



Uptake of scale-appropriate agricultural machinery in Bangladesh: Policy insights from historical and census survey analyses

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Research Report No. 3

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Mechanization and Irrigation
(CSISA-MI)**

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Executive Summary

In response to calls for increased crop intensification and technological options that alleviate labour and drudgery constraints in agriculture, donors and policy makers in South Asia increasingly advocate agricultural machinery appropriate for smallholder farmers' landholdings. When carefully utilized, 'scale-appropriate' machinery has the potential to boost returns to land and labour, and alleviate the sometimes substantial funds required for machinery investment that can exclude smallholders from purchase and ownership - especially where subsidies are not offered. Expanding demand among farmers for mechanized planting, irrigation, harvest, and post-harvest equipment has however resulted in popular systems of rural machinery services provision, whereby smallholders access machines through cost-effective fee-for-service arrangements. Such systems are especially prominent in Bangladesh, although the extent of rural mechanization markets are still not comprehensive. As such, a substantial number of farmers could still benefit from increased access. To help prioritize investments in development efforts focussed on scale-appropriate machinery, donors and policy makers require information explaining what influences farmers to purchase machinery and provide services to other farmers as clients. This research addresses this need, by using census data from 814,058 Bangladeshi farm households (HHs) collected by Bangladesh Bureau of Statistics surveyed in 2008. We applied a multinomial probit model estimation approach to identify the factors that are related to ownership of agricultural machinery, inclusive of HH characteristics and assets, as well as proximity and relation to institutional and civil infrastructural variables, to examine the ownership of irrigation pumps, threshers, and two-wheel tractor driven power-tillers. In addition to household asset ownership, credit availability, and electrification, we found that road density also significantly and positively affects machinery ownership in rural Bangladesh. We therefore suggest that donors and policy makers should focus not only on short-term projects aimed at increasing adoption of machinery or in improvement of machinery value chains; rather, sustained emphasis on improving regional physical and civil infrastructure appears to also be prerequisite to create an enabling environment for expansion of scale-appropriate farm machinery, and as such should also receive policy and donor prioritization.



Key Messages

1. Historical evidence points to unique policy reform and liberalization as an important driver of the wide-spread adoption and use of agricultural machinery by smallholder farmers in Bangladesh
2. Household (HH) wealth status and land size holding significantly and positively affected the prevalence of agricultural machinery ownership in Bangladesh. HHs that are relatively well endowed with physical assets are more likely to invest in agricultural machinery, and to provide services and thus facilitate access to machinery for other farmers.
3. Access to credit facilities (both formal and informal) significantly and positively affects agricultural machinery ownership. To increase the rate of adoption of appropriate agricultural machinery in Bangladesh, the provision of access to rural credit must be assured.
4. Basic civil infrastructure, including electrical networks and paved or gravel roads, positively affects the adoption of agricultural machinery in Bangladesh. It is thus important for government, donors, and development planners, or those who are tasked with expanding farmer uptake of agricultural machineries, to equally consider these necessary pre-conditions before and/or simultaneously when investing in programs that aim to increase adoption in the short term.

Key words: Farm mechanization, South Asia, scale-appropriate machinery, sustainable intensification, labour scarcity.

JEL classification: L64, Q12, Q15



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1. Introduction

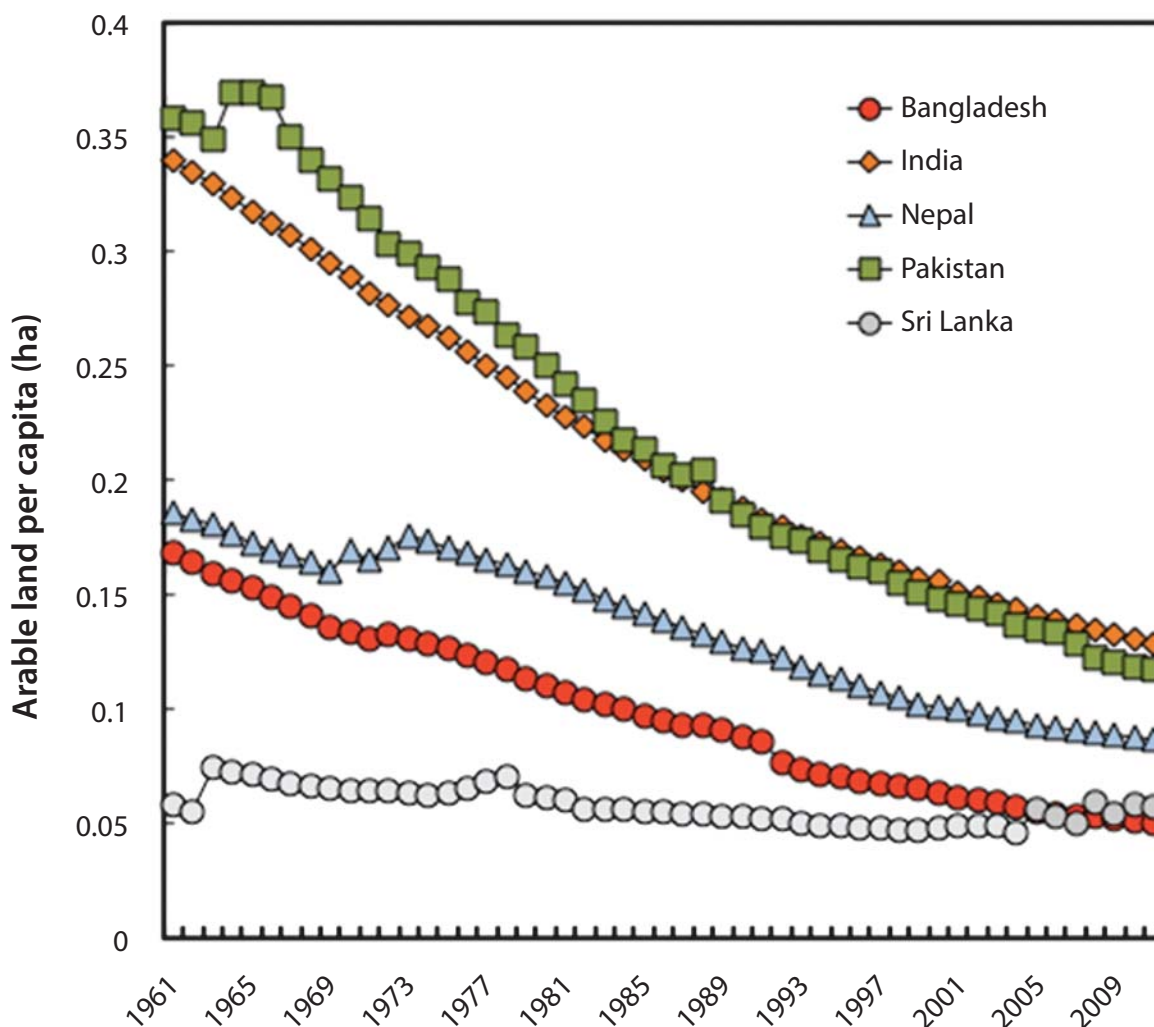
With a population of over six billion, available per capita cropland has shrunk to 0.23 hectares globally from approximately double that in the 1960s (Pimentel and Wilson, 2004). Population growth is expected to plateau at around 9.1 billion by 2050 (FAO, 2009). This will result in increasing pressure on agriculture as cropland availability is reduced due to competition from industrial and urban uses (Tilman et al., 2011). In line with anticipated population growth and observations of predominant dietary patterns, the consumption of three leading cereals, rice, wheat, maize, are expected to increase. Similarly, rising incomes in South Asia and China have resulted in the increased consumption of poultry and fish products, a trend which is expected to continue to increase in the future (Godfray and Garnett, 2014). To assure cereal-based food security alone in 2050, an estimated 100–110% increase in food production will be required. Additional structured efforts will be required to limit food wastage, and to intensify crop productivity on currently available cropland, in order to avoid land clearing and environmental degradation that can result from agricultural expansion (Miah and Sarma, 2000; Pimentel and Wilson, 2004; Tilman et al. 2011).

Such issues are crucially important to policy makers and development planners in South Asia, the world's most densely populated region. Mean farm size is already small, ranging from 0.53 hectares in Bangladesh (Hossain et al., 2007) to 2.1 hectares in Pakistan (PBS, 2010). In Bangladesh, India, Nepal, and Pakistan for example, the available cropland per person was 0.17, 0.34, 0.19 and 0.36 hectares, respectively, in 1961. By 2012, these figures fell by 71, 62, 58 and 67%, indicating increased pressure on farmland resources (Figure 1). In 2005, 48% of the total employed labour force in Bangladesh, 56% in India, 43% in Pakistan and more than 66% in Nepal was also directly involved in the agricultural sector, although the increasing availability of jobs outside farming has resulted in declining agricultural labour availability in many countries (World Bank, 2015a; Zhang et al., 2014). But despite the flow of remittances from family members who have migrated to urban areas and abroad to earn income for themselves and their families, South Asia nonetheless maintains the largest number of extremely poor people, at approximately 399 million people living on less than USD 1.25 a day in 2011 (World Bank, 2015b).

