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Interlinkage between food prices and agricultural wages and implications for farm mechanization in Bangladesh

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Md. Fuad Hassan

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Referent: Prof. Dr. Joachim von Braun

Korreferent: Prof. Dr. Thomas Heckelei

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Abstract

In recent decades, Bangladesh's economy has undergone a remarkable structural transformation. Agricultural wages are becoming high while staple food prices are becoming volatile. In the meantime, agriculture has experienced an expansion of machine rental services provided by specialized agents, which has contributed to the mechanization of agricultural production. The emergence of machine rental markets and the recent wage growth may have significant effects on the efficiency of farmers of different scales in rural Bangladesh through land reallocation and technology adoption. Proper understanding of the relationship between food prices and rural wages is essential for planning policies in support of the rural poor in Bangladesh. This dissertation analyzes the interlinkage of food price and agricultural wages and its implication in farm mechanization.

In exploring the link between food prices and rising agricultural wages, the first analytical chapter analyzes the dynamic relations between those two by using monthly data from 1994 to 2014. A standard vector error correction model (VECM) was implemented to determine the short-run and long-run relationships between wages and food prices in eight divisions in Bangladesh. Besides, autoregressive distributed lag (ARDL) models were fitted to estimate the pass-through coefficients and to compare the short-run effects of rice price and urban wage shocks on agricultural wages. We found statistical evidence of a structural break between January 2007 and January 2009. After the structural break, in six out of eight divisions, any shock in rice prices did not transmit to the farm wages in the short run. Moreover, in the long run, food prices became less influential in explaining the changes in rural wages while the influence of urban wages became stronger in some divisions.

To better understand the rural wages pattern this study also examines the implications of agricultural mechanization for agricultural wages using a unique data set of monthly wages and rice prices over the period from 1995 to 2015. Employing a dynamic panel model, estimated by generalized methods of moments, this study found that increasing agricultural mechanization was associated with an increase in real agricultural wages, both in the short, medium, and the long run. This has important implications for policymakers aiming to reduce rural poverty and for interventions put in place to reduce extensive rural-urban migration and create more employment opportunities in the agricultural sector.

The third empirical chapter examines the dynamics of land transactions and the demand for machine services using two-rounds of household panel data from 62 villages of the country. The empirical results show that despite an increase in farm wages, small farmers increased their total cultivable land and their net rented-in land. An increase in the wages of hired agricultural labor led to the substitution of labor with machines. The average investment in hiring farm machines was higher for larger farms. However, there was no significant evidence to suggest larger farmers experienced greater changes in machine hiring expenses.

Finally, this study analyzes the rental market for farm machinery services in Bangladesh. Using primary information collected from 371 machine owners and 239 client farmers, this study demonstrates that different rental service systems have emerged in Bangladesh over time. Ownership of machines (e.g., power tillers, tractors, and threshers) is largely determined by the owners' access to rural credit, land size, and the number of fragmented lands. The monopolistic-type of market prevails for tractors and a competitive market structure exists for power tiller. However, a monopoly exists in the rental market for transplanters and combine harvesters. Social capital seems to be an important factor that ensures the profit of owners as well as the timely availability of services for users. Farmers are willing to mechanize planting and harvesting operations regardless of whether they are owners or non-owners. This strongly indicates that machinery rental services have a bright future in the country.

Zusammenhang zwischen Nahrungsmittelpreisen und Agrarlöhnen und Auswirkungen auf die Mechanisierung der Landwirtschaft in Bangladesch

Zusammenfassung

In den letzten Jahrzehnten hat die Wirtschaft Bangladeschs einen bemerkenswerten Strukturwandel durchlaufen. Die Löhne in der Landwirtschaft sind hoch geworden, während die Preise für Grundnahrungsmittel volatil geworden sind. In der Zwischenzeit hat die Landwirtschaft eine Ausweitung der Maschinenvermietung durch spezialisierte Agenten erlebt, was zur Mechanisierung der landwirtschaftlichen Produktion beigetragen hat. Das Aufkommen von Maschinenvermietungsmärkten und der jüngste Lohnanstieg können durch Landumverteilung und Technologieübernahme erhebliche Auswirkungen auf die Effizienz von Landwirten verschiedener Größenordnungen im ländlichen Bangladesch haben. Ein genaues Verständnis der Beziehung zwischen Lebensmittelpreisen und Löhnen im ländlichen Raum ist für die Planung von Maßnahmen zur Unterstützung der armen Landbevölkerung in Bangladesch unerlässlich. Diese Dissertation analysiert den Zusammenhang zwischen Lebensmittelpreisen und landwirtschaftlichen Löhnen und deren Auswirkungen auf die Mechanisierung der Landwirtschaft.

Bei der Untersuchung des Zusammenhangs zwischen Lebensmittelpreisen und steigenden landwirtschaftlichen Löhnen werden im ersten analytischen Kapitel die dynamischen Beziehungen zwischen diesen beiden anhand von Monatsdaten von 1994 bis 2014 analysiert. Ein Standard-Vektor-Fehlerkorrekturmodell (VECM) wurde implementiert, um die kurz- und langfristigen Beziehungen zwischen Löhnen und Lebensmittelpreisen in acht Divisionen in Bangladesch zu bestimmen. Außerdem wurden autoregressive Distributed Lag (ARDL)-Modelle angepasst, um die Pass-Through-Koeffizienten zu schätzen und die kurzfristigen Auswirkungen von Reispreis- und städtischen Lohnschocks auf die landwirtschaftlichen Löhne zu vergleichen. Wir fanden statistische Beweise für einen Strukturbruch zwischen Januar 2007 und Januar 2009. Nach dem Strukturbruch wurde in sechs von acht Abteilungen ein Reispreisschock kurzfristig nicht auf die landwirtschaftlichen Löhne übertragen. Darüber hinaus wurden die Lebensmittelpreise langfristig weniger einflussreich, um die Veränderungen der Löhne auf dem Land zu erklären, während der Einfluss der städtischen Löhne in einigen Bereichen stärker wurde.

Um das Muster der Löhne auf dem Land besser zu verstehen, untersucht diese Studie auch die Auswirkungen der landwirtschaftlichen Mechanisierung auf die landwirtschaftlichen Löhne unter Verwendung eines einzigartigen Datensatzes von Monatslöhnen und Reispreisen über den Zeitraum von 1995 bis 2015. Unter Verwendung eines dynamischen Panelmodells, das mit verallgemeinerten Methoden der Momente geschätzt wurde, fand diese Studie heraus, dass eine zunehmende Mechanisierung der Landwirtschaft mit einem Anstieg der realen landwirtschaftlichen Löhne verbunden war, sowohl kurz-, mittel- als auch langfristig. Dies hat wichtige Implikationen für politische Entscheidungsträger, die die ländliche Armut reduzieren wollen, und für Interventionen, die zur Verringerung der extensiven Land-Stadt-

Migration und zur Schaffung von mehr Beschäftigungsmöglichkeiten im Agrarsektor eingesetzt werden.

Das dritte empirische Kapitel untersucht die Dynamik von Landtransaktionen und die Nachfrage nach Maschinendienstleistungen anhand von Haushaltspaneldaten aus zwei Runden von 62 Dörfern des Landes. Die empirischen Ergebnisse zeigen, dass trotz eines Anstiegs der landwirtschaftlichen Löhne die Kleinbauern ihre gesamte Anbaufläche und ihre Nettopachtfläche vergrößerten. Ein Anstieg der Löhne für gemietete landwirtschaftliche Arbeitskräfte führte zur Substitution von Arbeitskräften durch Maschinen. Die durchschnittliche Investition in die Anmietung von Landmaschinen war bei größeren Betrieben höher. Es gab jedoch keine signifikanten Hinweise darauf, dass größere Landwirte größere Veränderungen bei den Ausgaben für die Anmietung von Maschinen erfuhren.

Schließlich analysiert diese Studie den Vermietungsmarkt für Landmaschinenservices in Bangladesch. Anhand von Primärdaten, die von 371 Maschinenbesitzern und 239 Kundenlandwirten erhoben wurden, zeigt diese Studie, dass sich in Bangladesch im Laufe der Zeit verschiedene Mietservicesysteme herausgebildet haben. Der Besitz von Maschinen (z.B. Bodenfräsen, Traktoren und Dreschmaschinen) wird weitgehend durch den Zugang der Besitzer zu ländlichen Krediten, die Landgröße und die Anzahl der fragmentierten Ländereien bestimmt. Bei Traktoren herrscht eine monopolistische Marktstruktur vor, während bei Motorhacken eine wettbewerbsorientierte Marktstruktur existiert. Ein Monopol besteht jedoch auf dem Mietmarkt für Sämaschinen und Mähdrescher. Soziales Kapital scheint ein wichtiger Faktor zu sein, der sowohl den Gewinn der Eigentümer als auch die rechtzeitige Verfügbarkeit von Dienstleistungen für die Nutzer sichert. Die Landwirte sind bereit, Pflanz- und Erntearbeiten zu mechanisieren, unabhängig davon, ob sie Eigentümer oder Nicht-Eigentümer sind. Dies deutet stark darauf hin, dass die Maschinenvermietung in dem Land eine große Zukunft hat.

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List of abbreviations

ADF	Augmented Dickey-Fuller
GLS	Generalized Least Squares
ARDL model	Autoregressive Distributed Lag Model
BADC	Bangladesh Agricultural Development Corporation
BBS	Bangladesh Bureau of Statistics
BCR	Benefit Cost Ratio
BDT	Bangladeshi Taka
BRAC	Bangladesh Rural Advancement Committee
CSISA-MI	Cereal Systems Initiative for South Asia-Mechanization and Irrigation
DAM	Department of Agricultural Marketing
DAE	Department of Agricultural Extension
ERS	Economic Research Service
et al.	and others
FAO	Food and Agriculture Organization
FGD	Focus Group Discussions
FPMU	Food Planning and Monitoring Unit
GDP	Gross Domestic Product
GMM	General Methods of Moments
GOB	Government of Bangladesh
HIES	Household Income and Expenditure Survey
HP	Horsepower
KG	Kilogram
KM	kilometer
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
NGO	Non-Governmental Organization
OMS	Open Market Sales
PFDS	Public Foodgrain Distribution System
PKSS	Palli Kallyan Shikkha Society
SAAO	Sub-assistant Agricultural Officers
SAARC	South Asian Association for Regional Cooperation
SDGs	Sustainable Development Goals
ToT	Terms of Trade
UN	United Nations
USD	United States Dollar
USDA	United States Department of Agriculture
VAR	Vector Autoregression
VECM	Vector Error Correction Model
VMP	Versatile Multi-planter
2WT	Two-Wheel Tractor

1. Introduction

1.1 Background and motivation

The effects of agricultural wage growth on rural poverty and the adoption of labor-saving technology have been a topic of lively debate during the past few decades among development economists. In fact, prices of staple food, rural wages, and employment are three important indicators to understand the development stages of an economy. During periods of major structural transformation, similar sequences of events arose in all developed and developing countries, including India, China, Bangladesh, and other rapidly growing countries of Asia. From the perspective of a developing country, structural transformation of wages and food prices requires the adoption of new technologies and new types of service markets, and hence such transformation can influence poverty and food security. If rural wages are rising, both in Asia and in other parts of the developing world, then there must be some implications for rural development and poverty, for food prices, and economic growth. Despite the lasting impact of the 2008 global recession, the number of workers living in extreme poverty in some least developed countries, such as Ethiopia, Bangladesh, and India, has declined significantly (UNDP, 2015). Although the global economy continues to recover, the world is experiencing sluggardly growth, broadening inequalities, and weak job markets struggling to keep up with a growing labor force. According to the International Labor Organization, more than 204 million people were unemployed in 2015. The unemployment rate in developing countries is also rising; for example, in Bangladesh, the unemployment rate is 4.37% and about 46% of the total unemployed youths are university graduates (BBS, 2016). Farming activities account for the biggest percentage of total employment in the least developed countries, while it has a decreasing trend due to rapid urbanization (FAO, 2017). On the other sides, employment in the non-farm sector is increasing. As a result, changes in rural wages not only have an impact on the farming economy but also may affect wages in urban non-farm sectors and the adoption of modern labor-saving technologies. Goal number eight of SDGs is to achieve full and productive employment, and decent work, for all women and men by 2030. To achieve this goal, each of the developing countries has a target to promote sustained economic growth, higher levels of productivity, and technological innovation. However, to eradicate the problem of unemployment among semi-skilled and skilled workers, it is essential to encourage entrepreneurship that can be merged with technology. This study considered Bangladesh to be representative of the least developed countries and tried to find the interlinkage between food prices and agricultural wages and implications for farm mechanization.

Why Bangladesh?

In Bangladesh, the availability of farm labor is declining, and the agricultural population is aging. Most of the young people are not interested in agriculture as they think it is less profitable compared to other non-farm activities and also consider it unprestigious (Tarek, 2019). Compare to farm activities, non-farm activities generate higher income and are more technical, which most young people find attractive (Leavy and Hossain, 2014). Cultivation of crops, especially rice, wheat, and pulses, still requires large amounts of manual labor for different activities, such as harvesting and planting. The demand for agricultural labor per day is higher than the relative value of the product produced; for instance, the average wage rate (with one meal) during the Boro harvesting season in 2014 is 340 BDT (5.5 USD), whereas the average price of 38 kg of paddy is 550 BDT (8.5 USD) (BBS, 2016). Traditional farmers usually find it difficult to maintain their profit margin by using manual labor force, which is the case for rice cultivation. The use of farm machinery is one of the ways of minimizing the cost of hired labor as well as mitigating insecurity of finding hired labor on time for different farm activities. Previously, the introduction of small-scale engines for lifting groundwater contributed to a change in the farming pattern of certain crop varieties. The active irrigation water market also helps to grow other forms of agricultural mechanization, such as the rental market for tractors, power tillers, and threshers, by enhancing farmers' ability to cultivate different crop varieties.

Another feature of Bangladesh's agriculture is the use of technology, as embodied by modern inputs. Almost all farming households use fertilizers, and a vast majority have adopted high-yielding varieties and are becoming increasingly mechanized. The mechanization of agriculture is not necessarily the result of machinery ownership among farming households as most of them still rely on mechanization services. The service market for farm machines has grown rapidly, allowing even farmers who are poor to have access to cost-effective rental services. In fact, the active rental market for farm machines started to unlock capital constraints. In Bangladesh, the ground rules on the adoption of modern technology have shifted as a result of the liberalized policy framework adopted in the 1980s and early 1990s, which allowed the import of small machinery and wage employment (Hossain and Bayes, 2015). The government recognized the increasing need for mechanization to boost rural development and has adopted policies to ease the mechanization process in agriculture. However, specific regulations and local rules to ensure the implementation of these policies are yet to be developed. A recent study entitled "Mechanization for Sustainable Agricultural Intensification in SAARC Region" and the United Nations Food and Agriculture Organization (UN FAO) predicted that the percentage of labor force employed in on-farm agricultural activities would reduce from 43% in 2017 to 36% by 2020 and 20%

by 2030, posing a great challenge to Bangladesh's agriculture as the country needs to produce more grains to sustain an increasing population.

The following is a general overview of farm wages, prices, poverty, and rental markets:

Farm wages

The transformation of the economic structure in Asia has induced increasing real wages not only in urban and non-agricultural sectors but also in many parts of rural and agricultural sectors in Asia (Yamauchi, 2014). Bangladesh is not an exception to such economic growth in South Asia. The increase in real wages, in particular rural real wages, has accelerated since the late 2000s, suggesting that the Lewis turning point has arrived (Zhang et al., 2014). Rural wages are predominantly based on agricultural activities. Agriculture is the largest sector of employment in Bangladesh. Although the share of agriculture in the gross domestic product (GDP) has declined, it remains the predominant sector regarding employment and livelihood, with about half of Bangladesh's workforce engaged in it as their principal occupation. Agriculture in Bangladesh is a largely labor-intensive activity. The expenditure on farm labor constitutes a substantial share of total cost of cultivation of a crop. Hired laborers in agriculture earn a daily wage and do not own or lease land but work on farms owned by others in return for wages paid to them in cash or kind (Saini et al., 2020). Rice farming is the largest activity in the agricultural sector; it employs about 45% of the rural labor force and also provides two thirds of the calorie needs of the nation (BBS, 2017). There are numerous types of labor relations, and different forms of labor force participation are practiced in agriculture. Agricultural labor are compounded by the fact that many small and marginal farmers also work partly on the farms of others and provide services to supplement their income. This group of farmers mainly comprises landless, functionally landless, and marginal farmers and constitutes the majority of the rural population. Rising wages are seen as the major driver of rural poverty reduction in recent decades (Datt and Ravallion, 1998). Agricultural wages influence rural welfare, especially the welfare of the poorest groups, who rely heavily on these wages for income (Lasco et al., 2008). Rural wages in Bangladesh grew faster in the second half of the 2000s than before; the average wage of a male rural worker rose in real terms by 45% between 2005 and 2010 (Wiggins and Keats, 2014). Urban wages of female workers more than doubled from 2000 to 2005, whereas those of male workers increased by only 43% during the same period (Zhang et al., 2014). In the later period of 2005 to 2010, both male and female wages surged by more than 55% according to household income and expenditure surveys (HIES). Furthermore, the booming manufacturing sector has also increased the wages of urban laborers and attracted surplus labor from the rural sectors. Between 2000 and 2015, the agriculture wage rate grew by 10.74 percent while manufacturing grew by 8.85 percent (Mujeri et al., 2020).

Changes in food price

Fluctuation in the prices of staple crops is an important factor that determines the behavior of producers and consumers with regard to these crops. It also determines the government's approach to stabilizing the market and political economy. In Bangladesh, rural households in the bottom 5% income group spend 71.4% of their total consumption expenditure on food (BBS, 2016). Among the different foodgrains, rice alone is consumed by more than 90% of the population and covers 75% of the total cropped land (BBS, 2010). Annual rice price fluctuations in Bangladesh arise mostly from oscillation in production, which again can be attributed to the random effect of floods, droughts, and crises in world markets (Dorosh and Shahabuddin, 2002; Koizumi, 2017). There is a concern in Bangladesh that prices of essential commodities, including rice, wheat, pulses, sugar, edible oils, ginger, garlic, onion, and potatoes, have shown an upward trend since 2007 (World Bank, 2007). World food prices rose suddenly and sharply in late 2007 through to early 2008, fell in the aftermath of the global financial and economic crisis of 2008, and rose again in 2010 (Jayasuriya et al., 2012). The inflationary events in Bangladesh follow the trends of high global commodity price volatility, particularly rice prices in domestic and global markets (Hossain and Rafiq, 2014). However, international food prices declined by 14% between 2013 and 2015, sliding into a five-year low, which consequently reduced food prices in Bangladesh because of the increasing availability of cheaper imports (World Bank Group, 2015). However, in 2017, rice prices went up once again even though the world rice price kept declining.

In Bangladesh, it is necessary to acknowledge the high costs of inflation for the poor and disadvantaged groups. The traditional thinking is that inflation is costly for the poor, since their purchasing power deteriorates, and it is hard for the poor to hedge against inflation due to their limited access to the rural financial system (Hossain and Mujeri, 2020). Therefore, food policy in Bangladesh has several objectives; one major objective is ensuring food security for all households. In attempting to meet this goal, the Government of Bangladesh (GOB) undertakes several activities, including open market sales of foodgrains to limit foodgrain price increases, targeted food distribution to poor households, provision of emergency relief after natural disasters, and procurement of foodgrain to support producer prices and incomes. In the face of the present volatile condition of rice prices, the government continues to introduce new types of rice-based policies to control the food markets.

Land

The rural farmland is in continuous decay in Southeast Asia because of human-land interaction through urbanization and related development aggravations (Alam et al., 2016). Many existing researches support that average farm size has decreased in most low and lower-middle-income countries, whereas it has increased in some upper-middle and high-income countries (Lowder et al., 2016). Bangladesh is no exception with two-third of the population lived in villages (FAO, 2015). Bangladesh is densely populated, with small farms and high levels of land fragmentation (Rahman et al., 2009). The recent trend indicates that the average farm size of small landholders will slightly increase as the numbers of marginal and large landowners reduce (Salam and Bauer 2018). The land rental transactions enable farmers to adjust their operational farm size, and thus indirectly, agricultural yield (Eskander and Barbier, 2016). Understanding the determinants of land-use decisions made by medium and small farm holders of developing countries would provide valuable information for the promotion of food production and the fight against poverty (Nguyen et al., 2017).

As farmland can be transacted more fluidly and with fewer transaction costs, both large and small farms would be better able to optimally match their farm size to their labor endowment (Deininger et al., 1982). Thus, small farms with excess family labor might expand their farm size (if they can afford to do so). Larger farms with insufficient labor might rent out land, resulting in less severe productivity differences across relatively small and large farms. The decision of using less or more land for cultivation is related to the productivity of the land. However, there is a dated belief that farm sizes are still inversely related to productivity. Nowadays, there is a school of thought that believes in a diminishing inverse farm size-productivity relation when it is associated with the emergence of an active rental market for farm machinery. Generally, the use of labor-saving technology as a proxy factor of production is more suitable for large farms; an improvement in market activity for labor-saving technology can be expected to benefit large farms (i.e., to decrease their relative disadvantage of hiring labor and supervision costs) and weaken the inverse relationship.

Mechanization and rental markets

The use of agricultural machinery appropriate for smallholder farmers in South Asia has become one of the strategic issues for sustainable production. Scale-appropriate machinery can increase returns on land and labor, although the requirement for capital investment can preclude some farmers from owning machinery. The eagerness to adopt farm machines has resulted in relatively well-developed rental service markets for tillage, irrigation, and post-harvest operations. A large number of cultivators thereby access agricultural machinery that may have otherwise been cost-prohibitive to purchase through fee-for-service arrangements, although the opportunity for expansion remains. Farm machinery use has advanced considerably in Bangladesh, particularly for land preparation, irrigation, and post-harvest activities. Figure 1.1 shows the trend of machinery use after the trade linearization in the 1980's.

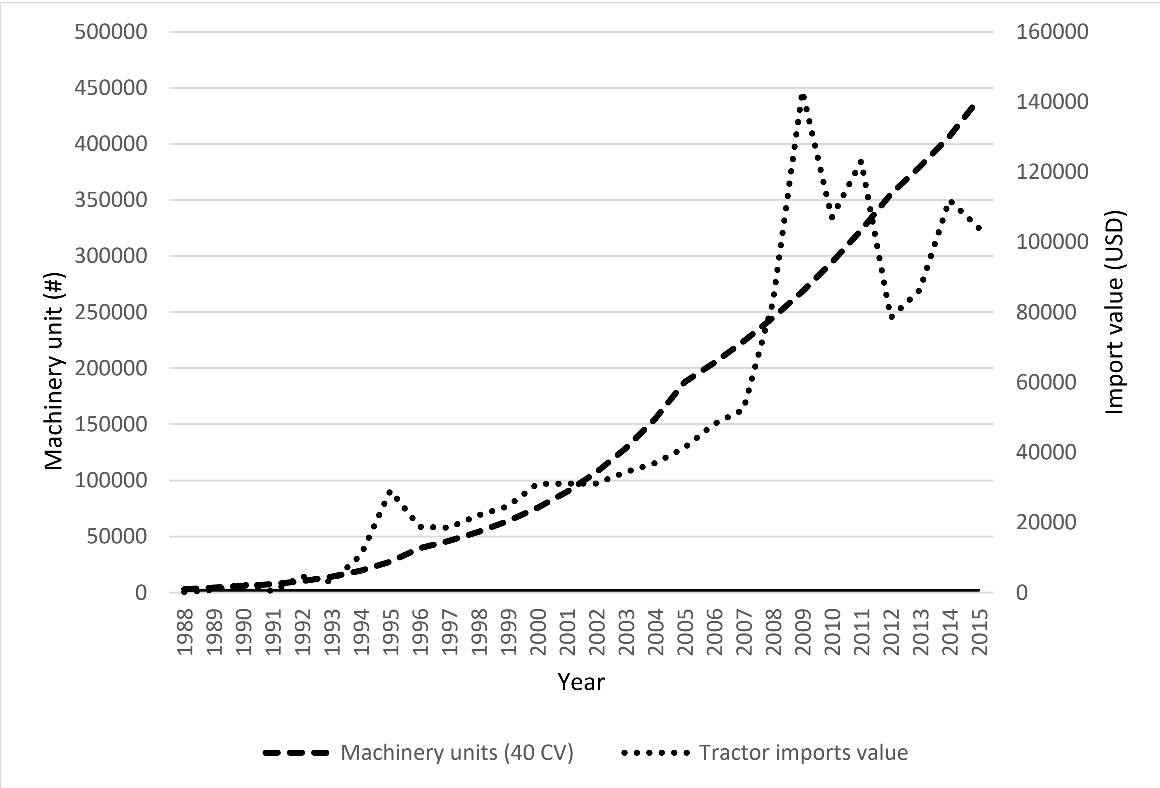


Figure 1.1: *Trend of machine use in Bangladesh*

Source: UN Comtrade (1980 to 2014)

The rural economy of Bangladesh is frequently characterized by formal and informal institutions which can create apparent economic inefficiencies and barriers to the access and adoption of technology. Among South Asian countries, Bangladesh has seen advancement in farm machinery use (Justice and Biggs, 2013). The availability of irrigation pumps through the water market has been a key ingredient in Bangladesh's current level of near rice self-sufficiency (Hossain, 2009; Mainuddin and Kirby, 2015). Following the demand for small-scale machinery, many small enterprises providing repair and maintenance services have developed in many corners of the country. Now, Bangladesh is a role model for other developing countries, such as those in Africa, in terms of mechanization. Although only a small number of farmers own farm machinery, many farmers are using machines with the help of rental services. The rental of specific machines like tractors, power tillers, threshers, and harvesters is seen as one of the profitable businesses in rural areas. It is important to recognize that when mechanization started to grow in Asia in the 80s, the average farm size was fairly small, and it is still the case today in some Asian countries. In countries like Bangladesh, agricultural productivity kept rising even though farm size has become smaller (Animaw et al., 2016). It is useful to note that labor and machine powers are often regarded as substitutes, particularly at the time of land preparation (Liu et al., 2016). However, they may be complementary if a particular farm uses traction (and is, therefore, able to expand in size) and hires labor at different times during the growing season.

1.2 Problem statement

The nexus between agricultural wages and staple food (rice) prices has been an issue of intense empirical analysis, as agricultural wages influence the welfare of the poorest groups in the rural areas comprising mostly the agricultural laborer households (Mujeri et al., 2020). In particular, rice being the staple, change in rice prices has a significant impact on agricultural wages in Bangladesh. In light of changing rural wages and food prices, assessing the relationship between agricultural wages and staple food prices is an important empirical issue. The responsiveness of wages to prices and productivity is often an important determinant of how the standard of living of the poor evolves over time (Boyce and Ravallion, 1991). The rising rate of food price inflation in recent years has raised significant concern relating to its negative welfare consequences including reduction of real income inefficiencies, and inequities particularly on the poor (Hossain and Mujeri, 2020). Neoclassical theories, where labor demand and wages are determined by the marginal physical product, cannot explain stable wages amid seemingly unlimited supply of workers and massive involuntary unemployment in developing countries like Bangladesh (Zhang et al. 2014). This is also true for the efficiency wage theory proposed by Leibenstein (1957) and Mazumdar (1959), where the main premise is that productivity depends on consumption, so the employer should pay a wage that covers the minimum calories needed by a worker to work effectively. But the emerging wage trend in South Asia raises a question regarding the consistency of these theories. In India evidence was found of a food-wage spiral where changes in food prices and farm wages were estimated to impact each other (Saini et al., 2020). Despite important gains in reducing poverty and increasing agricultural productivity, roughly 25% of the population are considered food insecure (Magnani et al., 2015). Almost 66% of the labor force make their living in farming and the vast majority of the farmers (81%) farm less than 1.5 acres (Ahmed et al., 2013). So the majority of the people in rural areas depend on their wages earned from selling their labor. This earning is directly related to their wellbeing and food security condition. Following the price shocks in 2008, there is a concession that this price disturbance increases the number of people living in poverty while there is no evidence regarding whether the increasing wages in the farm sector played a role in reducing the negative impact of the price hike. Even though media reports provided enough evidence of such suffering, few systematic longitudinal studies have been conducted to understand the intricacies of how people experience difficulty in maintaining their lifestyle and cope in different ways in an era of food-price volatility. It is established that the poverty rate decreases as real wages increases, but it is not known exactly how increasing farm wages helps lift people out of poverty considering the volatile food prices. A few studies in Bangladesh examined the relationship between agricultural wages and rice prices (Boyce and Ravallion, 1991; Ravallion, 1990; Palmer-Jones, 1993; Palmer-Jones and Parikh, 1998; Mujeri et al., 2020). Exploring the relationship between agricultural and non-agricultural wages, and staple food prices is an important empirical issue in view of such a transformation in the economy for proper policy planning for the poor.

The use of agricultural machines has been a subject of scholarly debate for several decades. In the early literature, it was a concern whether rural labors displacement were negatively influenced the wage welfares in the rural areas. An increase in real wages may induce a substitution between labor and machines, and could lead to a new institutional arrangement that reduces user costs of machines on farm irrespective to land consolidation. Such evidences are available in India, Indonesia, and China at household level (Foster and Rosenzweig, 2011; Yamauchi, 2014). However, there is a limited or no research to estimate the impact of using agricultural machines on real farm wages at national level. Increasing farm wages put pressure on farmers to maintain their production costs. A change in real wages might influence the relations between the use of human labor, cultivated land, and machines among farmers. In China, the introduction of machines to substitute for labor became active in the areas where real wages increased fast but were significantly constrained by land fragmentation (Wang et al., 2020). In the developing countries of Asia, when the hired labor wage rate increases, labor-saving, and machine-using production methods become efficient (Otsuka et al., 2016). The interaction between these three elements (land, labor, and machine rental) of production is unknown in the context of the current structural change in Bangladesh. However, not knowing how wage growth affects land reallocation and machine use will hinder the ability of policymakers to tailor interventions to this exact group (small or marginal farmers).

Success in the mechanization of irrigation, land preparation, and threshing has encouraged farmers to adopt other popular but unavailable machine services like harvesting, seeding, weeding. Several factors including the development of new roads improved access to loans, and farm sizes have positively influenced the probability of owning farm machines in Bangladesh (Mottaleb et al., 2016). However, the demand for the rental market of the farm machine is unexplored. The relationship between the users and owners of the machines has an immense importance in adopting the rental services of machines during the peak agricultural seasons (Cossar, 2017). Although the demand for small-scale machinery has been increasing, little is known about the custom hiring system of machinery and how the market operates in rural settings. Therefore, this study may provide important insights into the factors that influence the spread of custom hiring services of farm machines in Bangladesh.

Research objectives and questions

Considering the background and problems discussed above, this study aims to contribute to the literature concerning price-wage nexus in agriculture and its implication for farm mechanization, one of the important issues in development economics. The main objective is to identify the relation between food prices, agricultural and non-agricultural wages, and technology adoption. Additionally, this study also looks at the tendency of farmers to adopt farm mechanization and land reallocation under increasing labor demand, with special attention to rental service provision and farmers' access to such services. This dissertation answers the following central questions:

Food price and farm wage nexus:

Does the agricultural wage rate respond to changes in rice prices?

Are agricultural labor markets independent of urban labor markets?

Agricultural mechanization and real rural wages:

How does agricultural mechanization affect agricultural wages in Bangladesh?

Interlinkage of farm wage, farm machinery use, and land reallocation:

Is there any substitutional relationship between machine and labor capital in rice cultivation?

How does the farm wage influence land reallocation for agriculture?

Rental markets for agricultural machinery:

What is the structure of the rental markets in the rural area of Bangladesh?

What are the determinants of the demand for custom hiring systems?

1.3 Conceptual framework

Figure 1.2 shows the framework to assess the interlinkages of farm wage, food prices, and the impacts of farm wage growth on agricultural mechanization and its relation with labor and land reallocation in the context of a developing country. The framework essentially suggests that changes in urban wages and food prices influence agricultural wage policies aimed at inducing changes in markets, prices, or infrastructure or at creating an economic environment that in turn affects farmers' objectives and constraints. In addition, this framework assumes that government policies also have an impact on private sector investment in agriculture, such as import of farm machinery and development of farm machinery rental services as an enterprise. Meanwhile, farmers' objectives, for example, profit maximization, may be constrained by available farmland, capital, labor, technologies, and markets. However, the intensity of income or profit maximization depends on how a farmer allocates their productive resources (labor, land, and capital) to various farm and non-farm activities, such as the type and scale of farm power used (draft animals or power tillers), under the constraints the farming household faces. For example, a lack of capital to acquire a tractor or an inactive tractor rental market is a major constraint to the adoption of mechanical technologies. The government might design a microcredit program or establish a mechanization service hub to improve farmers' access to credit and labor-saving technologies. Once such constraints are lifted, farmers will likely adopt agricultural machines and increase their crop production and productivity. However, the emergence of private rental services for equipment like power tillers, tractors, or seeders may remove some constraints faced by farmers. The adoption of labor-saving technology or farm mechanization may determine cropland expansion and intensification patterns. Farm mechanization is driven by multiple factors, and understanding how these factors interact requires a comprehensive framework.

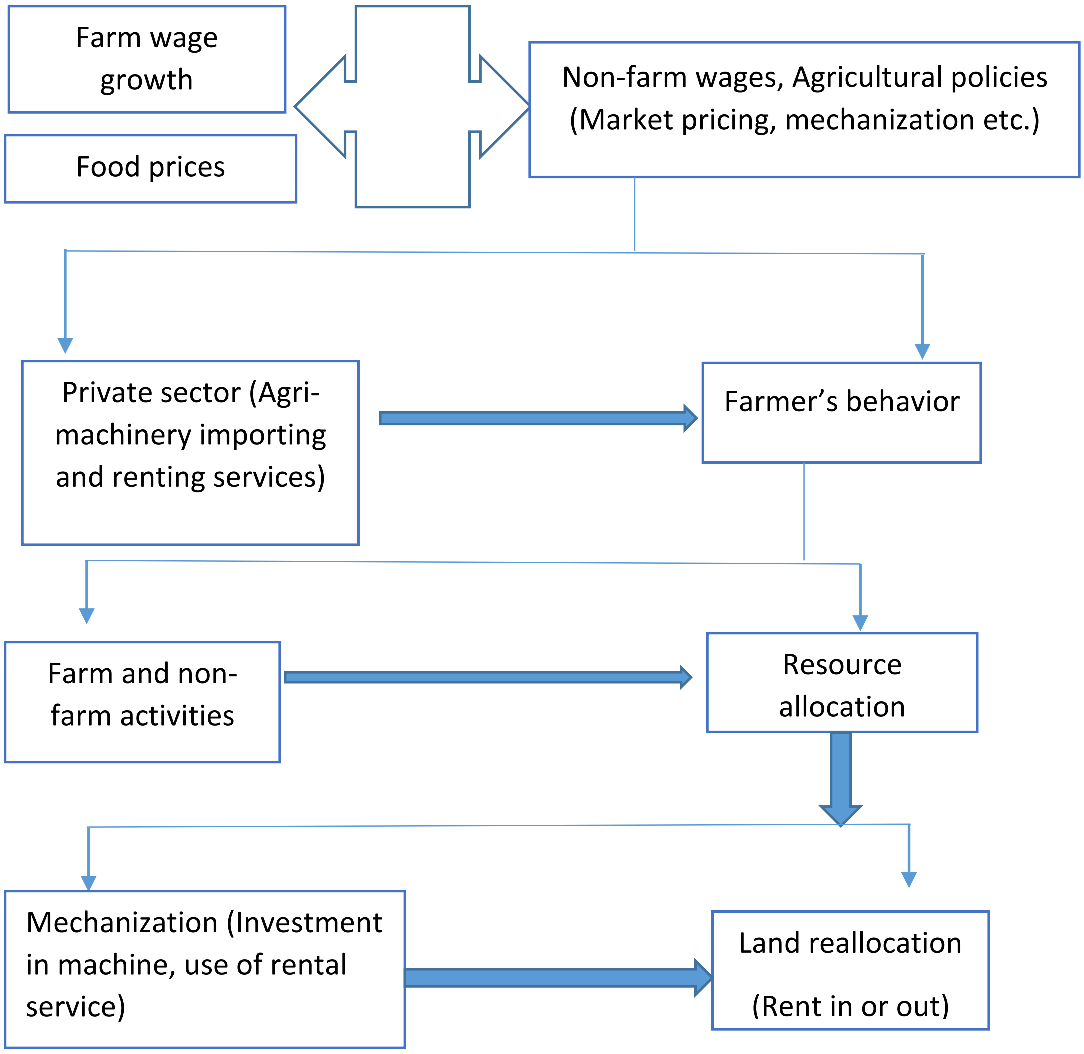


Figure 1.2: Conceptual framework

Source: Modified from Lariviere et al., (1998) and Reardon et al., (1999).

Given the chain of impacts that may result from mechanization, this dissertation tries to identify the drivers of interaction between mechanization and other key farming system components, such as cropland and labor. In exploring the link between food prices and rising rural wages, this research investigates the connections between rural wages in farming sectors and the relationship these wages share with unstable food prices and farm mechanization. By following the literature and theoretical background, we hypothesized that food prices would influence the rural wages in the different districts of Bangladesh. Food price inflation also induces day laborers to bargain for higher wages. However, public and private policies regarding slack period employment generation and food distribution influence food prices and the real wage demand. Rural labor supply in the different places is interlinked with the income available from farming wages. The higher cost of hiring labor for agricultural work would ultimately influence farmers to adopt mechanized farming. But the intensity of using such labor-saving technology also depends on the rental markets for farm machines. So this research also considers the empirical question of the role that rental market constraints play in the relationship between wages and the adoption of mechanized farming.

1.4 Research methods

This study analyzes both secondary and primary data. The data were collected from different organizations. The following paragraphs briefly describe the data sources used and methodology followed in each specific study:

Food price, farm, and non-farm wages:

The interlinkages between food prices and wages were assessed by using the monthly data from eight divisions of Bangladesh. Monthly rice prices were collected from 38 major markets of the 23 districts across a total of 8 divisions. Monthly farm wages were collected from all the 23 districts covering the whole country. However, in the case of farm wages, only the highest and lowest wages in each month were reported, and we used the average of these wages (no significant differences among the wages). In addition to farm wages, this study also examined data on urban wages in the industrial, manufacturing, and construction sectors. These data sets were provided by the Bangladesh Bureau of Statistics (BBS) and the Food Planning and Monitoring Unit (FPMU) of Bangladesh. There are multiple ways to investigate the price-wage nexus from time-series data. In this study, vector error correction models and autoregressive distributed lag models have been used to estimate the long and short-term elasticity of wage in respect to food price.

Machine investment data:

Three indicators of farm machines were used in the second empirical chapter. The first one is the number of tractors, which is available from the United States Department of Agriculture Economic Research Service (USDA ERS; 2018) based on Fuglie (2015). The second one is the capital-labor ratio in agriculture provided by the FAO (2018). The final indicator is the tractor stock measured in USD, collected from UN Comtrade (2018) reports. Information on the production and yield of rice has been collected from BBS. Considering the nature of the data, dynamic panel models were employed to see the impact of machinery investment on rural wages by using the Arellano-Bond estimator.

Data from 62 villages:

The fourth chapter is based on a panel data set collected from the Bangladesh Rural Advancement Committee (BRAC), a renowned non-governmental organization (NGO). Interaction between farm wage, land, and farm mechanization was estimated by using the longitudinal data collected from 62 villages comprising 1050 true panel households. Although the survey spanned about two decades (1988-2014), this study uses the latest two waves (2008 and 2014) covering true panel households. The sample size in the true panel is 1050 in each survey. The information was obtained through a semi-structured questionnaire designed to gather information on demographic details, land use, costs of cultivation, farm and non-farm activities, commodity prices, ownership of non-land assets, income, expenditure, and employment. Furthermore, the data set provides extensive details about the farms' characteristics, tenure arrangements, and specific investments in farm machines. Besides the descriptive statistics, the first difference regression models were employed to see the impact of wages on land reallocation and machinery investments.

Farm machinery rental markets:

Finally, farm machinery rental markets were investigated by collecting primary data from the four districts in Bangladesh – Rajshahi, Bogra, Kishorgonj, and Jashore. These areas are from different agricultural zones and have different demographics. The data on machine owners and machine users were collected using the multistage stratified random sampling technique. In total, 610 sample units were surveyed using the structural questionnaires and each group (owner and user) has different modules. By using the different means of descriptive and inferential statistics, this chapter focus on the present situation and prospects of the rental (custom-hiring) market for farm machinery.

1.5 Outline of the dissertation

The introductory chapter presents the overall background, problem statement and research questions, conceptual framework, study area, and survey data. The farm wage and rice price dynamics are addressed explicitly in Chapter 2 along with a discussion about the trend of poverty, long-run elasticities, and wage-price transmission in the short run.

