption of tractors and/or power tillers, Bangladesh, 2000–2008

Variable	Unbalanced panel		Balanced panel	
Head is female (Yes = 1)	–.054	(.323)	–.167	(.412)
Log (head age)	.203	(.227)	–.203	(.300)
Log (dependency ratio)	.196***	(.061)	.209***	(.078)
Dummy of head with primary education	–.061	(.063)	–.167**	(.080)
Dummy of head with secondary education	.020	(.128)	–.128	(.148)
Dummy of head with SSC and above education	.099	(.210)	–.111	(.244)
Any female worker in the HH?	–.210	(.215)	–.325	(.267)
Share of nonagricultural workers in the HH	.178**	(.073)	.240**	(.098)
Proportion of irrigated land	.749***	(.074)	.704***	(.104)
Proportion of rented/sharecropped land	.367*	(.192)	.254	(.240)
Crop diversification index	.457***	(.125)	.372**	(.161)
Fragmentation index	.032	(.174)	.272	(.217)
Proportion of high land in total cultivated land	.021	(.142)	.033	(.175)
Proportion of medium land in total cultivated land	–.207**	(.105)	–.202	(.138)
Proportion of low land in total cultivated land	–.189	(.153)	–.180	(.188)
Proportion of loamy land in total cultivated land	.568***	(.162)	.513**	(.205)
Proportion of sandy loam land in total cultivated land	.439***	(.158)	.410**	(.201)
Proportion of clay loam land in total cultivated land	.869***	(.165)	.795***	(.208)

found no evidence of yield differences between draft animal power and power tillage (Binswanger 1978; Herdt 1983). However, agricultural mechanization does help to improve the technical efficiency of farmers (Hormozi, Asoodar, and Abdeslahi 2012). Area expansion, substitution for labor shortages, and labor savings are other motivations for power-intensive operations in agricultural production. However, in a densely populated country like Bangladesh, the potential for cultivable land expansion is extremely limited because the amount of arable land per agricultural worker is tiny; for example, there was just 0.26 ha per worker from 2006 to 2011 in Bangladesh.

The empirical literature on the productivity effects of agricultural mechanization indicates that labor savings are the primary source of productivity gains from power-intensive agricultural operations (Pingali, Bigot, and Binswanger 1987). Given the limited scope of area expansion, labor savings or labor shortages are likely the primary factors motivating power-intensive agricultural operations in Bangladesh. Ahmed and Goodwin (2016) found that rural farm households that adopted labor-saving technology participated more

Variable	Unbalanced panel		Balanced panel	
CV of rainfall in last 10 years	-.003	(.006)	-.003	(.008)
Log (distance from Dhaka in km)	-.217**	(.098)	-.208	(.132)
Access to electricity (Yes = 1)	.231***	(.061)	.201**	(.079)
Village ecology (base = flood-prone)				
Drought-prone	-.576***	(.120)	-.715***	(.166)
Saline coast	-.957***	(.146)	-.923***	(.202)
Non-saline coast	-.895***	(.169)	-.860***	(.227)
Favorable	-.134	(.100)	-.253*	(.135)
Year dummy (base = 2000)				
2004	.425***	(.065)	.418***	(.084)
2008	.594***	(.085)	.723***	(.113)
Landownership (base = marginal farmer, less than 0.40 ha)				
Small farmer, 0.41–1.00 ha	-.046	(.072)	.003	(.092)
Medium or large farmer, 1.00+ ha	-.060	(.093)	-.030	(.116)
Observations	3,308	n.a.	2,070	n.a.
Log-likelihood	-6,055.47	n.a.	-3,670.18	n.a.

Source: Authors' estimations using data from Ahmed and Goodwin (2016).

Note: Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. CV = coefficient of variation; HH = household; n.a. = not applicable; SSC = secondary school certificate.

in and supplied more labor to the nonfarm sector, when compared with farm households that did not use agricultural machinery.