International donors and policy makers are increasingly responding to these problems by encouraging the use of appropriate agricultural machinery as a means to raise the productivity of smallholder farming, while reducing drudgery and alleviating labour constraints (Krupnik et al., 2013). Farmers may be particularly interested in machinery because mechanization can reduce production costs by replacing costly manual labour and traditional tools with increasingly efficient machineries (World Bank, 2007; Kienzle et al., 2013; Mahmud et al., 2014). Moreover, research has increasingly focussed on



FIGURE 1.
Decreasing
per capita
access to
farmland over
time in South
Asia. Data
from World
Bank (2014).



developing machinery appropriate for the small size of farmers' fields in South Asia, that can also facilitate the conservation of agricultural resources (Krupnik et al., 2013; Abdullaev et al., 2007). For example, the increasing use of laser levelling in India's irrigated rice systems has aided in the conservation of water resources, by reducing up to 32% unnecessary water application to fields with uneven surfaces. Laser levelling has also increased farmers' gross margins through reduced irrigation costs relative to conventional levelling (e.g., Ahmad et al., 2001). The practices of zero tillage and strip tillage, each of which require specialized machinery, can also reduce time requirements for planting and costs, largely by saving fuel, compared to conventional full tillage with animal or tractor power and manual planting (Kiel et al. 2015; Erenstein and Laxami, 2008; Fileccia, 2009; Krupnik et al., 2014). But despite donor and policy attention favouring mechanization initiatives, questions remain as to how to assure that appropriate machinery can be made more accessible to smallholders.

To address these questions, it is imperative to understand historical market trajectories for agricultural machinery, and also the characteristics of farm

households that invest in such machinery. Considering the latter, an understanding of how farmers access agricultural machinery both for their own use and in order to rent-out services to other farmers who may not be able to afford initial capital costs, are equally important. A better understanding of the latter is significant because in contrast to the predominant model of farmer machinery ownership on larger-sized farms in developed countries, in developing countries like Bangladesh, relatively few farm households invest in agricultural machinery, although farmers can more broadly access mechanized services through custom hiring arrangements (Biggs and Justice, 2015). Building on this model, a number of agricultural development initiatives are underway also in East and Southern Africa that seek to extend smallholder access to machinery through such service provision arrangements (cf. Baudron et al., 2015).

Studies on the farmers that invest in machinery and provide services to other farmers can bring insight into the factors that facilitate and limit agricultural machinery investment choices by rural households, thereby aiding policy makers and development projects to apply their investments more appropriately. However, a review of the literature indicates that there are no recent systematic studies that examine the characteristics of farm households in developing countries that invest in farm machinery, and provide services to other farmers, despite the upswing in donor and policy emphasis on rural mechanization. Using Bangladesh as a case study, this paper fills this gap by reviewing the historical and market trajectory that has led to the widespread availability of small-scale agricultural equipment in rural areas, and by identifying the factors that facilitate or limit the adoption of the most common agricultural machineries utilized, including irrigation pumps, threshers, and power tillers driven by two wheel tractors (Figure 2).

FIGURE 2.
The three
primary
agricultural
machines
considered in
this study.



Shallow tube well irrigation pump driven
by a diesel engine



Rice and wheat grain thresher



Two-wheel tractor
driven power tiller

The growth of smallholder mechoanization in Bangladesh is important to investigate for several key reasons. The contribution of agricultural sector (excluding fisheries) is 15.02% of the total GDP of Bangladesh (GoB, 2014). Out of 54.1 million economically active labourers in Bangladesh, 25.58 million (47.30 %) are currently engaged in agriculture (GoB, 2014). Yet evidence also indicates a shrinking of rural labour availability that will continue into the future, as workers migrate to urban areas and abroad to engage in more

remunerative employment activities, particularly in the garments and construction sectors (Zhang et al., 2014). This has resulted in an increase in the real average daily labour costs (Figure 4), which have increased on average by 61% since the early 1990s.

Estimates of future consumption requirements also indicate that Bangladesh will need to produce more cereal output to meet future growing demand (e.g., Ganesh-Kumar et al., 2012), a result of the additional two million people added per year to the existing population (Ziauddin and Ahmmed, 2010). At the same time, there is little scope to expand agricultural land to produce more food. Cropland in Bangladesh has actually declined by 68,760 hectares year⁻¹ (0.73%) since 1976, with consequent reductions in per-capita arable land availability (Hasan et al., 2013). Rice comprises 75% of total land area in Bangladesh, though the gains in production achieved during the Green Revolution, are near exhaustion (Pingali et al., 1997; Muragi, 2001). Food wastage is also rare in the predominantly subsistence farming economy. In other words, Bangladesh needs to produce more food without converting the little remaining amount of non-agricultural land to crop use, while concurrently easing farm labour requirements as it makes the transition into non-farm and increasingly profitable alternative forms of employment (Zhang et al., 2014). The use of farm machinery designed to be appropriate for the small-scale of farmers' fields and operations, and that boosts land and labour efficiency and reduces production costs, and that can conserve resources while maintaining or enhancing yield, has a role to play in achieving this goal (Figure 3).

FIGURE 3.
Promising new
agricultural
machineries
increasingly
used in
Bangladeshi
smallholder
farming.



Bed planter



Power tiller operated seeder



Multi-crop reaper

And as farm power is an important factor for facilitating land and labour productivity (FFTC, 2005; Matin et al., 2010), appropriate farm mechanization is an important policy and development goal in Bangladesh (Mandal 2002; 2014; Zhang et al., 2014). While the pace of agricultural mechanization in many developing countries has been slow (e.g., FAO, 2008; Hatibu, 2013), adoption has been rapid and comprehensive in much of Bangladesh, especially in comparison to other South Asian and African countries (IDE, 2012; Quayum and Ali, 2012; Justice and Biggs, 2013). The main agricultural activities that are currently mechanized include land preparation, hauling materials and equipment, irrigation, and post-harvest activities. For example,

in 1996 there were only 0.1 million two-wheeled tractors, 1.3 million pumps (including deep, shallow and low lift pumps), and 0.18 million thresher machines used in Bangladesh. But by 2011, use increased to 0.42 million, 1.61 million and 0.25 million, two-wheeled tractors, pumps, and threshers, respectively. Bangladesh has also been relatively successful in avoiding famine and food shortages problems by achieving self-sufficiency in rice food production, much of which has been facilitated by the growth of mechanization. As such, analysis of why Bangladesh was able to rapidly mechanize, and the factors that influence adoption and service provision, could provide important lessons for other developing economies with policy encouraging scale-appropriate mechanization.

This report applies both historical analysis and econometric modelling to study these issues. We begin by describing the growth of agricultural mechanization in Bangladesh since the 1970s, focusing mainly on government policy liberalizing the farm machinery sector and underwriting it with subsidy programs, before turning to analysis using a nationally representative data set to examine what factors contribute to machinery ownership. We characterize farm households who invest in agricultural machinery, while also assessing the role of civil and institutional infrastructure on the heterogeneous ownership of machinery and provision of mechanized services in Bangladesh. We subsequently detail the census datasets utilized, after which we specify the econometric model and present major findings of policy relevance for planners.

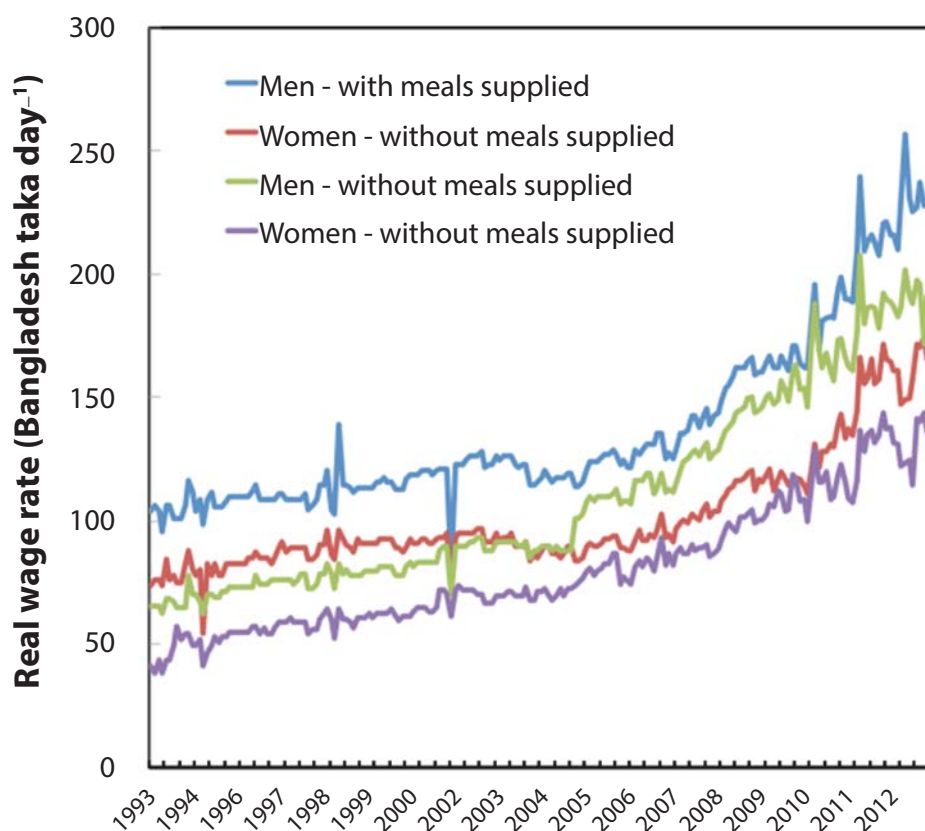


FIGURE 4.