In Chapter 3, we explore the impact of machinery investment on real farm wages. In this chapter, we measure the elasticities of wages in response to investments in farm machinery in short (monthly), medium (seasonal), and long (Annual) terms.

Chapter 4 features analysis of farm wage growth on labor-saving technology adoption and land reallocation. The discussion also highlights the most appropriate size of a farm in the interim phase of mechanization.

Chapter 5 presents the features of rental markets, present as well as future demand for rental services, and the interaction mechanism between owners and users of farm machinery. This chapter also discusses the role played by different factors like social capital and credit in making the custom hiring system an example to follow for other developing countries.

The conclusions presented in Chapter 6 summarize the major research findings, attempt to formulate a new research agenda for more accurate estimations of wage-price elasticities, and identify effective policy options.

2. Farm Wage and Rice Price Dynamics in Bangladesh

2.1 Introduction

It is one of the primary objectives of low-income countries to achieve economic development. To improve the well-being and socio-economic conditions of the population, it is essential for policymakers to create employment opportunities. However, rising food prices in recent years have created serious concern about rising poverty and food insecurity in the developing world (Barahona and Chulaphan, 2017). Against this background, there is also the view that farm households in developing countries, who are not only consumers but also food producers, could benefit from higher prices, yet the magnitude of such benefits is controversial (Ivanic and Martin, 2014). However, projections of benefits for producers are based on the assumption that higher food prices one-to-one translate to higher wages.

In Bangladesh, the agricultural sector provides both food and employment for the population. In the fiscal year 2016-17, its contribution to the GDP was about 14%, with an annual growth rate of about 3% from 2015 to 2016 (World Bank, 2018). The provisional estimates for fiscal year 2017-18 showed that the manufacturing and construction sectors had grown by about 13% and 10% in 2017, respectively (BBS, 2018). Most of the unskilled and semi-skilled laborers are involved in both agriculture and non-agriculture activities, i.e., providing manual labor in crop production and industries. In many developing countries, the responsiveness of wages to prices determines how the standard of living of the poor evolves (Boyce and Ravallion, 1991). The importance of the link between farm wages and food prices is also reflected in national statistics. In Bangladesh, the bottom 5% income group among rural households spends 71.4% of their total consumption expenditure on food (BBS, 2016) and in consequence, large spikes in food prices are a serious threat to this group (von Braun and Tadesse, 2012). Among the different foodgrains, rice alone is consumed by more than 90% of the population, and it covers 75% of the total cropped land (BBS, 2010). Rice farming is the largest activity in the agricultural sector, employs about 45% of the rural labor force, and also provides two-thirds of the caloric requirements of the nation. Thus, it is very likely that changes in rice prices will have a significant impact on agricultural wages, poverty, and food security.

The structural transformation process in many less-developed agrarian economies is characterized by strong changes in the agricultural sector. This can be both a cause and consequence of imperfections in food and labor markets (Timmer, 1988). However, the structural transformation of agrarian economies into industrialized and service-oriented economies is the key to sustainable development. The reallocation of labor from agriculture to other sectors of the economy is one of the aspects of economic growth. In this way, increases in urban wages may transmit to higher farm wages (Headey et al., 2012). Exploring the relationship between agricultural and non-agricultural wages as well as staple food prices is an important empirical issue in view of such a transformation of the economy for planning proper policies to support the poor. Soaring food prices in the last decades have caused the government to introduce interventions (e.g., rice distribution at a subsidized rate, controlled import duties, and subsidized production). These interventions are based on good intentions, but do not always improve the situation in a sustainable manner (Kalkuhl et al., 2016). This signifies the importance of providing empirical evidence on the welfare implications of rising prices to support policymaking.

The determination of the welfare effect of increasing food prices and wage changes in less developed countries requires the determination of wage-price elasticities among the rural poor. The quick or sluggish adjustment of wages to rice prices may have positive or detrimental effects on the poor because physical labor is the primary source of their earnings. Jacoby (2016) empirically estimated that rural wages in India respond to price increases, in particular, if the particular food crops that are increasing in price account for a large share of labor. In this way, increasing food prices may improve well-being. This finding is supported by Lasco et al. (2008) and Headey et al. (2014), who estimated wage-food rice price elasticities for Indonesia and Ethiopia, respectively. In both cases, the elasticity is close to unity.

However, several studies (e.g., Ivanic and Martin, 2014) estimating the implications of rising food prices for poverty have some theoretical and conceptual limitations as they assumed an instantaneous price-wage transmission in the general equilibrium framework. Ivanic and Martin (2014) assumed a medium-run wage-price elasticity of 0.6 for Bangladesh. Further, they ignored the possibility of structural breaks in the relationship between wages and prices. The implication is that if wages respond inelastically to a change in rice prices, then rural workers, who offer their labor on farms and who are net buyers of rice, will not be able to purchase as much rice as prior to the price change. Conversely, net sellers of rice will be able to hire more labor for rice cultivation and realize greater net income. The opposite is true if wages respond elastically to price changes.

Bangladesh’s economy has experienced a structural transformation. The country is projected to advance from the status of a least developed country to a developing country in 2024 (Zhenmin, 2018). Within the past ten years, this has contributed to a sharp increase in farm wages, which almost closed the gap between rural and urban wages. Earlier studies (Rashid, 2001; Zhang et al., 2014) suggest that neither the neoclassical theory of labor nor the efficiency wage hypothesis is consistent with the recent trends. Instead, unlike in many other Asian countries, the structural transformation in Bangladesh follows the prediction of the Lewis (1954) model, which proposes a dual economy with unlimited labor supply. The Lewis turning point is reached when rural wages increase in consequence of labor migration to the industrialized sectors.

The primary objective of this research is to understand the relationship between food prices, urban wages, and rural wages. This will enable us to comment on the extent to which the process of structural transformation in Bangladesh has advanced. Furthermore, we formally tested the Lewis hypothesis by examining the existence of a structural break in the relationship between rural and urban wages, the so-called Lewis turning point. For these purposes, standard time series econometrics was applied, which also allowed us to answer the central research questions in this study, including: (i) Does the agricultural wage rate respond to changes in rice prices or is there any one-to-one response? (ii) Are agricultural labor markets independent of urban labor markets? (iii) How fast do farm wage rates adjust in response to changes in rice prices and urban wages?

Understanding the interlinkages between food prices and wages is of vital importance to policymakers and development practitioners in a developing country like Bangladesh. It allows them to introduce appropriate policies to reduce hunger and poverty and to foster economic growth. This paper attempts to resolve the shortcomings of previous studies on the interlinkages between food prices and wages in Bangladesh. Within the existing literature, little attention has been given to understanding the wage-price responsiveness at sub-national levels, which would be essential to investigate in order to properly assess related policy implications. In doing so, we also updated early studies on wage formation in Bangladesh (e.g., Boyce and Ravallion, 1991; Rashid, 2001) by using a unique data series of prices and wages from 1994 to 2014. The utilization of such a long data series facilitates a reliable and meaningful interpretation of changes in wage-price elasticities over time and their implications regarding the structural transformation of the Bangladeshi economy. Most of the existing literature is limited to descriptive analysis. Closely related to the present work, the study by Zhang et al. (2014) discussed the structural transformation of labor markets in Bangladesh. However, their analysis focused on the welfare implications of this fundamental transformation process, and they considered the drivers of the structural change within a conceptual framework without the help of econometric tools. We close this gap by exploring the present trend of staple food prices and agricultural wages in Bangladesh empirically. Findings from this study will therefore help to establish whether rice price is still a significant determinant of rural welfare and poverty reduction, whether the government should continue to control the food price to reduce rural poverty, or whether it would be more beneficial to instead foster off-farm employment.

2.2 Structural transformation in Bangladesh

A country's economic development is strongly related to the structural transformation of the economy. In this process, the labor force moves from the primary, which includes the agricultural sector, into more productive industrialized sectors. In the course of this structural transformation process, the migration of workers to the non-agricultural sectors is said to reduce the pressure on farm wages (Nonthakot and Villano, 2008). However, there is not much support for this hypothesis looking at historical wage data for Bangladesh. Bose (1968) showed that real agricultural wages in Bangladesh reduced after the end of colonization colonialization. Later studies observed a decoupling of rural wages from agricultural prices in the late 20th century (Boyce and Ravallion, 1991; Rashid; 2001). Figure 2.1 shows the distribution share of Bangladesh's labor force between 1995 and 2015. It is apparent that the agricultural labor force increased until the 2002-2003 labor force survey. Thereafter, migration flows from agricultural into the manufacturing and construction sector can be observed. This shift of labor away from agriculture had positive effects on the development of rural wages (Zhang et al., 2014). In addition, agricultural wages grew much faster than urban wages. Moreover, Figure 2.2 illustrates that the growth in wages was not accompanied by a similar increase in food prices. Hence, real wages also grew. The terms of trade (ToT) between agricultural wages in rice, the most important staple commodity, doubled between 1995 and 2015.

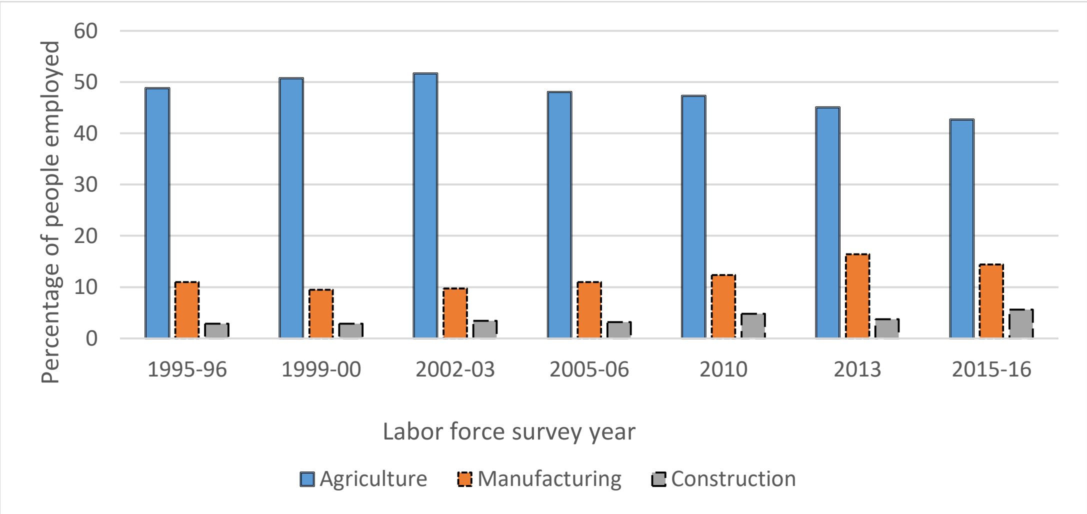


Figure 2.1: Distribution of labor force above 15 years

Source: Labor force surveys of Bangladesh (1995-2015)

In the meantime, rural wages in Bangladesh rose faster in the second half of the 2000s than before, i.e., the average rural wage rose in real terms by 45% between 2005 and 2010 (Wiggins and Keats, 2014). Furthermore, the booming manufacturing sector also increased the wages of urban laborers and attracted surplus labor from rural sectors. Since physical labor is the primary productive asset for the rural population, an increase in real wages is associated with an improvement in rural livelihood and poverty reduction. The recent estimate reveals that poverty dropped by 17% within the last decade (World Bank, 2019). This was mainly driven by the reduction of rural poverty. Zhang et al. (2014) examined the sources of poverty reduction by using household-level data. According to their estimation, poverty would have decreased by only 7.3% if agricultural wages had not changed. Alongside the importance of remittances, rural wage growth was the main driver of poverty reduction in Bangladesh.

Before the 1990s, Bangladesh rice market was isolated from the international markets. Trade liberalization during the 1990s helped to reduce production cost and raised profitability of the rice sector (Ahmed, 1999). Private businesses played a great role in responding quickly to the market demands through rice imports, mainly from India. However, supported by the National Food Policy Plan of Action (2008-15), which ensures that farmers do not produce at a loss by providing them with a support price higher than the cost of production, public involvement in the rice markets remains substantial. The objective of the Public Foodgrain Distribution System (PFDS) in Bangladesh is to build rice stocks for an emergency, like India's rice export ban in 2008, and to provide income support to farmers. The distribution works through a rationing system which has been introduced to distribute or collect rice at fair prices to protect poor consumers and marginalized farmers. Safety net programs are essential instruments under the PFDS. In recent years, there have been major programs, such as Vulnerable Group Development (VGD), Vulnerable Group Feeding (VGF), Open Market Sales (OMS), and Food for Work (FFW), that target poor consumers (Alam and Begum, 2014). On average, 2 million households are eligible to receive Fair Price Cards, which allow them to purchase 20 kg of rice per month at a reduced price. VGF provides 20 to 30 kg of rice per month to 12.2 million families per year (Alam and Begum, 2014).

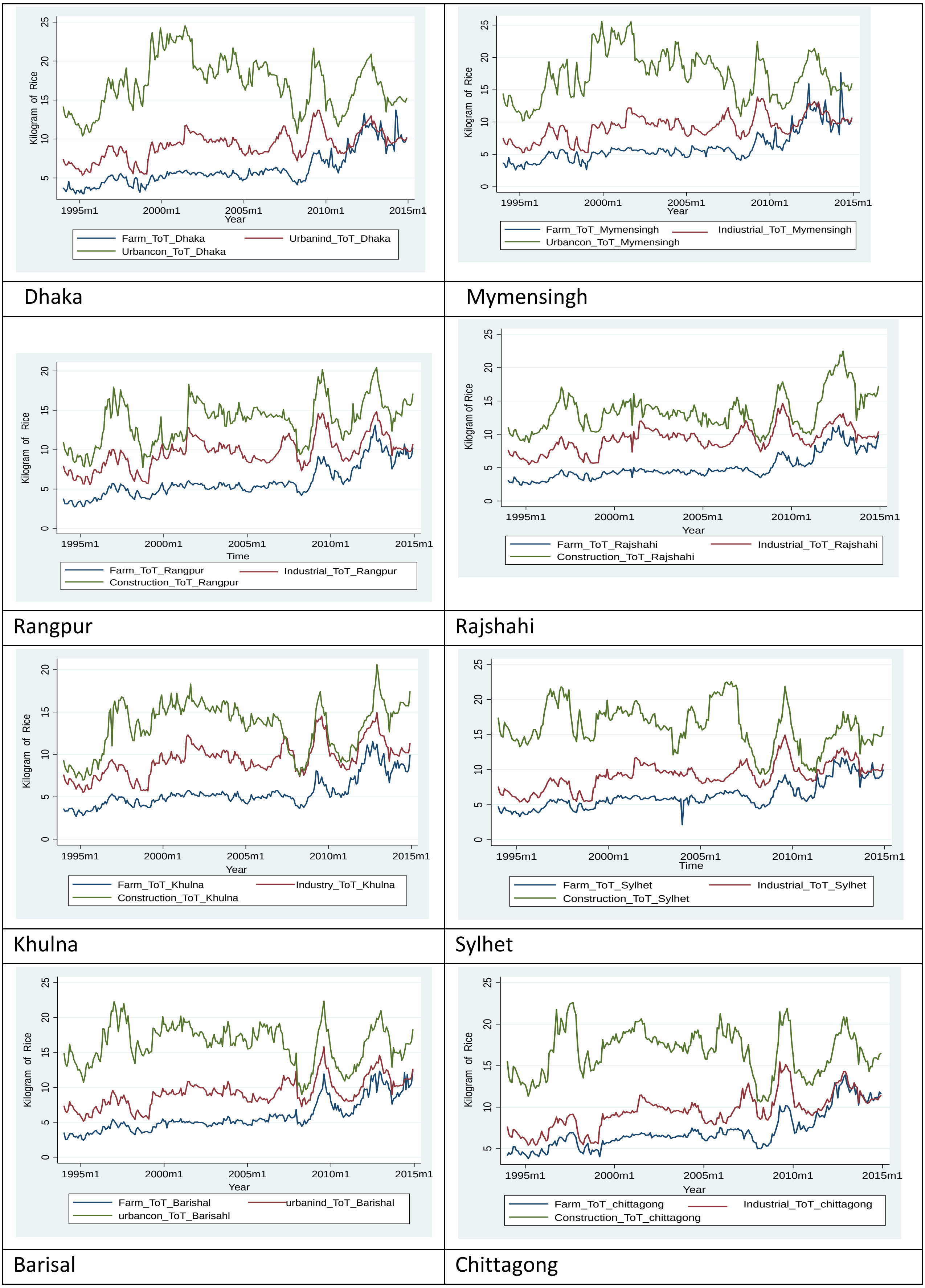


Figure 2.2: Terms of trade of rice per kg for rural and urban wage; Source: The authors' calculation based on monthly bulletins by the BBS and reports by the FPMU.

As in many other countries, the world food crisis in 2007/2008 also had a dramatic impact on food security and poverty in Bangladesh. Since 2007, there have been two major price shocks (2008 & 2011) in the food markets in Bangladesh (Hossain, 2012). The ToT for rural and urban laborers in all divisions exhibited a sharp dip during this period as illustrated in Figure 2.2. However, in the aftermath of the global financial and economic crisis, rice prices went down in 2010 and recover later (Jayasuriya et al., 2012). From the very beginning of trade liberalization, Bangladesh heavily imported rice from India, Thailand, and Vietnam (Akhter, 2017). Empirical analysis suggests a large transmission of international price shocks to domestic rice markets in Bangladesh (Murshid and Yunus, 2018). More recently, international food prices experienced a decline of 14% between 2013 and 2015, sliding into a five-year low, which consequently impacted food prices in Bangladesh because of the availability of cheaper imports (World Bank Group, 2015). Agricultural policies have been put in place to address these issues. This led to a substantial increase in public rice stocks. For instance, Open Market Sales (OMS) reached 13.8 million people by distributing 5 kg of rice per person per day at subsidized rates during the price shock in 2008 (Grosh and Rodriguez, 2011).

Besides policies keeping prices of staple low to make it affordable, there are also those that address labor market issues. For instance, minimum wages have been set for selected industries, most importantly the garment sector, currently amounting to 68 USD per month (Adnan, 2018)**.** However, since the wages are not updated regularly, there is little evidence on how wages in other sectors responded. Further, unemployment rates did not respond to increases in the minimum wage (Rabiul and Liton, 2018). The Employment Generation Program (EGP) has been running since 2009 to support the poor, unemployed rural people during lean seasons. The program is implemented with the support of the World Bank. The inauguration of such policies and strategies are ongoing, but their successful implementation may depend on the proper intervention at the proper place with efficient management.

2.3 Methodology

The main objective of this paper is the analysis of the development of farm wages and the wage-price pattern in the long- and short-run. For this purpose, we applied a standard time series econometrics approach, which includes the testing for the existence of a long-run relationship between the variables. The results of Johansen's rank test subsequently informed the way we modeled the wage-price relationship, either in error correction form or within the framework of an ARDL model. In order to calculate comparable short- and long-run adjustment values, we used the ARDL model to compute pass-through coefficients for different periods. The procedure is explained in detail in the following sections.

2.3.1 Empirical framework

A stochastic process is said to be stationary if its mean and variance are constant over time. However, most macroeconomic series are non-stationary. If the time series variables are non-stationary, fitting a regression model produces "t-ratios" that will not follow a standard t-distribution, and thus create spurious regression results (Engle and Granger, 1987). In less technical terms, a common underlying trend may create a statistical relationship even if there is no causal relationship between the variables. In consequence, normal regression methods like ordinary least square (OLS) are not applicable in the presence of unit root. Thus, the stationarity of the time series needs to be examined first (Maddala, 2007). In most cases, plotting the values against time will already provide valuable information regarding the general trend and the nature of the data. Examining the trends in rural and urban wages as well as rice prices, which are shown in Figure 2.2 for all divisions farm wage is indicated by the blue line, caused us to strongly suspect non-stationarity in at least one of our variables of interest. By using the unit root test, this can be statistically tested. The lag lengths used in the test were determined by the Akaike or Bayesian information criterion.

Two non-stationary series are said to be co-integrated if both series are integrated of the same order. If the unit root tests suggest the presence of a unit root in the series, then we need to check the order of integration necessary to make the series stationary, which should be the first step to choosing an exact model. The majority of the macroeconomic variables become stationary after observing their first differences, which makes them integrated of order 1, written as $I(1)$. If all the variables under the considered function are integrated of order 1, then we can check for the cointegration rank. The cointegration relationship between the variables of interest is analyzed using the Johansen cointegration method. The rank test of Johansen relies on the relationship between the rank of a matrix and its characteristic roots. Once cointegration is established, a long-run relationship among a set of non-stationary variables exists which always brings the variables back onto their long-run equilibrium path (Enders, 2010). Whenever the cointegration rank test confirms the existence of at least one rank, the vector error correction framework should be used. Otherwise, the alternative option available is a simple vector autoregressive (VAR) model. The VAR model is a natural extension of the univariate autoregressive model to dynamic multivariate time series in which case all the variables are assumed to be endogenous.

The simple form of vector autoregression (VAR) Y_t of n endogenous variables consisting of lags up to k is given below:

$$Y_t = \alpha_t + H_1 Y_{t-1} + H_2 Y_{t-2} + \cdots + H_i Y_{t-k} + \in_t \quad \text{.......................................} (2.1)$$

Where Y_t is the $(nx1)$ vector and each H_i is a (nxn) matrix. α_t is a vector of constants and $\in_t$ is a vector of residuals.

The corresponding VECM is as follows (Harris & Sollis, 2005):

$$\Delta Y_t = \alpha_t + \varphi_1 \Delta Y_{t-1} + \varphi_2 \Delta Y_{t-2} + \cdots + \omega_{k-1} \Delta Y_{t-k+1} + \theta_i Y_{t-k} + \Gamma + \in_t$$
…………………(2.2)

Where $\varphi_1 = -(I - H_1 - H_2 - \cdots - H_i)$ $(i = 1, \dots, k-1)$ and $\theta = -(I - H_1 - H_2 - \cdots - H_k)$. The above model consists of long-run and short-run information to changes in ΔY_t through estimated φ_1 and θ. In general, $\theta = \delta\beta^{/}$ is a square matrix where δ is the speed of adjustment and β is the matrix of coefficients generating long-run equilibrium (Patterson, 2000).

On the other hand, if some of the series are *I*(1) and some are *I*(0), it is suggested to use the ARDL model (Pesaran et al., 2001). However, the ARDL cannot be used if any of the series in the model has integration of order *I*(2). The autoregressive model (ARDL) for *k* month lags can be postulated as:

$$\Delta Wa = \alpha + \sum_i^k \alpha_i \Delta Wa + \sum_i^k \beta_i \Delta P_{ti} + \sum_i^k \gamma_i \Delta WI_{ti} + \sum_i^k \delta \Delta WC_{ti} + \in_{ti}$$
……………(2.3)

Where, Wa stands for farm wages, P_{ti} is the rice prices, and WI_{ti} and WC_{ti} indicate industrial and constructional wages.

In addition to modeling the long- and short-run adjustment in the cointegration format, it is worth comparing the impact of changes in urban wages and rice prices on agricultural wages for different time horizons. Varying the lag structure allows this to be done in the ARDL framework (Ianchovichina et al., 2014). ARDL models with alternating lag structure will be quite meaningful for detecting immediate pass-through effects. The respective pass-through coefficient for *k* periods can be computed from equation (2.3) as $\theta = \frac{\sum_i^k \beta_i}{1 - \sum_i^k \alpha_i}$.

For long-term time series, it is also essential to check whether the coefficients are constant throughout the whole period. This is because long time series data is often subject to structural breaks. Structural breaks likely occur when a time series abruptly changes its mean or other parameters at a point in time (Campos et al., 1996). In the context of a developing country, such as Bangladesh, the main reasons for a structural break are related to changes in government policies, domestic or international shocks of both natural and human origin as well as structural changes in the economy. Ignoring the presence of structural breaks might influence the outcome of the unit root test and steer incorrect parameter estimation (Akhter, 2017). The existence of a structural break was tested in two ways. Firstly, for all series of the eight divisions, we performed the Supremum Wald test for a structural break at an unknown break date. Secondly, we performed a series of likelihood-ratio (LR) tests to verify the stability of the coefficient estimates in a time-series regression over different periods defined by possibly known break dates (Maddala, 2007).

2.3.2 Data sources

The statistical models used in this study rely on a comprehensive database covering monthly data for the period between 1994 and 2014. At present, Bangladesh is divided into eight major divisions and sixty-four sub-divisions (districts). The BBS collects data on wages at the district level on a regular basis and publishes them in the Monthly Statistical Bulletin. Rural wages represent daily agricultural wages (male and female, without a meal) including for key agricultural activities like harvesting or transplanting. We introduced two types of urban wages, industrial and constructional. The wage of a constructional laborer was estimated by considering the average daily wage of carpenters, masons, and brick breakers. Industrial wage rates include the aggregate average of daily wage in cotton manufacturing, textile, and jute industries. We observed several missing values in the urban wage series; they were replaced by values obtained from the districts geographically nearest to the area in question. Distances were estimated based on the distance matrix provided by Roads and Highways Department, Ministry of Communications. Until 2010, the sample consisted of 23 districts only; only thereafter was the sample expanded. To maintain the same frequency, this analysis utilized aggregated wages and prices for eight divisions, which are shown in Figure 2.3.

The statistical bulletins also include information on the nation-wide consumer price index, which we used to deflate prices and wages. Rice prices were collected from the FPMU and the Department of Agricultural Marketing (DAM). We considered the coarse rice price that is available in the market during the respective rice marketing seasons (Aus, Aman, and Boro)[1]. Unlike in many related studies, the construction of the price series took into account the seasonal market availability of a specific category of rice, i.e., coarse rice. Coarse rice varieties during “Boro” and “Aman” seasons are available in most months of a year, while rice produced in “Aus” season is only available during the season, which is consistent with its low production rate all over the country. Missing values of rice prices were replaced by interpolation. The summary statistics (mean) of the major variables over the 24 years across the divisions are displayed in Table 2.1, which clearly indicate a shift in wage and price regime after 2005. However, there are certain similarities as well as differences between the

[1] Aus: rice sown in summer (May) during pre-monsoonal rains and harvested in autumn (July) is called Aus rice. Aman: rice sown in the rainy season (July-August) and harvested in winter (November) is called Aman rice. Boro: rice sown in winter (November) and harvested in summer (March-April) is called Boro rice.

divisions. In general, the eight divisions are situated in eight different agro-ecological zones of Bangladesh and have varying rates of poverty. HIES data from 1991 to 2015 were utilized to obtain in-depth knowledge of the poverty situation at the sub-national level of Bangladesh. Complete data of the past poverty rates of the Sylhet division are not available from HIES for a few of the survey rounds.

We found similarities between Dhaka and Mymensingh, Rajshahi and Rangpur, and Barisal and Chittagong in terms of wages and prices. In terms of general poverty, Rajshahi was the poorest division during the 1990s, and then the poverty line reduced between 2005 and 2010. Farm wages were higher in the Chittagong and Dhaka divisions than in the other regions. In contrast to the other divisions' average rice prices, urban wages were higher in Dhaka, Sylhet, and Chittagong. Nominal farm wage doubled between 2005 and 2010, and it increased by 73% between 2010 and 2014. Real farm wages also jumped in the period from 2005 to 2010, for example, from 87 BDT to 125 BDT in the Dhaka division. Both rural and urban wages experienced a similar shift between 2005 and 2010, with their pace of growth slightly diminishing between 2010 and 2014. Similarly, nominal rice prices increased significantly from 2005 to 2010. However, from 2009 to 2014, the increase in rice prices was low, while the average rice price decreased from 17.56 BDT to 15.14 BDT in Dhaka.

From Technical Appendix 1, it is clear that both the upper and lower poverty lines were following a downward trend. The Rajshahi division[2], located in the northern part of the country, had a higher poverty rate than the others. Over time, however, the poverty rate lowered drastically in this northern region, whereas the rate of poverty reduction was slow in Khulna from 1990 to 2005. From Technical Appendix 8, it is evident that the country as a whole experienced a change of direction in poverty after 2005. Dhaka experienced a large poverty decline despite a decline in the growth rate of real wages between 2000 and 2005. A large decline in head count ratio and a large increase in wages were observed in Chittagong between 2005 and 2010. While Barisal experienced a small rise in wages and a small decline in poverty during 2005. Rajshahi experienced a small poverty decline although wages had fallen prior to 2010. Khulna experienced the second highest rise in wages and a decrease in poverty between 2000 and 2010, but the rate of poverty reduction slowed down between 2010 and 2015.

[2] The greater Rajshahi division later split into two, the Rajshahi and the Rangpur division.

Table 2.1: Wages and rice prices over the 25 years in BDT

Divisions	1995		2000		2005		2010		2014	
	Nominal	Real	Nominal	Real	Nominal	Real	Nominal	Real	Nominal	Real
Dhaka										
Farm wage	43.56	*67.38*	63.91	*77.78*	84.63	*81.37*	188.71	*125.27*	334.83	*164.95*
Industrial wage	75.45	*117.39*	107.78	*132.84*	129.68	*278.12*	261.72	*176.67*	320.71	*160.50*
Construction wage	141.44	*220.31*	264.44	*325.97*	283.97	*187.23*	372.01	*255.48*	485.68	*243.48*
Rice price	12.48	*19.22*	11.74	*14.13*	15.64	*14.92*	27.98	*17.56*	32.53	*15.14*
Mymensingh										
Farm wage	43.05	*66.67*	63.61	*77.38*	82.63	*79.43*	183.86	*121.97*	342.17	*168.62*
Industrial wage	75.45	*132.32*	107	*167.90*	129.68	*270.68*	261.35	*157.29*	321.24	*160.50*
Construction wage	139.68	*227.10*	235.48	*283.55*	285	*186.56*	370.42	*227.63*	464.41	*210.04*
Rice price	12.72	*19.59*	11.70	*14.09*	15.23	*14.53*	28.21	*17.72*	31.58	*14.70*
Rangpur										
Farm wage	39.86	*61.63*	58.20	*70.08*	75.73	*72.79*	172.65	*145.47*	284.63	*140.17*
Industrial wage	75.45	*132.32*	107	*167.90*	129	*186.56*	260	*157.38*	298	*171.23*
Construction wage	104.81	*163.10*	124.09	*152.92*	218.54	*214.13*	343.61	*235.84*	462.06	*231.45*
Rice price	11.86	*18.26*	11.21	*13.50*	14.90	*14.83*	26.74	*16.78*	29.69	*13.82*
Rajshahi										
Farm wage	33.96	*52.56*	50.70	*61.68*	67.96	*65.32*	152.45	*101.03*	258.90	*127.42*
Industrial wage	75.45	*132*	107	*167.90*	129	*186.56*	260.41	*157.58*	299.91	*170.10*
Construction wage	124.44	*193.62*	161.11	*198.55*	186.58	*183.21*	309.58	*212.55*	491.53	*246.36*
Rice price	12.39	*19.03*	11.38	*13.70*	15.54	*14.21*	27.85	*17.59*	31.03	*14.44*
Khulna										
Farm wage	39.63	*61.30*	57.25	*69.64*	71.22	*68.47*	149.56	*99.16*	261.75	*128.92*
Industrial wage	75.45	*132*	107		129	*186.56*	263.91	*157.55*	309.83	*173.19*
Construction wage	95.62	*148.71*	179	*220.61*	207.54	*203.50*	289.30	*198.72*	473.58	*237.73*
Rice price	12.02	*18.52*	11.37	*13.69*	15.11	*14.42*	27.98	*17.58*	30.15	*14.04*
Sylhet										
Farm wage	49.5	*76.56*	68.92	*83.84*	92.08	*88.49*	172.25	*114.38*	302.58	*149.04*
Industrial wage	75.45	*132.24*	107	*167.90*	129	*186.56*	256	*157.29*	320	*173.19*
Construction wage	184.22	*286.76*	213.33	*262.96*	286.52	*280.10*	334.17	*229.86*	472.93	*237.05*
Rice price	12.98	*19.98*	11.81	*14.22*	15.45	*14.74*	27.48	*17.26*	32.35	*15.06*
Barisal										
Farm wage	40.08	*61.95*	59.17	*71.92*	80.25	*77.11*	195.75	*129.98*	309.92	*152.54*
Industrial wage	75.45		107.80	*167.79*	129	*167.90*	263	*157.55*	320	*180.38*
Construction wage	95.01	*148.24*	178	*220.64*	207.54	*203.50*	290	*198.72*	473.20	*237.15*
Rice price	12.54	*19.32*	11.71	*14.10*	15.74	*15.02*	29.06	*18.24*	30.38	*14.15*
Chittagong										
Farm wage	55.10	*85.22*	73.42	*89.32*	100.57	*96.69*	197.80	*131.14*	339.28	*167*
Industrial wage	75.45	*132.25*	107	*167.90*	129	*186.56*	263.25	*157.29*	331	*180*
Construction wage	160.44	*249.53*	218	*268.60*	270.97	*265.74*	367.36	*252.23*	474.86	*238.01*
Rice price	12.72	*19.58*	11.69	*14.08*	15.58	*14.87*	26.55	*16.69*	30.42	*14.16*

Source: Author's illustration using monthly bulletins of BBS and reports by the FPMU (1995-2015).

Notes: Rural and urban consumer price indices were used to estimate real wages and prices, 1 USD=69.70 BDT in 2010.

Figure 2.3: Divisions of Bangladesh

Source: Author's illustration.

2.4 Results

2.4.1 Unit root test, structural breaks and possible reasons for such breaks

Before testing for the existence of a unit root in the time series and determining the order of integration, it is essential to determine any structural breaks in the relationship among the variables. For each division, we considered four variables, namely farm wages, urban construction wages, urban manufacturing wages, and rice prices. The entire period spans 21 years (or 252 months) from 1994 to 2014. The structural breaks detected by the Supremum Wald test are listed in Table 2.2. In this test, we included all four variables. As we were more interested in the response of agricultural wages to changes in rice prices and urban wages, we examine the unknown structural break in which the farm wage is the dependent variable.

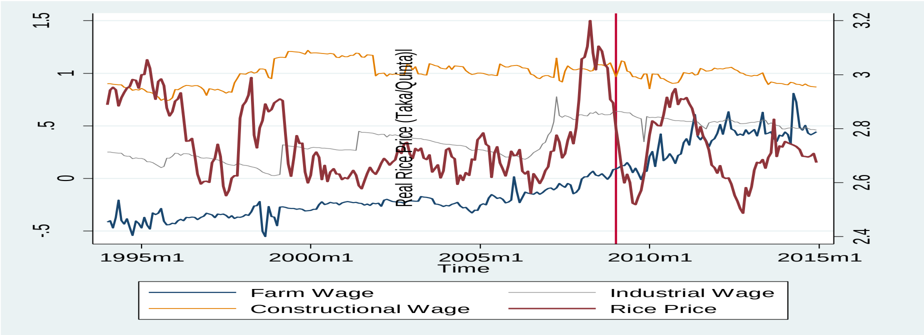
The respective breaks are illustrated in Figures 2.5 and 2.6, where the vertical red lines indicate the structural breaks.

Table 2.2: Structural break time in the different divisions

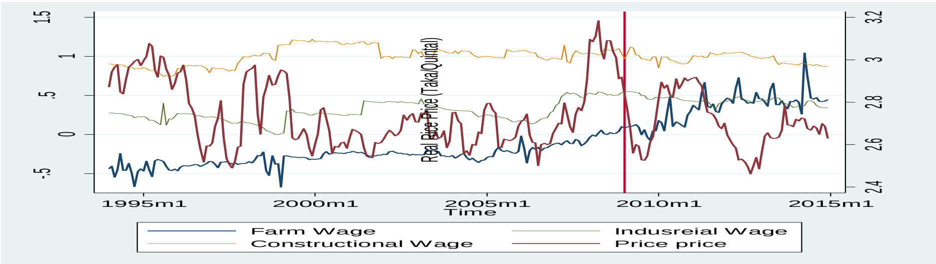
Division	Time of the unknown Structural break
Dhaka	2009M1
Mymensingh	2009M1
Rangpur	2008M12
Rajshahi	2008M12
Khulna	2007M1
Sylhet	2008M1
Barisal	2008M12
Chittagong	2008M12

Source: Author's calculation based on monthly bulletins by the BBS.

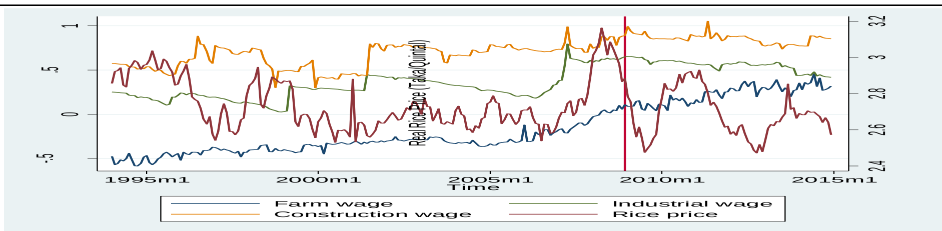
All structural breaks happened between January 2007 (in Khulna) and January 2009 (in Mymensingh). The detected structural breaks appear to be consistent with structural changes in Bangladesh's economy. The international financial crisis and recession in the international market took place in 2008. At the same time, international rice prices peaked, followed by the rice export ban imposed by India, one of Bangladesh's major trading partners. As a response to the economic turmoil, the hundred-day Employment Generation Program was implemented in 2009 to control short-term unemployment in a time where food prices were soaring. In addition, the period was also characterized by political instability. Between 2006 and 2008, a caretaker government was in power before an elected government took over in 2009. Lastly, the minimum wage of garment workers was raised twice, once in 2006 and again in 2010. Against this background, the existence of a structural break during this period appears to be very reasonable. The correlation matrix of the explanatory variables in their first differences can be found in Technical Appendix 2.