Ahmed and Goodwin (2016) studied the nonfarm labor supply behavior of farm households in rural Bangladesh using a unique longitudinal dataset. Table 7.6 presents the results from Ahmed and Goodwin (2016); the first two columns present marginal effects from a probit model that examined the nonfarm labor market participation of farm households due to agricultural mechanization, and the last two columns present results from a linear regression model that examined the changes in levels of nonfarm labor supply due to agricultural mechanization. Both regressions controlled for a range of other relevant covariates such as demographics, schooling, and land. The results from the probit model suggest that, when controlling for other relevant factors, rural farm households that have adopted agricultural mechanization are 25 percent more likely to participate in the nonfarm labor market than are non-adopter farm households. Similarly, the results from the linear regression show that mechanized farm households supply, on average, 24 labor-days

TABLE 7.6 Probit model and linear regression models (including correlated random effects variables)

Variable	Probit model		Nonfarm labor supply equation	
	Mar. eff.	Std. err.	Coeff.	Std. err.
Mechanized (yes = 1)	0.255***	(0.083)	23.790**	(9.260)
Age of household head	-0.004	(0.006)	-0.298	(0.799)
Household size	0.062***	(0.023)	3.750	(2.918)
Labor endowment dummies (ref: single working member)				
Two adult workers	0.217**	(0.103)	37.128***	(12.723)
Three adult workers	0.342**	(0.167)	87.527***	(21.861)
Female participation in labor force (yes = 1)	0.240*	(0.141)	22.229	(18.830)
Log (total schooling years of workers)	0.028	(0.020)	3.661*	(1.937)
Land endowment dummies (ref: marginal landowner, < 0.4 ha)				
Small landowner (≥ 0.4 ha and < 1.0 ha)	-0.013	(0.099)	0.415	(11.922)
Medium landowner (≥ 1.0 ha and < 2.0 ha)	0.059	(0.129)	-4.837	(15.814)
Large landowner (≥ 2.0 ha)	0.347*	(0.184)	28.082	(24.283)
NGO membership (yes = 1)	0.340***	(0.074)	32.485***	(8.493)
Log (gross margin of farming in 2008 BDT)	0.009	(0.038)	-0.071	(4.750)
Fragmentation index	-0.224	(0.213)	-59.365**	(23.835)
Cropping intensity	0.061	(0.117)	-0.186	(12.787)

more to the nonfarm labor market than do nonmechanized farm households. Generally, labor productivity is higher in nonfarm activities, and thus agricultural mechanization leads to increased incomes for the farm households through their increased participation in nonfarm-sector activities. The continuous tightening of rural labor markets in Bangladesh is likely to further support the nonfarm wage income effect on agricultural mechanization.

Conclusions

Mechanization in Bangladesh, particularly the spread of tractor use for land preparation, has grown in the last several decades. This is despite Bangladesh's having one of the smallest average farm sizes in the region and an abundant rural labor force. Several key lessons from the Bangladesh experience may be applicable to African countries.

Variable	Probit model		Nonfarm labor supply equation	
	Mar. eff.	Std. err.	Coeff.	Std. err.
Year dummy (2008 = 1)	-0.223***	(0.077)	-1.448	(8.891)
Correlated effects variables (group means of the variables)				
Age of household head	-0.002	(0.007)	0.292	(0.963)
Household size	-0.225	(0.160)	-2.680	(18.425)
Total adult workers	0.139*	(0.081)	10.235	(10.416)
Log (total schooling years of workers)	0.035	(0.022)	6.116***	(2.294)
Log (total landownership)	-0.085**	(0.041)	-4.836	(4.801)
Log (gross margin of farming in 2008 BDT)	-0.092*	(0.054)	-7.904	(6.677)
Fragmentation index	-0.180	(0.252)	-22.662	(30.109)
Cropping intensity	0.122	(0.135)	22.831	(16.224)
Constant	0.080	(0.281)	87.174***	(31.932)
Wald $\chi^2(21)$ / F(21, 1,669)	206.7***	12.62 (p-val = 0.000)		
R-squared/pseudo R-squared	0.084	0.15		
Observations	1,691			

Source: Authors' estimations using data from Ahmed and Goodwin (2016).