Real wage rate increases for a daily labour in Bangladesh from 1993-2012. Note that data are presented in two ways, the first being wage rates for men and women laborers who work for cash payment without being served meals by their employers, the second being a variation of the data showing the reduced wage rate when laborers are served meals by their employers. Data source: BBS (1994) - BBS (2013).

2. The Growth of Agricultural Mechanization in Bangladesh

Bangladesh has the globe's highest per-capita level of rice consumption at 172.6 kg person⁻¹ year⁻¹ (FAOSTAT, 2015). The government of Bangladesh (GoB) has tended to encourage mechanization as an avenue to increase rice production and move towards rice self-sufficiency. To facilitate this process, the GoB voluntarily reduced import restrictions and tariffs on select machineries, while also supplying subsidy to help purchasers offset fixed costs (GoB, 1999). The GoB first introduced irrigation pumps and tractors in the 1960s (Ahmed, 2001). Four wheel tractors were initially promoted, which are arguably scale-inappropriate in Bangladesh given the small average farm size at around 0.53 hectares, which is often divided into multiple fields (Hossain et al., 2007), making demand aggregation for tillage services among farmers, and between-field and -farm transport of tractor equipment problematic. The GoB also first introduced centralized irrigation facilities by establishing deep tube wells (DTWs) and supplying low-lift irrigation pumps (LLPs) to farmers on a rental basis from the Bangladesh Agricultural Development Corporation (BADC). The GoB also supplied fuel at 75% subsidized rate to pump owners through BADC until the 1970s (Hossain, 2009). By 1978, BADC had rented out and managed a total of 9,000 DTWs and 35,000 LLPs (IDE, 2012).

Irrigation and land preparation management under nearly complete government control however presented large logistical and financial burdens. Eight years after independence, Bangladesh undertook liberalization policies, and as a result, the government gradually opted out of state-led support of mechanization and began the privatization of irrigation, with additional efforts to open markets for land preparation equipment (Gisselquist et al., 2002). BADC initiated sales to liquidate DTWs and LLPs to farmers' cooperatives and also to individual farmers, many of whom became service providers (Hossain, 2009). Privatization, however, only gained full momentum when a number of tariff and non-tariff barriers on the import of irrigation and diesel engines and tractors were eliminated, actions that were linked to disaster response management by the Bangladeshi government.

On November 29, 1988, a cyclone with wind speed of more than 150 kilometres impacted Bangladesh (UNDRO, 1988), taking a major toll on



human lives, while also reducing the draught oxen and buffalo population used for land preparation, with the deficiency estimated at approximately 5.8 million animals, equivalent to approximately 132,000 tractors (GoB, 1989). During this period, the GoB's Standardized Committee was responsible for controlling the quality of imported machinery, including agricultural equipment. They did so by advising the import of high-cost Japanese tractors, pumps, and engines, while discouraging more affordable Chinese made machinery thought to be of comparatively lower quality (Justice and Biggs, 2013). The urgency resulting from the cyclone and consequent threat to food insecurity however prompted the GoB to reconsider such policies. In 1988, President Hussain Muhammad Ershad voluntarily eliminated most of the major import tariffs on standardized diesel engines and two-wheeled tractors, in order to facilitate the broader availability of two wheel tractors and the associated 8-16 HP Chinese engines that drove them. In the next step, President Ershad disbanded the Standards Committee, to facilitate the rapid import of comparatively inexpensive diesel engines and two-wheeled tractors from China (Justice and Biggs, 2013). Six years later, the import of two-wheeled tractors was made completely duty free (IDE, 2012).

These actions resulted in a drastic increase in imports of small diesel engines for mechanized irrigation and land preparation. The number of shallow tube wells (STWs) used for irrigation increased from 93,000 in 1982 to 260,000 in 1990 (IDE, 2012). Currently, more than 550,000 two-wheeled tractors, the vast majority of which are made in China, are used to prepare 80% of Bangladesh's cropland (IDE, 2012; Ahmmmed, 2014). A total of 1.63 million of STWs, DTWs and LLPs are also used to irrigate (BADC, 2013) nearly 55% of all cropland (BBS, 2011). The impact of these actions, in combination with other measures, appears to have had a dramatic impact on increasing Bangladesh's cropping intensity, or the number of crops grown per unit of land per year. This is acknowledged to have been partly attributable to the spread of irrigation (Hossain 2009), and which can be observed in national statistics (Figure 5) that indicate that cropping intensity appeared to be stagnating until the late 1980s, and then began to gradually but steadily increase as result of these actions.

Import of agricultural machinery in Bangladesh is still active until today. In 2012-13, the most recent year for which GoB data is available, 112 importers imported 30,771 two-wheeled tractor driven power tillers with an average price of USD 1,135 each. In the same year Bangladesh imported 2000 mechanical seed drills and rice transplanters, the former which can be attached to two-wheeled tractors for direct seeding, and USD 2.54 million worth of spare parts and other agricultural machineries from abroad (GoB, 2014a). Owners of agricultural machinery in Bangladesh also tend to work as



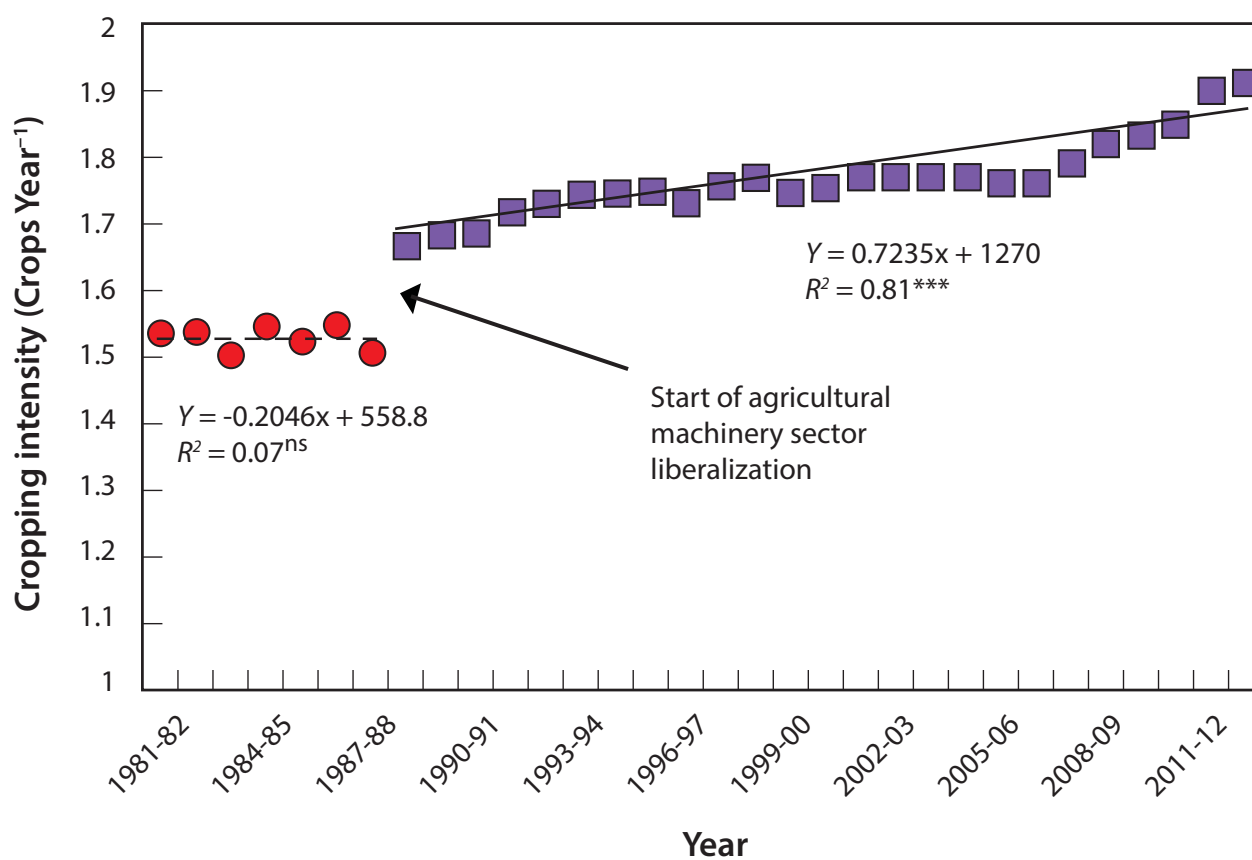


FIGURE 5.

Average number of crops grown per year in Bangladesh during 1981-2013. Data sources: SDNBD (2015)

service providers by renting or selling mechanized land preparation and irrigation services to other farmers (Krupnik et al. 2013). As a result, even relatively small farm holders are able to access affordable machinery services through custom hiring systems (IDE, 2012; Justice and Biggs, 2013). However, the characteristics that determine adoption and ownership of machinery – which is a crucial prerequisite donors or policy makers that wish to extend such service provision models – remains unclear. This gap in information is addressed in the subsequent sections using data from a large scale census survey conducted throughout Bangladesh.