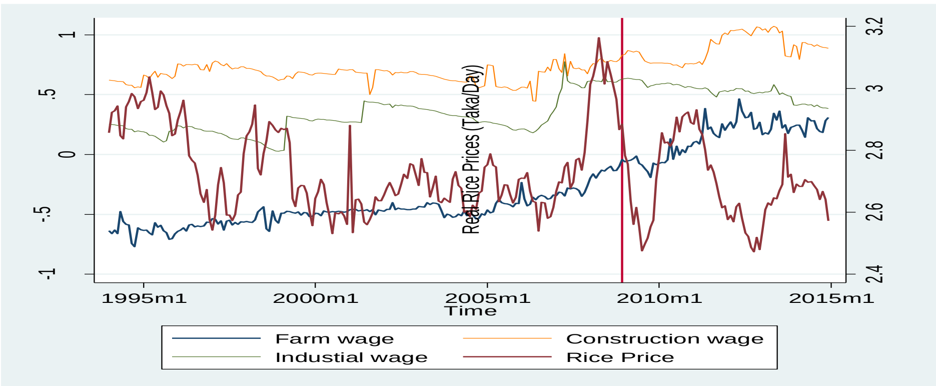
Dhaka



Mymensingh



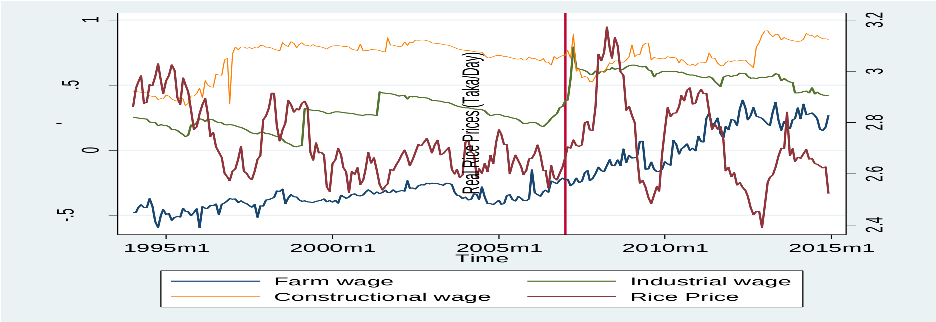
Rangpur



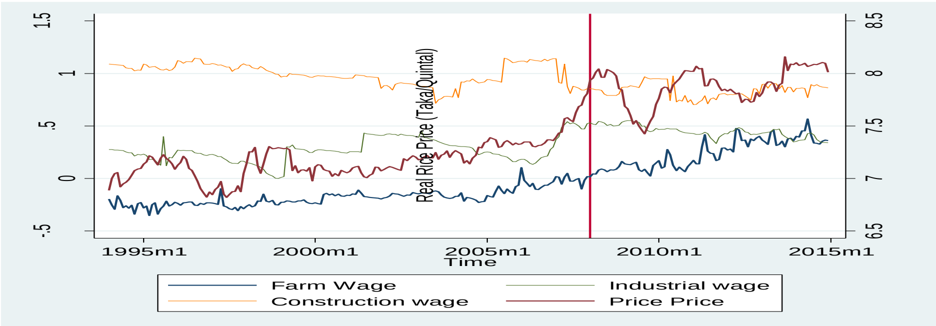
Rajshahi

Figure 2.4: Structural breaks of the Central and Northern divisions of Bangladesh

Source: Statistical monthly bulletin of BBS (1995-2015) and reports of FPMU



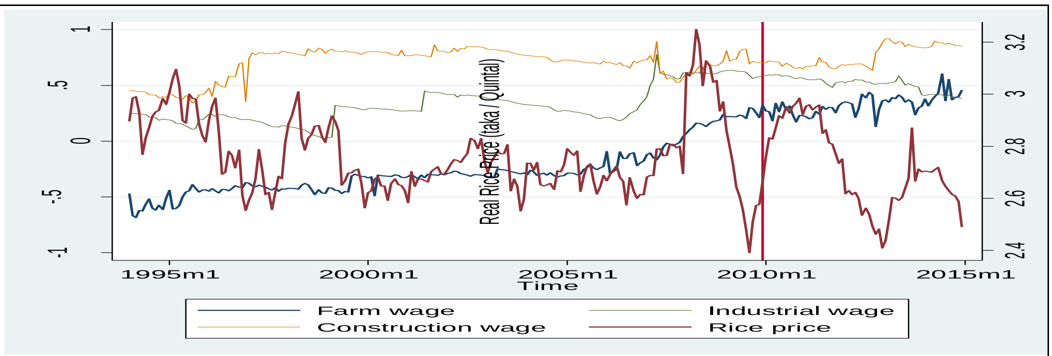
Khulna



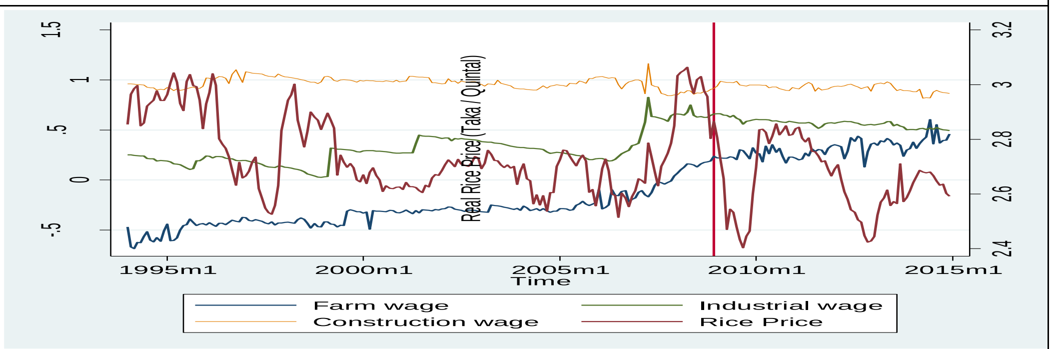
Sylhet

Figure 2.5: Structural breaks of the Eastern and Western divisions of Bangladesh

Source: Statistical monthly bulletin of BBS (1995-2015) and reports of FPMU



Barisal



Chittagong

Figure 2.6: Structural breaks of the Southern divisions of Bangladesh

Source: Statistical monthly bulletin of BBS (1995-2015) and reports of FPMU

Table 2.3: Regular unit root test (data in level)

Division	**Unit Root Test**	**Ln W_a**	**Ln F_p**	**Ln W_m**	**Ln W_c**	**Break point**	**Ln W_a**	**Ln F_p**	**Ln W_m**	**Ln W_c**
		Before break					**After break**			
Dhaka	ADF	2.481 (0.11)	2.583 (0.10)	0.914 (0.78)	2.482 (0.16)	2009M1	0.28 (.053)	1.98 (0.29)	3.77 (.043)	0.31 (0.16)
	GLS ADF	3.18	2.76	0.173	0.216		2.575	1.448	2.317	1.697
	KPSS	0.459	1.000	0.442	1.350		0.351	0.315	0.175	0.474
Mymensingh	ADF	3.209 (0.06)	2.801 (0.07)	1.833 (0.36)	2.312 (0.16)	2009M1	3.209 (0.02)	2.002 (0.28)	1.605 (0.48)	2.363 (0.15)
	GLS ADF	3.33	3.30	1.674	2.08		3.25	1.654	2.630	1.697
	KPSS	0.462	0.914	0.412	1.35		0.286	0.310	0.239	0.472
Khulna	ADF	3.62 (0.06)	2.668 (0.07)	1.663 (0.45)	2.452 (0.12)	2007M1	1.867 (0.34)	1.493 (0.53)	3.065 (0.05)	2.291 (0.17)
	GLS ADF	1.507	3.30	1.674	2.08		3.420	1.760	0.738	2.511
	KPSS	0.564	0.547	0.731	1.59		0.352	0.165	0.364	0.331
Sylhet	ADF	3.169 (0.02)	2.448 (0.13)	2.801 (0.06)	1.902 (0.33)	2008M1	2.166 (0.21)	1.771 (0.39)	2.370 (0.15)	5.281 (0.00)
	GLS ADF	2.918	3.061	2.007	1.220		3.40	1.823	1.674	1.495
	KPSS	0.222	0.914	0.698	0.988		0.218	0.184	0.166	0.375
Rajshahi	ADF	1.261 (0.65)	2.981 (0.04)	0.340 (0.03)	2.312 (0.16)	2008M12	2.305 (0.17)	1.891 (0.33)	0.293 (0.92)	1.754 (0.40)
	GLS ADF	2.242	2.520	1.699	3.303		2.636	2.365	2.201	1.590
	KPSS	0.680	1.010	0.431	.512		0.546	0.267	0.325	.455
Rangpur	ADF	0.679 (0.85)	3.082 (0.02)	0.857 (0.80)	2.619 (0.08)	2008M12	2.617 (0.06)	1.980 (0.07)	0.808 (0.36)	3.561 (0.00)
	GLS ADF	1.604	2.638	1.824	2.857		2.92	1.542	1.842	2.51
	KPSS	0.764	1.02	0.45	0.41		0.261	0.290	0.363	1.89
Barisal	ADF	0.457 (0.90)	0.893 (0.79)	0.893 (0.02)	2.858 (0.06)	2008M12	4.347 (0.04)	1.616 (0.47)	0.293 (0.92)	1.667 (0.44)
	GLS ADF	1.631	2.84	1.699	1.532		4.13	2.28	2.205	1.75
	KPSS	0.826	0.833	0.431	1.76		0.101	0.287	.325	.534
Chittagong	ADF	0.559 (0.87)	2.535 (0.09)	0.835 (0.80)	3.609 (0.03)	2008M12	3.270 (0.03)	2.101 (0.24)	1.78 (0.41)	2.530 (0.10)
	GLS ADF	1.665	2.90	1.76	2.47		2.943	2.113	2.481	2.767
	KPSS	0.868	0.867	0.480	0.641		0.107	0.307	0.193	0.245

Source: Author's calculation; *Note*: Tests were conducted on the natural log of wage and price series. Note: W_a, W_m, W_c, F_p stand for agricultural, industrial, constructional wages and food prices, respectively. Results are in absolute values. The ADF and KPSS critical values at the 5% level of significance are -3.07 and 0.463, respectively. The critical value for the ADF test is taken from MacKinnon (1991). The GLS-ADF critical value at 5% in lag 2 is 3.486. Parentheses represent *P*-values.

Table 2.4: Regular unit root test (1st differenced data)

Division	Unit Root Test	Ln W_a	Ln F_p	Ln W_m	Ln W_c	Break point	Ln W_a	Ln F_p	Ln W_m	Ln W_c
		Before break					After break			
Dhaka	ADF	16.29 (0.00)	11.95 (0.00)	13.72 (0.00)	2.31 (0.16)	2009M1	10.34 (0.00)	7.721 (.00)	13.77 (0.00)	15.16 (0.00)
	GLS ADF	14.28	7.462	9.423	10.73		9.847	3.578	9.674	5.288
	KPSS	0.016	0.025	0.041	0.039		0.016	0.101	0.022	0.038
Mymensingh	ADF	18.01 (0.00)	11.21 (0.00)	17.60 (0.00)	15.16 (0.00)	2009M1	10.69 (0.00)	6.829 (0.00)	6.792 (0.00)	9.534 (0.00)
	GLS ADF	13.11	7.308	9.48	10.37		9.391	4.341	4.615	5.281
	KPSS	0.011	0.020	0.047	0.039		0.286	0.310	0.239	0.472
Khulna	ADF	17.51 (0.00)	11.95 (0.00)	11.75 (0.00)	18.94 (0.00)	2007M1	11.57 (0.00)	8.775 (0.00)	9.811 (0.00)	13.84 (0.00)
	GLS ADF	12.41	6.550	7.615	15.10		9.268	5.020	3.745	6.271
	KPSS	0.018	0.028	0.068	0.031		0.020	0.089	0.066	0.038
Sylhet	ADF	18.50 (0.00)	13.05 (0.00)	17.04 (0.00)	15.74 (0.00)	2008M1	9.913 (0.00)	9.221 (0.00)	7.789 (0.00)	17.40 (0.00)
	GLS ADF	8.128	4.723	9.108	12.51		8.963	3.421	4.861	9.121
	KPSS	0.012	0.061	0.058	0.043		0.017	0.076	0.036	0.039
Rajshahi	ADF	16.67 (0.00)	15.03 (0.00)	13.62 (0.00)	16.54 (0.00)	2008M12	12.47 (0.17)	8.84 (0.33)	8.254 (0.92)	9.809 (0.40)
	GLS ADF	11.45	7.420	8.450	12.58		7.714	4.221	6.371	6.201
	KPSS	0.030	0.021	0.051	0.027		0.028	0.097	0.039	0.076
Rangpur	ADF	17.62 (0.00)	15.03 (0.00)	12.92 (0.00)	16.21 (0.00)	2008M12	11.92 (0.00)	9.789 (0.00)	8.490 (0.00)	12.92 (0.00)
	GLS ADF	4.970	7.481	9.511	11.01		7.790	4.021	5.061	9.04
	KPSS	0.043	0.023	0.048	0.021		0.018	0.095	0.048	0.028
Barisal	ADF	14.15 (0.00)	17.15 (0.00)	13.69 (0.00)	21.54 (0.00)	2008M12	14.19 (0.00)	8.705 (0.00)	8.230 (0.00)	8.980 (0.00)
	GLS ADF	9.082	7.720	8.453	14.15		7.13	4.705	6.37	4.35
	KPSS	0.035	0.017	0.052	0.033		0.017	0.097	0.03	0.08
Chittagong	ADF	17.12 (0.00)	12.43 (0.00)	13.10 (0.00)	20.40 (0.00)	2008M12	14.19 (0.00)	8.248 (0.00)	8.769 (0.00)	9.704 (0.00)
	GLS ADF	3.820	5.220	8.865	13.74		7.134	4.118	5.115	6.051
	KPSS	.0365	0.026	0.048	0.016		0.017	0.079	0.034	0.035

Source: Author's calculation; *Note*: Tests were conducted on the natural log of wage and price series. Note: W_a, W_m, W_c, F_p stand for agricultural, industrial, constructional wages, and food prices, respectively. Results are in absolute values. The ADF and KPSS critical values at the 5% level of significance are -3.07 and 0.463, respectively. The critical value for the ADF test is taken from MacKinnon (1991). The GLS-ADF critical value at 5% in lag 2 is 3.486. Parentheses represent *P*-values.

We performed several standard test procedures, namely the Augmented Dickey-Fuller (ADF) test, the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test and the modified Dickey-Fuller *t*-test (ADF-GLS). All of them are common methods to test for the presence of a regular unit root. The null hypothesis of the ADF and the ADF-GLS tests is that the data series is non-stationary. By contrast, the KPSS test tests the null hypothesis of stationarity. We omitted the detailed test statistics at different lags, which are available on request, and present the results in Tables 2.3 and 2.4. From the results, it is evident that all the log series exhibit a unit root. To verify the level of integration of the series, we again tested for a unit root for the differenced time series, which confirmed the existence of *I*(1) processes in the original series. In addition to that, we also tested for the presence of seasonal unit roots. The respective results are presented in Technical Appendix 3. Based on these results, we were able to reject the systematic existence of seasonal unit roots.

2.4.2 Long-run relations among the series and speed of adjustment

Based on the results of the structural break test above, we treated the periods before and after the structural break separately. The time series was tested for the existence of cointegrating equations by using trace statistics and eigenvalues. The lag length is chosen according to standard lag length selection procedures using the information criteria. The results are reported in Technical Appendix 4. The respective test statistics of the Johansen's cointegration test procedure are shown in Technical Appendix 5. The presence of cointegration indicates a long-run relationship between the tested series. Using the critical value of the 5% level of significance as the criterion, we found one cointegrating vector for all the eight divisions before the structural break. Table 2.5 shows the respective VECM estimates for farm wages as the endogenous variable. The results of the estimated VECM parameters indicate that farm wages are integrated with the other series, as evidenced by the statistically significant error correction term and its negative sign. Before the break around 2008, farm wages among all the divisions had significant long-run relationships with the rice prices. The same holds true for urban wages since in each division one of the two urban wages was positively associated with farm wages, indicating a significant long-run relationship.

Similarly, after the break, the Johansen test statistics suggest one cointegration relationship for all divisions. By contrast, farm wages exhibited a significant long-run relationship with rice prices in only three divisions (Dhaka, Mymensingh, and Rajshahi). After the break, the long-run farm wages in all divisions (except Barisal) were significantly influenced by urban wages. These results are in accordance with the findings of Rashid (2001), who projected more than a decade ago that the urban wage rate would become the most influential factor for farm wage determination. However, the relative effect of rice prices on farm wages is slowly diminishing over time despite the remarkable increase in rice production due to the advent of new drought- and salt-tolerant varieties. The economic growth accelerated and poverty reduction became significant between 2000 and 2014 despite the declining trend of the ToT of agriculture and the relative price of rice, meaning that the increased rice price did not affect the poor in rural areas. Any possible negative impacts of increased rice price on income only affected the people of Dhaka and Mymensingh. Such regional diversity in elasticities will be further discussed in the upcoming sections. Table 2.5 also presents the speed of adjustment for any deviation from the long-run equilibrium. The error term coefficient represents the speed of adjustment. We expected a statistically significant and negative coefficient of the error correction term, which would indicate that the system converged back to its equilibrium relationship. The exact value of the coefficient tells us the portion of the correction happening during the period of adjustment. It is apparent from Table 2.5 (columns 6 and 13) that the models behaved as expected, as indicated by the negative sign and the statistically significant coefficient (at the 1% level of significance) of the error correction term for both periods. These results also show that the models considering farm wages on the left-hand side of the cointegration equation were well specified. For instance, before the structural break, we found quick adjustment periods for Mymensingh (20 months), Sylhet (22 months), and Dhaka (23 months). Intuitively, this implies that in Mymensingh, it took 20 months to retain the long-run equilibrium condition, while in each month the error correction term corrected the previous period's disequilibrium at a speed of 58.2% to reach the steady-state level. By contrast, the adjustment was rather sluggish in Chittagong (68 months) and Barisal (88 months). After the break, Barisal exhibited the shortest adjustment period (14 months), while Khulna had the longest adjustment period (55 months). All the models were checked and diagnosed for the stable coefficients of the estimated parameters (cf. Technical Appendix 6).

Table 2.5: Long-run relation between farm wages, rice prices, and industrial and constructional wages

Farm wages (Dependent variable)	Break point	Rice Price	Industrial wage	Construction wage	Error Correction (Adjustment to the disequilibrium of Farm wage)	R-square	LM test (lag 2) $P>\chi^2$	After break	Rice Price	Industry Wage	Construction wage	Error Correction (Adjustment to the disequilibrium of Farm wage)	R-square	LM test (lag 2) $P>\chi^2$
		Long Run Coefficient							Long Run Coefficient					
Dhaka	2009M1	0.130*** (.048)	.222*** (0.062)	0.070 (0.061)	-0.512*** (23 months)	0.265	0.107		0.561*** (0.120)	0.692* (0.364)	1.86*** (0.250)	-0.582*** (21months)	0.328	0.125
Mymensingh	2009M1	0.104** (.047)	0.275*** (.061)	0.100 (0.069)	-0.581*** (20 months)	0.287	0.241		0.444** (.140)	0.655* (.390)	1.63*** (0.304)	-0.800*** (15 months)	0.402	0.301
Rajshahi	2008M12	0.186*** (0.066)	0.032 (0.092)	0.71*** (0.140)	-0.272*** (44 months)	0.149	0.102		0.408*** (.129)	-0.176 (0.500)	1.01*** (0.196)	-0.452*** (27 months)	0.224	0.292
Rangpur	2008M12	0.192** (0.083)	0.359*** (0.105)	0.154 (0.101)	-0.203* (58 months)	0.129	0.737		0.124 (.081)	0.106** (0.314)	1.53*** (0.213)	-0.278** (43 months)	0.113	0.592
Khulna	2007M1	0.135** (0.079)	0.194** (0.801)	0.294*** (0.062)	-0.396*** (30 months)	0.201	0.897		0.102 (0.162)	2.17*** (0.398)	-0.520 (0.338)	-0.131*** (55 months)	0.182	0.144
Sylhet	2008M1	0.101** (0.045)	0.240*** (0.054)	0.301** (0.061)	-0.532*** (22 months)	0.278	0.119		0.110 (0.065)	0.690** (0.304)	0.170 (0.162)	-0.570*** (21 months)	0.215	0.412
Barisal	2008M12	0.548*** (0.121)	0.276* (0.141)	0.317** (0.125)	-0.135*** (88 months)	0.104	0.861		-0.101* (0.054)	-0.210 (0.280)	0.101 (0.119)	-0.858*** (14 months)	0.440	0.208
Chittagong	2008M12	0.743*** (0.131)	0.528*** (0.125)	1.83*** (0.349)	-0.175** (68 months)	0.402	0.789		0.118 (0.108)	1.48** (0.749)	0.621 (0.531)	-0.436*** (27 months)	0.197	0.387

Source: Author's analysis (BBS & FPMU, 2015); Note: Brackets indicate the standard errors. *, **, ***, indicate significance at the 10%, 5% and 1% level respectively

2.4.3 *Rice price pass-through coefficients*

In order to better understand the transmission of shocks of rice prices and urban wages to farm wages, we also computed pass-through coefficients. The magnitude of the rice price passes through on-farm wages and allows us to explicitly test the sticky wages theory of Keynes. The pass-through coefficients, computed using Equation (2.3) for different time horizons, are shown in Table 2.6. We found that the pass-through coefficients vary across divisions and over time, specifically before and after the break. We found significant pass-through in Dhaka and Sylhet before the break and in Mymensingh after the break for the three months' time horizon. Six out of eight divisions exhibited a significant pass-through after six months in the period before the structural break, but all of them became insignificant after the structural break. Only half of the divisions, namely Rajshahi, Rangpur, Sylhet, and Chittagong, are estimated to have significant pass-through elasticities before the break for the twelve months' time horizon. With regard to the 12-month pass-through, except for Barisal, we did not find any significant pass-through after the break.

Table 2.6: Real farm wage response to real rice prices

Divisions	Three months pass-through coefficients		Six months pass-through coefficients		Twelve months pass-through coefficients	
	Before Break (2008)	After Break (2008)	Before Break	After break	Before Break	After break
Dhaka	**.163*** **	.102	**.216*** **	-.044	.113	-.058
Mymensingh	.055	**.395** **	.121	.191	.071	.100
Rajshahi	.037	.091	**.169*** **	.215	**.238** **	.307
Rangpur	-.019	-.053	**.106* **	-.034	**.216** **	-.066
Sylhet	**.084* **	.186	**.119** **	.297	**.178* **	-.004
Khulna	.030	.066	**.112* **	.050	.178	.156
Barisal	.002	-.0506	.095	-.083	.116	**-.140* **
Chittagong	.013	-.132	**.127** **	-.017	**.239* **	-.327

Source: Author's calculation based on BBS and reports by the FPMU (1995-2015).

Note: Significant pass-through coefficients indicates by bolding and *, **, ***, indicate significance at the 10, 5 and 1% level respectively

Hence, it is clear that the importance of rice prices in the determination of farm wages significantly declined after the structural break in 2008/2009. Moreover, all pass-through coefficients were below 0.4, which indicates that the price elasticity of wages in Bangladesh was not close to unity, even for relatively long time horizons. These pass-through effects nullify the assumption of a one-to-one relationship between staple food prices and rural wages supported by Ravallion. The picture for the urban wage pass-through is somewhat different. The details are shown in Technical Appendix 7. Generally, the amount of significant pass-through coefficients is limited. Yet, once the pass-through coefficients became significant, the magnitude was much higher for urban wages than for rice prices.

2.5 Regional differences

In general, we observed a common trend for all divisions which indicates that the importance of rice prices for farm wage determination declined over time, while urban wages in the construction and industrial sectors remained important. However, we also found regional differences. Before the break, farm wages were more responsive to rice price changes in both Chittagong and Barisal than in the other divisions. To be more precise, the magnitude of the rice-price coefficient varied greatly between 0.743 in Chittagong and 0.111 in Sylhet. Several factors might have influenced such variability, including demographic characteristics, the volume of rice production, the number of agricultural households, the cropping intensity, labor migration issues, the adoption of on-farm machinery as well as the overall poverty situation. For example, Chittagong and Sylhet, which used to be a single division, differ in several ways today. Chittagong is the largest among Bangladesh's eight divisions and a large portion of its land is used for rice production as well as for the cultivation of other hilly crops (cf. Technical Appendix 9). Sylhet's agricultural activities concentrate on tea production, although rice production also constitutes a significant portion of the activities. As land preparation for rice demands a lot of manual labor in the absence of machine power, low adoption of machinery services would lead to a greater positive relationship between farm wages and rice prices. Figures from the 2008 Agricultural Census indicate that the share of people owning a power tiller was lowest in Chittagong (0.23) and Barisal (0.24) (BBS, 2010). In addition to that, Barisal had the highest poverty rates among the districts (cf. Technical Appendices 1 and 8), which could induce labor supply at lower wage rates. Thus, farm wages in Barisal, due to the absence of other employment opportunities, were more responsive to rice prices than in other regions. Looking at the simple changes, we found that there was a significant increase in coarse rice prices in Barisal, for example, an increase of 23% from 2000 to 2005. In the meantime, the rate of poverty decreased in 2005 was slower than in the previous five years (1995-2000). The Barisal division also experienced two consecutive natural hazards, one in 2007 and another in 2009, which may have influenced the labor and commodity market. It is furthermore noteworthy that the farm mechanization rates in Barisal and Chittagong were lower than the other areas (Mottaleb et al., 2016). A more detailed discussion of the cross-division differences would require further analysis, including the utilization of additional counterfactuals, and is beyond the scope of the present study.

We also observed some changing trends of wage-price elasticities in the northern areas following the break, for example, in Rajshahi and Rangpur. The two divisions are traditionally rice-producing regions where many peoples are involved in agricultural activities, compared to other divisions (Khandker and Samad, 2016). It is evident that a large portion of the rice cultivation in the country belongs to the Rajshahi and Rangpur divisions (cf. Technical Appendix 9) and at the same time, a major fraction of the rural labor force of these areas are involved in selling their labor (Khandker and Samad, 2016). In these divisions, rice prices had been very important for farm wage determination in the absence of non-farm employment opportunities. However, with the structural transformation of the economy, the effects of rice prices became less pronounced compared to constructional and industrial urban wages. This is of particular importance in Rangpur, where seasonal famines (called ''Monga''), which were partly due to the lack of lean season farm activities, became less frequent. In contrast to those two divisions, a 10% increase in rice price increased farm wages in Dhaka and Mymensingh by 5.61% and 4.4%, respectively. In all the other divisions, wages did not respond to rice prices. In Barisal, we found that rice prices and wages were negatively correlated after the structural break. This is counterintuitive but could be explained by the incidence of a natural disaster, the cyclone Aila, in 2009. Barisal is prone to natural disasters like cyclones due to its proximity to the sea and its multiple river deltas. After the 2009 cyclone, agricultural productivity decreased dramatically due to the influx of saltwater into the rice fields, while rice prices increased due to low supply levels. Whenever employment opportunities decrease, disaster-related migration decouples labor and product markets.

In the provinces of the largest commercial centers Dhaka and Chittagong, industrial wages are the driving force for rural agricultural wages following the structural break, while construction wages are not important in explaining changes in farm wages. This may be due to the importance of the garment industry in these divisions, which attracts rural workers to urban centers. Specifically, around 1,000 textile factories and 7,000 readymade garment factories are clustered at the outskirts of the capital city of Dhaka and the city of Chittagong, where Bangladesh's largest port is located (Morshed, 2016). We observed a similar trend in Khulna and Sylhet, where industrial wages had a much stronger influence on farm wages than wages in the construction sector. On the other hand, farm wages in Mymensingh and Rangpur were highly sensitive to wages in the construction sector; this may be due to the many new infrastructural development projects, especially the construction of new roads and highways, which have been implemented in these divisions. Rangpur was declared a separate division only in 2010. Following its independence, massive development projects worth an equivalent of 4,302.16 million USD have been initiated. This led to a massive improvement in infrastructure and communication networks in Rangpur (BSS, 2018).

2.6 Conclusion and scope of further research

Rural wages and food prices are major determinants of rural livelihoods in Bangladesh. Rising food prices during the end of the 2000s have created additional threats to poverty reduction and rural welfare, although increasing food prices have also generated opportunities for net sellers of the respective commodity. The main objective of this study is to examine the drivers of farm wage formation and to increase the understanding of its implications for rural welfare. In this regard, it is also important to take into account the ongoing structural transformation of Bangladesh’s economy towards manufacturing and services, including having one of the world’s largest garment industries. It is believed that the increase in agricultural prices has led to higher farm wages. Higher farm wages have general welfare effects, like increasing the agricultural income of workers, but they also lower income from fixed capital resources, such as land, due to increasing costs of labor (Jacoby, 2016). To measure such effects and to ascertain the welfare implications of changing ToT, which is the real agricultural wage, an estimate of the relevant wage-price elasticities is required. In this study, we applied standard time series econometrics to analyze how the agricultural wage rate responds to changes in rice prices and urban wages. In addition, we tested for the stability of these relationships over time. In this way, we formally verified the Lewis turning point, after which the rural wage formation changes. Before the turning point, agricultural wages are merely determined at the subsistence level. Afterwards, labor supply becomes elastic, and prices increase when labor migrates into the other sectors of the economy.

We found strong empirical evidence for a structural break in the labor-food market relationship in the period between 2007 and 2008. This change might be associated with the adoption of labor-saving technologies in agriculture and the subsequent higher labor productivity as the result of the structural transformation of the economy. In addition, such changes in farm wages led to increased linkages between rural and urban labor markets. Although the structural break was observed for all eight divisions of the country, we found substantial differences in labor-food market integrations across all of them. For instance, after the structural break around 2008, rice prices were significantly correlated with farm wages only in Dhaka, Barisal, and

Mymensingh. Farm wages in all other divisions were influenced by either industrial or constructional wages, but not by rice prices. These findings suggest strong evidence in favor of the Lewis turning point.

But if rice prices have little influence on the agricultural wage rate, then an increase in the price of rice will have little effect on wage rates, and will thus not lead to poverty reduction. However, rising rice prices do not only increase the income of the day laborers, but also inflate the production cost of rice. To ensure food security in the face of increasing rice prices, policymakers need to guarantee that rising production costs of rice are accompanied by increases in labor productivity. Agricultural mechanization, previously considered to be associated with the risk of labor substitution, could be promoted to compensate for a decreasing agricultural labor force and to enhance agricultural production. Alternatively, government policy could aim to control rice price movements through the national rice price stabilization scheme to maintain the balance between labor income and rice prices. To avoid large fiscal interventions, targeted programs should be preferred, such as the 2016 initiative to distribute rice to the ultra-poor at 10 BDT/kg and the Fair Price Card program.

Nonetheless, the growth in the non-agricultural sector is the real driver of rural agricultural wages. Rising demand for labor due to growing industries in urban areas (the garment and construction sectors) has significantly driven up farm wages, which also has major implications for long-term poverty reduction. At present, farmworkers are no longer in abundant supply. Such a transformation of the economy calls for a reorientation of agricultural policies. Therefore, more importance needs to be placed on non-farm employment opportunities, especially in the five divisions (excluding Dhaka, Mymensingh, and Barisal) where farm wages do not respond to increasing rice prices, to raise the purchasing power of agricultural laborers in the long run. Policy programs, such as the Employment Generation Program for the Poorest, could be a viable means; however, evaluating different policy options goes beyond the scope of this work. Moreover, any other policy aimed at enhancing rural labor income by increasing domestic rice prices (e.g., import tax) needs to be evaluated in view of the limited transmission of rice price changes to farm wages in both the short term and the long term.

The results of the present study provide a better understanding of the welfare effects of staple food price changes on rural agricultural laborers. The effects need to be addressed by policymaking. Apart from rice prices and urban wages, rural labor markets are determined by several other factors, such as labor productivity, remittances, price stabilization policies, and weather conditions. Since we are mainly interested in the price-wage nexus, we opted for the cointegration framework, which makes it difficult to include further endogenous variables, partly due to their mixed frequency nature. The inclusion of such variables in the time series model might, however, help to improve the understanding of the causal relationship between the variables and should be the subject of future research.

3. Let's Get Mechanized – Labor Market Implications of Structural Transformation in Bangladesh

3.1 Introduction

A huge productivity gap still exists in agricultural activities between developing and industrialized countries. This productivity gap has several causes (e.g. input use, farming techniques, crop varieties), but can be partly attributed to the lack of mechanization in agriculture. Mechanized agriculture usually refers to the use of tractors and other agricultural machinery for land preparation, weeding, and harvesting, but also involves the automatization of value chain activities, such as processing, packaging, and other services (FAO, 2016). Beyond the controversy of whether increased trade liberalization result in improved incentives for technological resource use, mechanization has the potential to enhance agricultural production and to reduce the unit costs of production (Pingali, 2007). Productivity gains are mainly driven by technological progress referred to as total factor productivity (Apiors et al., 2016; Gautam and Ahmed, 2019). In addition, mechanized agriculture allows for cropland expansion and intensification of cropping activities (Verma, 2006; Houssou and Chapoto, 2015). This development can lead to poverty reduction and increased food security and can, therefore, contribute to the progress towards achieving the Sustainable Development Goals (SDGs).

The agricultural sector in Bangladesh, like in many other developing countries, is experiencing a structural transformation towards mechanization and industrialization of agricultural production and processing. Data from the periodical agricultural household survey conducted by BRAC show that agricultural yields have significantly increased over time. At the same time, machine ownership and the demand for machine rental services have increased. For instance, ownership of irrigation pumps and power tillers increased by 33% and 25%, respectively, between 2009 and 2015 (Hossain and Bayes, 2015). This was driven by a liberalization of import markets for agricultural machinery since the 2000s. In this respect, Bangladesh is no exception in Asia, where agricultural mechanization is much more advanced than in sub-Saharan Africa (Pingali, 2007). Gains in productivity are necessary to feed Bangladesh's growing population under hard agricultural land constraints.

The mechanization of agricultural activities is a consequence of the structural transformation of the Bangladeshi economy towards the industrial sector. Rural-urban migration has rapidly expanded and has contributed to a reduction of the rural-urban wage gap. Empirical evidence suggests that urban wages have become the main driver of agricultural wages in Bangladesh in recent years (Hassan and Kornher, 2019). Higher labor costs have induced the agricultural sector to look for labor-saving technologies to reduce production costs. Since early industrialization, there is the concern that mechanization, although productivity-enhancing, will lead to a replacement of labor. If this holds true, decreasing demand for low-skilled farm and non-farm workers will exert pressure on rural wages (Yamauchi, 2016). For instance, mechanization is accompanied by increasing supply of rural non-farm labor when labor-saving technologies are utilized on-farm (Ahmed and Goodwin, 2016). Missing employment opportunities in rural areas have severe welfare consequences for rural livelihoods. The substitution of human labor through farm machinery drives rural-urban migration. However, urban areas are not capable of building infrastructure and creating employment opportunities at the same speed as urbanization advances. In consequence, urban unemployment rises, and slum areas expand rapidly (Rashid, 2009). When a low-income agrarian economy experiences structural transformation, it usually causes policymakers to turn their attention to understanding the relationship between factor markets for agricultural labor and machinery. The implications of a structural transformation of a developing economy may motivate the introduction of agricultural and rural development policy interventions to mitigate adverse consequences for the development of agricultural and rural areas. With regard to the mechanization of agricultural activities, very little is known about how it affects rural labor markets. In labor market theory, the impact of mechanization on labor demand and wages is unpredictable due to two opposing effects: the substitution and the scale effect. Yamauchi (2016) and Wang et al. (2016) found that rising wages led to labor substitution by machines in Indonesia and China, respectively, but also reported economies of scale from mechanization which may create additional labor demand. Similarly, Gautam and Ahmed (2019) reported a diminishing inverse farm size productivity for Bangladeshi farms, which they attributed to productivity gains of larger farms. However, none of the existing studies have looked at the welfare implications for rural workers. To the best of our knowledge, this is the first study to investigate the relationship between agricultural mechanization and rural wages at the macro level. Specifically, we aim to understand the drivers of rural wages in Bangladesh. We examined the short, medium, and long-term dynamics of rural wage determination and were able to assess the impact of agricultural mechanization on rural wages.

By applying a dynamic panel model to account for the time series nature wage rates, this chapter provides evidence that agricultural mechanization had positive effects on agricultural wages in Bangladesh over the period from 1995 to 2014. The increasing opportunity for farmers to enhance agricultural productivity through the emergence of functioning rental markets for agricultural machinery has allowed for an increase in labor demand through productivity gains and production growth, which compensated for the substitution of farm labor by machines. That is, the substitution effect is outweighed by the scale effect of mechanization, which is the increase in labor demand in response to productivity gains and the expansion of agricultural activities. Thus, the empirical findings do not contradict earlier studies that found a significant substitution, but provide more evidence in support of the complementarity of labor and capital in agricultural production processes.

The present chapter is organized as follows: Section 3.2 describes the structural transformation of Bangladesh's economy and the level of mechanization currently observed. Then, Section 3.3 discusses standard labor market theory and illustrates the possible effects agricultural mechanization can have on rural wage rates. The empirical approach and the data used for the analysis are presented and discussed in Section 3.4. The regression results, split into the determinants of rural wage rates and the channels of the scale effect, are shown in Section 3.5, followed by concluding remarks in Section 3.6.

3.2 Structural transformation in Bangladesh

A country's economic development is strongly related to the structural transformation of the economy. In this process, the labor force moves from the primary, which includes the agricultural sector, into more productive industrialized sectors. This trend in Bangladesh is depicted in Figure 3.1. Official statistics from labor force surveys show an increase in agricultural employment until 2002, and stagnation, in spite of population growth, thereafter. This can be explained by migration flows from the agricultural into the manufacturing and construction sectors as indicated by the two panels in Figure 3.1. In the course of this structural transformation process, the migration of workers to the non-agricultural sectors will reduce the pressure on rural wages.

Bose (1968) found that real agricultural wages in Bangladesh reduced after the end of colonization. Other studies observed a decoupling of rural wages from agricultural prices in the late 20th century (Boyce and Ravallion, 1991; Rashid, 2001). The described shift of labor out of the agricultural sector had positive effects on the development of rural wages (Zhang et al., 2014). In addition to that, agricultural wage growth was much faster than the growth in urban wages as shown in Figures 3.2 and 3.3. Moreover, Figure 3.2 illustrates that the growth in wages was not accompanied by a similar increase in food prices. Specifically, the food wages, the value of the wage earnings measured in kg of rice, doubled between 1995 and 2015. Among other factors, this development has contributed to a significant reduction in rural poverty in Bangladesh (Zhang et al., 2014).

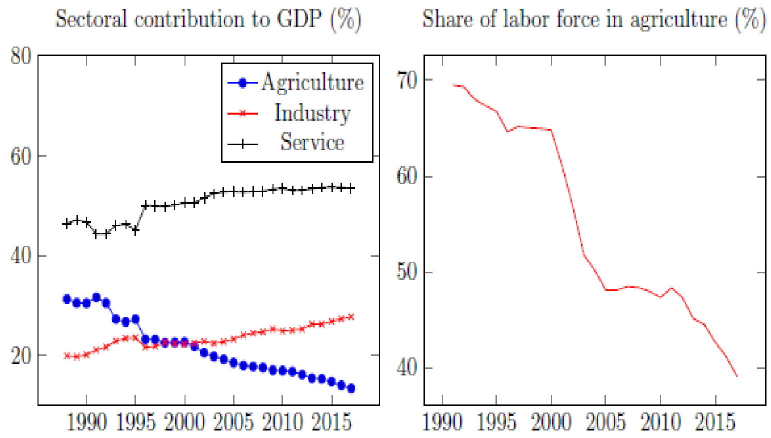


Figure 3.1: Trend in sector transformation

Source: World Bank (2018)

Related to the transformation of the economy towards more industrial activities and in light of the limited land resources of Bangladesh, there is strong advocacy for agricultural machinery use so as to increase returns on land and labor. The shift to mechanized agriculture is expected to induce significant changes in the agricultural sector. Given the substantial capital investment required, the government supports 'scale-appropriate' machinery, which can preclude machinery ownership among smallholders. The increasing demand for machinery has resulted in relatively well-developed rental service markets for tillage, irrigation, and post-harvest operations (Hossain, 2009). Rural people have access to agricultural machinery that may have otherwise been costly to purchase through fee-for-service provisions. On the other hand, machinery ownership remains related to asset ownership, liquidity constraints, electrification, and road density (Mottaleb et al., 2016).

Farm machinery use has increased considerably in Bangladesh within recent years (Biggs and Justice, 2015). In 1996 there were only 0.1 million power tillers, 1.3 million pumps (including deep, shallow, and surface water pumps), and 0.18 million rice-wheat threshers being used in Bangladesh. By the early 2010s, there were at least 0.55 million power tillers (Ahmmed, 2014), 1.61 million pumps (BBS, 2011; BADC, 2013), and 0.25 million threshers in use. Figure 3.4 shows the overall trend in agricultural mechanization for two indicators, namely tractor imports in USD and the capital-labor ratio in agriculture. The pace of adoption of mechanization was particularly strong around 2007 to 2011 during the global commodity price boom. In addition to that, the use of irrigation pumps has been a key ingredient in Bangladesh's current level of near rice self-sufficiency (Hossain, 2009; Mainuddin and Kirby, 2015).

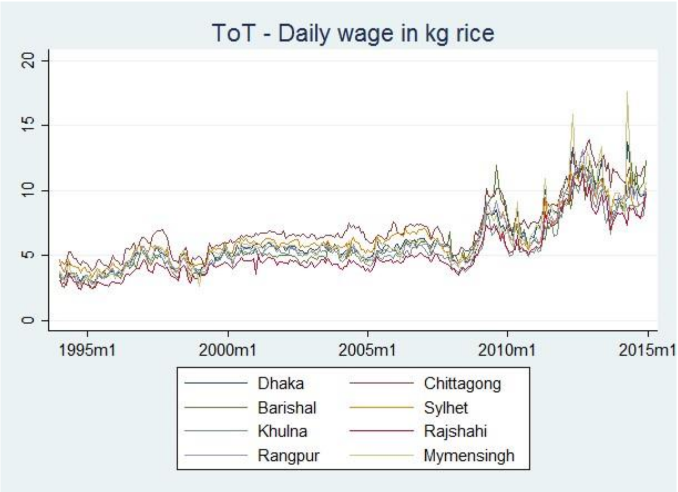


Figure 3.2: Trends in rural wages

Source: Author's calculation based on FPMU (1994-2018); DAM (1995-2018).

3.3 Labor market theory and agricultural mechanization

To understand the impact of agricultural mechanization on rural labor markets, in particular on rural wages, we made use of several interlinked theoretical concepts. All of them relate to the structural transformation of labor markets which we observed in Bangladesh. The first model is the efficiency wage hypothesis by Leibenstein (1957). Accordingly, as in the classical model, labor demand is related to labor productivity and supply is relatively elastic at a low wage rate (due to the surplus labor) since wages need to cover at least the expenditures on food consumption required to meet nutrition needs (see Figure 3.5). It follows that a reduction in the abundance of rural labor is a prerequisite for increases in rural wages.