Note: The results came from pooled regressions using a correlated random effects approach, which allows for fixed-effects estimates of variables that vary across households and over time. BDT = Bangladeshi taka; NGO = nongovernmental organization.

First, early spread of tractor use for land preparation was primarily led by technological factors, at least up until the mid-2000s. Since the 1970s, significant investments in agricultural research and development, including plant breeding, have led to higher demand for intensive farm power for land preparation, even on small plots of land. This effect was so strong that by the early 1990s, the intensity of draft animal power use had already far exceeded the levels in Africa today. Such an increase in demand was a critical precondition for the subsequent spread of tractor use from the late 1990s onward. The liberalization of power tiller imports in the early 1990s successfully led to increased power tiller use, but had the demand for power not reached a sufficient level at that time, we may not have seen the same effect.

The effects of wages on mechanization were relatively limited during this early takeoff stage. However, in the 2000s, as economic transformation continued and real wages rose, mechanization spread even further. At this stage,

mechanization was associated with farm households' increasing participation in nonfarm income-earning activities. As is indicated by the empirical results, it was at this point that mechanization became labor-substituting.

Given the fact that Bangladesh's small farm sizes prevented machinery ownership from being profitable for most farms, it is clear that the CHS market played a critical role in the spread of agricultural mechanization. The CHS market helped increase both adoption and ownership of agricultural machinery by decoupling farm size from use and ownership of machinery. Though the government has not been directly involved in the importation and supply of agricultural machinery, it has provided important support through the liberalization of tariffs on agricultural equipment imports. It has also granted subsidies and tax exemptions to local producers of agricultural machinery and to private businesses importing and selling agricultural machines and tools, as well as those engaging in fabrication, adaption, or manufacturing of spare parts, attachments, and power tillers.

The results and discussions in this chapter have important implications for further agricultural mechanization in Bangladesh. Favorable policy supports along with skills training could help to spread agricultural mechanization to other agricultural activities such as weeding, harvesting, and threshing. The CHS model can be further promoted through policies supporting the use of high-cost farm machinery such as combine harvesters, thereby making them viable options.

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Appendix 7A: Empirical Models on Mechanization Adoption

The econometric model is guided by the descriptive analysis in the previous sections and uses the HIES cross-sectional data in the following probit specification:

$$P_i = \alpha + \beta X_i + \varepsilon_i, \quad (1)$$

where P_i is the adoption or the ownership and service provision of tractors, power tillers, or both by the i th household, X_i is a vector of household and worker characteristics, and ε_i is the error term.

We complement (1) with another model using a unique panel dataset available for 2000, 2004, and 2008 (Ahmed and Goodwin 2016). The panel survey observes rural households from 62 villages to study their poverty, income, and productivity dynamics. Only farm households are considered in the regressions. Here, we use adoption of tractors, power tillers, or both in land preparation for agricultural production as a proxy for the adoption of overall agricultural machinery. Specifically, we estimate

$$P_{it} = \alpha + \beta X_{it} + \rho_t + \varepsilon_{it}, \quad (2)$$

where P_{it} denotes the adoption of agricultural machinery by the i th household in year t . X_{it} is a vector of household and worker characteristics, year-specific effects are represented by ρ_t , and ε_{it} represents the idiosyncratic normally distributed error terms.

Importantly, the agent simultaneously makes decisions on other relevant aspects, such as landownership, taking of credit or loans, whether to own

other agricultural equipment (such as threshing machines, motor pumps, deep or shallow tube wells, sprayers, husking machines, and ginning machines), and whether to use other modern inputs such as improved varieties. Estimating (1) and (2) as part of the system of equations that simultaneously estimate the determinants of these outcomes often leads to less biased and more consistent and efficient estimations of the determinants of mechanization-related outcomes, which are our primary interests. We therefore estimate (1) and (2) as multivariate probit models. In particular, (2) is estimated by combining multivariate probit with a Chamberlain (1984)-type correlated random effects model, in which we insert the time average of various exogenous variables as additional variables to approximate unobserved household fixed effects. However, due to the space limitations, we show only the results on mechanization-related outcomes.