3. Census Data Description

We rely on two data sets made available by the Bangladesh Bureau of Statistics (BBS), both of which are survey based (Figure 6). The 2008 Agricultural Census is the fourth and most recent agricultural census in Bangladesh. It was deployed on May 11-25, 2008. The census was a farm household based country wide project, in which all dwelling farm households were counted to determine arrangement and operational features of agriculture holdings managed by dwelling households. The BBS utilized a structured questionnaire from both rural and urban areas. Urban areas included the country's six primary metropolitan city corporations, and 58 municipalities and 58 district headquarters, the rest of the country included municipalities at sub-district headquarters and other areas were treated at rural areas.

In the 2008 agricultural census, a total of 28.69 million farm households were surveyed, of which 25.35 million qualified as rural. Out of 25.35 farm households, 1.73 million were from Barisal, 4.88 million were from Chittagong, 9.46 million were from Dhaka, 3.43 million were from Khulna, 7.66 million were from Rajshahi and Rangpur Divisions, respectively, with 1.53 million from Sylhet Division. The resulting dataset details information on irrigation pump, thresher, and two-wheeled tractor power tiller

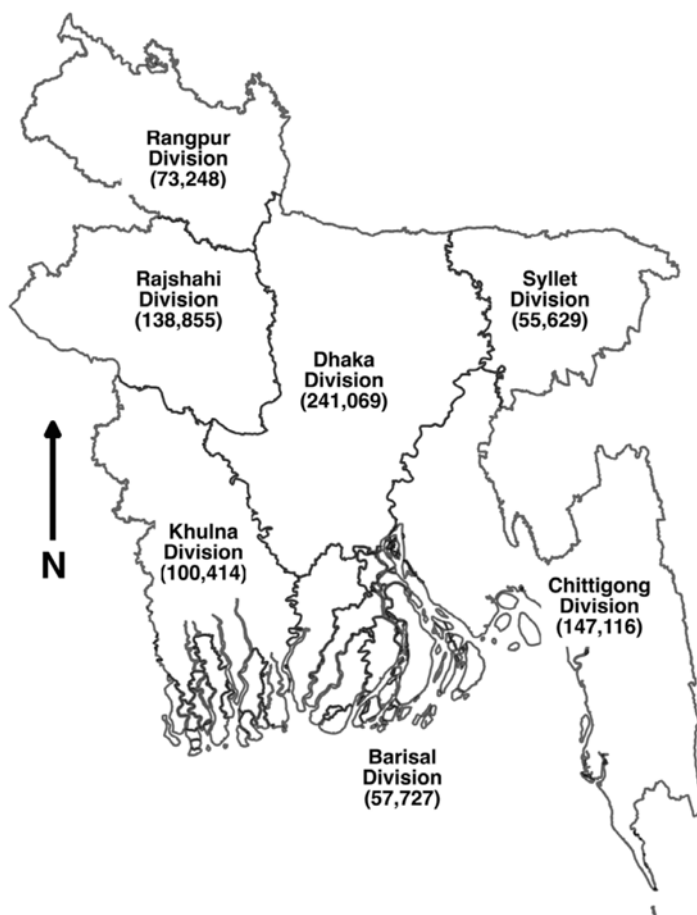
FIGURE 6.
An enumerator surveys a farmer in Jessore District of southern Bangladesh.



ownership at the household level (Figure 2). The census also provided household level information on land size, pond and livestock ownership, the family member number (segregated by number of adults and children), and gender of the household head. Although the 2008 Census covered the entirety of registered farm households in Bangladesh, BBS provided access only to a randomly generated five per cent of the entire census data, including 104,2595 households in 64 districts in all seven divisions: Barisal, Chittagong, Dhaka, Khulna, Rajshahi, Rangpur and Sylhet. Additional data on electricity availability for agricultural machinery (primarily DTW irrigation pump) operation, and the provision of both formal and informal loans accessed by farm households, were collected from the Agricultural Census 2008 data sets. Finally, following institutional request, we supplemented this information with available data on the length of paved or gravel roads at the sub-District level supplied by the Bangladesh's Local Government Engineering Department..

This study sought to understand the characteristics of rural farm households that invest in agricultural machinery. We therefore considered only rural farm households. Consequently, we removed urban farm households from our sample of BBS data, resulting in 814,058 sampled households comprised of 476 sub-Districts in 64 districts in seven divisions of Bangladesh, each with

FIGURE 7.
Distribution of
the sampled
households by
division.



different agricultural machinery and other resource endowments (Figure 7). The resulting data indicated that 3.38% of the sampled rural households owned one of the machines considered (2%, 1.68%, and 0.45% owning at least one irrigation pump, thresher, or two-wheeled tractor driven power tiller, respectively (Table 1)). We also observed that machinery ownership is highly uneven across the divisions. For example, in Khulna and Rajshahi divisions, more than 6% and 4% of sampled households owned at least one machine, respectively, while in Barisal, only 0.90% of observed farms owned the machines considered (Figure 8 and Table 1). Figure 8 visually demonstrates the heterogeneity in machinery ownership across divisions and districts, with consequences for smallholders' ability to access machinery services in different parts of the country. In this figure, the first panel depicts the distribution of the ownership of the sampled machinery across the country,

Table 1. Numbers of identified owners ($\times 10^3$) of the sampled agricultural machinery by rural households by division in 2008.

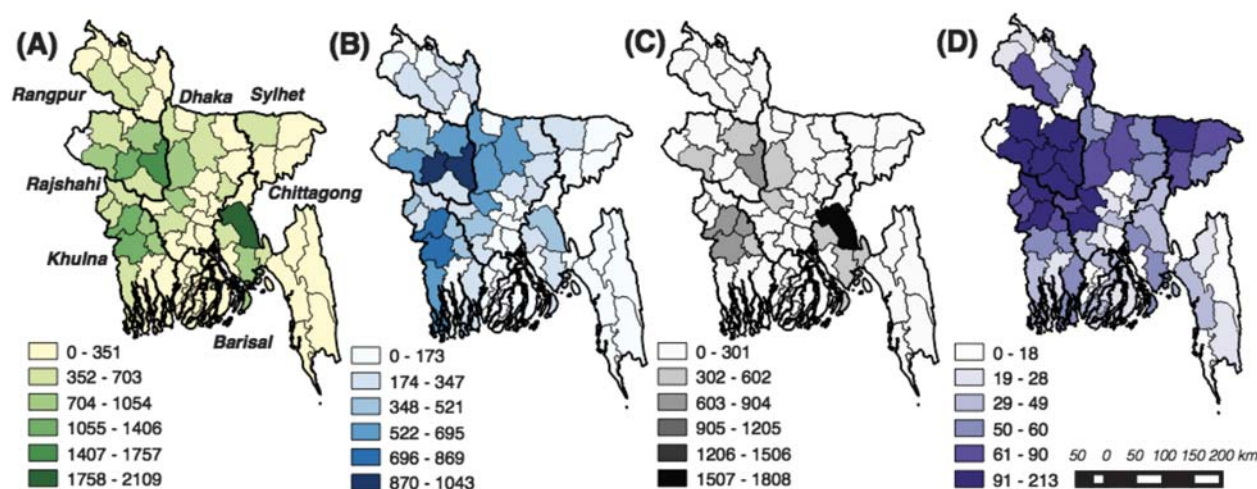
Division	Barisal	Chittagong	Dhaka	Khulna	Rajshahi	Rangpur	Sylhet	All
Number of farm households	57,727	14,7116	24,1069	100,414	138,855	73,248	55,629	814,058
Per cent owning a sampled machine	0.90	3.50	2.64	6.57	4.30	2.60	1.82	3.38
Per cent owning an irrigation pump ^a	0.28	0.98	1.96	4.33	3.05	2.05	0.99	2.08
Per cent owning a thresher ^b	0.50	2.61	0.87	3.55	2.06	0.76	0.80	1.68
Per cent owning a tractor ^c	0.24	0.23	0.39	0.66	0.74	0.40	0.51	0.45

Source: BBS (2010)

^a. Irrigation pump includes deep tube wells, shallow tube wells, and low-lift pumps.

^b. Thresher includes all types of threshers, including open and closed drum threshers.

^c. Tractor includes both two-wheeled tractor driven power tillers and four wheeled tractors.



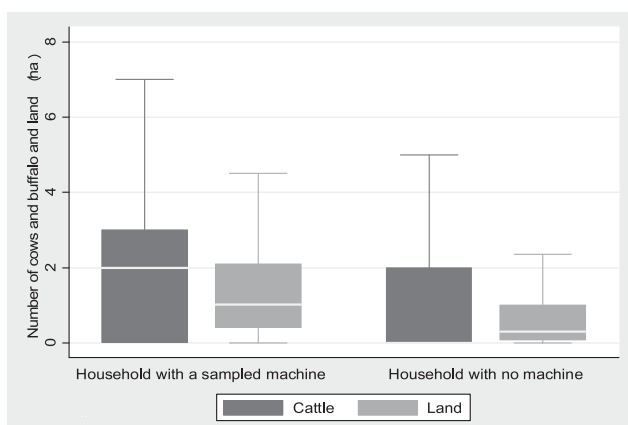
Source: BBS (2010)

FIGURE 8.