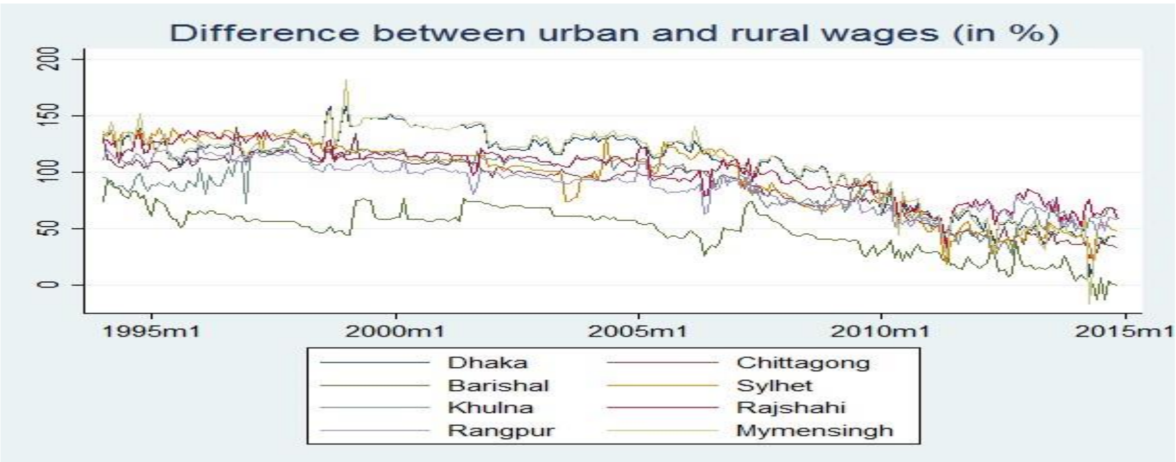


Figure 3.3: Trends in the rural-urban wage gap

Source: Author's calculation based on FPMU (1994-2018); DAM (1995-2018).

The expansion of urban employment opportunities, for instance in the manufacturing sector, induces migration of rural labor to urban centers. The Harris-Todaro model is the theoretical basis to describe rural-urban migration and its implications for wages. The model considers three sectors: the rural economy as well as an informal and a formal urban sector. Wages in the informal urban sector are much lower than wages in the formal sector. Rural laborers will choose to migrate to urban areas as long as the urban wage is higher than the rural wage level. However, urban wages in the formal sector are less flexible, and it is assumed that there is a certain minimum wage. At this wage level, there is a fixed level of labor demand. For this reason, the informal urban sector will absorb surplus labor in urban areas. In consequence, rural-urban migrants will face a probability of being employed in the informal sector only, instead of the formal sector. Therefore, the decision to migrate will be based on the expected urban wage, which is the weighted mean of the formal and the informal wage rates (Harris and Todaro, 1970).

The implications of the model for rural labor markets are straightforward. Increasing labor demand in urban areas will induce (seasonal) rural-to-urban labor migration. Thus, the expansion of non-farm employment opportunities in the manufacturing sector in urban areas causes rural labor shortages and increases rural agricultural wages (Zhang et al., 2014). In addition, as more unskilled laborers in rural areas are attracted to non-agricultural sectors, adoption of labor-saving technologies will become critical to sustaining current levels of agricultural production.

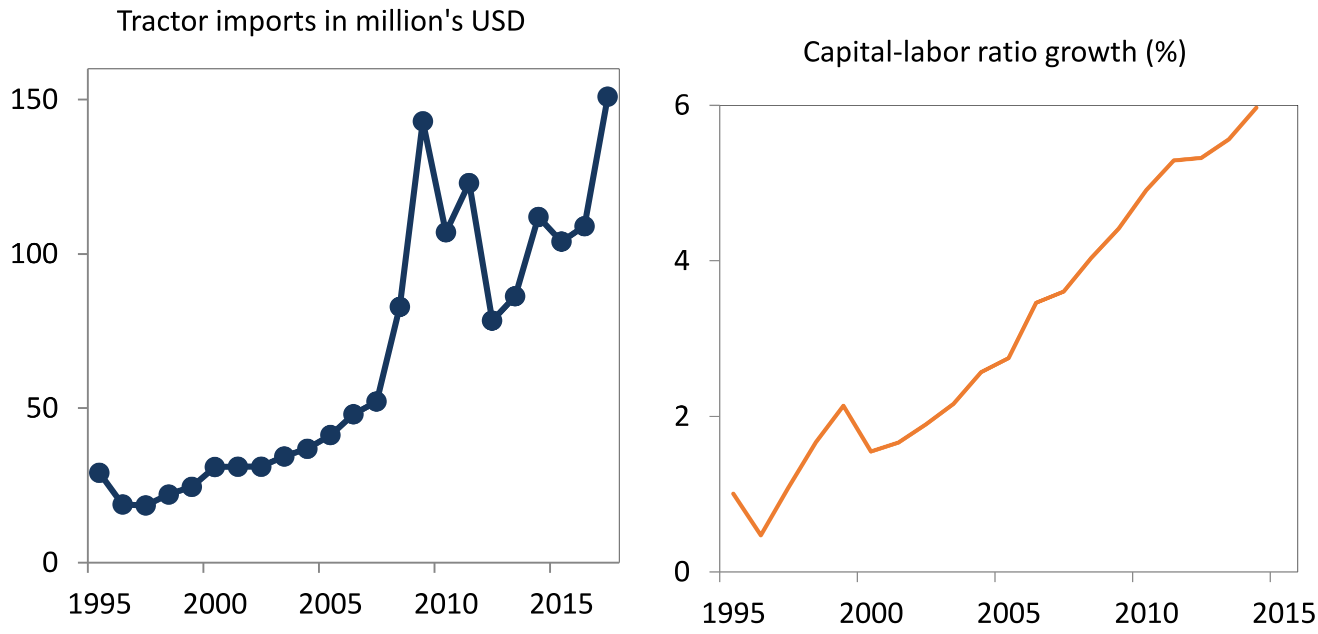


Figure 3.4: Agricultural mechanization in Bangladesh

Source: UN Comtrade (2018) and FAO (2018)

The theory of induced innovations by Hayami and Ruttan (1985) argues that relative prices dictate the direction of technical change. Based on this, the update of agricultural mechanization depends on the costs of agricultural labor. As long as the costs are low, farmers have little incentive to substitute labor with machines. Instead, high labor wages induce the adoption of mechanization (Ratolojanahary, 2016). In the present context, an increase in farm wages can induce the adoption of labor-saving technologies, such as mechanization, for instance through new institutional arrangements that increase the availability and affordability of agricultural machinery. More importantly, in light of the seasonal demand for machinery services, establishing a functioning rental market for machinery and machinery services and lowering the costs of tractors, threshers and seeders, will enable small and medium-sized farmers to effectively substitute labor with machines.

Many South Asian countries have observed a prompt increase in agricultural wages in recent years (Wang et al., 2016). Most of the small farms in the region tend to rely on family labor, while larger farms are more likely to draw on hired labor. With increasing rural-urban migration, those farmers are facing difficulties in hiring enough labor. Insufficient supply of farm labor as well as other frictions in the labor market, such as costs related to searching for, contracting, and supervising labor, reduce the use of labor in agricultural production (Foster and Rosenzweig, 2011; Deininger et al., 2016).

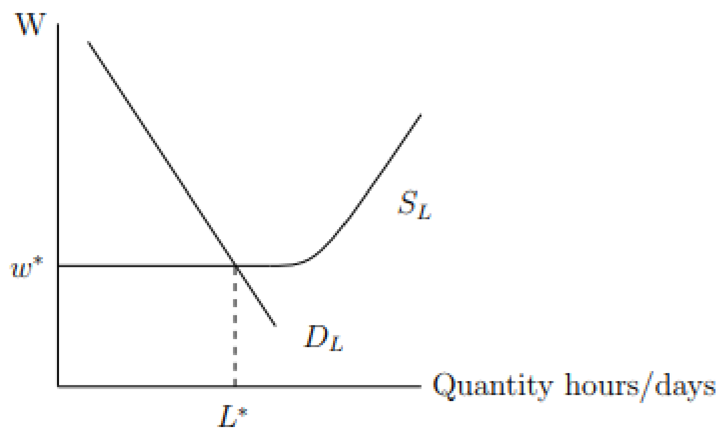


Figure 3.5: Labor supply at the subsistence level

Source: Felder (1988)

The expansion of new technologies and the liberalization of machinery imports have catalyzed the reduction of prices for agricultural machinery. In consequence, the relative price of machines, as compared to labor, has declined in an accelerating way (Mottaleb and Krupnik, 2015). In accordance with this trend, the demand for machinery services has rapidly increased; micro evidence shows that the same is happening in Indonesia (Yamauchi, 2016) and China (Wang et al., 2016). Both studies found a substitution relation between labor and machines. In an early study, Pingali et al. (1987) reviewed several studies in sub-Saharan Africa and found that in almost all cases, mechanized farms substituted labor with machinery, predominantly for land preparation. In this case, the demand for agricultural labor decreases and the marginal product of labor (wage) will also decrease, as shown in the left panel of Figure 3.6.

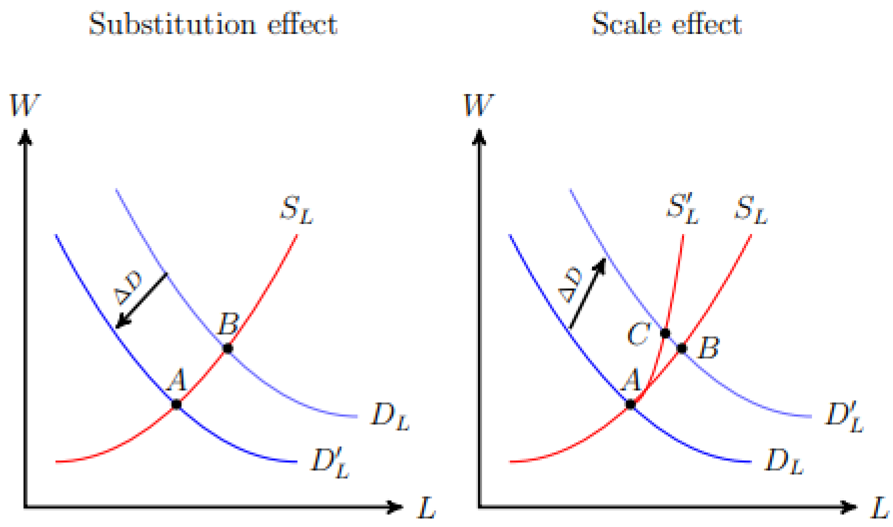


Figure 3.6: Labor market effects of mechanization

Source: Own illustration and Felder (1988)

On the other hand, agricultural mechanization has positive impacts on agricultural productivity, which could lead to overall agricultural growth. Increased technical efficiency allows not only agricultural activities to intensify on the existing land (MMP, 2018), but also cultivated area to expand; this is known as the scale effect (Wang et al., 2016; Apiors et al., 2016; Gautam and Ahmed, 2019). In this case, labor and machines are complementary inputs. Thus, there will be a positive shock to the demand for labor which reincreases agricultural wages, as illustrated in Figure 6 (right panel). Given that agricultural mechanization and productivity gains drive rural employment opportunities along the value chains (e.g. in the rental market for machinery), the opportunity costs for agricultural laborers increase, which could make labor supply less elastic (S_L to S_L'). In consequence, the new equilibrium wage rate (point C) could be above the initial wage rate (point B).

The overall effect of agricultural mechanization on rural agricultural wages depends on the size of the substitution and scale effect. However, it is unknown how large the changes in labor demand are for both effects and how attenuated the change in the slope of the labor supply curve can be. The different possible scenarios call for an empirical inquiry. The effect also has further implications for labor markets and urban welfare. If agricultural mechanization, ceteris paribus, has increased agricultural wages and has reduced the gap between rural and urban wages, enhancing agricultural mechanization is a viable policy option to reduce rural-urban migration, and thus the population pressure of increasing urbanization.

3.4 Empirical approach

3.4.1 Econometric model

Different from many of the existing studies (Zhang et al., 2014; Hassan and Kornher, 2019), this study analyzed the determinants of real agricultural wages, which we call the ToT or food-wage. The ToT is defined as the daily agricultural wage rate divided by the price of one kilogram of rice, the most important staple food commodity in Bangladesh. Using the rice price as the numeraire allowed us to explicitly test the efficiency hypothesis of Leibenstein and whether the Lewis turning point has been reached overcome in Bangladesh. The empirical model takes account of the time-series properties of the data by including lags of the dependent variable to account for the stickiness of agricultural wages. Further, we used a panel of the eight divisions of Bangladesh, namely Dhaka, Chittagong, Rangpur, Khulna, Barisal, Sylhet, Rajshahi, and Mymensingh.

The observation period was restricted to the time between 1995 and 2014, leaving us with 214 observations per division. We employed a dynamic panel model to tackle the omitted variable bias (OVB) due to the unobserved heterogeneity across the divisions. The model estimated is as follows:

$$\Delta ToT_{i,t}^{rural} = \beta \Delta ToT_{i,t-1}^{rural} + \Upsilon \Delta w_{i,t}^{urban} + \zeta \Delta M_t + ή \Delta K_{i,t}' + u_{i,t} \quad ……………(3.1)$$

Where i represents the divisions and t the time unit of observation. $\Delta w_{i,t}^{urban}$ stands for urban wages in the respective division, M_t for the indicators of agricultural mechanization, which are available on a country-level basis only, and K' is a vector of control variables. $u_{i,t}$ is the error term. We estimated Equation (3.1) on a monthly, seasonal, and annual basis to understand the dynamics of the change in rural agricultural wages. To obtain seasonal and annual values, we averaged the values of the observations in the respective time period. The indicators of agricultural mechanization are observable only on an annual basis.

As described above, motivated by the theory of induced innovations, the casual relationship between mechanization and wages is not unidirectional. To properly identify the effect of mechanization on wage growth, we employed the Arellano-Bond estimator based on the general methods of moments (GMM) estimator, which uses lags of differences and levels to instrument the endogenous variables. Since the data is non-stationary, we used the difference GMM estimator. This explains why all variables in Equation (3.1) are referred to as changes (Δ). The estimation was implemented in Stata 14 using Rodman's xtabond2 (Roodman, 2009a). This estimation technique also addresses the dynamic panel bias, as described by Nickell (1981); however, the problem disappears with sufficiently large T.

Table 3.1: Summary statistics

Variable name	Mean	Standard deviation	Minimum	Maximum
ToT (log)	-2.896	0.325	-3.737	-1.838
Urban wage (log)	5.401	0.442	4.299	6.259
Level of public rice stocks (log)	6.157	0.662	4.113	7.133
International rice price (log)	5.592	0.339	4.856	6.583
GDP growth (%)	5.568	0.740	4.100	7.100
Rainfall abnormality	-6.450	115.086	-424.972	779.250
Temperature abnormality	0.144	0.762	-3.154	3.263
Rainfall abnormality squared	13279.40	35,125.60	0.001	607231.00
Temperature abnormality squared	0.602	1.077	0.000	10.646
Machinery use # (mil.)	0.162	0.113	0.020	0.389
Tractor stock in mil. USD	208.511	152.711	19.314	515.366
Capital-labor ratio (%)	2.114	0.321	1.750	2.898
Yield (log)	0.829	0.465	-2.796	2.393
Production (log)	6.713	1.082	2.467	8.161
Labor productivity (log)	-6.883	1.098	-10.443	-5.091

Source: Author calculation based on BBS and UN Comtrade (1995-2015)

3.4.2 Description of the data

The statistical model of this study relies on a comprehensive database covering the period between 1994 and 2014. At present, Bangladesh is divided into eight major divisions and sixty-four subdivisions (districts). The BBS collects data on wages at the district level on a regular basis and publishes them in the Monthly Statistical Bulletin. Rural wages represent daily agricultural wages, including for key agricultural activities like harvesting, transplanting, etc. Division-level wage rates were computed as the average of the district-level wage rates. Rice prices were collected from the FPMU and the DAM. Among the different varieties in the market, we consider the price of coarse rice, which is available in the market during the respective rice marketing seasons (Aus, Aman, and Boro), as the most relevant reference price. Missing values of rice prices were replaced by interpolation.

The BBS reports two types of urban wages, industrial and constructional. The wage of constructional workers was estimated by considering the average daily wages of carpenters, masons, and brick breakers, while the industrial wage rate includes the aggregate average of daily wages in the cotton manufacturing, textile, and jute industries. Several missing values in the urban wage series were replaced by the wage rate in the nearest districts. Both constructional and industrial wages move together and are highly correlated. Hence, we took only constructional wages as the urban reference wage in our regression analysis. For Barisal, constructional wages were not available, and we, therefore, used the industrial wage as the urban reference wage.

The main challenge was to capture the level of agricultural mechanization through key indicator variables. We used three main indicators, namely the number of tractors (40-CV tractor equivalents), the capital-labor ratio in agriculture, and the tractor stock measured in USD. Data on machinery use in agriculture, measured in 40-CV tractor equivalents, was collected by the USDA ERS (2018) based on Fuglie (2015). We computed the capital-labor ratio as the ratio of fixed capital to total employment in the agricultural sector; the two data sets were provided by the FAO (2018). Both indicators are standard to measure the level of agricultural mechanization (Kiriu and von Braun, 2018). In addition to these two indicators, we made use of the fact that Bangladesh does not produce tractors domestically but relies on imports, mainly from China. UN Comtrade (2018) reported the quantity and value traded for different products and services by Harmonized Commodity Description and Coding Systems (HS). The product line 8701 represents tractors for agricultural use. We gathered data on exports to Bangladesh reported by its trade partners since Bangladesh does not report its import figures. To convert import values to an approximation of the actual capital stock, we based our calculation on the assumption that imports depreciate at an annual rate of 10%. Thus, the tractor stock in this study comprised current imports and a weighted sum of the imports of the past nine years. All these indicators were available only at the national level and on an annual basis. To avoid structural changes within individual years, we split the annual change in the indicators into equally sized monthly or seasonal changes. All summary statistics are available in Table 3.1.

In addition to that, we included several control variables in the panel regression, related to either rural agricultural wages or rice prices. The international rice prices were defined as the export prices of rice from India, a major trade partner of Bangladesh, and taken from GIEWS (2018)[3]. Data on public rice stocks were obtained from the FPMU (2018). Both public rice stocks and the international rice price are positively related to local rice prices. However, an increase in the public reserve level may also stimulate the demand for agricultural labor. The GDP growth rate, obtained from World Bank (2018), was included as a demand shifter, which potentially affects both rural agricultural wages and rice prices positively. We also included four weather

[3] For the period of the rice export ban imposed by India between 2008 and 2010, we used the export price of Vietnam.

indicators, namely rainfall and temperature anomalies, and their respective squared values. An anomaly is defined as the deviation of the monthly observation from its long-term trend. We expect an anomaly to have a negative relationship with the ToT, as weather shocks reduce agricultural supply, which drives up rice prices, and the demand for agricultural labor. Finally, we controlled for seasonality by including dummy variables for both the Aus and Aman season (the Boro season was used as the reference)[4].

To investigate possible channels of mechanization's impact on rural wages, we also conducted standard fixed-effects regression that tested the effect of changes in the mechanization indicators on agricultural outcomes. We considered the seasonal level of rice production, rice yield, and labor productivity. The level of labor productivity was measured as rice production divided by the number of agricultural households in Bangladesh. Rice production and yield were obtained from the annual Yearbooks of Agricultural Statistics in Bangladesh. Information on the number of agricultural households was taken from the 3rd and 4th agricultural censuses of Bangladesh conducted in 1991 and 2008, respectively. The annual number of households in each division was computed by linear interpolation.

3.5 Results

The Arellano-Bond estimator for dynamic panel models is highly sensitive to the specific instrument choice. Furthermore, over-identification, as a consequence of too many instruments, can cause biased coefficient estimates (Roodman, 2009b). Therefore, we limited our instruments to two lags (3rd and 4th) for the lagged dependent variable and all the other independent variables. We also excluded lag 1 and lag 2 from the set of instruments to avoid the risk of autocorrelation. The Arellano-Bond autocorrelation test was performed to confirm the validity of the lags as instruments. Hansen and Difference-in-Hansen tests were conducted for the over-identification and validity of GMM-type instruments, respectively. We present the instrument count, the Arellano-Bond autocorrelation test statistic, and the test statistics for both Hansen and Difference-in-Hansen test at the bottom of each regression table. To remove autocorrelation of second-order, we included lags of the independent variable urban wage.

3.5.1 The impact of mechanization

We start the discussion of the results with the monthly model (short term) presented in Table 2. The ToT, measured as the rural agricultural wage in kilograms of rice, is the dependent variable. Columns (1) to (3) show the different specifications using all three

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[4] Aus: sown in May along with pre-monsoonal rains and harvested in July. Aman: sown in the rainy season from July to August and harvested in November. Boro: sown in November and harvested in March to April.

indicators for the level of mechanization. In all models, the lagged dependent variable was positive and significant and was between 0 and 1. This expresses the persistence of the ToT. The persistence of the ToT indicates that agricultural wages in Bangladesh are no longer at the subsistence level but change with labor supply and demand. In all specifications, the indicator for agricultural mechanization was positively associated with the ToT. All coefficient estimates were significantly different from zero. More precisely, the model predicted that the use of an additional 100,000 tractors (equivalent to the increase in the number of tractor equivalents from 2010 to 2014) would increase the ToT by 4% in the short run. An increment in the capital-labor ratio by 0.3 (equivalent to the change from 2010 to 2014) and an increase in the tractor stock by 100 million USD (equivalent to the 2014 import value) could lift the ToT by 15% and 4%, respectively. Given that the unit price of a power tiller is around 10,000 USD (Mottaleb et al., 2017), the coefficient estimates for the regressions in Columns (1) and (3) correspond closely.

Among the control variables, we only found a systematic relationship between the ToT and the weather variables as well as the international rice price. In line with our hypothesis, positive changes in the international rice price reduced real rural agricultural wages, most likely through its inflating effect on domestic rice prices. Both higher-than-normal temperatures and rainfall were negatively associated with the ToT. In Bangladesh, where flooding is common during the monsoon periods, too much rainfall represents the biggest threat to crop production.

Interestingly, the coefficient estimates for public stocks were positive, yet only significant in Specification (2), suggesting that public policy intervention, besides its impact on rice prices, also stimulates labor demand and positively affects rural wages. The coefficient of the contemporaneous urban wage was significant and positive in Columns (1) and (3) and negative and significant in Column (2). At the same time, the lagged urban wage rate was negatively associated with the current ToT in Columns (1) and (3) and positively associated in (2). However, the sum of the coefficients of the contemporaneous and lagged urban wage was not different from zero in all specifications. Thus, the influence of the urban wage seems insignificant in the short run, which supports similar studies that underscored the stickiness of agricultural wages with respect to changes in urban wages (Hassan and Kornher, 2019). Last, seasonal dummies were insignificant. This is not surprising as both rural wages and rice prices are lower in the Boro season, which was used as the reference for the analysis.

Subsequently, the seasonal model was used to evaluate the medium-term effects, as presented in Table 3.3. Most importantly, the positive association between all indicators of agricultural mechanization and the ToT remained significant, whereas the coefficient estimates were slightly larger than in the monthly model, suggesting that the impact of mechanization increases over time. Similar to the monthly model, the coefficient of the lagged dependent variable remained significant but is smaller than in the monthly model. By contrast, the coefficient estimates of the international rice price, the public stock level, and the annual GDP growth rate were larger than in the monthly model. The coefficients for public stocks and GDP growth rates were also significantly different from zero. Hence, it appears that both public rice procurement and overall economic growth increase the demand for rural labor and lift rural agricultural wages. Unlike in the monthly model, rural ToTs were at their highest during the Aus season in the seasonal model. Last, the coefficient of the urban wage was significant and positive in Specifications (1) and (2). This finding supports recent literature on the relationship between rural and urban wages in Bangladesh as well as the hypothesis that changes in wage rates are sticky and take time to transmit to rural areas.

The annual model in Table 3.4 confirms the findings of the seasonal and monthly models. In general, all the coefficients of all variables increased in magnitude with increasing observation period. This is particularly true for the indicators of agricultural mechanization. For instance, the annual model predicted that an additional 100,000 tractors, an increment in the capital-labor ratio by 0.3, and an increase in the tractor stock by 100 million USD would have a positive effect on rural ToTs with a magnitude of 33%, 39%, and 25%, respectively. Notably, all these effects are short-term effects in the respective models. The long-term equilibrium effects can be computed by $\zeta/(1-\beta)$. The only observed difference between the annual and the other models was for urban wages, which are negatively associated with the ToT (Food wage).

Table 3.2: Monthly model ToT

VARIABLES	(1) **ToT**	(2) **ToT**	(3) **ToT**
L.ToT	0.871***	0.400***	0.815***
	(0.0214)	(0.0654)	(0.0469)
Urban wage (nominal)	1.868***	-1.013***	1.615***
	(0.437)	(0.349)	(0.387)
L. Urban wage (nominal)	-1.848***	1.332*	-1.613***
	(0.449)	(0.808)	(0.396)
L2 Urban wage (nominal)		-0.368	
		(0.527)	
Level of public rice stock	0.00404	0.0983***	0.00869
	(0.0199)	(0.0281)	(0.0272)
Aus (=1)	-0.00867	0.115***	0.00440
	(0.0199)	(0.0192)	(0.0178)
Aman (=1)	-0.00558	0.0237*	-0.000765
	(0.0160)	(0.0124)	(0.0161)
International rice price	-0.0532***	-0.179***	-0.0750***
	(0.0190)	(0.0306)	(0.0266)
GDP growth	-0.0108***	0.00809	0.00435
	(0.00321)	(0.00524)	(0.00550)
Rainfall abnormality	-8.68e-05**	2.72e-06	-8.00e-05**
	(3.52e-05)	(3.16e-05)	(3.17e-05)
Temperature abnormality	-0.00945**	-0.00761**	-0.00835**
	(0.00372)	(0.00356)	(0.00370)
Rainfall abnormality squared	8.80e-08	8.49e-08	9.15e-08
	(7.07e-08)	(8.73e-08)	(7.21e-08)
Temperature abnormality squared	0.00246	0.00636***	0.00177
	(0.00253)	(0.00244)	(0.00241)
Machinery use	0.362***		
	(0.0725)		
Capital labor ratio (%)		0.549***	
		(0.0988)	
Tractor stock in USD			0.000389***
			(7.49e-05)
Observations (N)	1,816	1,744	1,816
Number of divisions	8	8	8
N Instruments	17	17	17
AR(2)	0.372	0.647	0.457
Hansen Test	1.000	1.000	1.000
Diff.Sargan (gmm)	1.000	1.000	1.000

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Author’s computation based on USDA, FAO, UN Comtrade (1990 to 2015)

Table 3.3: Seasonal model ToT

Dependent variable ToT	(1)	(2)	(3)
L.ToT	0.309***	0.243***	0.252***
	(0.0239)	(0.0195)	(0.0200)
Urban wage (nominal)	0.489***	-0.0137	0.396***
	(0.102)	(0.0630)	(0.0428)
Aus (=1)	0.110***	0.129***	0.110***
	(0.0103)	(0.0117)	(0.0119)
Aman (=1)	-0.00967	0.00722	-0.00627
	(0.0122)	(0.0124)	(0.00912)
Level of public rice stocks	0.112***	0.141***	0.119***
	(0.0134)	(0.0114)	(0.0149)
International rice price	-0.309***	-0.348***	-0.339***
	(0.0287)	(0.0170)	(0.0198)
GDP growth	0.0173**	0.0323***	0.0433***
	(0.00845)	(0.00699)	(0.00835)
Rainfall abnormality	-0.000294***	-0.000259***	-0.000261***
	(0.0000825)	(0.0000678)	(0.0000747)
Temperature abnormality	-0.0404***	-0.0289***	-0.0325***
	(0.00700)	(0.00865)	(0.00738)
Rainfall abnormality squared	0.000000317	0.000000293	0.000000307
	(0.000000354)	(0.0000003380)	(0.000000341)
Temperature abnormality squared	0.00550	0.00236	0.00391
	(0.0120)	(0.0120)	
Machinery use #	0.619*		
	(0.371)		
Capital-labor ratio (%)		0.664***	
		(0.0516)	
Tractor stock in USD			0.000777***
			(0.000120)
N	448	432	448
N Instruments	17	17	17
AR(2)	0.604	0.911	0.550
Hansen Test	1.000	1.000	1.000
Diff.Sargan (gmm)	1.000	1.000	1.000

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation based on USDA, FAO, UN Comtrade (1990 to 2015)

There might be two possible explanations for this: first, urban wages might, in the long run, be a significant demand shifter and cause a stronger increase in rice prices than in rural wages; second, the diminishing wage gap between urban and rural areas could cause circular migration back to rural areas, which increases labor supply and reduces rural wages. This hypothesis needs to be tested further.

Table 3.4: Annual mode ToT

Dependent variable ToT	(1)	(2)	(3)
L.ToT	0.639***	0.288***	0.537***
	(0.169)	(0.0755)	(0.125))
Urban wage (nominal)	-1.451***	-1.126***	-1.149***
	(0.492)	(0.261)	(0.292)
Level of public rice stocks	0.828***	0.620***	0.593***
	(0.112)	(0.0806)	(0.0773)
International rice price	-0.152***	-0.373***	-0.318***
	(0.0624)	(0.0643)	(0.0334)
GDP growth	0.844***	0.135***	0.142***
	(0.0256)	(0.0235)	(0.0295)
Rainfall abnormality	0.00117**	0.000636	0.000426
	(0.000590)	(0.000535)	(0.000501)
Temperature abnormality	-0.0504	-0.0609	-0.0239
	(0.0402)	(0.0399)	(0.0358)
Rainfall abnormality squared	0.00000124	0.00000156	0.00000193*
	(0.00000133)	(0.00000121)	(0.00000108)
Temperature abnormality squared	0.152**	0.146**	0.0620
	(0.0741)	(0.0662)	(0.0491)
Machinery use #	3.391***		
	(0.887)		
Capital-labor ratio (%)		1.311***	
		(0.200)	
Tractor stock in USD			0.00247***
			(0.000440)
Observations	144	144	144
N Instruments	14	14	14
AR(2)	0.275	0.047	0.172
Hansen Test	1.000	1.000	1.000
Diff.Sargan (gmm)	1.000	1.000	1.000

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation based on USDA, FAO, UN Comtrade (1990 to 2015)

3.5.2 Channels of the mechanization impact

Finally, Table 3.5 shows the regression results of a standard fixed-effects model regressing indicators for a possible scale effect of mechanization on the indicators for agricultural mechanization. We found the regressions for the following indicators: labor productivity in Columns (1)-(3), production in Columns (4)-(6), and yield in Columns (7)-(9). All coefficient estimates were positive, with those for production and yield being significantly different from zero. Hence, the regressions suggest that agricultural mechanization has increased productivity and overall rice production. Given that agricultural land in Bangladesh is scant, productivity gains are the only option to increase agricultural production. The results could imply that labor and machines are complementary inputs in agricultural production; however, we were unable to test the hypothesis due to a lack of sufficient variation in the data on agricultural labor.

Table 3.5: FE regression on channel of mechanization impact

Dependent variable	Labor productivity			Production			Yield		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Aus (=1)	-1.824*** (0.088)	-1.822*** (0.088)	-1.823*** (0.088)	-1.825*** (0.088)	-1.824*** (0.088)	-1.826*** (0.088)	-0.625*** (0.035)	-0.626*** (0.035)	-0.628*** (0.035)
Aman (=1)	-0.359*** (0.088)	-0.356*** (0.088)	-0.356*** (0.088)	-0.365*** (0.088)	-0.364*** (0.088)	-0.365*** (0.088)	-0.612*** (0.035)	-0.615*** (0.035)	-0.616*** (0.035)
Rice price (nominal)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Weather abnormalities	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Machinery use #	0.436 (0.759)			1.286* (0.757)			1.806*** (0.297)		
Capital-labor ratio (%)		0.262 (0.245)			0.425* (0.244)			0.449*** (0.098)	
Tractor stock in USD			0.001 (0.001)			0.001* (0.001)			0.001*** (0.001)
Observations	432	432	432	432	432	432	432	432	432

Robust standard errors used; * p < 0.10, ** p < 0.05, *** p < 0.01

Source: Author's computation based on USDA, FAO, UN Comtrade (1990 to 2018)

3.6 Conclusions

This study examines the implications of agricultural mechanization for rural labor markets in Bangladesh. Mechanization of agricultural activities seems imperative to sustainable intensification, food security, and poverty reduction in many developing countries. This is particularly important in land-constrained countries, such as Bangladesh, where land ownership is scattered and a growing population needs to be fed. The present study shows that agricultural mechanization has positively affected real rural wages, and thus has contributed to the reduction of the rural-urban wage gap.

This study has several distinguishing features. First, our data spans a long period and uses a unique subnational-level data set on rural and urban wages and rice prices. Second, we empirically tested how agricultural mechanization has affected rural wages in Bangladesh since the 1990s. Third, by estimating different models with varying time horizons, we were able to test the dynamics of rural wage determination. Last, we investigated the channels of the mechanization effect, namely its impact on agricultural productivity and production. By providing a theoretical framework, we are confident that the positive effect of mechanization on rural wages can be attributed to the scale effect associated with the increase in agricultural activities facilitated by agricultural mechanization. Hence, our findings dispel the concern that the substitution of manual labor by machines has led to reduced employment opportunities and lower wage rates in rural Bangladesh. This has important implications for policymakers aiming to reduce rural poverty and interventions intended to reduce extensive rural-urban migration and create more employment opportunities in the agricultural sector.

Although agricultural mechanization in Bangladesh has considerably advanced in recent years, there is still a need to increase the adoption of machine use, in particular on small farms. The rental market for farm machinery is available in most rural areas, which may help accelerate the adoption of such services; nevertheless, it is often the case that only a few suppliers are available, leading to rationing of the services. Further, the adoption of new types of rental services may create new employment opportunities for the rural labor force. Mechanization can certainly create jobs if it is scaled out across the whole value chain, meaning when it is introduced in sectors where there are labor shortages, like harvesting. Although the general conception is that there are a lot of people in low-income countries like Bangladesh, seasonal labor shortages remain an issue. Mechanization can create jobs if it responds to sectors that are on average labor-intensive, such as rice, wheat and potato cultivation in Bangladesh, where farmers experience labor shortages. However, it is able to do so only if it is scaled out across the whole value chain. This means mechanization should not only be limited to the ownership, operation and maintenance of farm machinery, but also extend to equipment for processing, grading, quality assurance, transport, packaging and distribution; all of these are areas where there are ample opportunities to create jobs for semi-skilled labor forces. Jobs are created when new market opportunities arise; however, the extent to which mechanization creates new jobs rather than destroying old ones is a fundamental question. If mechanization is done right, then it can create jobs (e.g., equipment maintenance and repair technicians, electricians, and mechanics) by improving the timeliness and efficiency of agricultural operations and reducing drudgery and the time spent on manual labor. But for this to happen, the GOB needs to invest in vocational training and skills development. There is a seasonal shortage of labor in Bangladesh. A successful mechanization process cannot be achieved in Bangladesh when the push is only coming from the outside. Bangladesh needs its own agricultural machinery industry. Such a development is already taking place in the industry in Africa, albeit on a small scale. To make the process of mechanization in Bangladesh successful, the country needs to build an intelligent, technical and organizational partnership together with other developed countries. Acknowledging the importance of rural labor markets, it is recommended that policymakers continue investing in rural (on-farm and non-farm) productivity to create proper employment opportunities in the agricultural sector.

4. Interlinkage of Farm Wage, Farm Machinery Use and Land Reallocation

4.1 Introduction

The Asian population is expected to reach 5 billion by 2050, which will be approximately 54% of the world population (Retherford, 2002). As a consequence, the demand for staple foodgrain is expected to increase markedly in developing countries (Godfray and Garnett, 2014). More than a doubling of production is required to ensure staple foodgrain security alone in 2050 (Tilman et al., 2011). However, it becomes challenging to increase food production and utilize cultivable land in the face of rising production costs due to the increase in real wages in agriculture. The transformation of the economic structure in Asia has induced increasing real wages not only in urban and non-agricultural sectors but also in many parts of rural and agricultural sectors in Asia (Yamauchi, 2014). It has been observed in recent years that South Asian agriculture has been facing higher growth in farm wages driven by factors such as labor shortage and non-farm job opportunities, which requires a substitution of labor by machines to ensure sustainable agricultural production. The reasons identified for the labor scarcity include higher wages in other locally available jobs, the seasonal nature of agricultural jobs, and the perception that agricultural jobs are unprestigious. Labor-saving technologies may be attractive to smallholder farmers because of potential savings on production costs and reduction in drudgery by substituting manual labor (Mahmud et al., 2014; World Bank, 2007; Kienzle et al., 2013).

However, the issue is whether it is rational for farmers to use farm machinery or invest in machine hiring when there is a tendency for the average farm size to reduce. However, the issue is whether it is rational for farmers to use farm machinery or invest in machine hiring when there is a tendency for the average farm size to reduce due to the high burden of the population. In China, India, Indonesia, and Vietnam, farmers started increasing their cultivable land and investing more in machine services in response to rising real wages (Wang et al., 2016). Thus, mechanization is unequivocally taking place in the densely populated countries in Asia, and Bangladesh is not an exception in South Asia. The increase in real wages, in particular, rural real wages, has accelerated since the late 2000s, suggesting that the Lewis turning point has arrived (Zhang et al., 2014). Free trade and market amalgamation have contributed to the economic growth of developing nations (Van den Berg et al., 2007) like Bangladesh. However, per capita land availability for cultivation in Bangladesh is low compared to other South Asian countries. The use of farm machines on smaller plots is always questionable. Machinery use is also sometimes constrained by a lack of capital and an imperfect or inactive rental market. Surprisingly, Bangladesh has set a better example for other developing countries with regard to the adoption of irrigation and land traction technologies (Animaw et al., 2016). From a developmental perspective, it is necessary to clarify how the changes and growth of farm wages are associated with the adoption of labor-saving technology and how this adoption influences land reallocation in Bangladesh.

The impact of farm wage growth on farmers' behavior has many dimensions related to future agricultural production. In general, labor constitutes 30% of the production cost (IFPRI, 2012). The major problem associated with higher farm wages is the increasing production cost that may reduce farmers' profit as well as the incentives to produce the same crop in the next season. Most producers in South Asia are small-scale farmers and have small cash capital to invest during cultivation. Many of them tend to sell their crops during the harvest season to pay any outstanding factor costs. Ultimately, a higher wage rate for hired labor may induce small farmers to think about the rationality of investing in agriculture for the next season. On the other hand, large farmers may consider whether it is rational to hire manual labor or to invest in farm machinery to reduce the production cost as well as the risk of not being able to find labor on time. Otsuka et al., (2013) suggested that increasing real wages would reduce demand for physical labor in agriculture, promote the use of machinery as a substitute for labor, and decrease the disadvantage of larger farms. This may perhaps even flip the inverse relationship to a direct relationship due to economies of scale resulting from machine use. Foster and Rosenzweig (2011) estimated that the optimal farm size in India would increase due to the substitution of machinery for labor. Although such transformation has helped reduce poverty in many countries (for example, poverty rate in Bangladesh dropped from 49% in 2000 to 32% in 2010), it has also created a challenge for farming, which depends on small-scale and family-based operations. However, the emergence of machine rental markets and the recent wage growth may have significant effects on the efficiency level of small- and medium-scale farming in rural Bangladesh through land reallocation and technology adoption. With this in mind, this chapter tries to find out whether wage change induces machine investment and expansion of cultivable land.

4.2 Rationale and objectives of the research

Rural-to-urban migration is increasing with the expansion of non-farm employment opportunities, causing seasonal rural labor shortages (Zhang et al., 2014). The necessity of adopting labor-saving technologies may play a crucial role in sustainable agricultural production in agricultural-based countries especially when more unskilled labor force in rural areas is increasingly attracted to non-agricultural sectors. The adoption of farm machines is also seen as a major indicator of the establishment of diminishing inverse farm size-productivity relations. The mechanisms of varying inverse relationship between farm size and productivity through imperfections in various factor markets depend on the particular factor (such as farm wage and capital) that experiences structural transformation over time. South Asian countries have experienced a prompt increase in real agricultural wages in recent years, while real machine prices have remained relatively unchanged (Wang et al., 2016). The expansion of new technologies and the introduction of free trade markets between countries are catalytic in reducing machine prices. For example, the relative price of machines to agricultural labor has declined in an accelerating way in China, which is consistent with the observed rapid introduction of machine services (Van den Berg et al., 2007). With regard to changes in farm wages, there might be an increasing trend of using machine power, which induces changes in cultivable land and productivity as well.

The argument of induced innovation by Hayami and Ruttan (1985) is that relative prices dictate the direction of technical change. In particular, an increase in farm wages may induce mechanization or could lead to a new institutional arrangement that reduces users' costs of operating machines on the farm. For example, if machines (e.g., tractors, threshers, and seeders) can be rented cheaply or professional or commercial machine services are available at low or no additional transaction costs, small and medium farmers may be able to effectively save labor by utilizing machine services or directly hiring machines through rental markets. Most of the small farms in South Asia tend to rely on family labor, and larger farms are more likely to draw in hired labor. Unlike small farms, medium and larger farmers face the problem of hiring labor due to labor market frictions. Timely availability of farm labor and other frictions in the labor market, such as search, contracting, or supervision costs, would lend a disadvantage to larger farms (Foster and Rosenzweig, 2011; Deininger et al., 2016). Also, transaction costs for machinery rental and an imperfect land market would differentially affect small and large farms. If land markets are not active, it may be difficult for small farm holders to expand their farm size to use their labor endowment effectively. Evidence of inverse farm size-productivity attenuation over time was found in Vietnam (Liu et al., 2016) and Indonesia (Yamauchi, 2016) in favor of larger farms, which is attributed to rising agricultural wages and the introduction of labor-saving technology.

When a low-income agrarian economy experiences structural transformation, policymakers are usually keen to know whether factor markets for agricultural labor and machinery become more active and reduce the inverse relationship between farm size and productivity. Disentangling of the relations between land, labor, and machinery capital of rural households under the ongoing structural transformation of the economy may motivate agricultural and rural development policy interventions. This study is important especially in the context of a developing country with a changing farm structure that has witnessed a rising proportion of cultivated cropland coming under the control of medium-scale farms. Such kind of changes in farm structure may contribute to the formulation of national goals concerning agricultural productivity and food security. Assessing the relationship between farm power and manual labor in Bangladesh has gained policy importance in light of recent studies that questioned the viability and even the objectives of promoting small-scale agriculture in other developing countries in Africa (e.g., Collier and Dercon, 2014; Dercon and Gollin, 2014).

This study aims to assess the relationship between agricultural land and labor markets in Bangladesh in the light of farm mechanization. Most agricultural policies in the country are focused on increasing the efficiency of smallholder farmers in their production. However, the emergence of machine rental markets, and changes in the rural wage growth and land reallocation may alter the efficiency of farm households. In this study, we examine how changes in rural wages influence land allocation among the different categories of farmers (based on farm size), and how changes in rural wages influence investments in machines, which are either substitutes for or complements to labor, among the different categories of farmers.

4.3 Methodology

4.3.1 Study area and data

Panel data of 62-villages were gathered from a nationally representative sample survey of rural households in Bangladesh. The survey spanned about 26 years (1988-2014) and was conducted to assess changes in rural poverty and livelihoods in response to rural credit, technological progress, and food price hike, etc. The baseline survey was conducted by the Bangladesh Institute of Development Studies in 1983. The initial survey included 1,240 rural households from 62 villages in 57 out of 64 districts in Bangladesh (Rahman and Hossain, 1995). The households were revisited in 2000, 2004, 2008, and 2014. However, this study limits its scope of analysis to the period between 2008 and 2014. The sample sizes in the repeat surveys of 2000, 2008, and 2014 were 1880, 2010, and 2800 respectively. Information was collected through a semi-structured questionnaire designed to gather data on demographic details, land use, costs of cultivation, livelihoods, farm and non-farm activities, commodity prices, ownership of non-land assets, income, expenditure, and employment (Ahmed and Goodwin, 2016). Besides, the data set provides information on farm's characteristics, soil type, and land renting arrangements.

4.3.2 General characteristics of the data

The panel survey covers the total expenditures on all major inputs, including expenses on machinery and labor. All the variables were estimated by covering the three seasons (Aus, Aman, and Boro) in the respective years. Table 4.1 shows the average farm sizes in Bangladesh for 2008 and 2014, in terms of both area owned and area operated or cultivated, calculated from the rich panel survey used in this study. While Table 4.2 presents the descriptive statistics of the intact households. Both the average farm size and the average number of family members working in agriculture declined. Further, the mean amount of rented-in land and the percentage of mechanized households both increased. Similar types of studies in Indonesia and China assumed a threshold of cultivable land size of 0.6 ha and 0.42 ha respectively to better understand the land reallocation behavior of the households (Yamauchi, 2016; Wang et al., 2016). In Bangladesh, the mean technical efficiency falls with farm size and clustered densely between 0.2 ha to 0.4 ha (Gautam and Ahmed, 2019). Following those previous studies, in this study, we try to find a threshold (0.35 ha to 0.45 ha) that may indicate a changing pattern of land reallocation and machine use. Table 4.3 shows that farm households having less than 0.45 hectares of land in 2008 had a greater amount of rented-in land in 2014, while the average amount of land rented in by larger landholders decreased during the same period.

Table 4.1: Descriptive statistics of the variable (all households)

Year	**2008**		**2014**	
Household Characteristics	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
Family size	4.938	2.31	4.32	1.90
Age of household head	48.099	14.4	47.30	14.97
Household head education	3.900	4.26	4.51	4.44
Number of Agricultural workers	.843	.861	.757	.678
Land (ha)	-	-	-	-
Total owned land	.46	.90	.38	.70
Total cultivated land	.31	.54	.29	.50
Per capita cultivated land in hectares	.06	----	.052	
Rented-in land in hectares	.12	.31	.15	.37
Rented-out land in hectares	.16	.59	.14	.43
Income	-	-	-	-
Income from agricultural sector	42474.57	62996.8	66890.87	98369.21
Income from non-agricultural sector	55315.62	101103.3	112386	177716.8
Mechanization				
Percentage of mechanized	88.70		90.30	
Percentage of electricity	82.50		87.50	
Number of households	2010		2846	

Source: Author's calculation using the 62-village panel survey.

Table 4.2: Descriptive statistics of the variable (intact households)

Year	**2008**	**2014**
Household Characteristics	**Mean**	**Mean**
Family size	5.636	4.668
Age of household head	49.822	48.713
Household head education	4.012	4.759
Total agricultural worker	1.804	1.369
Land		
Total own land	.508	.401
Total cultivated land	.709	.661
Per capita cultivated land in hectares	.131	.153
Rented-in land in hectares	.201	.260
Rented-out land in hectares	.158	.115
Income		
Income from agricultural sector (BDT)	60435.41	93542.1
Income from non-agricultural sector	55362.93	94741.24
Mechanization		
Percentage of mechanized	88.145	98.298
Number of households	1058	1058

Source: Author's calculation using the intact households of the 62-village panel survey

Meanwhile, the cost incurred by the group with smaller land size in 2008 became three times higher in 2014, while the cost incurred by larger farmers only doubled within this period. In this study, each household's land endowment was captured by farm size and the number of plots. Farm size is measured as self-cultivated land, which is further broken down into own land and net rented-in land. The net rented-in land is measured as land rented in by a farmer from either a village or other farmers minus land rented out by the farmer. Investment in the machine was calculated by considering the cost of land preparation by tractors and power tillers, irrigation by motors, threshing by open-drum and closed-drum threshers, and harvesting by reapers and combine harvesters.

Table 4.3: Threshold land group characteristics

Total intact Households	**2008**		**2014**	
Farm size characteristics	<0.45 Hectares	>0.45 Hectares	<0.45 Hectares	>0.45 Hectares
Total rented-in land	0.225	0.742	0.31	0.59
Total machine investment (BDT)	2,684.516	9,286.744	8,017.768	20,034.77

Source: Author's calculation using the intact households of the 62-village panel survey

Figure 4.1 displays the total cost of hiring labor and machines for all the households in 2008 and 2014. Total expenses on machine hiring in 2014 was doubled compared to 2008. Figure 4.2 shows the input cost per hectare for the intact households in 2008 and 2014. Per hectare expenditure on machine hiring in 2014 was approximately 22,830 BDT, which was more than double the amount in 2008 (9,585 BDT). Farmers in 2014 tended to invest more money in hiring machine than labor.

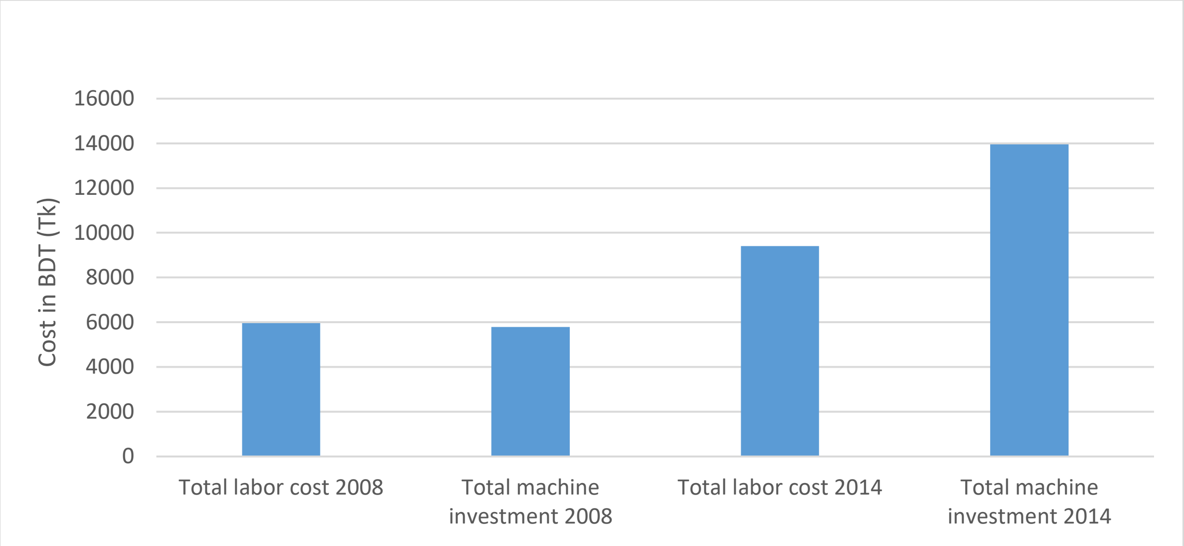

Figure 4.1: Average cost of cultivation for manual labor and farm machines in 2008 and 2014 (all households)

Source: Author's illustration based on 62-villages data (2008 and 2014)

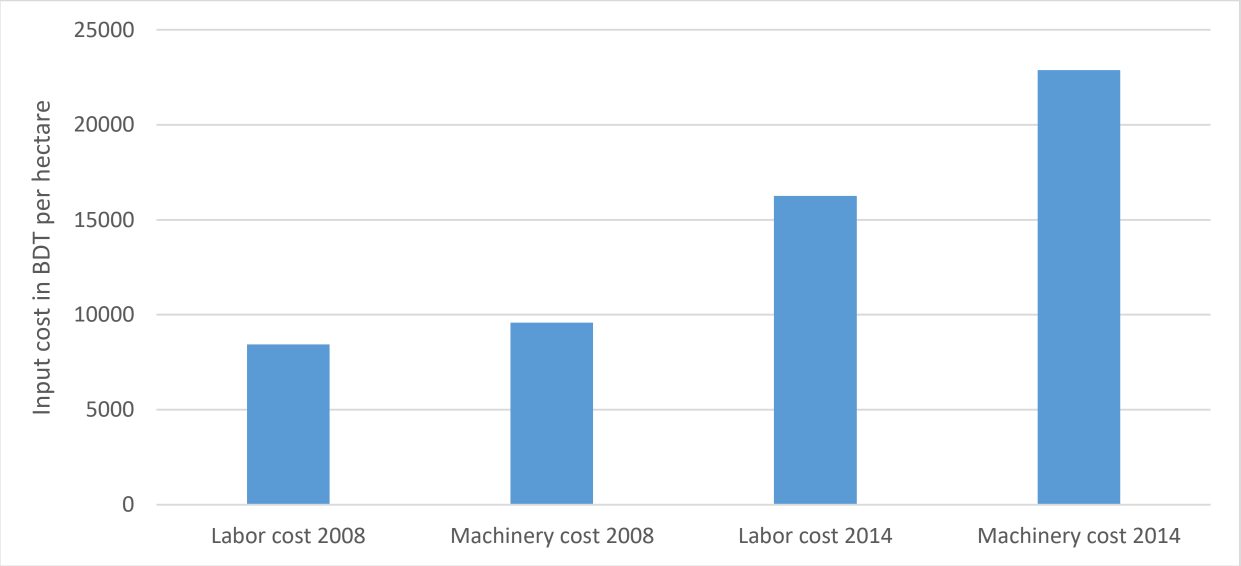

Figure 4.2: Farm labor and machinery cost in 2008 and 2014 (1058 intact households)

Source: Author's illustration based on 62-villages data (2008 and 2014)

Figure 4.3 shows the seasonal farm wages. There are significant differences between the mean seasonal wage rate in 2008 and 2014. The wage rate in Boro 2014 was much higher than in 2008.

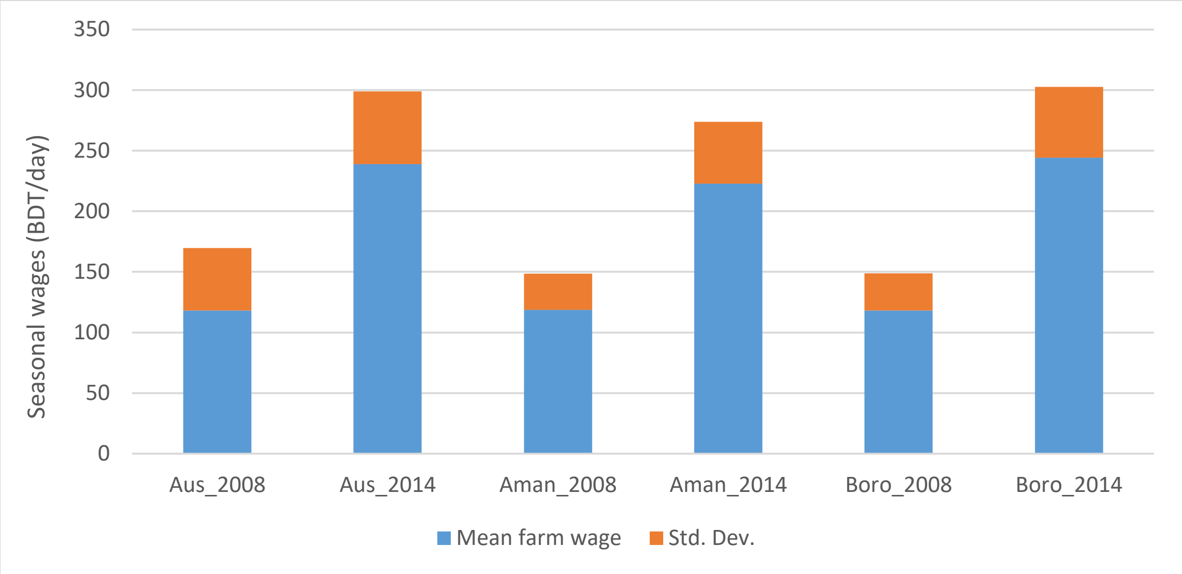

Figure 4.3: Seasonal farm wages in 2008 and 2014

Source: Author's illustration based on 62-villages data (2008 and 2014)

4.3.3 Estimation issues and strategies

This section describes the specifications and estimation strategy used in the analysis. Land transactions and machine investments were analyzed using the first-differenced equation shown below. In all the econometric estimations, first differences were taken to wipe out unobserved fixed error components, which could lead to bias in the cross-sectional estimation. The three major key variables are farm wage, area of cultivable land, and cost of renting and purchasing machinery (use of farm machines). We may expect a substitutional relation between farm labor and farm machinery use. The essence of agricultural mechanization is the substitution of capital for labor, and the degree of substitution depends on the relative scarcity of capital and labor. The more labor is transferred from agriculture to non-agriculture fields, the scarcer agricultural labor will become.

Machinery hiring cost and land allocation were analyzed using the following first-differenced equation:

$$\Delta y_{ij(0,1)} = \alpha + \beta_1 \Delta W_{ij(0,1)} + \beta_{21} \Delta W_{ij(0,1)} * land_{ij0} + \beta_{22} * land_{ij0} + Z'_{ij0}\gamma \\ + \Delta \epsilon_{ij0} + Village\ fixed\ effect \ldots \ldots \ldots \ldots \ldots (4.1)$$

Here $\Delta y_{ij(0,1)}$ is the change in machinery hiring expense or change in cultivated land or rented-in land for household 'i' in village 'j' in the period between 2008 and 2014, (0, 1). $\Delta W_{ij(0,1)}$ is the change in hired farm wages of the households. $land_{ij0}$ is the total cultivated land in 2008, Z'_{ij} is the vector of household characteristics in 2008, and $\Delta \in_{ij0}$ is the difference in random shocks. Note that β_1 is the effect of change in the farm wage rate on the dependent variable, and β_2 captures how the initial land holding affects the impact of change in the wage rate. The wage rate interacts with the initial self-cultivated land size. We hypothesized that $\beta_2 > 0$. This means, when faced with rising wages, relatively large holders would tend to increase their operational size and incur higher machinery hiring expense. Change in mechanization investment may also have an impact on the area of cultivated land and rural wages.

4.4 Empirical results

This section reports our empirical results. Firstly, the estimation results focus on the demand for machine services followed by land transaction. The estimation procedure used first differencing in all the cases.

Table 4.4 summarizes the regression results for changes in the log of machinery hiring expenses of the individual households from 2008 to 2014. The exogenous variable includes the log of changes in farm wage rates between 2014 and 2008, a logarithm of the total cultivable land in hectare in 2008, the interaction between changing wages and initial land sizes, age of the household head, years of schooling of the household head, and the total number of adult agricultural workers. Village fixed effect is considered as a control for village-specific changes in the unit cost of the machine uses. There are five regression lines. The result from regression line 1 shows that an increase in change in nominal farm wages significantly increased the machinery hiring expenses. In other words, a 10% change in nominal farm wages increased the change in machine hiring cost by 5.91% at a 10% level of significance. But in real terms, the effect of wages became insignificant in regression lines 3 to 5. Initial land size had a significantly negative effect on machinery investment in regression lines 1, 3, and 4, but it became insignificant if the initial land size was greater than 0.45 hectares. In other words, having a higher amount of land in the initial period (2008) did not indicate that farmers will invest more in renting machinery. Table 4.3 also shows how much each group of farmers invested in machinery. At the same time, an increase in the total number of agricultural workers significantly reduced machinery hiring expenditure, which is relevant to the rational use of family endowment in households. In table 4.5, the dependent variable is the change in machinery cost per hectare and the main exogenous variable is the change in the total cost per hectare. Here a 10%

change in the total labor cost per hectare significantly increased the machinery cost per hectare by 2.68%, which is evident in regression line 1. Labor-machine elasticity grew slightly (0.272) for the households having larger land size in 2008. So, it is evident that positive changes in farm wages induced the substitution of labor by machines. Total cultivable land in 2008 also positively influenced machinery expense, but the effect became insignificant for the larger farmers. This may indicate that large and medium farmers had already adopted machinery, so the change in machinery cost per hectare was not significantly different. On the other hand, small farmers started to increase their investment in machinery as the labor cost per hectare grew. The interaction term was positive and significant, which is compatible with the initial hypothesis that an increase in wages would induce machine use among the farmers who owned more land in the initial period. However, the interaction term became insignificant for relatively larger farmers who owned more than 0.45 hectares of cultivable land, but the sign of the coefficient remained positive.

Table 4.4: Impact of nominal and real farm wage rate on machinery investment

Dependent Variable	**(1)** **All**	**(2)** **Land 2008 > 0.45 hectares**	**(3)**	**(4)**	**(5)** **Land 2008 > 0.45 hectares**
Ln change in machine hire expenses	Non-deflated		Real terms (deflated)		
Change in Farm wage (log)	0.591*	0.256	0.184	0.726	-.0349
	(0.332)	(0.421)	(1.109)	(1.025)	(1.37)
Ln change in Farm wage * Ln Total cultivated land (2008)			-.0851		
			(0.690)		
Total cultivated land_08 (log)	-0.502***	-0.125	-0.366**	-0.497***	-0.132
	(0.111)	(0.270)	(0.145)	(0.103)	(0.259)
Age of the head (2008)	0.00755	0.00249	0.00747	0.00738	0.002
	(0.00849)	(0.0133)	(0.00787)	(0.00787)	(.012)
Adult workers in agriculture _08	-0.257***	-0.384***	-0.255**	-0.255**	-0.381***
	(0.0972)	(0.128)	(0.105)	(0.105)	(0.142)
Education of the head (2008)	0.0266	-0.0111	0.0263	0.0254	-0.012
	(0.0234)	(0.0374)	(0.0231)	(0.0231)	(0.033)
Constant	-1.248	1.686	0.0665	1.610	2.790
	(1.754)	(1.942)	(0.850)	(1.985)	(2.84)
Village fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	1,051	528	1,052	1,052	529
R-squared	0.134	0.169	0.133	0.132	0.168

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation based on 62-villages data (2008 and 2014)

Table 4.5: Impact of real farm wage rate on machinery investment per hectare

Dependent variable Machinery cost per hectare	**(1)** Households hired labor	**(2)** Land cultivated in 2008 > 0.45
Change in total labor cost per hectare (Ln)	0.268***	0.272***
	(0.0387)	(0.0383)
Total cultivated land in 2008 in hectare (Ln)	0.122***	0.121
	(0.0431)	(0.0812)
Change in total labor cost per hectare * Total cultivated land in 2008 in hectare (Ln)	0.0759** (0.0349)	0.0224 (0.0656)
Age of the head (2008)	-0.00520**	-0.00613
	(0.00262)	(0.00374)
Adult workers in agriculture	0.00462	0.0803**
_08	(0.0388)	(0.0407)
Education of the head (2008)	-0.00449	0.00615
	(0.00727)	(0.0111)
Village fixed effect	Yes	Yes
Constant	0.706***	0.655***
	(0.199)	(0.250)
Observations	681	404
R-squared	0.363	0.391

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation based on 62-villages data (2008 and 2014)

Table 4.6 summarizes the results on changes in total cultivated land. The results show that agricultural wage changes (nominal or real) did not affect the change in total cultivable land. Surprisingly, the interaction term of changing real wages and initial land size was negative and significant, which means that the relatively larger farms did not increase their land size, rather, small farmers were able to cultivate their fallow land due to the emergence of the active rental market for agricultural machinery. Years of schooling had a significant positive effect on land cultivation; this is an interesting finding as most of the relevant literature suggests that educated individuals are diversifying more into non-farm activities. It might be the case that the availability of farm machinery services at the village level induced better educated farmers to both diversify into non-farm activities and maintain their involvement in agriculture by retaining more land. Total adult working member in agriculture (2008) had a negative effect for the households having total cultivable land more than 0.45 hectares.

Table 4.6: Impact of farm wage on land cultivation

Dependent variable Log of Total cultivable land change (hectare)	**(1)** All *Non-deflated*	**(2)** Total cultivated land (2008) > 0.45	**(3)** All *Deflated* (real wages)	**(4)** Total cultivated land (2008) > 0.45
Ln change in Farm wage	0.0227	-0.202	-0.231	-0.316
	(0.0901)	(0.124)	(0.269)	(0.311)
Ln Total cultivated land (2008)	-0.428***	-0.419***	-0.373***	-0.393***
	(0.0298)	(0.0720)	(0.0395)	(0.105)
Real wage change * Total hectare land cultivated in 2008			-0.351**	-0.172
			(0.177)	(0.492)
Age of the head (2008)	-1.83e-05	-0.000992	1.54e-05	-0.000957
	(0.00215)	(0.00294)	(0.00215)	(0.00296)
Total adult working member in Agriculture (2008)	-0.0437	-0.0986***	-0.0436	-0.0999***
	(0.0361)	(0.0368)	(0.0363)	(0.0366)
Education of the head (2008)	0.0109*	0.0147*	0.0112*	0.0148*
	(0.00576)	(0.00763)	(0.00574)	(0.00764)
Village fixed effect	Yes	Yes	Yes	Yes
Constant	0.607	1.626***	-0.337	-0.0730
	(0.466)	(0.550)	(0.212)	(0.323)
Observations	1,051	528	1,052	529
R-squared	0.331	0.260	0.333	0.258

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation based on 62-villages data (2008 and 2014)

The impact of real wage growth on total cultivable land was evaluated and is presented in Table 4.7. From regression lines 1 to 3, it is evident that real wage growth had no significant effect on the change in the total cultivable land. The interaction term and the initial land size were significant. Households having larger land size in 2008 tended to reduce their total cultivable land. The variable machine cost per hectare was also added as an exogenous variable in logarithm form and presented in Table 4.7. In addition to the initial land size, the percentage of total cultivable land significantly decreased with an increase in machinery cost per hectare. However, for the larger farmers, machinery cost was not significantly associated with the change in total cultivable land.

Table 4.7: Impact of farm wage growth on land cultivation

	(1)	(2)	(3)
Dependent variable	**Ln Total cultivable land change (hectare)**		
			Land 2008 > 0.45
Real change in wage growth	-4.52e-06	-0.000116	-7.91e-05
	(0.000192)	(0.000187)	(0.000169)
Ln Total cultivable land in 2008 (hectare)	-0.400***	-0.427***	-0.420***
	(0.0328)	(0.0299)	(0.0721)
Real wage change growth *.Ln Total cultivable land in 2008 (hectare)	-0.000787*		
	(0.000404)		
Age of the head (2008)	1.57e-05	-2.38e-05	-0.000933
	(0.00215)	(0.00215)	(0.00295)
Total adult working member in Agriculture (2008)	-0.0428	-0.0438	-0.0990***
	(0.0362)	(0.0362)	(0.0365)
Education of the head (2008)	0.0108*	0.0108*	0.0145*
	(0.00574)	(0.00575)	(0.00761)
Constant	-0.383*	0.726***	0.761***
	(0.199)	(0.110)	(0.176)
Observations	1,052	1,052	529
R-squared	0.332	0.330	0.257

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation based on 62-villages data (2008 and 2014)

We also ran separate regressions to see the impact of changes in wages and machinery cost on rented-in land. The results are displayed in Tables 4.8 and 4.9. Increases in agricultural wages significantly reduced the total amount of land rented in by farmers who owned more than 0.45 hectares of land. Real wage changes had a much greater impact on the amount of rented-in land, which indicates that a 1% increase in real wage reduced the total rented-in land by 1.91%. Initial land size also significantly reduced changes in the total rented-in land. By using the changes in real wage growth as a regressor in Table 4.10, we also found that they had a significant impact on the amount of land rented in by the farmers who owned more than 0.35 hectares of land in 2008. In this particular regression, we observe the significant effect of real wage on rent-in land up to the farmers having 0.35 hectare of land. However, for the farmers who owned more than 0.45 hectares of land are not influenced by the changes in real wage growth. Other variables, such as age and education, were associated with an increase in the total rented-in land in all the regression lines in Tables 4.9 and 4.10.

Table 4.8: Impact of farm wage growth and machine investment on total land cultivation

	(1)	(2)
Dependent variable	All	Land > 0.45 hectare
Ln Total cultivable land change in hectare		
Real change in wage growth	-6.29e-05	-0.000115
	(0.000183)	(0.000196)
Ln Total cultivable land in 2008 (hectare)	-0.387***	-0.365***
	(0.0353)	(0.0801)
Real wage change growth* Ln Total cultivable land in 2008 (hectare)	-0.000507 (0.000410)	-0.000104 (0.000491)
Ln machine cost per hectare	-0.0627**	-0.0595
	(0.0319)	(0.0401)
Age of the head	-0.000437	-0.000116
	(0.00236)	(0.00327)
Total adult working member in agriculture (2008)	-0.0425	-0.102***
	(0.0380)	(0.0385)
Education of the head in 2008	0.00997	0.0134
	(0.00625)	(0.00833)
Village fixed effect	Yes	Yes
Constant	-0.249	-0.148
	(0.207)	(0.334)
Observations	919	474
R-squared	0.330	0.260

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation based on 62-villages data (2008 and 2014)

There might be some potential reverse causality between wages and machine investment as a potential cause for not finding any significant effect in the regression models (Table 4.4 and 4.6) using real wages change for the group having more than 0.45 hectares of land. As elaborated in chapter 3, the relationship between mechanization and wage is complex, as the level of mechanization also affects wages at the household levels. Further analysis should focus on identifying the different channels through which machinery investment may have an impact on productivity and yield at household level.

Table 4.9: impact of nominal wages and machine cost on rented-in land.

Dependent Variable	**All**	**Land cultivated > 0.45**	**All**	**Land cultivated > 0.45**
Ln Total rented-in land change		Non-deflated (nominal wages)		Deflated (real wages)
Ln change in Farm wage	-0.123 (0.310)	-0.864* (0.478)	-0.471 (0.817)	-1.921* (1.112)
Ln machine cost per hectare	-0.0134 (0.0880)	0.0505 (0.127)	-0.0186 (0.0877)	0.0340 (0.126)
Ln Total cultivated land (2008)	-0.528*** (0.0871)	-0.541** (0.237)	-0.529*** (0.0870)	-0.533** (0.236)
Age of the head	0.0171** (0.00672)	0.0339*** (0.0104)	0.0171** (0.00672)	0.0338*** (0.0103)
Total adult working member in agriculture (2008)	0.152 (0.0997)	0.0282 (0.125)	0.151 (0.0999)	0.0176 (0.125)
Education of the head in 2008	0.0374* (0.0196)	0.0612** (0.0306)	0.0382* (0.0195)	0.0647** (0.0304)
Village fixed effect	Yes	yes	yes	yes
Constant	-0.755 (1.418)	3.439 (2.487)	1.509 (1.191)	-1.960*** (0.731)
Observations	918	473	919	474
R-squared	0.150	0.192	0.152	0.193

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation based on 62-villages data (2008 and 2014)

Table 4.10: Impact of real wage growth and machinery cost on rented-in land

Dependent variable Ln Total rented-in land change	**(1)** All	**(2)** Land cultivated >0.35	**(3)** Land cultivated >0.45
Real change in wage growth	-0.000434	-0.00157*	-0.000863
	(0.000664)	(0.000837)	(0.000698)
Ln Total cultivable land in 2008 (hectare)	-0.478***	-0.417**	-0.522**
	(0.0933)	(0.202)	(0.254)
Real wage change growth* Ln Total cultivable land in 2008 (hectare)	-0.00139	7.08e-05	-.00035
	(0.00115)	(0.00166)	(.00167)
Ln machine cost per hectare	-0.0144	-0.0501	0.0408
	(0.0880)	(0.112)	(0.126)
Age of the head	0.0172**	0.0270***	0.0342***
	(0.00672)	(0.00904)	(0.0103)
Total adult working member in agriculture (2008)	0.154	0.126	0.0205
	(0.0999)	(0.123)	(0.125)
Education of the head in 2008	0.0381*	0.0599**	0.0633**
	(0.0195)	(0.0253)	(0.0304)
Village fixed effect	Yes	Yes	Yes
Constant	-1.578**	-2.261**	-0.882
	(0.681)	(0.994)	(0.598)
Observations	919	582	474
R-squared	0.152	0.162	0.188

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation based on 62-villages data (2008 and 2014)

4.5 Conclusion and policy recommendation

This chapter contributes to the existing literature in two ways. First, the unique data set containing information on production cost across seasons enabled us to estimate the total annual cost and identify the changes in cost. Second, the relatively long panel data from a period of large structural transformation in Bangladesh offer relatively large variations in factor prices, especially wages, and also captured the accelerating process of urbanization (labor shortages in agriculture). Most policies aim to expand institutional credit disbursement for agriculture, particularly to small farmers. And there are hardly any incentivizing policies for medium to large farmers. For example, in the 7th five-year plan of Bangladesh, no priority was given to relatively large farmers. If an increase in cultivated land is associated with farms that are larger than smallholder farms, then it would be useful for policymakers to react accordingly in a region where most farmers are smallholders. However, this study found that increasing the availability of rental services, when coupled with increased farm wages, did not significantly favor large farmers. This paper showed that an increase in farm labor costs induced farmers to reduce the size of their operational farmland. Rising agricultural wages per hectare had a significant effect on machine investments. The empirical results also showed that machine investments and land size are complementary as an increase in machine service cost per hectare reduced the demand for total cultivable land. However, the results indicate that both land transfer and machinery use were not seriously constrained in the current empirical setting largely because, in both transactions, rental markets seemed to function relatively smoothly. In response to an increase in wages, both land transfer and machinery use behaved in a manner consistent with price theory. In the context of Bangladesh, the introduction of large-scale mechanization is generally challenging if farm size is constrained by some factors, such as total land endowment, high population density, and a relatively high value of non-agricultural land use.

The total change in wages in real terms did not have a significant effect on the total machinery hiring expenses. However, the results support the substitution of labor by machine as an increase in per hectare labor cost significantly increased the machinery investment per hectare. But there is no conclusive evidence to show that the larger farmers rented more land to make use of machinery. Besides, the increase in labor cost significantly reduced the area of rented-in land. We observed a downward trend in the amount of land rented in by relatively larger farmers as farm wages increased. In other words, among the intact households, the relatively larger farmers who owned more than 0.45 hectares of land in 2008 rented less land in 2014. Non-farm income opportunities strengthened the income level of smaller farmer. Due to the growing market for rental machines, small farmers would have better access to machinery services in 2014, therefore encouraging them to rent in more land, which consequently allowed them to redistribute their family labor and available machine power. Smaller farmers also have the advantage of having less supervision costs due to the smaller land size. On the other hand, relatively larger farmers are still not in the position to fully benefit from machinery services due to the surge in farm wage rates as well as due to having limited or no access to mechanized transplanting and harvesting.

Historically, land reforms in developing countries have typically aimed to create small farmers by redistributing land from landlords to tenants. Successful land reforms could contribute to promoting equity as well as efficiency in agriculture but could impose a historical constraint on production efficiency in the event of serious labor shortages. While small farmers find it difficult to maintain family labor-intensive production, it is also politically challenging to redistribute land to enlarge operational land sizes by taking land from smallholders, for example, through land consolidation programs. In the current empirical setting, the land rental market, as well as the machine rental market, seems to be functioning in a way that is capable of supporting an expansion of operational farm size to some extent. Similar conditions have also been observed in other countries, such as China (Wang et al., 2016). Activating roles of rental markets and transactions seems to be a socially cost-effective solution to the problems faced by small farms in Asia resulting from rising real wages.

5. Present Status and Future Prospects of the Rental Market of Agricultural Machinery in Bangladesh

5.1 Introduction

Due to non-farm income opportunities, many people after the 2000s left crop cultivation as their only source of income (Mishra et al., 2015). Consequently, they must rely on farm machinery rental services to cultivate their land. Furthermore, the advantage of free-market economies and the development of paved roads in rural areas have accelerated the adoption of farm machinery in Bangladesh (Mottaleb et al., 2016). Additionally, private sectors have played a major role in supplying small-scale machines to the rural areas of Bangladesh (Islam and Kabir, 2018). Despite such progress in farm mechanization, there is still a potential gap for the adoption of machinery in different farming activities among farmers. Although Bangladesh is one of the most populated countries in the world, producers at the farm level are still facing manpower shortages as well as inadequate access to alternatives to human power i.e., machine rental services. Farm wages increase for harvesting activities during the peak seasons. For instance, in the Boro season of 2019 (May), an acute shortage of farm laborers for paddy harvesting severely increased the labor wage rate up to 900 BDT per day, which was equivalent to 76 kg of paddy. In fact, the harvesting cost per 38 kg (or 1 maund) of paddy exceeded the government-declared price of 850 BDT for buying 1 maund of paddy. Adoption of labor-saving technology was inevitable due to the higher demand for hired labor (Hayamai and Ruttan, 1985), but partial adoption or unequal access to farm machinery will not stop the miseries of farmers during the peak agricultural season.

Mechanization in Bangladesh has become a success story for other developing countries to follow. In recent years, there are about 70 foundries, 800 equipment manufacturing plants, 1,500 spare parts manufacturing plants, and 20,000 repair and maintenance workshops in the agricultural machinery (AM) sub-sector of the country (Alam et al., 2017). The annual market size of the country's AM and spare parts sector is estimated to be 802.3 million USD with a repair and maintenance market worth 105.2 million USD annually. This means that the size of the overall AM market is about 907.5 million USD per year, with the local production market accounting for 402.7 million USD. There is no doubt that the AM manufacturing sub-sector in Bangladesh is growing quite healthily and has the potential to make a substantial contribution to the much needed non-farm economic growth.

In recent years, trends of agricultural mechanization have taken on a new significance with concerns about land grabs, food security, and rural employment (Sims et al., 2011). Farmers in Bangladesh remain highly dependent on manual labor for seeding, transplanting, and harvesting of their crops due to a lack of access to suitable machinery. Hire services, either rental, custom or leasing services, can commonly be found in developing countries like Bangladesh and concern production, post-harvest, and marketing operations (Sims et al., 2011). The most popular hire services are those devoted to land preparation, threshing, shelling, and transportation. In rural areas of many developing countries, consumers of hire services are typically smallholder farmers within village communities cultivating less than one hectare of land. Providers of hire services in this context are primarily farmers themselves who have invested in equipment, both for their own use and because they have identified the potential of hiring services in their local markets. However, very little is known about the demand and supply of these rental services and their market structure in Bangladesh. For sustainable growth of production and for increasing productivity, the use of farm power at a cheaper price is essential. That is why it is important to understand how custom hiring of agricultural machinery operates and how service providers and users interact with each other. It is also crucial to know what kinds of policies are needed to overcome any shortcomings of these services on both the demand and supply sides. This study attempts to take account of agricultural machinery supplies, traders/wholesalers and retailers, and their associations. Principally, this paper aims to assess the market structure of rental services, present and future demand of the rental services, and the viability of this provision as a stable economic enterprise.

Agricultural mechanization in Bangladesh: role of market liberalization

Bangladesh has a long history of smaller-scale rural mechanization, where small engines have been used to powerboats and road vehicles, pump sets, and two-wheel tractors (2WTs) in rural areas, among other uses. Government policy has played an important role in the rapid mechanization in Bangladesh. In the 1980s, there was a major expansion of shallow tubewells powered by Chinese diesel engines. In the late 1980s, the government liberalized the importation of agricultural inputs such as fertilizer, irrigation pumps and engines, pesticides, seeds, and power tillers (Ahmed, 1999). In 1988 although the parastatal continued to import agricultural machinery for several years, private traders took over the import market with cheaper power tillers from China, causing a 40% drop in the cost of the machinery (Gisselquist and Grether, 2000; Roy and Singh, 2008). By 2007, approximately 400,000 power tillers were in use in Bangladesh; in contrast, there were only 12,000 four-wheeled tractors (4WTs) at that time (Ziauddin and Ahmmed, 2010). In 2011, smaller-scale equipment saw more widespread adoption in Bangladesh, with 420,000 2WTs and 1.4 million shallow tubewells in use during this time. This is a clear example of a situation in which the deregulation of machinery imports, combined with a reduction in trade tariffs, triggered the adoption of mechanization by small farmers and the simultaneous development of the private sector's active engagement in the mechanization supply chain. Because of the private sector's role in the machinery supply market, including imports, the right machines have been brought into the country at affordable prices, which is the first necessary condition for small-scale farmers to invest profitably in power tillers.

The use of power tillers as a power input in land preparation is seasonal. Such specialized machinery will limit the profitability of its owners, which will lead to a lack of demand for it (Alam et al., 2017). Again, the private sector's engagement helps individual small farmers broaden the utilization of tractors by developing local fabricators. Multifunctional machines have become another important condition for incentivizing small farmers to own agricultural machinery. Indeed, it is common in Bangladesh and in many other Asian countries to see power tillers used to power a threshing machine during the harvest season or as a transport tool in both agricultural and non-agricultural activities. Multifunctional operations make power tillers a more valuable investment for individual farmers. Roy and Singh (2008) showed that power tiller owners in Bangladesh can repay their purchase cost after one or two years when they use the machine to provide a range of paid services as well as to service their farms for land preparation. Calculation of returns from different types of services including own use, provision of paid services to other farmers, threshing, and transport could not be found in the literature. Additionally, discussion about how to finance investments in power tillers, tractors, and threshers is virtually non-existent in the literature. Given that the prices of two-wheel power tillers are low, they are probably affordable for many small farmers without the support of formal financial institutions.

Although subsidy policies exist in some countries, in Bangladesh such policies seem to have little effect on the capacity of the private sector to lead the import of power tiller and accelerate supply chain development. Bangladesh's manufacturing capability is limited to spare parts and other basic implements due to the low level of expertise and high tariffs on raw materials (Roy and Singh, 2008). However, this domestic capability has led to the adaptation of imported power tillers to power other equipment (such as threshers) or to be used for transportation. Simple equipment, including threshers and haulers, can easily be produced locally. The mechanization supply chain also includes repair and maintenance services, which have developed considerably alongside the increased use of power tillers and other agriculture-related equipment. The existing literature has paid little attention to the supply side of agricultural mechanization, as it is commonly believed that demand is the driving force behind mechanization. When demand for mechanized services is present and high enough, supply from the private sector will come to meet the demand (Pingali, 2007).