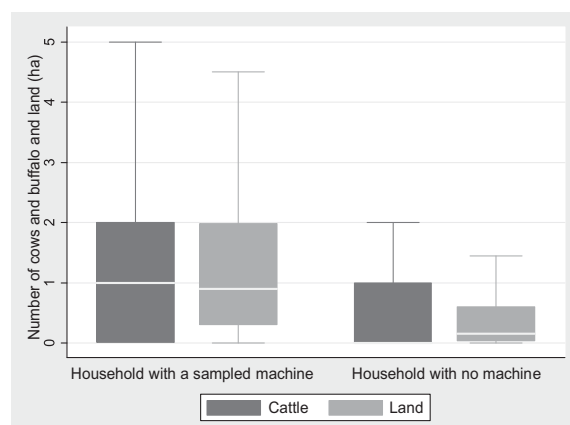
Density of agricultural machinery ownership by census survey respondents in each administrative District (separated by thin black lines) but grouped into administrative Division (thick black lines) labelled in the first figure, including observations of (A) any machinery ownership (survey respondent owns at least one of machines B-D), (B) irrigation pumps, (C) thresher ownership, and (D) two-wheeled tractor driven power-tillers.

and the second, third and fourth panels show the distribution of the irrigation pump, thresher, and two-wheeled tractor driven power tiller separately. This information also confirms that in Barisal division, the overall the number of sampled machinery owners were less than in other divisions considered by the census survey.

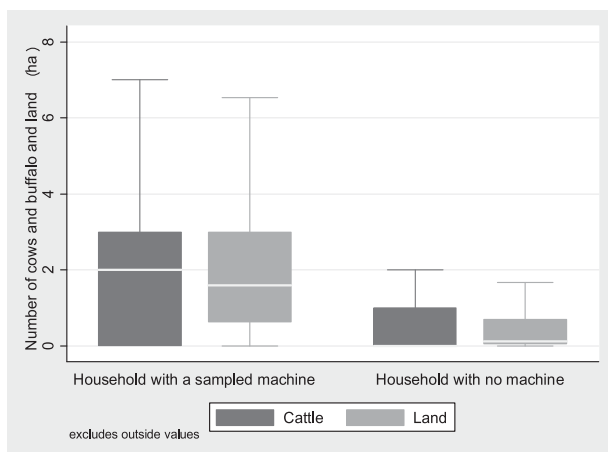
We developed box plots illustrating the distribution of land and livestock among sampled households across divisions to indicate the distribution of physical assets among households owning and not owning agricultural machineries, by division (Figure 9). After removing outliers, box plots of the sampled data in general show that the upper adjacent values (75th percentiles), as well as median values (mid line) of both land and livestock ownership were higher for the households across all seven divisions with a sampled machine compared to other households. As both land and livestock are capital intensive assets, these observations indicate the relatively higher wealth status of households observed to invest in two wheel tractor driven power tillers, threshers, and irrigation pumps.



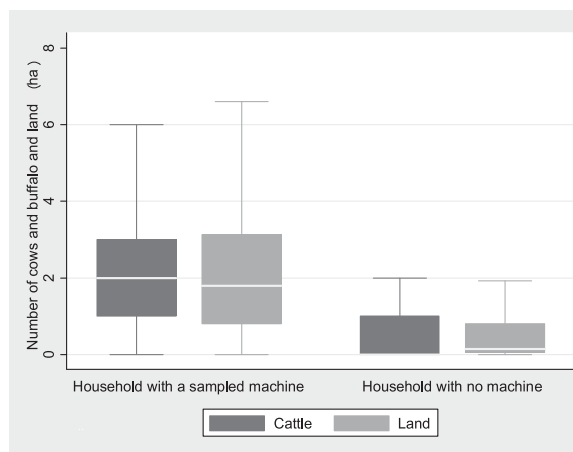
Barisal



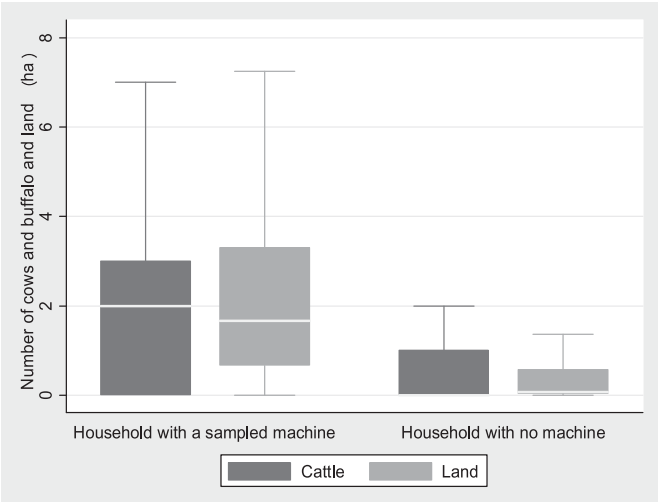
Chittagong



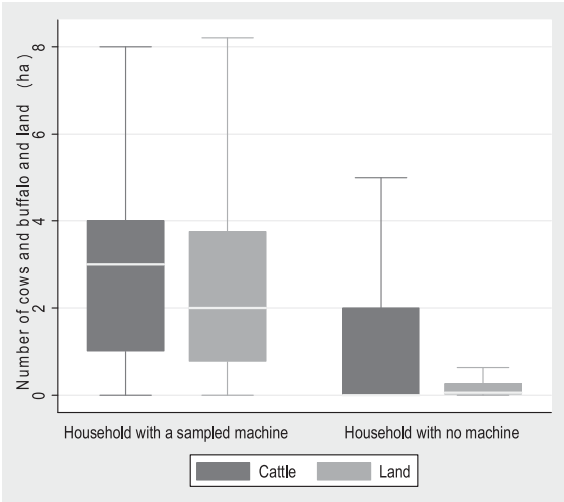
Dhaka



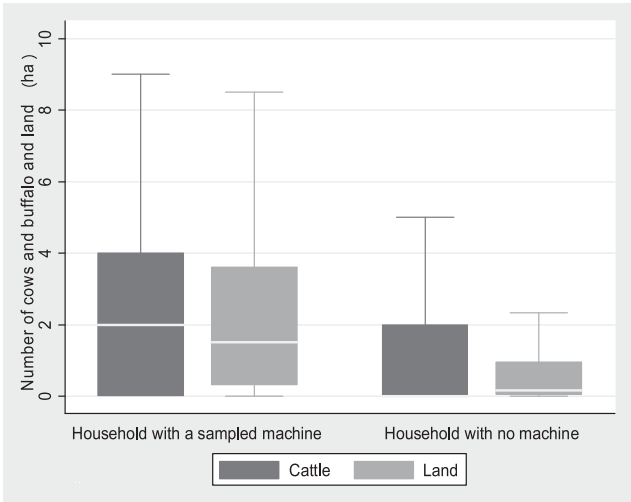
Khulna



Rajshahi



Rangpur



Sylhet

Source: BBS (2010)

FIGURE 9.
Box plot presenting distribution of land and cattle (cows and buffalos) owned by the sampled rural households by ownership of agricultural machineries (Y axis), including irrigation pumps, threshers, or two-wheeled tractor driven power tillers, excluding outliers.



4. Econometric Model Specification and Estimation

Equation 1 was developed to examine the factors that limit or facilitate ownership of agricultural machinery in Bangladesh:

$$Y_i = \alpha_0 + (HHC_i)\phi + \alpha_1(Road_d) + \sum_{d=1}^6 \beta_j(DD_j) + \varepsilon_i \quad (1)$$

where Y_i is a vector of dependent variables that includes a base value of zero if a household did not own any of the specific sampled agricultural machinery in 2008, an irrigation pump ownership dummy that assumes a value of 1 if a household owned an irrigation pump, a thresher ownership dummy that assumes a value of 2 if ownership was recorded in 2008, and a two-wheeled tractor driven power tiller ownership dummy that assumes a value of 3 under the same circumstances. Among the explanatory variables, HHC_i is a vector of independent variables that includes a gender dummy that assumes a value of 1 if a household head is female and 0 otherwise, a dummy that assumes a value of 1 if the household head does not work as an agricultural labour on other farms and 0 otherwise, and the total number of adult family members who are more than 15 years old.

Additional explanatory variables also included a pond ownership dummy (1 if yes, 0 if no, and total number of livestock owned (cows and buffalos). In Bangladesh pond ownership can play a role in generating income through the provision of aquacultural resources. In equation 1, the explanatory variables also include total land owned by a household (hectares), and a dummy that assumes value 1 if a household owned more than 1.01 hectares of land or 0, otherwise. According to the specifications of the BBS (2011a), smallholder households owned up to 1.01 hectares of land, medium-sized farm households owned 1.01–3.03 hectares of land, and large farm households owned > 3.03 hectares. The land ownership dummy in the model therefore represents medium and large farm households, which captures the specific effect of farm size on the ownership of agricultural machinery even after controlling for the effect of total land size owned by a household. Finally, the explanatory variables, HHC_i also include a dummy that assumes value 1 if a household borrowed money from any formal or informal sources or 0, otherwise, and a dummy that assumes value 1 if a household run at least one of his agricultural machinery using electricity or 0, otherwise. The independent variable $Road_d$ presents sub-district-level information on the length of paved or gravel road (km).