5.1.1 Research objectives and questions

The majority of the farmers in Bangladesh are smallholder farmers who mostly cultivate less than half an acre of land to provide for their family's basic needs. Despite such small farm size, the evaluation and adoption of farm machines in Bangladeshi have been referred to as ideal modes of mechanization in several pieces of literature (Kienzle et al., 2013). In the Bangladeshi model, small-scale farmers own small machines and lease out their services to other farmers. This style of mechanization is more applicable to large parts of Eastern and Saharan Africa and has been proposed as a desirable model of technology adoption for these countries (Baudron et al., 2015). This makes it imperative to understand the demand and supply pattern of farm machines as well as the characteristics of rental service providers. Early adopters or owners of farm machines are the mainstays of the service provision process. They take financial risks to invest in machinery in order to provide services to client farmers based on specified rent or negotiated fees. Existing studies, however, seldom focus on the provision of rental services. Most of the researchers have focused on the irrigation or water market in Bangladesh (Mottaleb et al., 2019). The likelihood of farmers buying and using power tillers, irrigation equipment, and threshers have been assessed in the context of Bangladesh (Mottaleb et al., 2017). However, no previous studies have been carried out in Bangladesh to investigate the factors affecting the rental market and economic value of machinery hiring services using either market- or non-market-based valuation techniques. Only a few studies have addressed the issue of custom hiring within a limited scope (Mottaleb et al., 2016 & 2017; Hussain and Wijerathna, 2004). Mrema et al. (2008) are among the few exceptions that have emphasized the factors influencing mechanization beyond demand-side constraints. Mobilizing the demand for farm machines, and identifying farmers who are willing and able to pay are the most challenging part of the mechanization ecosystem. It is well known that mechanization is capital intensive. Particularly, it is necessary to understand who is investing in agricultural machinery, why they are investing in machinery and providing services to others, and how the service charges are set. The broader objective of this study is to understand the rental service market for tractors, power tillers, versatile multi-planters (VMPs), and threshers. The other specific objectives are as follows:

1. Describe the supply chain of farm machinery and its adoption in rural areas
2. Determine the factors associated with machinery ownership in the selected study areas

3. Estimate the cost-return for the selected machines and its viability as a profitable enterprise
4. Estimate the present demand and future willingness to pay for the desired rental services

Some of these questions will be considered in subsequent sections, but here we are providing the context necessary for examining these questions.

5.1.2 Conceptual framework and theories

This chapter tries to identify the market structure and demand for agricultural machine services in Bangladesh. To conceptualize the process of agricultural mechanization in developing countries like Bangladesh, we developed a hypothetical framework, as shown in Figure 5.1. Roger Everett's diffusion of innovation theory is based on the premise that innovation is communicated to market actors through the process of diffusion over time and the adoption of a given technology is influenced by the communication channels and the social system. The use of machine power on farms is not new among developed countries and less developed countries; its adoption is closely associated with free-market economies. However, the rate of adoption and acceptance of mechanization has been low among the least developed countries due to their restricted market economy. After entering an era of free-market economy, Bangladesh began replacing human labor with labor-saving technologies for farm activities. During the 1980s, the use of water pumps was perceived by potential adopters as a new desirable technology, marking the beginning of the era of farm mechanization. After getting the entrance into the era of free-market economies, replacing human labor in the farm activities by labor-saving technology i.e., the water pump machine was new as an innovation, at least for Bangladesh.

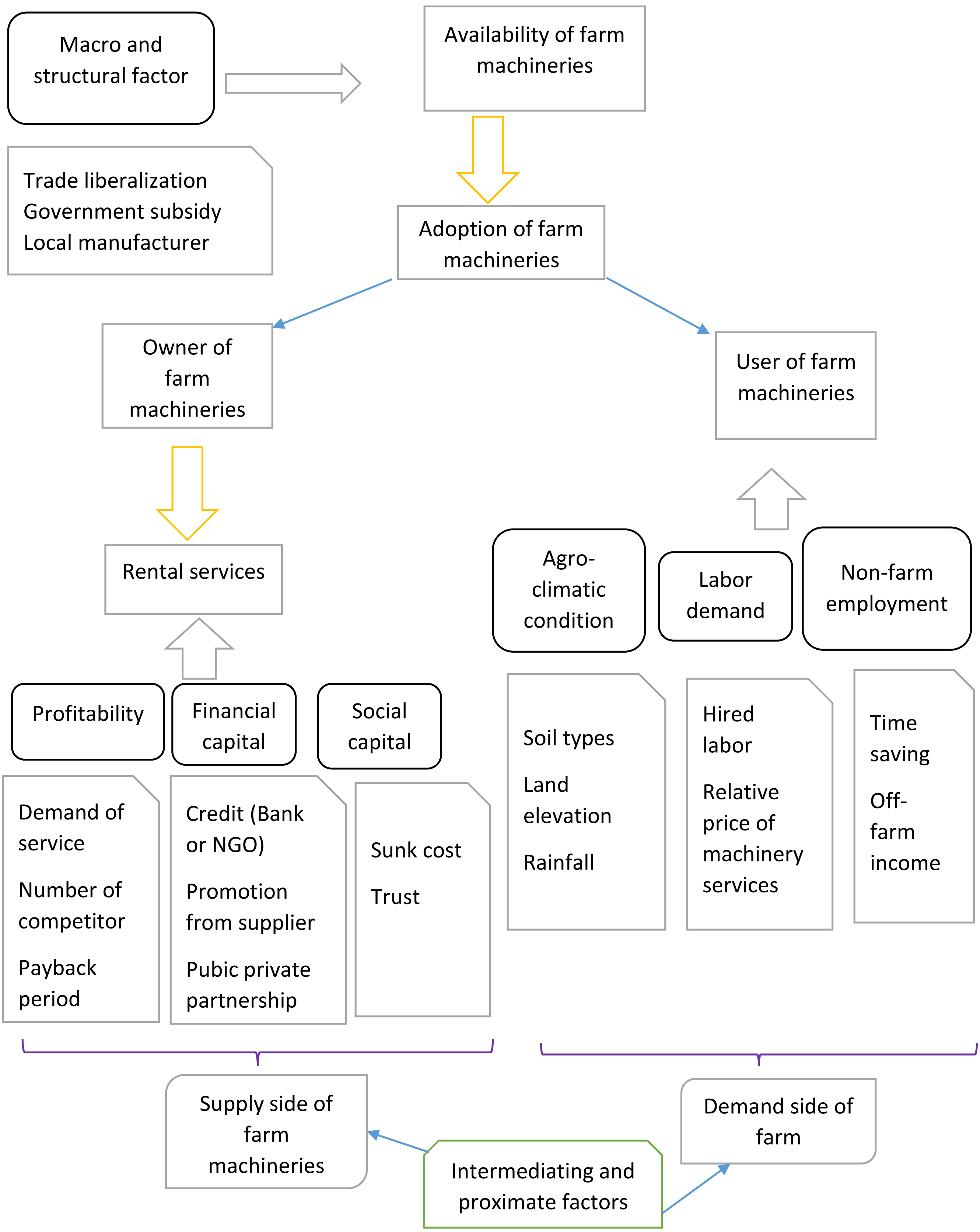

Figure 5.1: Conceptual framework

Source: Adopted from Rogers (2003)

Trade liberalization measures, such as removing import tax, providing government subsidies on new technologies, and developing the local private sector, encourage users in a particular country to adopt new technologies from innovator countries. Policies at the macro level have an impact on the availability of machines at the national level. If the intensive adoption of new technology, for example, owning a machine is costly, then early adopters may think about the recovery of their initial investment as well as its potentiality as a business enterprise (Rogers, 2003). Adopters of capital-intensive technology may try to sell services and offer equipment rental after fulfilling their own needs. Ultimately, owners of a new machine become suppliers of the particular technology to other partial adopters through their rental business.

5.2 Operations in the market environment (supply and demand side of the rental services)

Suppliers of machinery services (tractors, power tillers, etc.) seek to minimize the cost of their service and maximize their profit, similar to the cost structure of public utilities. Profit in the rental business also depends on the demand for specific services among customers, the number of competitors, and the payback period. If the rental market for a specific service is imperfect (e.g., monopolistic, which is more likely at the initial phase of adoption due to the presence of fewer competitors), then the initial investment would be recovered soon because suppliers have the power to set prices. However, the adoption of capital-intensive technology greatly relies on activities in the rural finance sector, such as access to credit granted by banks or NGOs, installment facilities provided by dealers, and other subsidies from government or non-government projects (Gashaw et al., 2015). Profitability in the rental business can work as a catalyst to attract actors in the rural finance market. If the provider of service knows the demand for their service in different places, then they can utilize the sunk cost. For example, there is a sunk cost of the service provider traveling to a specific area or searching for customers. When that sunk cost has been incurred, the marginal cost for each additional unit of services will be less than a service provider who has traveled to the area already (Cossar, 2017). In this regard, there is a natural monopoly at the specific area level for service providers. If this holds, one can expect a handful of different service providers servicing farmers in a particular village over the peak seasons. In the ideal competitive rental market of farm machines, the assumption is that each product or service in the market is perfectly homogenous. In addition, there can be variation in the marginal cost of providing rental services as the quantity of service increases. However, the provider's marginal cost is dependent upon consumer or plot characteristics. If the provider has perfect knowledge of consumer characteristics, then it would be rational for the provider to only service those farmers whose associated marginal costs are less than or equal to the market price. Because of the lack of competition, monopolies in custom hiring markets tend to earn significant economic profits. That means the number of competing providers is small at the initial stage of technology adoption, which may help set rental prices above the marginal cost and also ensure that providers have enough customers to serve. Such profits should theoretically attract strong competition, but this may not be the case because of one particular characteristic of a monopoly. Barriers to entry are the legal market forces that prevent potential competitors from entering a market and can exist in different forms (Fang, 2017). One such barrier is capital intensiveness. For example, purchasing a power tiller (four-wheeler) requires a huge investment. In some cases, barriers to entry may lead to monopoly. In other cases, they may limit competition to a few firms. However, barriers to entry (investment) in the rental market are influenced by some external factors over time, such as the availability of credit from banks or NGOs and public-private partnerships (PPP). However, a monopoly structure still may arise in the rental market if the marginal cost of adding an additional customer is very low, once the fixed costs of the overall system are in place. Because of economies of scale, one provider can serve the entire market (village) more efficiently than several providers because they would need to make duplicate physical capital investments.

On the demand side of the market, one can consider the objectives of and constraints on farmers or users. There are several agro-ecological and climatic characteristics (e.g. soil and rainfall) that influence the nature of the demand for custom hiring services. Employment opportunities in the non-farm sectors will encourage people to participate in the unskilled and semi-skilled jobs which have higher income potential than agriculture (Ahmed and Goodwin, 2016). Furthermore, the cost of hired labor goes up during the peak agricultural seasons. Ultimately, many farmers try to diversify their income by taking advantage of non-farm income opportunities, and more of them attempt to reduce the amount of time spent working on their farm by replacing manual power with farm machines. When the demand for hired labor is high, then a rational farmer will always consider the relative price of using mechanical services compared with hiring human labor. Meanwhile, mechanization can create jobs locally through trickle-down effects. When mechanization leads to increased agricultural production and improves farmers' livelihood and earnings, the farmers will spend more on the local economy, resulting in increased business activities, which will, in turn, lead to more jobs being created. At the same time, farmers are also trying to maximize their profit from farming. Demand for rental services varies depending on the types of activities; for example, there are only a few months in a year where farmers want to prepare their land, sow seeds, transplant seedlings, harvest their crops, and perform other post-harvest activities. If a machine has significantly fewer owners than users, then the demand for the machine's rental will be high and the custom hiring market will become imperfect.

5.3 Methodology

5.3.1 Study area

The study area covers four districts in different agro-economic zones situated in three divisions of Bangladesh. The Rajshahi and Bogra districts belong to the northern part of Bangladesh. They are also known as "Borendra" areas and are more prone to drought than flooding. The Rajshahi district has more fertile land and different crop cycles. The rate of mechanization in this region is also higher, while Bogra and Jashore are known as the mechanization hub of Bangladesh. More than 70% of the total machinery supply comes from manufacturers in the Bogra district (Alam et al., 2017)**.** On the other hand, Jashore has also developed a market for machine spare parts and manufacturing. The majority of imported machines (tractors) pass through the Indian border in the Jashore district. Finally, data were collected from the Kishorgonj district, also known as a "Haor" area, where flooding regularly occurs for a few months in a year.

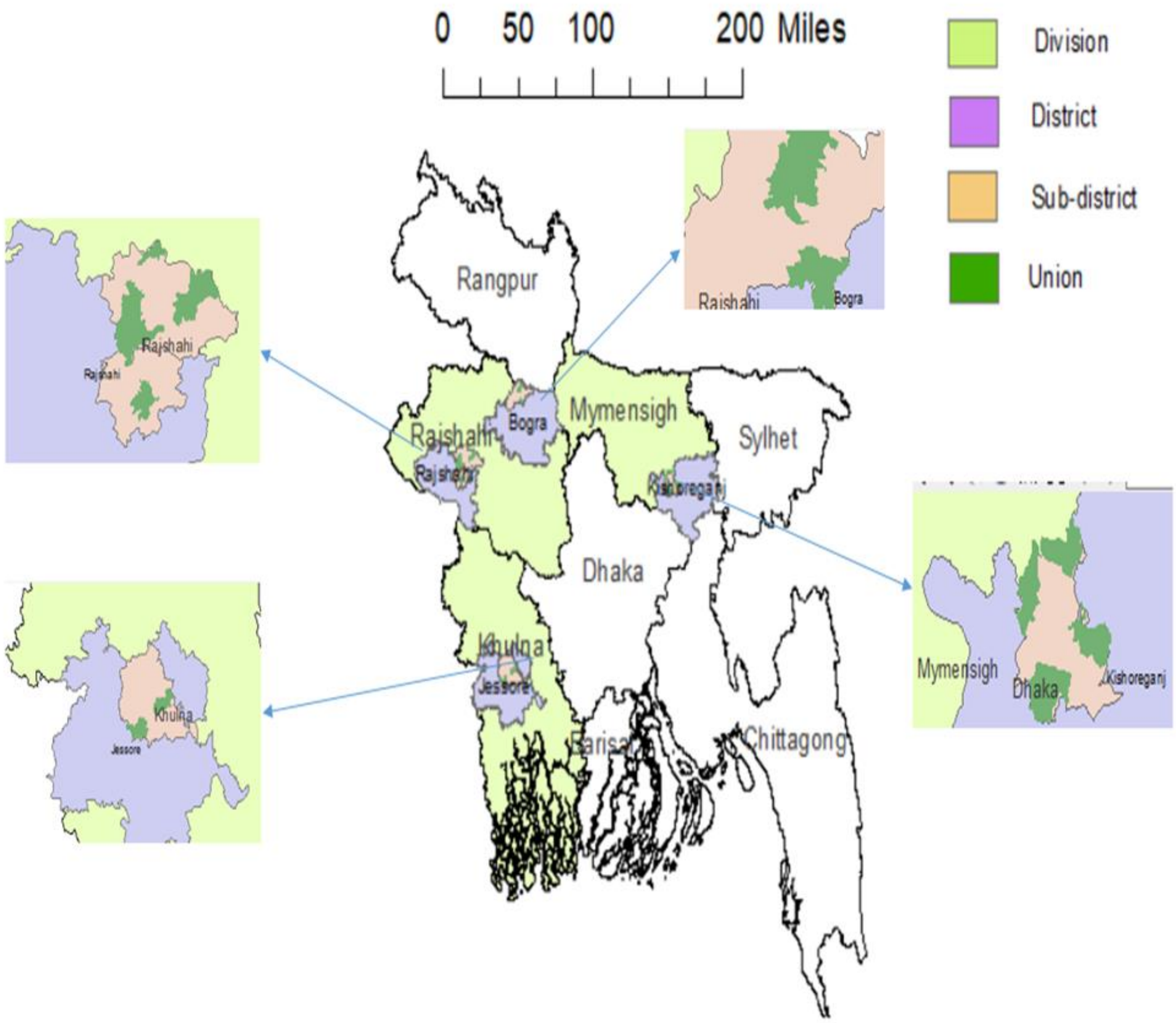

Figure 5.2: *Map of the study area*

Source: Author's illustration from the survey (2017)

5.3.2 Survey technique and sample size

The sample selection was based on multistage stratified random sampling. In the first stage, we randomly selected four districts. Subsequently, we randomly chose two unions (sub of the sub-districts) from each of the four selected districts. In the third stage, we randomly selected two villages from each of the unions. Then in the fourth stage, with the help of the local agricultural extension office, we collected a list of machine owners and users and randomly selected individuals from the list following the fifth interval in each selection. Finally, household-level data on owners and users of machines were collected using a structured questionnaire through face-to-face interviews.

The total sample size distribution is shown in the following table:

Table 5.1: Sample Sizes

Districts	Owner				User	Total
Machines	Power Tiller	VMP	Tractor	Power Thresher		
Rajshahi	74	28	5	63	89	259
Bogra	25	-	9	18	56	108
Jashore	13	-	54	12	54	133
Kishorgonj	56	-	4	10	40	110
Total	168	28	72	103	239	610

Source: Author's illustration from the survey (2017)

We focused on four agricultural machines that are prevailing in the rental market in rural areas. Machine owners were randomly selected based on lists of irrigation service providers supplied by the Department of Agricultural Extension (DAE). After selecting the owners for the study, we requested them to give the names of four client farmers who used their services between 2016 and 2017. A total of 371 owners and 239 users were sampled from Kishorgonj, Rajshahi, Jashore, and Bogra (Table 5.1). Harvesting machinery is not commonly available. Only four owners of reapers and two owners of harvesters were surveyed in the Rajshahi division. The sample thereby covers 3 divisions, 4 districts, 5 sub-districts, 10 unions, and 31 villages (Figure 5.2). Most of the farmers in Bangladesh are small and medium-scale farmers (98.45%) who have less than 7.5 acres, or 3 hectares, of land; there are only very few large-scale farmers (1.55%). According to the agricultural census of Bangladesh, farm households are classified into three categories: small (up to 2.4 acres or less than 1 hectare), medium (2.5 to 7.4 acres or 1 to 3 hectares), and large (more than 7.5 acres or 3.10 hectares) (BBS 2011). In our study, 81% of the sample households, including owners and users of machines, had less than 2.5 acres of land.

5.4 Reasons for machine use

Considering the ratio of land to labor is 0.65 (own calculation from BBS 2016) in Bangladesh, it is easy to assume that there will be an abundant supply of labor at a low cost. However, the reasons for increasing machine use have not been deeply explored; rather, it has been speculated that labor shortages may be the main reason for the adoption of machines in farming activities. From the previous chapter, it has been observed that the wages of urban unskilled labor has an impact on increasing agricultural wages. People are more likely to take on jobs in urban places and to consider these jobs more prestigious than working as a hired laborer on farms.

Descriptive statistics from the sample survey (Table 5.2) provide support to the speculations. The increasing cost of hired labor (51%) and shortage of labor (21%) were the main reasons for increasing machine use in farming activities. Approximately 17% of the survey participants cited the availability of machines as a reason. The explanation for this is slightly technical. Considering land preparation is more than 80% mechanized and only one in thirty farm households own a power tiller (Justice and Biggs, 2013), we would expect a higher percentage of farmers citing the availability of machines as a reason for increasing machine use. On the other hand, owners of power tillers provide tilling servicers to others and the hiring of such services is relatively common, so the survey respondents may have thought about other relatively new services, such as threshing, transplanting, and milling, during the interview.

Table 5.2: Main reasons for increasing machine use

	Owners		Users	
Reasons	Frequency	Percent	Frequency	Percent
Increasing cost of hired labor	186	50.68	107	46.12
Shortage of agricultural labor	77	20.98	75	32.33
Shortage of family labor	25	6.81	22	9.48
Availability of machines services	60	16.35	21	9.05
Others	17	4.63	7	3.01

Source: Author’s calculation from the survey (2017)

Allocation of time and cost for different intercultural operations (human power vs. machine power):

One of the biggest universal advantages of machine use is that it reduces cost and saves time for a specific task. In the agricultural sector of Bangladesh, planting, weeding, and harvesting have not been fully mechanized. Only a few villages have planters, reapers, and combine harvester, and a majority of those are incentivized by the government or other privately funded projects. Based on the field survey, the following tables present the time and cost required to do the same activities with and without machinery. The time for each task was calculated by considering the number of hours required to complete the task by one adult individual. The costs were calculated based on the average number of laborers needed per hectare in the Boro season and wages observed during this period for each activity. Manual harvesting and tilling of land required a significant amount of time, on average 245 and 161 hours, respectively. Harvesting by hand includes cutting crops as well as binding and carrying these crops to the owner's house. In comparison, a 16 HP power tiller took only 15 hours to cultivate one hectare of land and a combined harvester required just 7 hours to harvest one hectare of grains and pack them in sack bags. Even if five people were involved in manually harvesting and tilling one hectare of land, it would still require at least 31 and 41 hours respectively to complete the work, exceeding the number of hours required by machines. Table 5.3 shows the number of hours required for tilling, weeding, harvesting, and threshing works in the selected districts.

Table 5.3: Time (hours) required per hectare of land for rice farming

Operations	Kishorgonj		Rajshahi		Bogra		Jashore	
	Manual	Machine	Manual	Machine	Manual	Machine	Manual	Machine
Land tilling	156	16	178	15	160	17	152	13
Weeding	48	-	56	5	42	6	54	-
Planting	128	12	140	14	136	15	162	12
Harvesting	206	6	240	8	308	7	228	6
Threshing	86	15	95	14	108	17	98	16

Source: Author's calculation based on survey data (2017)

In terms of cost, farmers can save a significant amount if they have access to certain machine services. Table 5.4 displays the cost in different districts. Except for Bogra, the cost of harvesting crops either by hired labor or machinery is significantly higher than the other activities. The cost of using hired labor for harvesting was 720 BDT in 2019; this figure was 600 BDT during the data collection in 2017.

Table 5.4: Cost (BDT) incurred per hectare of land for rice farming

Activities	Kishorgonj		Rajshahi		Bogra		Jashore	
	Manual	Machine	Manual	Machine	Manual	Machine	Manual	Machine
Land tilling	14,850	7,735	13,260	7,850	13,654	7,654	14,320	8,230
Planting	9,600	3,560	11,988	3,850	10,200	3,600	12,150	3,800
Harvesting	15,450	10,600	18,000	11,480	19,500	12,000	17,100	13,200
Threshing	12,500	10,750	12,660	8,654	13,440	9,500	11,050	12,560
Weeding	4,260	950	4,650	860	4,800	1,200	4,100	1,080

Source: Author's calculation based on survey data (2017)

Figure 5.3 shows the average costs and differences between the cost of machine rental and hired labor. A paddy farmer can save a significant amount (7,300 BDT) per hectare by planting paddy with the help of a mechanical planter. In other words, if a farmer is able to mechanize all the activities in paddy cultivation, then their revenue per hectare will be significantly higher than that of a farmer who has not fully adopted mechanical services.

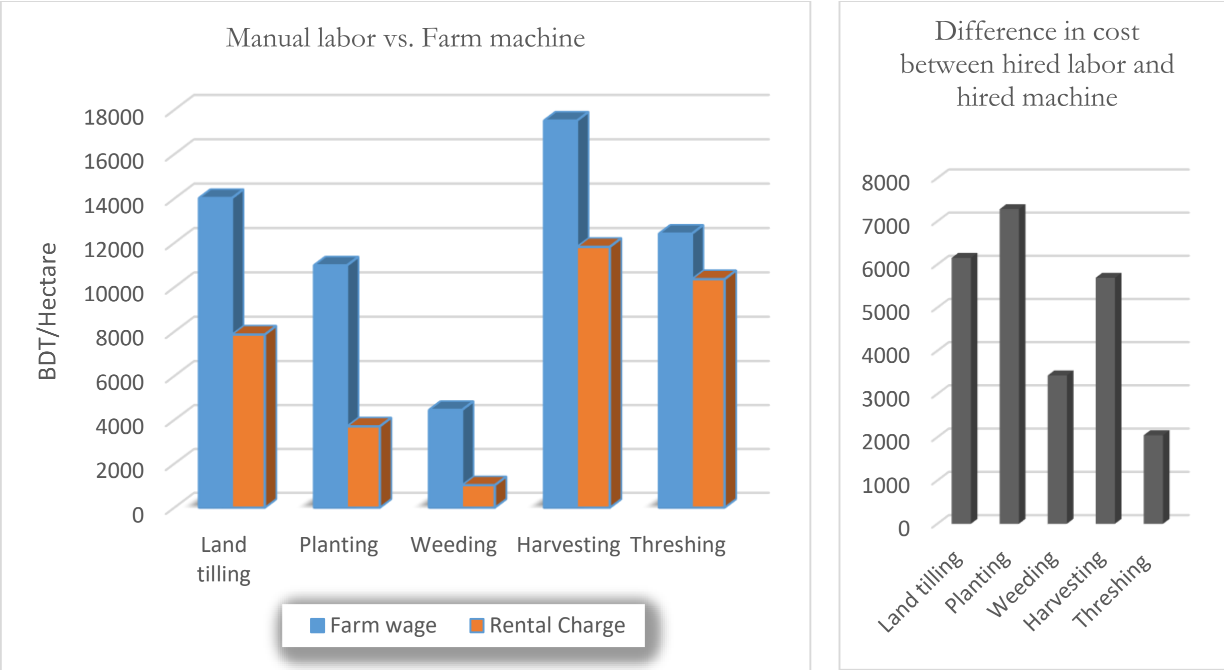

Figure 5.3: Average cost of farming activities

Source: Author's calculation based on survey data (2017)

Table 5.5: Percent hiring labor by activity

Percent hiring labor by activity		
	Small	Medium
Land clearing and tilling	46	40
Planting	55	80
Fertilizer application	25	60
Weeding	36	52
Harvesting	60	87
Threshing	35	46

Source: Author's calculation based on survey data (2017)

Table 5.5 presents the number and percentage of farmers hiring labor by activity for their largest rice plot. In general, the results show that manual planting and harvesting were the two most common activities for which farmers hired labor. Nowadays most farmers use herbicides to help control weeds. That is why a lower percentage of farmers hired labor for weeding. Across different activities, a higher percentage of medium-scale farmers hired labor than smaller farmers. This indicates smaller farmers were more likely to use family labor.

5.5 Identifying the supply chain of farm machinery

To determine the major suppliers of farm machines and their marketing channels, we collected data from the manufacturers' and dealers' offices located in each of the selected districts. For this purpose, we formulated two different questionnaires, one for sellers or dealers and another for buyers or owners of the various farm machines. Information from the key dealers of farm machines was collected through on-site interviews in their showrooms or from their regional offices using open-ended structured questionnaires. We also conducted two to three focus group discussions (FGD) consisting of at least six machine owners in each of the selected sub-districts. In addition, the secondary data generated from reports of the CSISA-MI project provided base knowledge of the generic machine supply system and the main importers and manufacturers of agricultural machinery in Bangladesh. The following sections briefly discuss how the supply chain of farm machinery works based on field observation and secondary reports.

Actors in the supply chain of farm machinery

There is no public enterprise in Bangladesh to distribute or manufacture heavy farm machines, such as tractors, power tillers, and reapers. However, there is a vibrant and committed private sector working in the agricultural machinery sector in Bangladesh. A critical element in raising the adoption of agricultural mechanization is to induce suppliers to open sales and service centers in the major farming areas of the country. Most of the farm machines in Bangladesh are imported from China. Machinery importers are well organized and have networks established throughout the country. The private sector is fulfilling the demand for machinery that is locally adapted for the country’s farming systems, which ultimately has created an opportunity for users to purchase machines at lower prices than if all components were imported. Another important feature that has accelerated the development of the farm machinery market is the development of repair services which provide easy access to spare parts and services.

Pre-harvest machinery: power tillers, tractors, and VMPs

Figure 5.4 displays the supply chain of power tillers, tractors, and related attachments. Chittagong Builders, Metal Pvt. Ltd., Mollah Machinery (which sells diesel engines and some 2WTs), and ACI are the leading importers of farm machines in Bangladesh. For example, the market for power tillers is heavily dominated by Chittagong Builders, which controls more than 80% of the market and has 321 dealers across the country. Only one Bangladeshi manufacturer, Alim Industries Ltd., is involved in producing power tillers, frames for threshers, and other machinery using imported engines. Recently, the local conglomerate brand ACI has generated better publicity for their farm machines and has established a large network with eight sales and service centers and hundreds of dealers all across the country. Both ACI and Metal Pvt. Ltd. have a special division exclusively dedicated to screening of credit applicant, credit management, and repayment monitoring. Importers provide aftersales services with warranties, which help machine owners have low-cost access to timely repair services and spare parts in the early stage of machine ownership. Janata Engineering is another growing local manufacturer working with government-based research organizations (e.g., the BADC) and different projects (e.g., CSISA-MI) to produce and deliver specific machinery required by farmers, including seeders and harvesters. The majority of the dealers mentioned that power tillers sold by importers are mainly from three brands: Sifeng, Dongfeng, and Changfa. The horsepower of these power tillers varies from 12 to 20. We found that each of the importers of power tillers has its own dealers in our study areas. These dealers have a strong connection with local seed dealers and sub-assistant agricultural officers (SAAO). According to the dealers, the majority of new customers come to them via information provided by front-line agricultural extension workers, known as SAAOs, and seed dealers. The same notion was confirmed by interviews with machine buyers. In fact, dealers reported that they had targeted and provided special offers to potential buyers based on information provided by SAAOs. Buyers of power tillers who already had prior experience as a service provider in the rental market usually buy a new machine from the same dealer within an average time of 2.5 years of their previous purchase.

However, the supply of tractors is region-specific. We found very few owners of tractors in the Rajshahi and Kishorgonj districts, but plenty in the Jashore district. Besides the four importers mentioned above, there are six other importers active in the business. Most of the 4WTs come from India through the Benapol land port in the Jashore district. Historically, Jashore has been advanced in agriculture, with some of its people receiving training on how to drive and operate 4WTs as early as before 1971. A large percentage of 4WT drivers who work for different 4WT owners all over the country comes from the Jashore district. Importers have outlets in different places of the Jashore district. A four-wheeled tilling machine requires a double investment of a two-wheel power tiller. So dealers are always trying to find potential new buyers through some intermediaries, especially brokers. Outlet operators mentioned they rely on brokers who are trained 4WT drivers to serve as local-level sales agents for the 4WT dealers. Brokers provide information about the potential demand for tractors in certain areas and a list of potential new buyers who have the minimum financial capital to afford a new tractor. We also found the existence of a special cooperative developed to help farmers buy tractors, arrange funds, providing repair and maintenance, and finding new tillage areas and transportation services. Tractor owners also reported that they had used credit facilities from some NGOs to buy tractors in installments. In fact, most of the dealers have mutual contracts with NGOs and cooperatives to which they sell new tractors upon some initial payment. However, we found 82% of the members of such cooperatives and NGOs are medium-scale businesspeople or Aratders, also known as wholesalers of crops. There are very few buyers of power tiller-operated attachments. Adoption of power tiller-operated seeders or transplanters is region-specific and project-oriented. Among the six sub-districts, we only found one sub-district (Durgapur) where nine villages had adopted VMPs. However, the adoption of VMPs was initiated through several non-GOB projects by International Development Enterprises (IDE) and Australian Centre for International Agricultural Research (ACIAR)

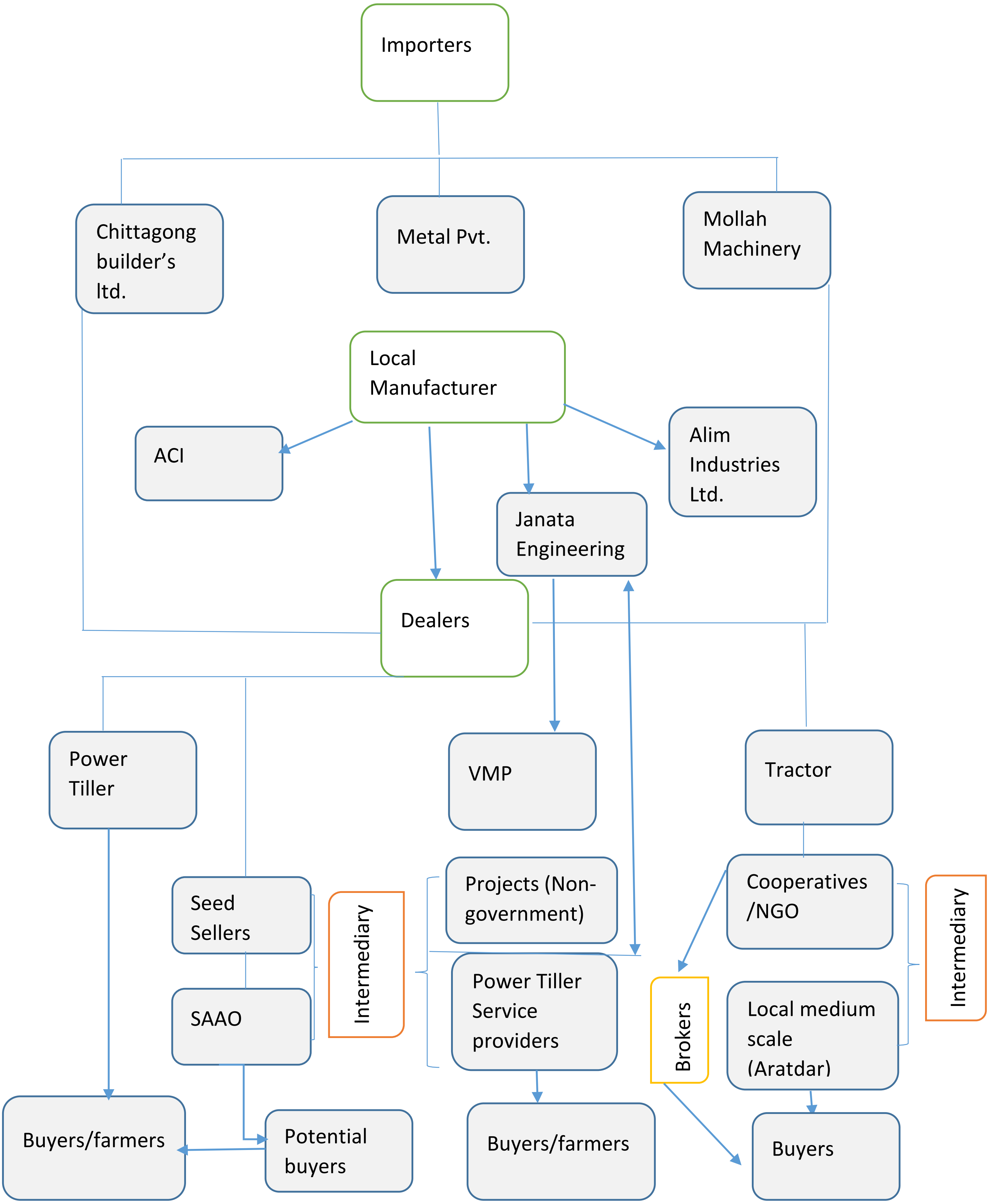

Figure 5.4: Supply chain of pre-harvest farm machinery (2 and 4 wheeler operated)

Source: Author's own illustration based on survey data (2017)

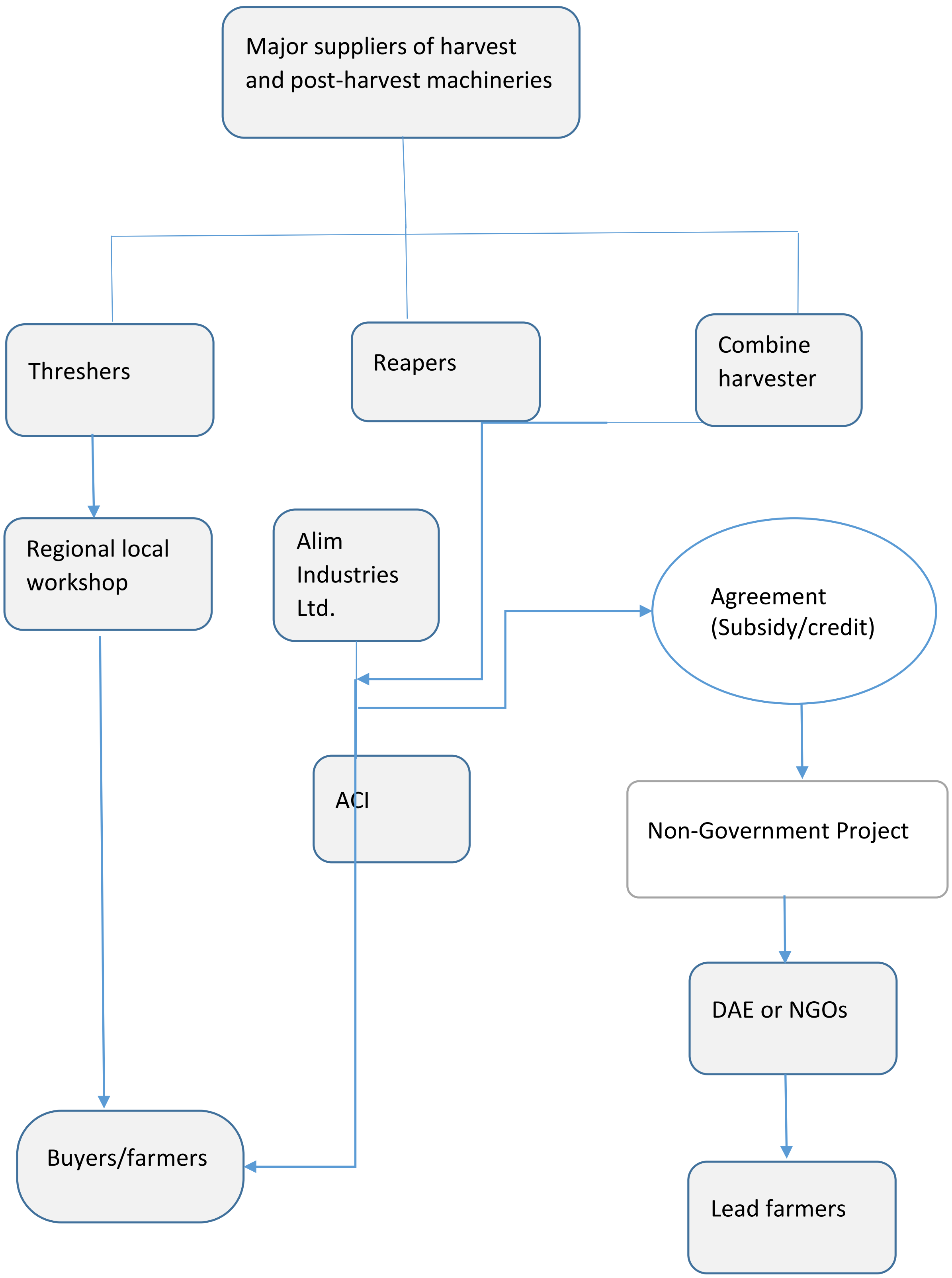

Figure 5.5: Actors in the supply chain of post-harvest farm machinery

Source: Author's own illustration based on survey data (2017)

Alim Industries and ACI Motors co-operate with these projects, and since 2014 ACI Motors has engaged “Janata Engineering Workshop” to manufacture and sell VMPs. Only local power tiller service operators had the chance to be included in the ACIAR project and received a 25% subsidy. There are a few government projects funded by the BADC as well as some others not funded by the government, such as the International Maize and Wheat Improvement Center (CIMMYT), throughout the country, but the mechanism of supply of such attachments (seeders or transplanters) remains the same. However, all twelve dealers mentioned that they sold some readymade transplanters directly to the farmers at irregular intervals, but overall, the market and the demand for such attachments have not flourished, unlike for threshers and tractors.

Post-harvest machines: threshers and harvesters

In terms of post-harvest machinery, we saw wider availability of threshers and quite a few combine harvesters or reapers in use. Threshing machines were widely available in all the villages visited. All the sub-districts had local thresher manufacturers, and threshers were quite affordable. Many farmers owned paddle threshers that were supplied by local service providers. As shown in Figure 5.5, farmers bought threshing machines directly from the dealers of Alim Industries and ACI. Alim Industries manufactures and supplies different varieties of threshers directly to farmers. However, 67% of thresher owners reported that they had bought their machine from the local workshop where they usually send their equipment (such as water pumps) for repair. Combine harvesters are infrequently used; owners of combine harvesters sometimes bring their machines down from the Rajshahi district (in the north of the country) after they have finished working there. The BADC has a few combine harvesters at its research stations which it uses for demonstrations and lends out. Mechanical reapers and combine harvester were largely unknown apart from a handful owned by the DAE or BADC used for demonstration purposes. The GOB has a contract with ACI to provide a 25-50% subsidy on the purchase of a mini combine harvester. In recent years, the DAE has been actively demonstrating and promoting machines introduced by the BADC, BARI, and other GOB and non-GOB projects. ACI introduced a new combine harvester that has generated some interest among farmers due to its ability to harvest crops that are lying flat. But as it requires a huge amount of investment to buy the machine, the GOB and a few private organizations came together to support the promotion of this machine through systematic projects. At the end of 2016, the GOB decided to provide subsidies for each type of harvester (reapers or combine harvesters) at the national level. These subsidies were then allocated to DAE offices at the regional and district levels. In our study area, the sub-district DAE specified the maximum number of farmers eligible for the subsidies and selected the subsidy recipients based on specific criteria. After the selection of the farmers, the DAE sent the farmers a list of dealers in their area from which they could purchase reapers or combine harvesters at a subsidized rate. After the farmers had bought the machines, the DAE reimbursed the dealers. The subsidy rates were set at fixed percentages of the market retail prices, but farmers could negotiate lower prices with dealers.

The government's approach to boosting the supply of mechanized farming:

From 2009 to 2011, the GOB offered a 25% subsidy for power tillers and tractors, but the subsidy program was stopped for power tillers in 2012. In 2014, the GOB reinstated the subsidy to 30% of a machine's retail price. In 2017, the government raised the subsidy level for purchasing farm machinery from 30% to 50% in order to expand mechanized seeding, transplanting, and harvesting. According to the current government policy, the government provides combine harvesters, reapers, rice transplanters, power threshers, and seeders at half price to a selected group of growers at the Upazila level. However, subsidies are no longer provided for tractors and power tillers under the revised scheme as the use of these machines is already prevalent in the fields. For Haor and southern coastal farmers, the government has increased the subsidy rate to 70% for buying farm machinery. The hike in subsidy is necessary as prices of agricultural machinery are still high for growers. For instance, a combine harvester costs 7 to 10 lakh BDT (8,000 to 11,500 USD) and a rice transplanter 4 lakh BDT (4,700 USD). Since 2017, the government provides a 50-70% subsidy on a combine harvester marketed by ACI Motors.

5.6 Characterizing the rental market

It is tricky to summarize which type of market structure prevails in the rental market: perfect competition, monopoly, or oligopoly. It depends on the geographic areas of rental services, the type of crops cultivated, and the crop calendar of the specific areas. In a monopoly (or near-monopoly) situation with decreasing average costs, a machine owner has an incentive to fix the maximum price at a low level, which may prevent competitors from entering the market. In the study areas, the rental market for different machines differs based on the types of activities and seasons. During peak seasons, demand for specific machines increases; for example, the demand for land preparation machinery is high prior to the sowing of paddy seedlings. In the same fashion, the supply of farm machines varies according to the seasons and types of activities. However, the initial demand for relatively new technologies, such as rice transplanters and harvesters, is limited within a specific locality due to their limited supply and the fear of using new technology. During the peak season, demand for known technologies, such as tilling machines, is inelastic. The rental fee for a machine is fixed before it is put in operation, and payment is made either in cash or in kind. Specific information on machinery services is given below:

Tractor rental services (four-wheelers):

The basic features of tractor services are summarized in Table 5.6. There are many tractor owners in the Jashore district. It is common for local farmers to see tractor service providers from elsewhere in the district. Despite the cost of entry to owning a tractor, 78 tractor owners were found in Jashore Sadar, and the majority of these tractor owners provided plowing services to other farmers and also used their tractor for non-farm purposes, such as transportation of crops, soil, and bricks. There are a high number of farmers and tractor providers engaged in the market. Among the tractor owners, 53% were between 31 and 50 years of age. The study found that 34% of the owners were younger than 30 years old, indicating that younger people are also engaging in this business. All of the tractor owners in the sample were literate and 58% of them had secondary education. Further, 63% and 28% of the owners had up to 5 and 10 years of experience in this rental business, respectively. Almost 35% of the owners were using TAFE tractors, while 20% owned Mahindra tractors. Tractors made by ACI, the only local brand, were owned by 10% of the owners in our sample. Several types of engines with varying horsepower (HP) are used in tractors. Around 40% of the owners had a tractor with an engine rated at more than 55 HP. Annually 30% of the owners tilled more than 100 hectares of the land. About 58% of the owners traveled up to 120 km for tilling purposes and on average 84% of the owners received cash as rent. Approximately 73% of the owners charged less than 2,400 BDT for one full pass, and 27% demanded more than 2,400 BDT per hectare. Throughout the year, 75% of the tractors had a migration period of up to 15 days. We found that in the Jashore district, 65% of new entrepreneurs were tractor helpers and drivers. Service charges were found to vary significantly between the Jashore district and regions outside the district. However, service charges did not vary significantly among the villages of the Jashore district, which indicates a competitive price setting. In a monopolistic situation, as there are fewer entry barriers, owners may be encouraged to reduce service charges to discourage others from joining the market. In other words, as the number of owners increases in a specific area, service charges may reduce. The correlation between the number of tractor service providers available and service charge was negative at the Thana level (Appendix 10). The average service charge for tilling with a rotavator was 1,900 BDT per hectare for one full pass. However, tilling services performed using a cultivator was more expensive, averaging 4,450 BDT per hectare. If brokers were involved, they received on average 8% of the total earning for each customer. During fieldwork, we found that the number of passes varied significantly, ranging from three to eight depending upon soil texture and the types of crops to be sowed. For paddy, potatoes, and onions, the minimum required number of passes is three, four, and six respectively. Rental marketing of tractor services generates demand for new customers through the network marketing of drivers and brokers. We found only 32% of the owners allowed drivers to use their tractors for tilling. In this case, an owner provides a driver with all the necessary information, such as the address of the customer. In return, the driver receives 12-15% of the total amount earned, but food and accommodation are arranged separately by the owner. If a service user and a tractor owner know each other personally, then the user is usually able to receive the service on credit, which is normally paid at the end of the last tillage operation (pass) or after the harvesting. We also observed 15% of owners with more than one tractor usually rented their tractors to drivers and received 20-25% of the total earning in return. Receivers of the tilling service, in this case, are not provided with credit facilities by the drivers. Tractor owners who drive by themselves usually hire a helper for covering long distances and manage the tilling operation through their brokers. In such an arrangement, the helper gets on average 220 BDT per day and the broker 25-30% of the total income.

Tractor operators provide tilling and haulage services sequentially around the cropping seasons. The major business seasons reported by tractor owners are October to January and April to mid-June. On average, a tractor is used 135 days per year in the fields. However, demand for tractors becomes low during the rainy season even though tractors are used for haulage purposes in this period. Owners who sell their services on credit within their sub-district collect money at the end of a cropping season or at the end of the last pass. On the other hand, users of tractor services who received tillage services from outside their sub-district are provided with credit facilities by brokers if they do not know the owners of the machine personally. Some brokers receive payments from the farmers at the end of the harvesting seasons. However, most brokers allow payments to be aggregated and made in the following year. Thus, a dependency relationship has formed over the years between brokers and farmers.

The emergence of 4WT owners' cooperatives

During the individual interviews as well as during the FGDs, we observed several cooperatives among tractor owners in Jashore. In these cooperatives, owners jointly invest in tractors and share the profit as well as the burden of repair. From the FGDs, it is evident that the formation of such cooperatives helped them to expand their services to other districts. The name of one such cooperative is "Pooler Hat Tractor Samiti", which is situated in the Chasra union and comprised 16 tractors and 23 members. In general, a cooperative member generated higher annual profit (33,400 BDT) than a typical tractor owner.

Table 5.6: Basic features of tractor services

Variable	Frequency (%)
Age, household head	
Up to 30	24 (33.33)
31 to 50	38 (52.77)
>50	10 (13.88)
Years of schooling, household head	
Up to primary (grade 5)	24 (33.33)
Grade 5 to 10	42 (58.33)
>Grade 10	6(8.33)
Experience in the business	
Up to 5 years	45 (62.50)
6-10	20 (27.77)
More than 10 years	7 (9.72)
Model	
New Holland	37.50 (16.07)
TAFE	25 (34.72)
Mahindra	14 (19.44)
ACI Sonalika	6 (8.33)
Changfa	7 (9.77)
Machine horsepower	
Up to 45 HP	20 (27.78)
45 to 55 HP	23 (31.94)
>55	29 (40.28)
Total land served (Hectare)	
Up to 100 ha	51(70.83)
>100 ha	21(29.17)
Payment method (outside of sub-district)	
Only cash	60 (83.33)
Credit	12 (17.77)
Used for haulage purpose	65 (90.02)
Highest distance traveled (cultivation)	
Up to 120 km	42 (58.33)
>250 km	30 (22.77)
Days of migration (annual)	
Up to 15 days	54 (75)
>15days	27 (25)
Service charge (one full tillage, BDT per hectare)	
Up to 2400	53(73.61)
>2400	19 (26.38)

Source: Author's calculation based on survey data (2017)

Power tiller rental services:

The term "power tiller" is synonymous with implements used for mechanized land preparation either by a 2WT or 4WT. In Bangladesh, power tillage is primarily associated with 2WTs. They are more appropriate for small farms and also popular among all categories of farmers. Power tiller service is more available than tractor service. From Table 5.7, we can see that the average cost of tilling is 2,100 BDT per hectare for one tillage. However, the service charges did not vary significantly among the villages of all districts, which may indicate a competitive price setting. The correlation between the number of owners and the service charge varied (positive or negative) at the Thana level (Appendix 10).

Table 5.7: Basic features of power tiller services

Variable	Frequency (%)
Age, household head (year)	
<30	34 (20.23)
31-50	100 (59.52)
>50	34 (20.24)
Years of schooling, household head	
Up to primary (grade 5)	88 (52.38)
Grade 5 to 10	62 (36.90)
>Grade 10	18 (10.71)
Experience in the business	
Up to 5 years	109 (64.88)
6-10	26 (15.47)
More than 10 years	33 (19.64)
Model	
Sifeng	77 (45.86)
Dongfeng	43 (25.59)
Changfa	16 (9.52)
ACI	17 (10.11)
Others	15 (8.92)
Machine horsepower	
9 HP	13 (7.74)
12 HP	118 (70.24)
16 HP	37 (22.02)
Total land served (Hectare)	
Up to 30 ha	78 (46.43)
30 to 70 ha	54 (32.14)
>70 ha	36 (21.42)
Payment method	
Kind	9 (7.96)
Cash	104 (92.04)
Used for haulage purpose	104 (61.90)
Highest distance traveled (cultivation)	
Up to 5 km	116 (69.04)
>5 km	52 (30.09)
Service charge (one full tillage, BDT per hectare)	
Up to 2000	83(49.40)
2000 to 2400	43(25.56)
>2400	42 (25.04)
Total revenue (BDT, Annual)	
Up to 100000	96 (57.14)
100001 to 200000	49 (29.16)
>200000	23 (13.69)

Source: Author's calculation based on survey data (2017)

On average, 60% of power tiller owners were between 31 and 50 years of age. We found 20% of the owners were younger than 30 years of age and another 20% older than 50 years, suggesting that both younger and older people are engaged in this business. At least 53% of the owners had primary education. About 20% of the owners had more than 20 years of experience in the rental business. Sifeng was the most popular brand among the power tiller owners, with around 46% of them using the brand's power tillers, followed by Dongfeng (26%) and ACI (10%). There are three types of engines; around 70% of the owners had an engine rated at 12 HP. During the Boro season, 20% of the owners tilled more than 70 hectares of land. Further, 70% of the owners traveled up to 5 km for tilling purposes and on average 92% of the owners received cash as rent. Around 49% of the owners charged 2,000 BDT for one full pass per hectare and 24% demanded more than 2,400 BDT. More than 57% of the owners reported that they had earned up to 100,000 BDT annually in total revenue.

Transplanter rental services (seeds and fertilizers):

There were 28 VMP owners in the Durgapur sub-district. There are few planters available for conservation agriculture for planting seeds and plants by using the two-wheel power tiller. A VMP functions as a seeder and can also deliver fertilizer into the soil. The seeding depth is adjusted according to the agricultural technique used, such as strip planting, zero tillage, single-pass shallow tillage, shallow beds, and conventional tillage. VMPs have been gaining popularity as they can perform two tasks simultaneously and thus help save labor and cost. VMP owners provide services to farmers involved in conservation agriculture. Janata Engineering and Haque Corporation produce VMPs with the help of Murdoch University. The price of a VMP is around 50,000 BDT. The charges for VMP services are around 3,560 BDT per hectare of land. The demand for VMPs is high particularly among farmers who cultivate paddy and pulses. The correlation between the number of owners and the service charge is negative in Durgapur Thana (Appendix 10). All 28 VMP owners had primary education. On average, a VMP can cultivate 32 hectares per year.

Thresher rental services:

In general, farmers spent 7% of the total harvested paddy on renting threshing machines in the surveyed villages. During group discussions and individual surveys, it was observed that both open- and closed-drum power-operated threshers were widely used for processing rice and other crops. The majority of the people utilized the engines of the water pumps for threshing work by adding an extra wooden body with it to use as a thresher. However, we found that not many people owned open- or closed-drum threshers from commercial manufacturers or special brands. Open-drum threshers were more preferred than closed-drum threshers in the northern region because they ensure that the straw remains long after threshing. Owners who bought threshers to provide services travel from one village to another during the harvesting seasons to perform threshing work. The key informants mentioned that threshing service providers accepted both payments in cash and in kind for their work (paddy and wheat). For example, a specific amount of paddy can be used as payment in kind for threshing 40 kg of rice. On average, the charges for threshing services ranged from 2.5-5 kg of rice equivalent per 40 kg of paddy threshed, while the cost of hiring a thresher ranged from 350-470 BDT per day in the districts surveyed, depending on the type of threshers. It should be noted that the fuel cost and operator wage are included in the charges for threshing services, while farmers have to pay the fuel and labor costs separately when hiring a thresher. There were very few owners of pedal threshers in the survey areas.

***Reaper and combine harvester services*:**

Harvesting crops with the help of machines are scarce and not yet popular throughout the country. During the field survey, we only found very few reapers or harvesters owners providing rental services. This study tries to investigate the demand and supply of mechanized harvesting services based on case studies and FGDs. Not many people owned combine harvesters and reapers in Bogra and Rajshahi; we surveyed four owners in Rajshahi and two owners in Bogra. A sales representative of ACI Motors also provided important information regarding their customers and harvester rental services. Mini combine harvesters can cut, reap, thresh, and store crops, while reapers can only cut crops in line. Initially, the idea of using machines to harvest rice and wheat was not well known among the farmers in the surveyed areas, and farmers in a few places did not even know that such services existed. Later, mechanical intervention in harvesting operations slowly gained popularity when the local SAAO and agents of private companies ensured the timeliness and faster operation of the machine that reduced the cost of harvesting crops. The major entry barrier in the harvester rental business is the initial investment required to buy a machine. The market price of a harvester ranges from 1,250,000 BDT to 2,950,000 BDT. The initial investment required for buying a harvester is quite high. Even with subsidies and installment facilities, a harvester buyer has to make a down payment of around 425,000 BDT. The cost of harvesting one hectare of paddy by a mini combined harvester is 10,000 BDT; this figure is around 14,700 BDT for a tank-type harvester and 12,000 BDT for a bag-type harvester. An owner of a Yanmar harvester (tank-type) mentioned that it would take one hour to reap, thresh, and pack 0.40 hectares of paddy. In comparison, a mini combine harvester can cut 0.17 hectares of crops per hour. In other words, on average, a mini combine harvester can harvest one hectare of paddy within eight hours, where five hours are required for harvesting and the other three hours are used for travel and break (rest and food). Farmers are more familiar with reapers than the combine harvester. The price of a reaper is around 170,000 BDT. The cost of harvesting one hectare of paddy by a reaper is around 4,200 BDT, and a reaper can cover 0.22 hectares of land in one hour. Recently, ACI and the government collectively promoted the mini combine harvester and reaper by offering buyers a 50-70% subsidy through their sub-district agricultural office, based on the buyers' location. During the Boro season, if a mini combine harvester owner uses the machine to harvest one hectare of land each day and provides services for 15 days, then the average profit of the owner will be around 97,500 BDT after considering variable costs, except for repair. The harvester rental market is monopolistic as there are only a few providers and a larger number of clients. The providers are able to set the charges for their services and offer clients little to no room for bargaining. Owners also reported that they had received more and more requests each harvesting season and they had not been able to meet all the requests.

5.7 Determinant of participating in the rental business of farm machinery

To examine the factors associated with the ownership of agricultural machinery in Bangladesh, we developed Equation (5.1):

$$Y_i = \alpha_t + \Omega_i(HHC_i) + \beta_2(\ Credit_d) + \beta_3(\ Fragmented\ plot_n) + \mu_i + \epsilon_i \text{.........(5.1)}$$

Where Y_i is a vector of dependent variables including a base value of zero if a household did not own any machines and one if the household owns a machine. Among the explanatory factors, HHC_i is a vector of independent variables including an occupational dummy that assumes a value of one if a household head is a businessman (and zero otherwise), the total number of adult family members greater than 15 years old, education of the household head, and the amount of land owned by a household. It is expected that a risk-taking household head, with more years of schooling and endowed with more male family members, is more likely to be a service provider. Explanatory variables also include credit access as a dummy that assumes a value one if a household has access to credit facilities either from an NGO or a bank and interaction of credit access with the amount of land owned and the number of fragmented lands. μ_i represents district fixed effect and ϵ_i is the random error.

In the case of Equation (5.1), the dependent variable is a binary response variable (0, 1), and thus to estimate the probability of machine ownership by a household, a maximum likelihood estimation procedure using a logit model estimation method was applied. Table 5.8 presents the results of the four regression models. The first regression includes all users and owners. However, the higher number of owners than non-owners may cause biasness in the results. To check the robustness and enhance the balance, three more regressions were specified for the three machines. The second regression includes 168 power tiller owners, the third one includes 72 tractor owners, and the fourth regression includes 103 thresher owners.

Among the demographic variables, age of the household head negatively influenced the adoption of all types of machines. The household head's level of education (years of schooling) had no significant effect in the full model, while it positively influenced tractor acquisition. Education seems to be an important factor for tractor ownership because it facilitates access to market information and understanding of equipment rental as a profitable enterprise. In contrast to the findings of Mottaleb et al. (2016), adoption of power tillers was negatively influenced by education. Schooling might provide more off-farm income opportunities and thereby enhance the capacity to invest in costlier agricultural machinery, such as tractors. The total number of working members and the amount of cultivated land owned had a positive influence on the probability of machine ownership. If a household head is involved in non-farm businesses in addition to farming, the household would have more flexibility to invest in agricultural machinery, especially tractors.

Table 5.8: Determining the factors influencing the adoption of machine ownership

Exogenous variables	(1) Ownership	(2) Power tiller	(3) Tractor	(4) Thresher
Age (year)	-0.0389***	-0.0412***	-0.0590***	-0.0368***
	(0.00833)	(0.0110)	(0.0186)	(0.0129)
Education	0.000930	-0.0571**	0.101**	0.00804
	(0.0224)	(0.0285)	(0.0428)	(0.0296)
Occupation dummy (Business)	0.997***	0.476	3.040***	0.0510
	(0.283)	(0.336)	(0.518)	(0.461)
Adult worker (#)	0.133**	0.254***	-0.0702	-0.0167
	(0.0638)	(0.0801)	(0.150)	(0.112)
Land cultivated	0.901*	1.411**	0.191	0.926
	(0.476)	(0.712)	(0.544)	(0.645)
Credit access dummy (No)	-1.821***	-1.551***	-1.025*	-1.958***
	(0.358)	(0.515)	(0.534)	(0.516)
Credit access* Land cultivated dummy	0.0349	-0.321	0.279	0.368
	(0.572)	(0.759)	(0.563)	(0.816)
No. of fragmented lands/plots (#)	-0.0729***	-0.0725**	0.0424	-0.204***
	(0.0199)	(0.0290)	(0.0514)	(0.0555)
Sub-district fixed effect				
Kishorgonj	0.661**	0.815**	-0.158	-0.693
	(0.333)	(0.356)	(0.767)	(0.552)
Jashore	0.0706	-1.007*	2.097***	-1.073**
	(0.316)	(0.516)	(0.678)	(0.443)
Rajshahi	0.768***	0.441*	-1.128	1.196***
	(0.239)	(0.265)	(0.785)	(0.326)
Constant	1.678***	0.689	-0.647	1.881**
	(0.548)	(0.676)	(1.291)	(0.885)
Observations	608	407	311	340

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Author's calculation based on survey data (2017)

The probability of machine ownership declined if a household had no access to credit. In other words, credit access can lessen capital constraints. Similar to credit access, a higher number of fragmented lands significantly reduced the incentive to adopt farm machines and participate in the rental business.

5.8 Profitability of farm-machine rental enterprises

We hypothesized that custom hiring markets for machinery consist of machine owners and client farmers. Both groups settle on a negotiated fee or a payment in kind that tends to maximize the profit of the owners, while also minimizing the users' costs of purchasing these services. An equilibrium rent is likely to be associated with the negotiation power of the machine owners and client farmers. During face-to-face interviews and group discussions, we discussed the factors that influence the service charges. Correctly calculating the costs of service provision is one part of the equation; the other part is the correct assessment of the market. Based on experience, costs are often underestimated and potential income overestimated. The following expressions explain how the rental rates for different machines are determined in rural areas.

Rental rate (ha) = Opportunity cost on capital + Oil price + Operator cost + Time of services (earlier or later in the specific season) + Social capital

An entrepreneur can estimate the machine rental cost by considering the opportunity cost on investing the particular capital, input prices, and the expected profit margins. Here the term social capital means the relationship and trust between an owner and a service user. Agricultural machine operation cost consists of (a) fixed costs, which include depreciation, and interest on investments, (b) variable costs, such as labor, fuel, oil, repair, and maintenance.

We considered the following assumptions during the calculation of machine operating cost: the cost and return were determined on a per annum basis; the interest rate was assumed to be 10%.

Rental rates, benefit-cost ratio, and the payback period of machines:

Table 5.9 presents a summary of the different enterprises. The hiring market seemed to generate an income flow that justifies the investment in power tillers, tractors, harvesters, etc. The benefit-cost ratio was estimated for the year 2017. Most power tiller owners maintained record books of the services they had provided to their clients. One of the reasons that may inspire other potential entrepreneurs to enter the machinery rental market is the shorter payback time. Different machines have different payback periods. Although the investment requirement for a tractor is almost triple that for a power tiller, a tractor has a shorter payback time of eight active months. The time needed to recoup the investment in a thresher is three months or ninety days. The payback period of a harvester was estimated based on case studies of two harvester owners, one from Bogra and the other from Rajshahi. However, the payback period estimated for the ACI mini-combine harvester is higher than our estimation for a harvester.

Table 5.9: Service charges, benefit-cost ratio (BCR), and payback times of the enterprises

Machinery	Kishorgonj	Rajshahi	Bogra	Jashore	Investment	Payback Period (months)
	BCR	BCR	BCR	BCR		
Tractor	1.57	1.87	1.85	1.91	400,000	8
Power tiller	2.01	1.66	1.87	1.76	85,000	5
Thresher	1.35	1.68	1.67	1.43	25,000	3
Harvester	-	2.07	1.55	2.35	70,0000	11

Source: Author's calculation based on survey data (2017)

Users of machinery services seek to maximize their profit from farming. They are concerned with not only the use of machinery as input but also the timing of when they access machinery. The utility a farmer gains from consuming services on time will be much higher than from consuming services late. Given the dependence of households on agricultural production, and the shortage of labor at peak times, the alternative of not consuming rental services at all appears to be unthinkable from a farmer's point of view.

On the other hand, the profit of an entrepreneur depends on the socio-economic conditions of the owner and their clients. Environmental and market factors may also influence the profitability of a particular entrepreneur. It also depends on the stage of technology adoption a country is in. Some countries are late adopters, but the adoption rate accelerates after a certain stage. In this study, the profit of an entrepreneur was estimated based on the owner's point of view in Bangladesh.

We hypothesized that the strength of the social relationship between an owner and a client farmer would have a considerable influence on the service charges, timing of services, and the number of new clients (Mottaleb et al., 2019). For example, a machine owner and a client farmer may be relatives and have social interactions. Social interactions may involve owners and users residing in the same village as neighbors, gathering in the same markets, or praying together in a mosque or temple. These social interactions and their resulting relationships, therefore, can also influence rental prices and payment methods. In a functional form, rental charges and profit of a farm machine rental enterprise can be represented as:

$$RP_i = f(HHC_i, SC_i, \gamma_i, Credit_d, Fragmented\ plot_n) + \mu_i + \epsilon_i \text{………(5.2)}$$

$$SC_{i_i} = f(HHC_i, SC_i,, Credit_d) + \mu_i + \epsilon_i \text{………(5.3)}$$

$$RS_j = f(HHC_j, SC_j, \gamma_j) + v_i + \epsilon_i \text{………(5.4)}$$

Where RP_i is the profit of a rental service in the year 2017, determined based on the interaction of the negotiation power of the owner and client farmer, and social and environmental factors that maximize owner profits. HHC_i includes all the socio-economic variables in Equation (5.1). The education variable is a dummy that takes on a value of one if the household head had more than five years of schooling and zero otherwise. γ_i indicates factors in a market environment, such as years of experience in rental service and the competition among service providers, which can be captured by the number of service providers in a village. The number of new clients is also included in the market environment domain. The variable SC_i in Equation (5.2) is an indicator of the social relationship between the owner and user (client). A Likert scale was used to generate the social capital indices for each owner household based on information regarding the owner's relationship with friends, whether the owner provides services to own relatives and neighbors more frequently than to others, whether the owner performs a service on credit only for friends and relatives, whether the owner is able to meet demand in their village, and how much trust the owner has in transactions. Responses were collected using a five-point Likert scale. Each of the factors of social capital was given a weight based on the importance of the factor captured during the FGDs. An owner having a score of more than 30 was assumed to have a higher level of social capital. The importance of social capital in mitigating market failure is recognized in the literature by Otsuka and Hayami (1988), and Francis Cossar (2017). However, the application of social capital in determining the profit of rental services has not been explored previously.

Factors affecting the profitability of power tiller owners:

The economic use of machines depends on the maximum utilization of its capacity within an operating condition. For this, the conditions under which the power tiller operates must be identified first, and then options for utilizing the power tiller to its fullest capacity would be taken into account. At present, power tillers are used mainly for tilling and carrying harvested crops. The type of soil and cropping pattern also influence the demand for power tillers in a different time span. Houssou et al. (2013) found that with adequate demand for rental services, combined with the benefits for their own farming, power tiller ownership can be profitable for even medium- to small-scale farmers. Table 5.10 presents the factors influencing the profitability of power tiller hiring services.

Table 5.10: Factors affecting the profitability of power tiller services

Dependent variable: Log of profit	**(1)**	**(2)**
Credit access (yes=1, dummy)	0.414*	0.397*
	(0.212)	(0.211)
Total number of household members	-0.209	-0.196
	(0.129)	(0.128)
Education (> 5 years of schooling, dummy)	-0.990***	-1.016***
	(0.307)	(0.304)
Social capital index (> 30, dummy)	-0.428	-0.408
	(0.266)	(0.260)
Education * social capital index (dummy)	0.901**	0.922**
	(0.377)	(0.372)
Land owned	-0.0838	-0.0721
	(0.168)	(0.169)
Distance from market (km)	-0.00434**	-0.00562***
	(0.00207)	(0.00189)
Age year	-0.0228**	-0.0237**
	(0.00922)	(0.00920)
New farmers under the service (#)	0.00835	0.00736
	(0.00867)	(0.00867)
Competitor (#)	-0.0123	-0.0329
	(0.0466)	(0.0417)
Types of credit offered by the owner[a]		
Partial credit	0.426	0.456*
	(0.279)	(0.252)
No credit	-0.586**	-0.451**
	(0.244)	(0.228)
District fixed effect	Yes	No
Constant	12.02***	12.27***
	(0.583)	(0.501)
Observations	168	168
R-squared	0.194	0.184

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

a: Full credit dummy as base

Source: Author's calculation based on survey data (2017)

A higher level of education, a higher age, and a greater distance between the service station and the local market negatively influenced the profitability of power tiller owners. In contrast, access to credit from banks or NGOs significantly increased the profit of owners. From regression line 1, power tiller owners who had access to credit from either banks or NGOs earned 51% higher profits than those who had no credit access. The mode of the transaction also influenced profitability. Owners who provided full credit to their clients achieved significantly higher profits than those who did not perform services on credit at all. The interaction of education and social capital significantly increased the profit. In other words, having secondary education and higher social capital increased the profitability of power tiller owners. The following tables (5.11 & 5.12) explore factors that influence the profit of tractor and thresher services.

Table 5.11: Factors affecting the profitability of tractor services

Dependent variable: Log of profit	**(1)**	**(2)**
Credit access (yes=1, dummy)	0.692**	0.396
	(0.291)	(0.333)
Total number of household members	-0.130*	-0.170**
	(0.0753)	(0.0678)
Education (> 5 years of schooling, dummy)	-0.438	-0.269
	(0.346)	(0.398)
Social capital index (> 30, dummy)	0.359*	0.402*
	(0.201)	(0.211)
Age year	-0.0260**	-0.0178
	(0.0107)	(0.0110)
Distance from market (km)	-0.391**	-0.416*
	(0.177)	(0.224)
New farmers under the service (#)	0.00795**	0.00876**
	(0.00311)	(0.00389)
Competitor (#)	0.00191	0.00200
	(0.00415)	(0.00490)
Experience in rental business	0.0800***	0.0963***
	(0.0254)	(0.0313)
Highest distance traveled	0.00193**	0.00113
	(0.000834)	(0.00113)
Types of credit offered by the owner[a]		
Partial credit	-0.254	-0.234
	(0.242)	(0.290)
No credit	-0.486*	-0.520*
	(0.280)	(0.305)
District fixed effect	Yes	no
Constant	10.54***	11.64***
	(0.935)	(1.221)
Observations	67	67
R-squared	0.656	0.494

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
a: Full credit dummy as base

Source: Author’s calculation based on survey data (2017)

Tractor and thresher ownerships were positively influenced by access to credit and social capital. As social capital by itself influenced the profit of an owner, its interaction with education was not considered here. Due to multicollinearity, we excluded the factor “experience in rental business” from Tables 5.10 and 5.12, but there was no collinearity problem in the tractor equation. In Table 5.11, we added the factor and found that experience in the rental business positively influenced profit.

Table 5.12: Factors affecting the profitability of thresher services

Dependent variable: Log of profit	**(1)**	**(2)**
Credit access (yes=1, dummy)	0.870***	0.868***
	(0.265)	(0.274)
Social capital index (> 30, dummy)	0.424*	0.406*
	(0.236)	(0.208)
Education (> 5 years of schooling, dummy)	-0.346	-0.394
	(0.262)	(0.265)
Total number of household members	-0.0689	-0.0904
	(0.0989)	(0.102)
Distance from market (km)	0.255**	0.329***
	(0.108)	(0.111)
Age year	-0.0193*	-0.0178
	(0.0112)	(0.0112)
New farmers under the service (#)	0.0373*	0.0376*
	(0.0198)	(0.0197)
Competitor (#)	0.0192	0.0177
	(0.0130)	(0.0119)
District fixed effect	Yes	no
Constant	9.054***	9.288***
	(0.716)	(0.654)
Observations	98	98
R-squared	0.296	0.237

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
a: Full credit dummy as base

Source: Author’s calculation based on survey data (2017)

5.9 Role of credit and social capital in the machine rental service

It has been shown in the previous section that an owner's access to credit and social capital has a significant influence on profit.

Access to credit:

Bangladesh is well known for its innovation in microcredit led by microfinance institutions and NGOs, such as Grameen Bank and BRAC. Over the last decades, a significant portion of rural people has become members of NGOs and credit-providing institutions. From the surveyed villages, it was found that both Grameen Bank and BRAC have a good number of stakeholders. Table 5.13 shows the rural financing institutions where farmers were members and could access loans and credits. The dominance of local informal institutions was also observable. Farmers were also asked about the sources of their farming advice and reported that SAAOs were a major source of information regarding any new technology.

Table 5.13: Members of rural credit-providing institutions

Micro-Finance Institution	Small	Medium
Total number of farmers	76 (out of 97)	423 (513)
Cooperative (local)	10	53
Association for Social Advancement	9	51
Grameen Bank	16	111
BRAC	13	80
Palli Kallyan Shikkha Society	7	63
Local NGO (informal)	21	64

Source: Author's calculation based on survey data (2017)

Social capital: The agricultural machinery rental business is seasonal. Time constraint is an important issue in the rental business as it matters for the coordination as well as for the overall efficiency. When farmers do not receive services on time, their utility from consumption of the services will decline after a certain point in the season. On the other hand, there is a deadweight loss if several service providers travel to the same village. To overcome such problems, actors in the rental market use different components of social capital. Social capital plays an important role in ensuring the successful functioning of the hiring or rental market for machinery in Bangladesh. By utilizing their social networks and repeated transactions, users can obtain timely services while providers can minimize the cost of searching for customers. The majority of users first look for service providers to whom they are related within the village. They believe that having family members who are service providers is helpful as they can request these family members to perform the necessary services earlier during peak seasons, such as planting time. If they do not have any family members who are service providers, they would request specific tasks from a neighbor who owns an appropriate machine.

In this study, the smoothness of rental services is expressed as an index. From FGDs, we initially identified important factors that determine whether users will have a good impression of the service they receive from a provider or machine owner. Five important situations were identified and considered collectively to develop a scale that measures user satisfaction with the services received. From the user's point of view, we call it the smoothness of rental services. These five situations are as follows: (1) a user is completely dependent on the provision of mechanical services for cultivation, (2) there are sufficient service providers in a user's locality, (3) a client is able to find a service provider on time if any immediate operation is needed, (4) a client can bargain with a provider regarding the service charge, and (5) a client can purchase services on credit. A five-point Likert scale has been used to construct the questionnaire for the smoothness of rental services. Following Equation (5.4), we fitted the regression presented in Table 5.14.

Table 5.14: Factors determining the smoothness of rental services (users' perspective)

Variables	**Log of rental service smoothness index for users**
Age (years)	-0.000831
	(0.000865)
Education (dummy, base 0 if schooling <5)	-0.00214
	(0.00234)
Calling provider (dummy, 1= individual)	0.0686**
	(0.0303)
No. of providers of tillage	0.00230***
	(0.000880)
Provider's location (dummy, 1= outside of village)	-0.310***
	(0.0672)
Relation with the provider	
Friends	-0.0847**
	(0.0400)
Relatives	-0.0481
	(0.0305)
Others	-0.0600
	(0.0371)
Village-level fixed effect	yes
Constant	3.016***
	(0.0551)
Observations	215
R-squared	0.308

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Author's calculation based on survey data (2017)

Purchasing services as a group increased the smoothness of getting services to the user. An increase in the number of providers also increased the smoothness. The bond or relationship between an owner and a client had a significant effect on the smoothness of rental services. The smoothness of receiving services was significantly lower if the owner and client were friends instead of relatives. The smoothness decreased if a provider is located outside of the village of a client farmer.

5.10 Present Supply and demand of mechanizing farming operations

Agricultural mechanization service provision – motivation for providing services:

All of the owners surveyed provided rental services. Purchasing a power tiller or tractor requires a good amount of investment. As the demand for such machines is seasonal and it is not feasible for owners to use their machines only for their own purposes, most owners would want to rent out their machines. Some owners may provide rental services as their main business or may want to earn some money as operating capital. From Table 5.15, we can see that 46% of the power tiller owners provided rental services as their main business and 30% considered rental services a way to generate extra revenue. Around 73% of the tractor owners operated rental services as their main business and source of income. A VMP is an extra attachment used with power tillers; that is why almost 52% of the VMP owners rented their VMP out to source operating capital, and only 7% considered VMP rental as their main business. Very few thresher owners provided rental services as their main business, but a considerable amount (54%) rented out their machine to make extra revenue.

Table 5.15: Main reasons for providing hiring services (%)

Reasons	Power tiller	Tractor	Thresher	VMP
Main business	45.51	73.24	3.03	7.41
To source operating capital	21.56	8.45	42.42	51.85
To make extra revenue	29.34	18.31	53.54	40.74
Others	3.37	0.00	1.01	0.00

Source: Author's calculation based on survey data (2017)

Meeting demand in 2016:

In 2016 almost 63% of the power tiller owners surveyed were unable to meet the demand for their services, while 52% of the tractor owners were able to fulfil all requests for their services on time. Such a scenario indicates the demand for services is higher than their supply. There is still room for new entrepreneurs to enter the rental market as existing owners are not fully able to meet the demand of their clients on time. Owners of power tillers and tractors reported that the limited number of machines was the main reason for not fulfilling the demand of clients on time. For all machines, more than 60% of the owners reported that the area covered by them had been growing each year.

Table 5.16: Status of meeting all client requests in 2016 (%)

	Power tiller	**Tractor**	**Thresher**	**VMP**
Yes	37.53	51.34	62.37	52.38
No	62.47	48.76	37.63	47.62
Reasons for not meeting client demand on time				
Limited number of machines	57.45	51.35	37.37	62.96
Farms are too far away	37.23	10.81	13.13	29.63
Fragmented farm	5.33	16.22	12.12	7.41
Broken machines		8.11	9.09	
Others				
Quantity of services between 2015 and 2016				
Increased	67.86	60.56	67.33	70.37
Decreased	21.43	38.03	22.64	19.60
Constant	10.71	1.41	10.03	10.03

Source: Author's calculation based on survey data (2017)

Willingness to mechanize farming operations:

Table 5.17 presents farmers' willingness to mechanize farming operations that had not been mechanized yet in their locality. The respondents were categorized based on machinery ownership, and land size. If an individual owned a tractor, power tiller, or planter, then they were considered an owner. It was observed that non-owners were more willing to mechanize planting and harvesting than owners**.** Generally, a higher percentage of medium-scale farmers and owners were willing to mechanize these operations compared with small-scale farmers and non-owners. In general, regardless of whether they were owners or non-owners, most of the farmers were highly interested in mechanizing planting and harvesting operations. About 43% of non-owners would like to mechanize their planting operation, while only 35% of owners expressed their willingness to do so.

Table 5.17: Willingness to mechanize various farming operations

Households want mechanized service (#)	**Total**	**Small**	**Medium**	**Owner**	**Non-owner**
593	593	513	97	354	239
Farmers willing to mechanize by operation (%)					
Land cleaning	9.61	9.58	9.78	13.28	4.18
Plowing/Tilling	7.42	7.78	5.43	6.78	8.37
Planting	37.77	36.73	43.48	34.46	42.68
Irrigation	0.34	0.20	1.09	0.56	0.08
Weeding	5.06	5.19	4.35	5.65	4.18
Fertilizer Application	2.70	2.59	3.26	4.52	0.142
Threshing and shelling	3.04	3.39	6.51	4.13	3.77
Harvesting	30.86	31.74	26.09	27.40	35.98

Source: Author's calculation based on survey data (2017)

We also observed a similar trend for harvesting; a lower percentage of owners (28%) were willing to mechanize harvesting compared to non-owners (36%). This study also tries to explore farmer characteristics that may induce farmers to mechanize their harvesting operation. Use of combine harvesters and transplanters are relatively new and not available in all parts of the country. The respondent households were initially asked a dichotomous choice question, such as whether they would be willing to pay a specific amount for a service received. However, when a respondent was asked a dichotomous choice question, their response was usually dependent on the individual's willingness to hire labor to perform the same service.

Table 5.18: Factors determining the willingness to mechanize harvesting operations

	Mechanized Harvesting of paddy		
	Willing to mechanize Mean (a), (standard error)	Not willing to mechanize Mean (b), (standard error)	Mean difference, t-statistic and the level of significance
Age (year)	42.898	42.625	-.2733
	(0. 976)	(0. 595)	(-0.24)
Education	6.523	5.601	-.925**
	(0.351)	(0.221)	(-2.27)
Family size	5.037	4.793	-0.244 **
	(0.124)	(0.075)	(-1.735)
Land (hectare)	0.621	0.548	0.073**
	(0.331)	(0.023)	(1.825)
Variables in % (Proportion-test)			Mean difference, Z-statistic and the level of significance
Credit	0.452	0.367	-0.084***
	(0.0362)	(0.0238)	(-1.961)
Livestock	0.744	0.805	-0.061**
	(0 .031)	(0.019)	(-1.699)
Observations	188	422	

Notes: Differences = Mean (b) – Mean (a). H_0: Diff= 0, H_1: Diff<0 (one sided t and z-test). ***, ** and * indicate the 1%, 5%, and 10% levels of significance, respectively.

Source: Author's calculation based on survey data (2017)

From Table 5.18, as expected, households that were willing to adopt mechanized harvesting services were likely to be more endowed compared to others. A farmer willing to adopt mechanized harvesting service was likely to have more land and livestock, a higher level of education, a larger family size, and access to credit. According to the two-sample t-test, there were significant differences in the means of education, family size, and land size between the farmers who were willing to mechanize harvesting operation and those who were not. In general, those who were willing to mechanize harvesting operation had a higher level of education, a larger family size, and more land. The sampled respondents were also asked to indicate whether or not they had access to credit and income from rearing livestock. From the two-sample proportion-test, it was observed that those who were willing to mechanize harvesting had higher access to credit and higher income from livestock than the other group.

Table 5.19 presents the service charges that farmers were willing to pay for the five major operations. In general, farmers were willing to pay more compared to the existing rent of the specific machines. Such willingness to pay may indicate the potential demand for mechanized services. For example, the prices that farmers were willing to pay for mechanical planting were three times higher than the actual service fees currently charged in villages. In the case of harvesting, farmers were willing to pay two times as much as the prevailing charges for a harvesting operation performed using a reaper. We observed an opposite trend for weeding. This is because most farmers have started to use herbicides to control the growth of weeds.