To understand whether sub-district level infrastructure such as paved or gravel road and loan facilities have different effects in terms of machinery adoption on medium and large farm households compared to small farm



households, we also included two multiplicative dummies, in which we multiplied the medium and large farm household dummy with the length of paved or gravel road. We also multiplied the medium and large farm household dummy with the dummy for borrowed money originating from either formal or informal sources. DD_j represents six division dummies for seven divisions, where Chittagong division is the base. α_0 is the scalar parameter, and ϕ , α and β are the vectors of parameters; i stands for household, and ξ is the random error term.

In our dataset, the most common agricultural machine owned by a farm household is an irrigation pump; however, a household can also own a thresher, and/or a two-wheel tractor driven power tiller (Table 1). To estimate the ownership of multiple machines at the same time, we applied a multinomial probit model, which is appropriate for explaining farmers' adoption of different agricultural technologies. Mottaleb et al. (2014a), for example, applied multinomial logit model to estimate the ownership of different types of rice varieties in Bangladesh, while Quayam and Ali (2012) also applied single logit model to estimate the adoption of two-wheeled tractor driven power tillers in selected locations within Bangladesh.

To examine the impacts of different socio-economic factors on the ownership of agricultural machinery by rural farm households in Bangladesh, we estimated four independent models. In the first model (hereafter referred to as the unrestricted full model), we included all possible explanatory variables to explain agricultural machinery ownership, but in the restricted models (termed R1, R2, and R3, respectively) we removed some selected variables in order to control against potential endogeneity as well as redundancy (if any). In R1, for example, we removed the dummy for medium- and large-farm size (yes=1), and the related multiplicative dummies. Because we already included the size of the land owned, one might argue that further inclusion of a dummy variable for medium and large farm household (yes=1) and allied multiplicative dummies might generate redundancy problems. Hence in the second restricted model R2, we removed the pond ownership dummy (yes=1), and the number of cows and water buffalos and land owned by a household (which includes agricultural fields, the homestead, and pond area, etc.). We removed these variables as one may argue that a household might first invest in agricultural machinery, and later after generating income they may gradually invest in other resources, such as in additional land or ponds. As such, their restriction helps to control for these potential effects, allowing better interpretation of the results. In the third restricted model R3, we removed the dummy variable for household receipt of loans, because access to loan might depend on human and physical capital of a household such as the land size owned by a household what can be used as collateral, hence skewing interpretation of the results in the unrestricted model. To verify the acceptability among these estimated models, we conducted log likelihood ratio tests treating all restricted models (R1, R2 and R3) as nested within the unrestricted model. The estimated chi-squared statistics (R1: 866.56; $P < 0.001$; R2: 3611.93; $P < 0.001$; and R3: 3858.96; $P < 0.001$) and the corresponding



P-values suggested that the unrestricted model (in which all restricted models are nested) in predicting the ownership of sampled agricultural machinery is more acceptable than the restricted models (Table 4), though each can be interpreted individually to gain a more robust understanding of the factors affecting machinery ownership, contingent on the caveats indicated above.



5. Results and Discussion

5.1. General survey results

A sampled household was endowed with 0.31 hectares of land on average, and nearly two animals including cows and water buffalos. 24% owned a pond (Table 2). 92% of the sampled farm households were classified as are smallholders, with < 0.5 hectares of land owned (Table 2). Only 3.3% of the sampled households owned at least one of the machines of interest (Table 1), broad access to mechanization services in Bangladesh indicates that many of these farmers hire their machines to other farmer-clients. The prevalence of custom hiring in Bangladesh may be because average farm size is small, and after completing tasks on their own farms, agricultural machinery owner farmers can efficiently serve other farmers as an income generating activity (Mandal 2014). This approach has resulted in a large number of service providers providing access to irrigation services and two- and more recently four-wheel tractors in selected areas, in addition to post-harvest threshing and shucking services in the case of rice and wheat, and maize, respectively (IDE, 2012; Quayum, and Ali, 2012; Justice and Biggs, 2013; Mandal 2014).

We observed that when compared to the national average and to households from other divisions, farm households in Barisal, on the central southern coast are less likely to own agricultural machinery than other locations where the surveys were conducted (Table 2). Households in Khulna, Rajshahi and

Table 2. Physical, institutional and infrastructural resource endowment of the sampled rural households, by division in 2008.

	Division							All
	Barisal	Chittagong	Dhaka	Khulna	Rajshahi	Rangpur	Sylhet	
Land owned (ha)	0.37	0.27	0.29	0.36	0.30	0.24	0.43	0.31
Per cent small-farm	90.71	93.74	92.53	89.82	91.88	93.49	88.05	91.95
Per cent medium-farm	8.02	5.52	6.61	8.91	7.03	5.37	9.58	6.96
Per cent large-farm	1.27	0.74	0.86	1.27	1.09	1.14	2.36	1.09
Number of cows and buffalos owned	1.06	0.64	0.75	0.99	0.88	1.06	1.17	0.86
Per cent owning ponds	58.57	45.27	13.46	25.50	8.39	7.12	34.58	23.90
Per cent receiving loans	34.37	17.12	24.97	32.90	25.69	25.73	21.43	25.15
Per cent using electricity to run machines	0.82	1.70	2.79	5.39	4.04	2.89	1.82	2.93
Paved or gravel road (sub-district level, '000 km) ^b	2.08	1.96	1.72	2.72	1.94	1.32	1.53	1.90

Source: BBS (2010), and GoB (2014a) ^b.

^a Small-, medium- and large-farms are < 1.01, 1.01-3.03, and > 3.03 ha, respectively.

Chittagong Divisions, conversely, are more likely to own machinery, though in Barisal, 0.9% households owned one or more units of the sampled agricultural machinery. Of this, 0.3% owned an irrigation pump, 0.5% owned a thresher, and 0.2% owned a two-wheeled tractor driven power tiller. The cropping intensity is typically low in Barisal (MoA and FAO, 2013), owing

partly to the difficulty of establishing a dry season crop in this coastal region, where tidal flooding, seasonal cyclones and salinity are concerns, and also due to farmers' perception of production risks that encourage a lack of investment in agriculture (Mottaleb et al., 2013; MoA and FAO, 2013). For example, during 1960 to 2010, a total of 45 major cyclones hit coastal divisions of Bangladesh of which 19 directly hit Barisal and Khulna divisions (with the remainder directly impacting Chittagong division, but also causing damage in Barisal). This resulted in considerable losses, both in terms of property and human lives (Mottaleb et al., 2013). Consequently, comparatively few farm households (HHs) invest in agricultural machinery or intensified cropping in this region. As such, a logical starting point to boost cropping intensity in Barisal would be to put into place measures to lower farmers' production risks as a fundamental part of efforts to develop mechanization.

Over than one quarter of the sampled households received loans or credit from formal banking or NGOs, as well as from informal sources. On average, a sampled sub-District was cumulatively equipped with 190 km of paved or gravel road. Close to 3% of the sampled households operated at least one agricultural machine using electricity as the power source, primarily for irrigation pumps that require electricity connections for deep tube well extraction. These factors could influence farmers' decision to invest in agricultural machineries by affecting overall operation and transaction costs of the owner operators. For example, electricity availability might encourage a household to purchase an irrigation pump, as the estimated 1.4 billion per year electricity subsidy for agriculture in Bangladesh can be used as an inexpensive energy source compared to diesel (BIDS, 2012), the latter of which requires pre-season purchases and stocking of fuel, and entails costs for transporting fuel from the point of sale to the pumping station. Similarly, the extent of loan facilities at the household level could affect farmers' decision to purchase machinery, especially for more costly two-wheeled tractor driven power tillers, as access to loans can mitigate household credit constraints. Across the entire survey dataset, less than 4% of the households were female headed. Nearly 65% of the farmers indicating ownership of machinery were owner operators who worked in their own farms and had not worked as agricultural labourers on other farms (Table 3).

Table 3. Basic demographic and other characteristics of the sampled households by division in 2008.

	Division							All
	Barisal	Chittagong	Dhaka	Khulna	Rajshahi	Rangpur	Sylhet	
Per cent female headed household	2.66	5.46	3.39	2.7	2.44	3.44	4.81	3.57
Per cent of machine owner-operators not employed as agricultural labourers	72.59	70.64	67.65	58.38	60.05	50.42	68.24	64.59
Total household family members	3.27	3.78	3.09	2.81	2.81	2.76	3.99	3.18
% Adult family members ^a	51.07	47.88	50.81	50.80	53.02	50.0	45.11	50.31

Source: BBS (2010).

^a Indicates family members above 15 years of age.



5.2. Estimated Functions and major findings

Estimated functions explaining the ownership of sampled agricultural machinery at the household level can be found in Table 4. Considering the unrestricted function in which we included all possible explanatory variables, all of the household level variables considered in this study were highly statistically significant, with the expected signs of coefficients explaining ownership of irrigation pumps, threshers, and two-wheeled tractor driven power tillers at the household level. The household owner dummy variable who never worked as agricultural wage labour, number of adult family members, pond ownership, and livestock number, total land owned, and medium and large farm household size dummy positively and significantly influenced ownership of the sampled agricultural machinery. Conversely, the female headed household dummy was negative yet also highly statistically significant ($P < 0.001$) across the estimated functions for explaining thresher and power tiller ownership, although there was no significant difference in ownership of irrigation pumps between male and female headed households. These findings reflect convention in Bangladesh that women headed households are less likely to own productive agricultural assets than male headed households (cf. Quisumbing et al., 2001), potentially because use of agricultural machinery requires frequent movement among villages to provide services to client farmers. As customs in Bangladesh limit women's movement outside the household, especially without supervision by male guardians (Jahan, 2015), our data indicate that female headed households are less likely to invest in threshers and two-wheel tractor driven power tillers that require frequent movement and negotiation to provide services to client farmers, while ownership of irrigation pumps which can be placed in the field and operated with a fixed-client base by hired operators, appears to be more plausible. The more general lack of widely observed agricultural machinery ownership among women is important for policy planners and development organizations concerned with increasing gender equity in Bangladesh, as solutions are needed to boost women's access to additional productive assets.

The medium and large farm size dummy was positive and highly statistically significant in explaining ownership of all three machines investigated. Medium and large farm households tend to have a higher probability of having a sampled agricultural machine compared to a smallholder household, reflecting the more resource endowed nature of larger households which tend to have ownership over more productive agricultural assets than smallerholders, and hence capacity to invest in capital intensive assets. This is again a crucial point for policy planners focused on promoting the use of appropriate machinery for smallholders in Bangladesh. Development organizations are under increasing pressure to develop functioning value chains that deliver rural services to farmers, including mechanization (IDE, 2012). Our data however suggest that even at somewhat subsidized rates, poorer households may still not be willing to invest in self-ownership of machinery, as opposed to custom hiring arrangements that do not require large one-time capital payments. As such, programs focussed on machinery



Table 4. Estimated functions applying a multinomial probit model explaining ownership of irrigation pumps, threshers, and two-wheeled tractor driven power tillers by farm households in Bangladesh.

Model specification	Unrestricted full model			Restricted model (R1)			Restricted model (R2)			Restricted model (R3)		
Dependent variables	Pump	Thresher	Power tiller	Pump	Thresher	Power tiller	Pump	Thresher	Power tiller	Pump	Thresher	Power tiller
Female headed household dummy (yes=1)	-0.08 (-1.29)	-0.19*** (-4.73)	-0.30*** (-3.83)	-0.08 (-1.39)	-0.19*** (-4.96)	-0.32*** (-4.09)	-0.09 (-1.64)	-0.21*** (-5.22)	-0.32*** (-4.19)	-0.10* (-1.73)	-0.21*** (-5.56)	-0.33*** (-4.21)
Dummy for machine owner-operators not employed as agricultural labourers	0.21*** (10.52)	0.08*** (5.77)	0.15*** (6.60)	0.23*** (11.97)	0.10*** (7.56)	0.21*** (9.63)	0.22*** (11.22)	0.09*** (6.80)	0.17*** (7.63)	0.21*** (10.82)	0.08*** (5.97)	0.16*** (7.40)
Number of adult family members (> 15 yrs)	0.07*** (9.79)	0.12*** (17.35)	0.12*** (13.28)	0.08*** (12.33)	0.12*** (29.62)	0.13*** (23.09)	0.09*** (12.39)	0.15*** (18.76)	0.15*** (13.97)	0.10*** (14.80)	0.15*** (35.78)	0.15*** (26.09)
Pond ownership dummy (yes=1)	0.33*** (17.00)	0.47*** (35.86)	0.36*** (16.71)	0.36*** (18.66)	0.50*** (37.89)	0.42*** (20.18)						
Number of cows and buffalos	0.06*** (17.49)	0.07*** (27.07)	0.07*** (24.36)	0.06*** (21.09)	0.08*** (40.34)	0.08*** (32.65)						
Land owned (hectares)	0.02*** (5.83)	0.03*** (10.98)	0.05*** (16.79)	0.05*** (19.42)	0.06*** (29.52)	0.08*** (40.63)						
Medium- and large-farm size dummy (> 1 ha) yes=1	0.42*** (8.20)	0.20*** (5.18)	0.52*** (10.27)				0.65*** (14.11)	0.51*** (15.19)	0.97*** (20.81)	0.66*** (15.66)	0.50*** (15.08)	0.99*** (22.71)
Dummy for loan and credit access (yes=1)	0.13*** (6.12)	0.18*** (11.84)	0.13*** (5.11)	0.13*** (7.23)	0.15*** (11.55)	0.15*** (7.21)	0.14*** (6.95)	0.20*** (13.43)	0.15*** (5.94)			
Dummy for agricultural machinery run using electricity (yes=1)	4.37*** (233.39)	3.17*** (196.05)	3.04*** (147.45)	4.39*** (236.66)	3.19*** (198.31)	3.08*** (148.50)	4.42*** (238.49)	3.23*** (202.85)	3.10*** (151.92)	4.42*** (240.21)	3.24*** (203.14)	3.11*** (150.09)
Km ('000) of paved or gravel road at the sub-district level	0.05*** (4.52)	0.03*** (4.08)	0.01 (1.04)	0.03*** (3.33)	0.05*** (7.11)	0.01 (0.75)	0.06*** (4.42)	0.03*** (4.69)	0.01 (0.97)	0.04*** (3.83)	0.03*** (3.86)	0.01 (0.57)
Km ('000) of paved or gravel road at the sub-district level × Medium- and large-farm size dummy	-0.02 (-0.96)	0.11*** (7.52)	0.03 (1.32)				-0.02 (-0.90)	0.11*** (7.76)	0.01 (0.52)	-0.02 (-1.12)	0.11*** (7.32)	0.01 (0.26)
Dummy for loan and credit access × Medium- and large-farm size dummy	0.02 (0.35)	-0.08** (-2.41)	0.04 (0.89)				0.02 (0.36)	-0.07** (-2.28)	0.03 (0.64)			
Barisal division dummy	-0.94*** (-12.19)	-1.21*** (-32.06)	-0.30*** (-5.47)	-0.94*** (-12.91)	-1.19*** (-33.24)	-0.28*** (-5.32)	-0.85*** (-11.11)	-1.08*** (-29.96)	-0.17*** (-3.18)	-0.82*** (-11.35)	-1.04*** (-29.81)	-0.13*** (-2.59)
Khulna division dummy	0.40*** (12.81)	-0.07*** (-3.83)	0.29*** (7.76)	0.42*** (13.21)	-0.03 (-1.59)	0.35*** (9.89)	0.35*** (11.30)	-0.14*** (-7.78)	0.25*** (6.84)	0.37*** (11.81)	-0.11*** (-6.39)	0.28*** (7.89)
Dhaka division dummy	0.28*** (9.21)	-0.76*** (-40.34)	0.09** (2.56)	0.29*** (9.95)	-0.73*** (-39.10)	0.13*** (4.05)	0.17*** (5.87)	-0.91*** (-49.77)	-0.02 (-0.53)	0.18*** (6.39)	-0.89*** (-49.99)	-0.01 (-0.11)
Sylhet division dummy	-0.39*** (-7.42)	-1.09*** (-31.76)	-0.07 (-1.51)	-0.38*** (-7.53)	-1.08*** (-31.22)	-0.03 (-0.68)	-0.37*** (-7.09)	-1.06*** (-32.17)	0.01 (0.17)	-0.367*** (-7.42)	-1.05*** (-31.24)	0.01 (0.29)
Rajshahi division dummy	0.25*** (7.94)	-0.35*** (-18.97)	0.39*** (11.25)	0.28*** (8.80)	-0.31*** (-16.23)	0.46*** (13.69)	0.14*** (4.50)	-0.52*** (-29.67)	0.28*** (8.53)	0.15*** (4.87)	-0.50*** (-28.01)	0.29*** (9.07)
Rangpur division dummy	0.22*** (5.74)	-0.83*** (-26.79)	0.08* (1.70)	0.24*** (6.23)	-0.81*** (-25.86)	0.14*** (3.21)	0.13*** (3.50)	-0.96*** (-32.21)	0.01 (0.24)	0.14*** (3.66)	-0.94*** (-31.61)	0.02 (0.51)
Constant	-4.82*** (-70.44)	-3.76*** (-85.90)	-5.06*** (-58.43)	-4.81*** (-71.42)	-3.82*** (-89.70)	-5.09*** (-59.31)	-4.66*** (-69.15)	-3.52*** (-81.56)	-4.88*** (-58.16)	-4.64*** (-69.04)	-3.48*** (-83.87)	-4.85*** (-57.35)
No. of households	814058			814058			814058			814058		
Wald chi ² (54)	90260.53			91104.35			91159.25			90258.10		
Probability> chi ²	0.00			0.00			0.00			0.00		
Log pseudo likelihood	-81477.318			-81910.6			-83283.282			-83406.798		
Log likelihood ratio (chi ² (9))				866.56 ^a			3611.93 ^b			3858.96 ^c		
Probability> chi ²				0.00			0.00			0.00		

Notes: Numbers in parentheses are z-statistics based on robust standard errors.

Significant at the 5% level. *Significant at the 1% level.

a. Presents log likelihood ratio (LR) test statistics between full (unrestricted) and restricted R1 model

b. Presents log likelihood ratio (LR) test statistics between full (unrestricted) and restricted R2 model

c. Presents log likelihood ratio (LR) test statistics between full (unrestricted) and restricted R3 model

should seek to further extend and facilitate access to machinery use by small farm households through such service provision models. Experience has shown that this is the main mechanism by which farmers in much of Bangladesh have been able to access the use of irrigation pumps, threshers, and two-wheeled tractor driven power tillers (Hossain 2009; Justice and Biggs, 2013; Mandal 2014), underscoring that not all farmers must own a machine to multiply farmers' use of mechanized services at a larger scale.

The dummy for households who have received financial loans both from formal and informal sources, and the infrastructural dummy variable for electricity availability within sampled households significantly and positively affect the ownership of all sampled agricultural machinery including irrigation pumps, threshers and two-wheeled tractor driven power tillers (Table 4, the unrestricted model). The extent of paved or gravel road however positively affected the ownership of all sampled agricultural machinery, although it was only significant in explaining ownership of irrigation pumps and threshers, but not two-wheeled tractor driven power tillers. In Bangladesh, the two-wheeled tractor driven power tillers are versatile and can be transported easily even on difficult terrain (Krupnik et al. 2013). The power tiller attachment can also be removed, and attachable flatbed trailers can be hitched to the tractor and used to haul people and materials prior to, or after agricultural land preparation and tillage is completed, thereby extending the use of their machines for more days of the calendar year. Use of these tractors provides a key mode of transport in underserved and difficult to reach areas with poor road networks. Levying fees for transport provides an extra source of income to repay investment in areas where road communication is not well developed and public transport is less available (Justice and Biggs, 2013). This may explain why the extent of paved or gravel road has no significant impact on the adoption of two-wheel tractor driven power tillers at the household level, although our findings do not deny the fact that the prevalence of paved roads and highways can enhance the adoption of other agricultural machineries (Table 4). Road networks are also important to enhance the flow of information, as farmers can easily visit government extension offices in the cities or vice versa, and farmers can also gain more direct access to markets where road networks are both dense and of higher quality (Mottaleb et al., 2014)

The dummies in which we multiplied the medium- and large-farm household dummy with the length of paved or gravel road at the sub-district level, and formal and informal loan facilities, further indicates how infrastructural and institutional variables may differently affect the adoption of agricultural machineries by households of different farm sizes. The coefficients and the corresponding t - values ranged between 0.32 to 7.52 in the unrestricted estimated function, showing that while institutional and infrastructural variables positively influence agricultural machinery ownership, these variables do not generate bias towards medium- and large-farm households compared to smaller farm sizes. Instead, it indicates that the institutional and infrastructural variables exert a similar influence on all farm



households, irrespective of the sizes of their land holdings. Also working in Bangladesh, Quayum and Ali (2012) also found that credit availability can significantly and positively affect the adoption of two-wheeled tractor driven power tillers, while Mottaleb et al., (2014a) demonstrated that physical infrastructure can play significant role in adoption of new agricultural technologies, such as hybrid rice.

5.2.1. Major findings from restricted models

The dummies for medium- and large-farm size were removed in restricted model 1 (R1). We also removed the product of this dummy with the length of paved or gravel road and Sub-district level, and the dummy for loan access. The dummy for pond ownership, total land area owned, and numbers of livestock were removed in the second restricted model (R2), while in the third restricted model (R3), the dummy for loans were removed. In both R1 and R2, the institutional variable dummies for provision of credit from formal and informal sources, and the infrastructural variable dummy for use of machinery reliant on electricity, were highly statistically significant and positive, explaining the ownership of irrigation pumps, threshers and two-wheeled tractor driven power tillers (Table 4). The estimated functions in model R1 and R2 thus emphasize the robust influence of credit and infrastructural facilities such as the availability of electricity at the village level on the ownership of agricultural machinery at the farm household level. Importantly, R2 again confirms that institutional and infrastructural facilities do not generate any significant bias towards agricultural machinery ownership based on sampled farm size (t -statistics ranging between -0.39 – 7.76). Besides removing any potentially endogenous variables, we also removed dummy variable for households receiving loans from formal or informal sources in R3. Similar to the estimated functions R1 and R2, the restricted model R3 also presents the robustness of the influence of physical infrastructure such as the availability of electricity at the village level on household ownership of agricultural machinery.

5.3. Regional heterogeneity in machinery ownership

To compare the spatial dynamics of machinery adoption at the division level, we treated Chittagong division as base division in our estimated functions in Table 4. Chittagong lies to the extreme southeast of Bangladesh, and has nearly 65% of its land area in mountain or hilly coastal environments under predominant forest cover, with very deep water tables inaccessible to most tube wells, in which agriculture is poorly developed (MoA and FAO, 2013). As such, machinery use would assumedly be low in this division, and we consequently chose it to provide a conservative estimate of overall mechanization potential.



The extent of adoption of agricultural machinery in Barisal and Sylhet Divisions, in the coastal south central area, and hilly northeast, respectively, was observed to be low in comparison to other administrative Divisions. The challenges agricultural development in Barisal division include an above average prevalence of poverty, increasing soil salinity in the coastal fringe, regular tidal flooding, and high risk of cyclones, in comparison to other parts of the country. Out-migration by agricultural labourers is also common (MoA and FAO, 2013), in response to growing employment opportunities in both Dhaka and abroad (Zhang et al. 2014), and also potentially due to the frequent and relatively inexpensive ferry services that travel from Barisal to Dhaka on a nightly basis, making migration relatively easy. One might expect that the loss of agricultural labour would encourage an increase machinery ownership, in order to offset seasonal labour deficits, although our results provided no backing for this hypothesis. Conversely, risk prevalence, agronomic production constraints, farmers' limited investment capacity, and lower level of electrification (2.11% below the national average) appear to influence the limited uptake of machinery in Barisal.

These study results indicate that the GoB and donor agencies may wish to consider special programmes to boost scale-appropriate mechanization in Barisal, where farmers could be encouraged to use surface water for irrigation with low-lift pumps, and mechanized land preparation services to move from single to double cropping (Krupnik et al. 2014; MoA and FAO, 2013), in order to spur the sustained intensification of the agricultural sector. Crop insurance schemes, abiotic stress resistant varieties, and best agronomic practices could be useful in this regard, although the former also presents adoption constraints related to farmers' relatively limited ability and interest in investing in insurance (Akter et al., 2015). Given these constraints, we stress that sufficient attention must also be placed on the development of infrastructural facilities, and to the mitigation of investment risk, which could be potentially reduced through low-interest and low risk credit programs. Given these findings, rather than focus on immediate interventions to encourage farmers to secure machinery and supply services to others as part of a strategy to scale-out inclusive agricultural technology access, it may be more logical to sequence interventions by concentrating on infrastructural development as prerequisite to create an enabling environment in which machinery value chains can be established to accelerate adoption. Conversely, each goal could be considered and funded simultaneously, rather than focus primarily on increasing solely the number of immediate farmer-adopters, as is the case for success metrics in many short time-frame development projects that do not address broader sustainability concerns.



6. Conclusion

Farmers' use of scale-appropriate agricultural machinery is important for enhancing labour productivity and reducing drudgery in developing agricultural economies. International donors, policy makers, and development organizations can benefit from information on the factors that most robustly influence farmers' ability to purchase and adopt appropriate agricultural machineries, in addition to information on how and where they can extend their use through service provision arrangements to farmers lacking sufficient capital for actual machinery purchase. Based on our review of the literature, however, relatively little recent research has considered these issues, and no prior empirical studies have employed population-scale data to examine household characteristics, socio-economic, and infrastructural variables as they correlate with machinery ownership in developing nations. Following a review of the historical policy actions that were put into place to facilitate the development of agricultural machinery markets, this paper presented a first-step to fill this crucial knowledge gap by identifying some of the factors that influence the ownership of irrigation pumps, rice and wheat grain threshers, and two-wheel tractor driven power tillers, which comprise the most common and small-scale agricultural machineries that are utilized in Bangladesh.

Household wealth status and land size significantly and positively affected machinery ownership, as did the number of livestock and ponds owned. Our data also indicate that Sub-District level civil infrastructure such as electricity to power tube well pumping, and access to credit, significantly and positively affects rural household ownership of the studied machines. Paved or gravel road at the Sub-District level- also significantly and positively affected the ownership of machinery, although statistical relationships could not be established for two-wheel tractor power tillers. We hypothesize that the lack of influence observed is because two-wheeled tractors are relatively all-terrain vehicles, and can easily be moved down village paths and unpaved roads. Conversely for irrigation pumps, road networks are important for assuring that harvestable products can be efficiently brought to markets, while for threshers, quality roads are usually required to carry equipment to consolidated threshing work stations after which grain is carried in bulk to markets. These hypotheses however require further study and confirmation. Finally, we observed that where farmers are able to access credit and loans, either through banks, NGOs, or informal means, that machinery ownership was significantly more likely. As such, access to credit facilities and the provision of basic civil infrastructure appear to be prerequisite to irrigation pump, thresher, and tractor ownership by farm households, and by consequence to the development of an agricultural machinery service provision economy. In conclusion, we underscore that the GoB, donors, and



development agencies working to expanding farmer uptake of agricultural machineries should equally consider the importance of more basic work to facilitate these necessary pre-conditions to create an enabling environment for mechanization either before and/or simultaneously as direct farmer beneficiary work proceeds.



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