Table 5.19: Prices farmers were willing to pay for various mechanize operations per hectare

Operations	**Average Price**		**Existing market price**		**Cost of hiring manual labor**	
	BDT	USD	BDT	USD	BDT	USD
Tilling (mean)	11,807.62	138.10	7,000	82.84	14,021	163.98
Power Tiller	11,577.53	135.40	6,500	76.92	-	-
Tractor	12,037.71	140.70	7,500	88.76	-	-
Planting	10,614.12	125.61	3,455.76	40.90	9,350	110.65
Weeding	3,340	39.53	3,500	41.42	11,220	132.78
Harvesting	10,083.08	119.33	4,940.54	58.47	18,000	210.52
Threshing	3,822.28	45.23	2,670	31.60	3,276	38.77

Source: Author's calculation based on survey data (2017), Note*: 1 USD = 85.50 BDT*

Table 5.20 shows the reasons that were considered the top priority for mechanizing certain services. The highest percentage of farmers (37%) indicated that labor intensiveness was the main reason for wanting to mechanize tilling, planting, harvesting and threshing operations. Timely performance of each of these activities was the second most cited reason for the desire to use mechanical services.

Table 5.20: Main reasons for preferring to mechanize operations

Reasons listed as the first priority	Overall	Tilling	Planting	Harvesting	Threshing
Labor intensiveness	37.27	34.09	39.91	40.44	27.78
Timely performance of the activity	30.02	36.36	29.60	26.23	38.89
Low productivity in the absence of supervision	4.05	4.55	6.73	0.55	5.56
Higher effectiveness and efficiency	5.90	15.91	2.69	6.56	4.56
Shortage of labor	14.84	6.82	9.87	19.13	22.22
Others	7.92	2.27	11.21	7.82	1.00

Source: Author's calculation based on survey data (2017)

Table 5.21 presents the types of machines that farmers would like to own. Over 95% of the owners wanted to own a machine irrespective of the machine they owned at that time. The majority of owners wanted to own a tractor (22%), a power tiller (40%), and a combine harvester (13%). Among tractor owners, 36% wanted to own a combine harvester. It is interesting to note that the desire to own a combine harvester was higher among medium farmers and tractor owners than among small-scale farmers and non-tractor owners. Conversely, fewer tractor owners had the desire to buy a tractor compared with small-scale farmers and non-tractor owners. Except for tractor plowing operation, it is worth mentioning that many farmers were willing to mechanize various farming operations, but fewer farmers were willing to own a machine or an attachment.

Table 5.21: Desire to own a machine

Desire to own a machine by owners

Type of machine	Frequency	Percent
Tractor	78	22.10
Power tiller	142	40.23
Planter	33	6.23
Combine harvester	50	13.31
Sheller	8	2.27
Thresher	20	3.68
Water pump	7	1.98
Cart trailer	9	2.55
Others	6	0.28

Machines that service users wanted to buy

	Frequency	Percent
Number of farmers	168	73.04
Power tiller	95	56.55
Tractor	48	28.57
Thresher	5	2.98
Harvester	13	7.74
Weeder	4	2.38
Others	3	1.80

Source: Author's calculation based on survey data (2017)

Table 5.22 presents the dependency of farmers on hiring services in the surveyed areas. The highest percentage of farmers (about 90%) were completely dependent on tilling services, followed by irrigation and threshing services (each about 50%). All of the farmers who were completely independent of irrigation services owned a deep tubewell. On the other hand, there was a lack of access to harvesting, weeding, and threshing services among the farmers.

Table 5.22: Dependency on machinery hiring services

Dependency on hiring services	Completely	Partially	Not at all
Tilling	91.60	5.04	3.06
Transplanting	27.82	14.50	54.96
Irrigation	48.74	25.30	27.96
Weeding	8.50	7.50	83.90
Fertilizing	3.94	5.04	61.34
Threshing	52.34	43.40	3.40
Harvesting	0.50	2.30	97.20

Source: Author's calculation based on survey data (2017)

5.11 Perceived impact of rental services and their prospects

In developing countries, it has been generalized that farm mechanization might greatly help the farming community in the overall economic uplift. Farm mechanization may lead to an increase in inputs, such as fertilizer use, due to higher average cropping intensity, and to an increase in the productivity of farm labor. Furthermore, farm mechanization can increase agricultural profitability on account of timeliness of operations, efficient utilization of crop inputs, and better quality of work. In Chapter 2, we already observed that investment in machines will increase real wages as well as employment. The field survey data in Table 5.23 shows that around 90% of respondents believed that farm mechanization would enhance the production and productivity of different crops due to better quality of operations and higher precision in the application of inputs. More than 80% of the farmers surveyed believed that the use of machines would enhance their income and crop yields. The amount of fertilizer and pesticide used has increased, while the use of labor would decrease by 60%. Several studies have indicated that mechanization is able to significantly increase cropping intensity (Barman et al., 2019).

Table 5.23: Impact of machinery used in the agricultural household

Reasons	Fertilizer use	Seed use	Labor use	Pesticide use	Timeliness	Yield	Income
Increased	62.94	22.28	26.80	71.07	60.27	88.92	81.04
Decreased	12.81	23.12	59.22	20.94	38.08	8.31	15.11
No change	24.25	54.60	14.08	7.99	1.64	2.77	3.85

Source: Author's calculation based on survey data (2017)

Agricultural mechanization has helped in the overall increase in the employment of human labor, while it may decrease the amount of casual male labor used (Barman and Deka, 2019). There is a growing problem of farm labor shortages during peak seasons, which is a major contributor to post-harvest loss. To address such problems, the GOB recently drafted the "National Agricultural Mechanization Policy 2020". The main focus of the policy is to provide credit for buying farm machines through the development of cooperative societies. At present, the rental or custom hiring business has already proved to be a profitable enterprise. The rental business may attract young people to join such an enterprise. It may help to introduce new smarter technology to rural farmers, which may also induce them to adopt other new technologies and reduce their fear of accepting new methods of farming.

5.11.1 Determining the potential hub of rental services in the respective study zones

The rationale of setting up a service station for farm machinery rental is reasonable and must be taken into consideration for each sub-district level. Based on the maximum and minimum distance of travel of each machine, the number of owners, the number of households in each of the villages surveyed, we calculated the average distance traveled by a specific machine from its station. The estimated distances here refer to the radius within which a specific machine traveled to provide services. Except for Jashore, we found that on average a two-wheel power tiller owner traveled 4.8 km from their village and covered a minimum of 380 households annually. Additionally, the nearest service provider (2WT) was located 600 m away from the user on average. Jashore is one of the important hubs for tractors. Around 93% of tractor service providers here traveled to other divisions not only for tillage work but also for soil digging and transportation work. On average, a tractor owner traveled 39 km from their station to perform tillage services and 185 km for transportation and digging services. As with harvesters, transplanters are a relatively new technology in Bangladesh; therefore, no existing research was found that accurately indicates the radius covered by transplanter services. During the Boro harvesting seasons, service providers using mini combine harvesters traveled around 20 km from their service station. A power-operated transplanter in Durgapur Thana traveled a minimum of 8 km from its station.

5.11.2 Major constraints on agricultural machine use reported by farmers

As shown in Table 5.24, farmers identified four major constraints which had affected their use of agricultural machinery: lack of access to credit, lack of land, high service charges, and lack of machinery know-how. The lack of access to credit was the greatest constraint among owners. On the other side, lack of knowledge of machines was the main barrier among the users.

Table 5.24: Constraints faced by farmers

	Owners			Users		
Reasons	**Factor-1**	**Factor-2**	**Factor-3**	**Factor-1**	**Factor-2**	**Factor-3**
Lack of access to credit	20.44	15.00	22.23	21.54	31.53	13.36
Lack of land	10.08	14.71	10.73	13.64	21.85	14.14
High service charges	12.53	15.01	12.20	7.80	26.89	20.49
Lack of knowledge of machines	2.45	4.63	16.50	26.46	11.84	12.71

Source: Author's calculation based on survey data (2017)

Major barriers to the adoption of harvesting and planting machines:

Lack of awareness among farmers about the advantages of mechanical harvesting systems and lack of skilled manpower for operating and servicing harvesters were major barriers to adopting mechanized harvesting in the survey areas. Mechanical harvesting services were not readily available. Some rental service providers owned reapers and combined harvesters. Although all farmers wanted to harvest their crops at the proper time with mechanical power, they did not use the services available to them. The reasons for such behavior are twofold:

1. Fear of new technology and lack of promotional activities: Adoption of such machines is strongly associated with the network of agriculture extension officers and local branches of machinery manufacturers. Around 80% of the sampled farmers owned a machine as they had received subsidies and promotional incentives from either agriculture extension officers or local branches of machinery manufacturers.

2. Current harvesting machines are unable to harvest crops if the crops are tilted or if the land is waterlogged. Farmers who also keep domestic cattle are unwilling to use

harvesting services again because the leftover by-products are no longer edible to ruminants, such as cattle.

3. It is well known that mechanization is capital intensive. So, farmers will more likely be able to buy and use capital intensive technologies if they have proper access to credit or loans from formal or informal institutions. A marginal farmer is unable to buy a harvester or transplanter alone. At present, 5% of the total loanable fund of a bank has to go to agriculture. But there is no specific amount allocated to mechanization, especially for financing the purchase of a combine harvester, reaper, or rice transplanter.

4. Farmers need experts to demonstrate the use of new technologies to help them build confidence and encourage them to adopt new techniques. There is an absence of regular machinery demonstrations, and demonstrations are sometimes only for show rather than for information purposes.

However, the solutions to these constraints are not market-driven. There should be a government-driven handout to some extent because these issues cannot be solved by the private sector at the national level. The absence of complementary things that are required with mechanization creates some bottlenecks, where the government can intervene through incentives, fiscal policy, and training.

5.12 Conclusion:

This chapter has examined the workings of the custom hiring market in Bangladesh through a qualitative and quantitative approach. Using primary information collected from 371 machine owners and 239 client farmers, this study demonstrates that different rental service systems have emerged in Bangladesh over time. Firstly, based on field observations, a framework was developed which posited the supply chain of the custom hiring market of different machines. The use of imported tractors, rice transplanters, reapers, and combine harvesters has become cost-effective because the wages of agricultural laborers have increased over time. The owner group invests in machinery and provides machinery rental service as their main business. There is a growing number of entrepreneurs in the field of farm machinery, in particular, power tillers, tractors and threshers, providing services to farmers across the country. However, there is an obvious lack of farm machinery for transplanting, weeding, and harvesting across the regions. Cost analysis indicates that the expense of manual harvesting and carrying is higher than that of manual weeding and transplanting. The adoption of reapers and combine harvesters will reduce the cost of harvesting rice substantially. Thus, the development of entrepreneurship in the area of transplanters and harvesters has a wider scope of application for self-employment activities.

Secondly, this study reveals the prevalence of different types of markets for machinery rental. Price competition among tractor owners varied depending on the distance traveled. The number of tractor service providers and price variation among clients suggests the existence of a monopolistic-type market. Power tiller service charges were the same across neighboring villages, and there were a handful of power tiller service providers available, indicating a competitive market structure. However, a monopoly exists in the rental market for transplanters and combine harvesters. Thirdly, this study has also examined various factors that induce individuals to participate in the rental business and contribute to the development of machine rental enterprises. Household access to credit increases the probability of machine ownership while having several fragmented lands significantly decreases the probability of adopting farm machines and participating in the rental business. After credit, social capital seems to be an important factor that ensures the profit of owners as well as the timely availability of services for users. We observed that social capital improves the smoothness of the rental market by increasing the profit of an enterprise. Farmers can use social capital to secure rental services on-time and optimize their agricultural output. Social capital can play an important role in supporting mechanization in rural areas by making mechanization affordable for smallholder farmers. Social businesses through social capital may have an important role in making mechanization affordable for farmers.

Finally, we also found that farmers are willing to mechanize planting and harvesting operations regardless of whether they are owners or non-owners. We also found that the willingness to mechanize these operations is generally higher among medium-scale farmers and owners than among small-scale farmers and non-owners. The current owners of transplanters and harvesters are not fully able to meet the market demand. New entrepreneurs in the rental market may create a huge demand for their services; however, it is only possible if the barrier to entry in the market is lowered.

To strengthen the existing capacity of custom hire service entrepreneurs and to develop new entrepreneurs, appropriate adoption and information dissemination programs should be launched all over Bangladesh. Machinery importers in the private sector may also take responsibility for disseminating the findings alongside the government. Considering the socio-economic conditions of farmers and the high initial cost of owning machines and implements, special agricultural credit should be provided to potential entrepreneurs. Public and private financial institutions may step forward to extend such credit facilities. Large-scale financial assistance for the purchase of high-value machines like transplanters and harvesters may enhance mechanized cultivation, increase productivity, and reduce cost. Poor rural infrastructure, especially concerning road quality, can be a major challenge to hiring service providers. Finally, a major policy recommendation is to encourage and maintain healthy competition among service providers to enhance smallholder adoption of sustainable and environmentally sound machine services alongside increased food security, given Bangladesh's pursuit of the Sustainable Development Goals. The government has the vision to mechanize harvesting and transplanting activities by creating self-maintained cooperative societies and providing credit through these cooperative societies. Besides, the government also has plans to develop sustainable machine rental hubs across the country, which may help fulfill the demand for farm machine rental services on time. Therefore, future research should attempt to evaluate the level of mechanization in different demographic areas with access to credit and cooperatives where it is particularly feasible to establish a sustainable mechanization hub.

6. Conclusion

The conclusion completes this dissertation. It has a special function insofar as each analytical chapter already closes with a summary and discussion of its findings. Therefore, the main objective of this last chapter is to connect the results and examine the policy implications of the study. The conclusion concentrates on Chapters 2 to 5, which answer the research questions raised in the introduction.

6.1 Summary of the findings

A lot of research has focused on the causes of food price spikes and volatility as well as the micro-consequences of food crises for vulnerable groups. The contribution of this study is to look at the food and labor markets in developing countries using Bangladesh as a proxy and to examine which factors contribute to real farm wages and how increasing farm wages interact with investment in farm machinery and land allocation. In doing so, the dissertation contributes to the current debate on the unit impact of food prices on real farm wages, and on the adoption and development of labor-saving technologies in a densely populated country with high land fragmentation like Bangladesh. Thereby, the study made use of econometric techniques as well as the construction of a conceptual framework model in which both land and machine market development can be properly justified under the scenario of rising farm wages. One of the novelties of this research is to use different sorts of secondary data sources. Furthermore, primary data were used to gain insights into the rental markets. In detail, the dissertation set out to explore the linkages of farm wages, food prices, land allocation, and the prospects of rental markets for farm machines. First, a time series model called VECM analysis was employed to determine the causal direction as well as the contribution of food prices and urban wages to changes in farm wages from 1994 to 2014. Secondly, the autoregressive distributed lag model was employed to understand the pass-through effects of price and urban wage shocks on real farm wages. Then, the impact of machine investment on wages and land was analyzed by using existing secondary data and applying dynamic panel models and first-difference models, respectively. Finally, the present demand and prospect of farm machinery rental services were analyzed with primary data collected from the study districts.

Following the introduction, which describes the context and motivation of the dissertation, Chapter 2 and 3 introduce the reader to food-wage modeling and machine investment and its impact on land use. In Chapter 2, we found empirical evidence for a structural break in food wages in the period between 2007 and 2008. After the structural break around 2008, rice prices were significantly correlated with farm wages only in Dhaka, Barisal, and Mymensingh. Except for Dhaka, Mymensingh, and Barisal, farm wages in all other divisions were either influenced by industrial or constructional wages, but not by rice prices. These findings suggest strong evidence in favor of the Lewis turning point.

In the third chapter, by assessing different models with varying time horizons, this study was able to check the dynamics of rural wage determination. By giving a theoretical framework, we are certain to attribute the positive effect of mechanization on rural wages to the scale effect related to the increase in agricultural activities expedited through agricultural mechanization. Subsequently, the investigation findings disperse the worry that the replacement of manual labor by machines has prompted decreased employment opportunities and lower wage rates in rural Bangladesh. This has vital implications for policymakers expecting to diminish rural poverty and mediations proposed to lessen broad extensive rural-urban migration and set out greater employment opportunities in the agricultural sector.

In Chapter 4, we further explored how wages and machine investments are interlinked at the farm level. The effect of rising agricultural wages per hectare is significant for machine investments. However, increasing the availability of rental services, when coupled with increased farm wage, did not significantly favor large farmers. The results also support the substitution of labor by machine as the changes in per hectare labor cost significantly increased the machinery investment per hectare. But there is no conclusive evidence to suggest that larger farmers rented more land to adopt intensive machinery use. Rather a decreasing trend was observed for the amount of land rented by the relatively larger farmers as farm wages increased. The empirical results also show that machine investments and land are complementary. Land transfer and machine use are not seriously constrained in the country because rental markets seem to function actively.

Finally, chapter five inspected the functions of the custom hiring market in Bangladesh through a subjective and quantitative approach. We found a developing number of entrepreneurs in the field of farm machinery, specifically, power tillers, tractors and threshers, providing services to farmers across the country. Cost investigations demonstrate that the expenses of manual harvest and carrying are beyond that of manual weeding and transplanting. The adoption of reapers and combine harvesters can cut back the cost of harvest rice generously. Accordingly, the development of entrepreneurship in the area of transplanters and harvesters has a more extensive scope of utilization for self-employment activities. Price rivalry among machine owners differed relying upon the distance voyaged. The quantity of tractor service providers and price variation among clients recommends the presence of a monopolistic-type market. A monopoly exists in the rental market for transplanters and combine harvesters. The willingness to mechanize harvesting, transplanting, and other farming operations are found to be higher among medium-scale farmers and owners than among small-scale farmers and non-owners. Among the different factors, credit and social capital appear to be the most important factors that ensure the profit of owners as well as the timely availability of services for users, while having several fragmented lands considerably diminishes the likelihood of adopting farm machines. By increasing the profit of an enterprise, social capital can improve the smoothness of the rental market.

6.2 Policy implication, limitations, and further research

In the past, one could see hapless farmers laboring behind a wooden plow drawn by a pair of bullocks tilling the fields. Putting in backbreaking labor and long hours to prepare the land for harvest not only was physically draining but also stunted the growth of agribusiness in rural Bangladesh. However, Bangladesh has turned its back on such a traditional form of agriculture in favor of mechanized farming. In the late 1990s, the use of heavy engines became common for tillage despite not many people owning the machine. Subsequently, we observed the emergence of new rental services for threshing, planting, and harvesting in the early 2000s. If all the modern agricultural technologies available in Bangladesh were to be adopted judiciously, farmers, agricultural scientists and extension personnel would be able to feed the growing population despite the 1.36% population growth and 1% reduction in cultivable land every year. However, to arrive at such a state of sustainability in food production and poverty reduction, we need to follow certain research outputs that focus on burning issues like the challenges in the food and labor market under the scenario of rising wages.

In the second chapter, it was observed that price changes do not have a one-to-one relation with farm wages, but rather urban wages have a greater impact on rural wages. In that chapter, we employed a multisector labor market model. Aggregate monthly wage and price data were used, as the goal is to get a broad sense of the country's general vulnerability to staple food price shocks. After the structural break around 2007-2008, farm wages in all other divisions were influenced by either industrial or constructional wages, which imply strong evidence in favor of the Lewis turning point in Bangladesh. Policymakers should take initiatives to smooth the urban-rural linkages in the labor market. Besides, policymakers need to guarantee that production costs of rice cultivation are accompanied by similar changes in labor productivity to ensure food security in the face of unstable rice prices. For a more in-depth understanding of pass-through effects, one would need to go beyond staple food price analysis and estimate these effects by commodity. In the future, empirically grounded theoretical labor market models can be used in the formulation of policy. Although there is some value in developing single-sector models, it would be more helpful to have multi-sector models in which labor markets are segmented to incorporate the key features of labor markets in the country being analyzed. There is also a need for in-depth empirical analysis of which particular policy interventions are relevant to farm wages and which are not, such as the hundred-day Employment

Generation Program implemented by the World Bank since 2014. Recently, we had no access to such data at the disaggregated level. Thus, efforts should be made to collect more readily available domestic commodity price data as well as several government intervention quantities at the district level.

The present study also shows that agricultural mechanization has positively affected real rural wages at the national level, suggesting that mechanization has not reduced employment opportunities but rather contributed to the reduction of the rural-urban wage gap. This study supports the government's expenditure on mechanization as it enhances the rural economy by increasing labor productivity and production efficiency. The current agricultural policy also strives to achieve full mechanization, but further research may be required to understand whether this will have a positive or negative effect on rural laborers. Mechanization in terms of pursuing rental services at the farm level favors small farmers over relatively larger farmers. It is recommended to invest in small farmers by providing small credit and targeting the economic use of rental services. The government could ease land transfer or the tenure system, for example by reducing land transfer cost or related costs and induce farmers to cultivate the fallow land. An active, functioning rental machinery market with an active land tenure system may enhance the expansion of operational farm size and production efficiency.

The fifth chapter has shown the prevalence of different types of rental markets for farm machinery. The growth of agricultural mechanization through custom hiring is an important process in many developing countries in Asia. The rent of agricultural machine is now considered as a variable input cost in agricultural production. The total mechanization of agricultural activities will help to reduce the cost of production, loss of foodgrains, and dependence on farm laborers extensively. Although many might think that mechanization would reduce employment opportunities for day laborers, but it could also create opportunities for young people to work in farm machine enterprises. As mentioned before, almost 95% of cultivation has undergone mechanization through the use of tractors or power tillers. Increasing the price competition among power tiller and tractor owners will make the service available at an affordable price. The competitive market structure of power tiller rental service ensures the availability of this service all over the country. However, timely service is still one of the concerns of the farmers. The local government may take initiatives to encourage farmers and the service providers to create small groups among the farmers and service providers for availing and providing the rental services efficiently. Due to the initial barriers to entry in the market, the number of tractor service providers is less than the power tiller across the country. Removing the market entry barriers in the rental market of farm machinery and improving the access of the small and medium scale farmer to rural finance market will induce the adoption of farm machinery use across the country. Understanding the market imperfections has been important for scale-biased inputs like tractors. Further research is needed to understand and separate the effect of marginal and intensive technology adoptions.

In addition, this study shows that manual harvesting and transplanting are slow and cost-intensive. It is, therefore, necessary to build awareness among farmers about the benefits of a mechanical harvesting system to encourage the adoption of mechanized paddy harvesting in the labor scarce areas like, Haor and the northern region. This study also found a high demand for mechanized transplanting and harvesting operations as farmers are willing to pay a handsome amount for these rental services. Farmers found combine harvesters more attractive than the reapers as the machines can perform several post-harvest activities in a single operation. Scale-appropriate combine harvesters can help save costs, reduce harvesting losses, decrease human drudgery, and increase crop productivity. This could increase the total agricultural production, which will contribute significantly to improving the food security status in rural areas of Bangladesh. Emerging harvester and transplanter hiring services can significantly reduce the cost of such services for non-owners through specialization. However, a monopoly exists in the rental market for transplanters and combine harvesters.

The farm machinery rental business is recommended not only for commercial purposes but also because it increases efficiency in agricultural production. To make their rental business more profitable, service providers need to decrease their searching cost by prioritizing clients in the village closest to their homes, establishing trust between the actors, and utilizing their social capital. Social capital improves the smoothness of the rental market, so social businesses through social capital may have an important role in making mechanization affordable for farmers. Participation of female labor has increased from 2013 to 2017 in the agricultural sector (BBS, 2018). Although more than half (59%) of the agricultural labor force is female (BBS, 2018), females in Bangladesh are less likely to own or operate productive agricultural machinery. In this study, there was no female machine owner. The social inclusiveness of women into agricultural machinery service provision remains a real challenge, and future research should spiel this particular issue. Household access to credit increases the chance of participating in the rental market. Although it is common in some areas to use credit to purchase inputs none of the farmers in the study areas currently uses credit from formal institution to pay for power tiller and tractor hiring services. The improvement in credit access for resource-constrained farm households may reduce capital constraints and encourage them to invest in costly agricultural machinery. Awareness creation among the farmers regarding new technology is very important. The decision to use credit facilities to pay for the harvester or transplanter hiring service would be a very new idea to farmers. Fragmented lands significantly decrease the probability of adopting farm machines and participating in the rental business. A cooperative harvesting system should be encouraged among farmers to increase land size as well to widen the entrance passage for machinery in the fields

The government or the private sector should set up agricultural machinery centers that can support maintenance and rent out tractors to small scale farmers at subsidized rates. Principally, effort should now be directed toward the mechanization of harvesting and rice transplantation. The use of manual laborers in these two activities needs to be replaced step by step to reduce the negative impact of labor shortages during the peak seasons. However, policymakers should be cautious about the mechanization levels, partial or full adoption, as many laborers are still involved in transplanting and harvesting activities to earn their livelihood. Further research is essential to measure the impact of machine use on the overall welfare of the labor market outcomes at the household level. Although the survey found that farmers in several districts are getting more familiarized with and interested in using harvesters and reapers, they have yet to use rice transplanters on a large scale. The government is liberally providing a 70% subsidy on these machines to farmers in the Haor areas and 50% to those in other areas. However, Government needs to think the consequence of such subsidies on the agricultural input market. More market-based researches are necessary to understand whether it is the right time to increase subsidy in the national budget as banks do not directly provide financing to farmers for purchasing agricultural machinery. Further, the adoption of new types of renting services may create new employment opportunities for the rural labor force. Given the importance of rural labor markets, policymakers are advised to continue investing in rural (on- and non-farm) productivity to create proper employment opportunities in the agricultural sector. Besides good policy and strategy, implementing agencies should give priority to climate-smart agriculture technologies and sustainable agricultural mechanization.

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Technical Appendix **1**

Table 1: Upper poverty line

Division	Year					
	1991	1995	2000	2005	2010	2015
Dhaka	58.7	52	46.7	32	30.5	16
Barisal	42	59.9	53.1	52	39.4	26.5
Chittagong	46.5	44.9	45.7	34	26.2	18.4
Khulna	59.9	51.7	45.1	45.7	32.1	27.5
Rajshahi	71.8	62.2	56.7	51.2	29.8	28.9
Sylhet			42.4	33.8	28.1	16.2

Table 2: Lower poverty line

Division	Year					
	1991	1995	2000	2005	2010	2015
Dhaka	42.3	33	34.5	19.9	15.6	7.2
Barisal	59.7	43.9	34.7	35.6	26.7	14.5
Chittagong	24.6	32.4	27.5	16.1	13.1	8.7
Khulna	47.2	32.2	32.3	31.6	15.6	12.4
Rajshahi	59.7	41.6	42.7	34.5	16.8	14.2
Sylhet			26.7	20.8	20.7	11.5

Technical Appendix **2**

Table 3: Correlation matrix of the explanatory variables

Divisions		Rice price	Industrial wage	Constructional wage
Dhaka	Rice price	1		
	Industrial wage	0.0466	1	
	Constructional wage	0.0838	0.2366	1
Mymensingh	Rice price	1		
	Industrial wage	0.0307	1	
	Constructional wage	0.1078	0.0188	1
Rajshahi	Rice price	1		
	Industrial wage	0.0257	1	
	Constructional wage	-0.0596	0.2162	1
Rangpur	Rice price	1		
	Industrial wage	-0.0116	1	
	Constructional wage	0.0614	0.0022	1
Khulna	Rice price	1		
	Industrial wage	0.0173	1	
	Constructional wage	0.0173	0.2226	1
Sylhet	Rice price	1		
	Industrial wage	0.0338	1	
	Constructional wage	0.0077	0.0154	1
Barisal	Rice price	1		
	Industrial wage	0.0553	1	
	Constructional wage	0.0533	0.2366	1
Chittagong	Rice price	1		
	Industrial wage	0.0727	1	
	Constructional wage	0.0802	0.4015	1

Technical Appendix **3**

Seasonality and unit root of the respected series

Sometimes both seasonal unit roots and seasonal heterogeneity are common in time series data. The HEGY (Hylleberg et al., 1990) test is a common tool for detecting seasonal unit roots. For all the series, considering the structural break, we checked for the possibility of a regular unit root along with the seasonal unit root test. The results are displayed in the following table.

Table 4: HEGY test of regular and seasonal unit roots

Division	Stages of unit root	Farm wage	Food price	Industrial wage	Construction wage
Dhaka	Zero frequency (non-seasonal)	yes	yes	yes	Yes
Khulna	4 months per cycle	No	No	No	No
Sylhet	2.4 months per cycle	No	No	No	No
Rajshahi	12 months per cycle	No	No	No	No
Rangpur	3 months per cycle	No	No	No	No
Chittagong	6 months per cycle	No	No	No	No

Technical Appendix **4**

Optimal lag length selection

Using both the Schwarz criterion (SBIC) and Hannan-Quinn information criterion (HQIC), we estimated the optimal lag length. Most of the models have two periods of lags before the structural break; after the break, they have one period of lag. If the selection criteria suggested different lag structures, we selected the maximum lag.

Table 5: Lag selection

Division	SBIC	HQIC	SBIC	HQIC
	Before structural break		After structural break	
Dhaka	1	2	3	3
Khulna	2	1	2	2
Sylhet	1	2	1	1
Rajshahi	1	1	2	1
Rangpur	2	2	1	1
Chittagong	2	1	1	1
Barisal	1	1	1	1
Mymensingh	1	1	1	1

Technical Appendix 5

Rank of the cointegration vectors

Table 6 (i): Dhaka division

Rank	Parameters	Lower limit	Eigen value	Trace statistic	Value
Sample: 1994m2- 2009m1					
0	8	1181.32	.	85.24	54.64
1	15	1211.83	0.29	24.22*	34.55
2	20	1217.75	0.06	12.38	18.17
3	23	1222.06	0.05	3.76	3.74
4	24	1223.94	0.02		
Lags = 1					
Trend: trend					
Number of observations = 180					

Structural break

Rank	Parameters	Lower limit	Eigen value	Trace statistic	Value
Sample: 2009m1 - 2014m12					
0	4	506.43	.	78.44	62.21
1	12	528.88	0.29	33.54*	42.68
2	18	538.90	0.18	13.49	25.41
3	22	543.09	0.11	4.59	12.76
4	24	545.65	0.04		
Lags = 1					
Trend: constant					
Number of observations = 72					

Table 6 (ii): Mymensingh division

Rank	Parameters	Lower limit	Eigen value	Trace statistic	Value
Sample 1994m2 - 2009m1					
0	8	1095.68	.	94.14	54.64
1	15	1130.00	0.32	25.50*	34.55
2	20	1136.62	0.07	12.27	18.17
3	23	1140.98	0.05	3.55	3.74
4	24	1142.75	0.02		
Lags = 1					
Trend: trend					
Number of observations = 180					

Structural break

Rank	Parameters	Lower limit	Eigen value	Trace statistic	Value
Sample: 2009m1 - 2014m12					
0	8	475.10	.	91.74	54.64
1	15	499.76	0.50	42.42*	34.55
2	20	513.77	0.32	14.40	18.17
3	23	518.46	0.12	5.03	3.74
4	24	520.97	0.07		
Lags = 1					
Trend: trend					
Number of observations = 72					

Table 6 (iii): Rajshahi division (Sample: 1994m2 - 2008m12) & (Sample: 2008m12 - 2014m12)

"Johansen tests for cointegration"												
Rank	Parameters	Lower limit	Eigen value	Trace Statistic	5% critical Value		Rank	Parameters	Lower limit	Eigen value	Trace statistic	5% critical Value
0	4	1188.49	.	49.04	47.21		0	4	528.00	.	43.72	47.21
1	11	1200.16	0.12	25.69*	29.68		1	11	545.08	0.37	9.56*	29.68
2	16	1208.47	0.09	9.06	15.41		2	16	548.17	0.08	3.38	15.41
3	19	1213.01	0.05	0.00	3.76		3	19	549.82	0.04	0.09	3.76
4	20	1213.01	0.00				4	20	549.86	0.00		
Lags = 1							Lags = 1					
Trend: constant							Trend: constant					
Number of observations = 179							Number of observations = 73					

Table 6 (iv): Rangpur division (Sample: 1994m2 - 2008m12) & (Sample: 2008m12 - 2014m12)

"Johansen tests for cointegration"												
Rank	Parameters	Lower limit	Eigen value	Trace Statistic	Value		Rank	Parameters	Lower limit	Eigen value	Trace statistic	Value
0	4	1479.32	.	54.79	47.21		0	4	690.35	.	76.06	47.21
1	11	1493.02	0.14	27.37	29.68		1	11	711.31	0.44	34.15	29.68
2	16	1502.07	0.10	9.27	15.41		2	16	723.86	0.29	9.05	15.41
3	19	1506.43	0.05	0.57	3.76		3	19	727.29	0.09	2.19	3.76
4	20	1506.71	0.00				4	20	728.38	0.03		
Lags = 1							Lags = 2					
Trend: constant							Trend: constant					
Number of observations = 156							Number of observations = 96					

Table 6 (v): Khulna division (Sample: 1994m2 - 2007m1) & (Sample: 2007m1 - 2014m12)

"Johansen tests for cointegration"												
Rank	Parameters	Lower limit	Eigen value	Trace statistic	Value		Rank	Parameters	Lower limit	Eigen value	Trace statistic	Value
0	4	1086.32	.	61.63	47.21		0	20	616.01	.	51.92	47.21
1	11	1104.36	0.21	25.55	29.68		1	27	630.94	0.27	22.08	29.68
2	16	1112.59	0.10	9.09	15.41		2	32	638.07	0.14	7.81	15.41
3	19	1116.14	0.04	1.98	3.76		3	35	641.12	0.06	1.72	3.76
4	20	1117.13	0.01				4	36	641.97	0.02		
Lags = 1							Lags = 2					
Trend: trend							Trend: trend					
Number of observations = 156							Number of observations = 96					

Table 6 (vi): Sylhet division (Sample: 1994m2 - 2008m1**)** & (Sample: 2008m1 - 2014m12)

"Johansen tests for cointegration"												
Rank	Parameters	Lower limit	Eigen value	Trace Statistic	Value		Rank	Parameters	Lower limit	Eigen value	Trace statistic	Value
0	4	1185.25	.	60.66	47.21		0.00	8.00	613.51	.	62.08	54.64
1	11	1207.92	0.24	15.32*	29.68		1.00	15.00	627.12	0.28	34.86	34.55
2	16	1212.39	0.05	6.39	15.41		2.00	20.00	638.33	0.23	12.43*	18.17
3	19	1214.88	0.03	1.41	3.76		3.00	23.00	642.30	0.09	0.09	3.74
4	20	1215.58	0.01				4.00	24.00	644.55	0.05		
Lags = 1							Lags = 1					
Trend: constant							Trend: trend					
Number of observations = 168							Number of observations = 84					

Table 6 (vii): Barisal division (Sample: *1994m2 - 2008m12*) & (Sample: 2008m12 - 2014m12)

"Johansen tests for cointegration"												
Rank	Parameters	Lower limit	Eigen value	Trace statistic	5% critical Value		Rank	Parameters	Lower limit	Eigen value	Trace statistic	5% critical Value
0	8	1145.36	.	59.23	54.64		0	4	525.86		54.22	47.21
1	15	1161.51	0.17	26.91	34.55		1	11	547.71	0.45	10.53	29.68
2	20	1169.20	0.08	11.54	18.17		2	16	551.40	0.10	3.15	15.41
3	23	1173.76	0.05	2.42	3.74		3	19	552.97	0.04	0.00	3.76
4	24	1174.97	0.01				4	20	552.97	0.00		
Lags = 1							Lags = 1					
Trend: trend							Trend: constant					
Number of observations = 179							Number of observations = 73					

Table 6 (viii): Chittagong division (Sample: 1994m3 - 2008m12) & (Sample: 2008m12 - 2014m12)

"Johansen tests for cointegration"												
Trace 5% critical												
Rank	Parameters	Lower limit	Eigen value	Trace statistic	5% critical Value		Rank	Parameters	Lower limit	Eigen value	Trace statistic	5% critical Value
0.00	20.00	1291.01	.	72.79	62.99		0.00	4.00	578.20	.	83.40	62.99
1.00	28.00	1311.51	0.21	31.79*	42.44		1.00	12.00	599.41	0.44	40.97*	42.44
2.00	34.00	1319.78	0.09	15.25	25.32		2.00	18.00	612.02	0.29	15.75	25.32
3.00	38.00	1325.60	0.06	3.61	12.25		3.00	22.00	617.83	0.15	4.13	12.25
4.00	40.00	1327.41	0.02				4.00	24.00	619.90	0.05		
Lags = 2							Lags = 1					
Trend: trend							Trend: trend					
Number of observations = 178							Number of observations = 73					

Technical Appendix **6**
Stability test

Post-estimation of the VECM model is required to check whether the co-integrating equations are stationary. This process requires computing the eigenvalues of the companion matrix and counting the number of unit moduli in the whole system. If the number of unit moduli (*k*) is less than the number of endogenous (*T*) variables after subtracting the number of co-integrating vectors (*r*), that means $k< T-r$, then the co-integration equation is stationary. Also, the Lagrange multiplier (LM) test for autocorrelation provides evidence of whether the residuals of the VECMs are autocorrelated or not. The Wald and Lagrange multiplier test found no autocorrelation of the residuals at the selected lags. The normality of the residuals was also examined. However, one minor limitation of the models is that they passed the examination of the stationarity and autocorrelation but marginally failed to form a normal distribution of the residuals.

Technical Appendix 7
Price transmission in the short run

Table 7: Real farm wage response to real industrial wages

Division	Three-month pass-through coefficients		Six-month pass-through coefficients		Twelve-month pass-through coefficients	
	Before Break	After break	Before Break	After break	Before Break	After break
Dhaka	-0.083	**0.548****	0.030	0.599	0.033	-0.010
Mymensingh	-0.025	**0.855****	0.048	**1.11****	0.024	0.510
Rajshahi	0.001	0.222	0.155	0.231	0.212	0.399
Rangpur	0.071	0.072	0.057	0.011	0.0901	-0.30
Sylhet	-0.032	0.291	0.157	0.242	0.2574	-0.32
Khulna	0.009	-0.219	0.081	-0.23	0.089	**-0.90****
Barisal	-0.113	0.373	-0.155	0.282	-0.353	0.129
Chittagong	0.085	0.126	-0.179	0.320	0.249	-1.0

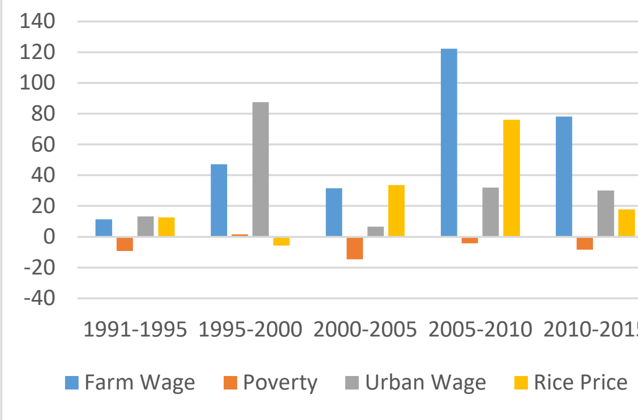
Source: Author’s calculation based on BBS and reports by the FPMU (1995-2015).

Table 8: Real farm wage response to constructional wages

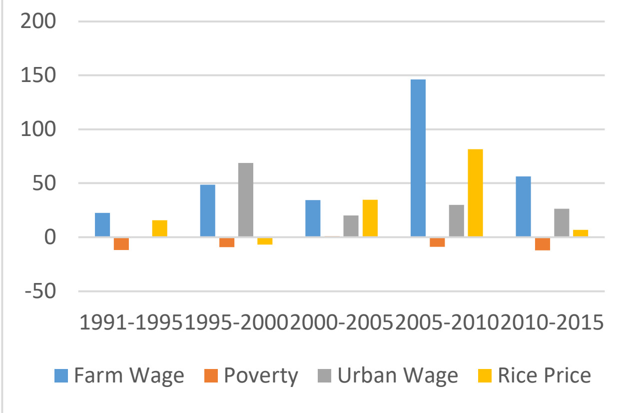
Division	Three-month pass-through coefficients		Six-month pass-through coefficients		Twelve-month pass-through coefficients	
	Before Break	After break	Before Break	After break	Before Break	After break
Dhaka	0.063	**0.766****	0.082	0.112	0.061	-0.011
Mymensingh	0.125	0.697	0.141	1.18	0.108	0.381
Rajshahi	0.0859	**0.949****	0.069	-0.202	0.112	-0.638
Rangpur	-0.033	0.317	0.0791	-0.683	0.175	-0.282
Sylhet	0.0339	-0.034	0.039	0.4842	0.107	0.796
Khulna	0.003	0.463	0.097	0.2582	0.138	**1.27****
Barisal	-0.003	0.242	0.138	-0.54	**0.234***	-0.813
Chittagong	-.021	0.630	**0.169***	-0.136	**0.313****	-1.92

Source: Author's calculation based on BBS and reports by the FPMU (1995-2015).

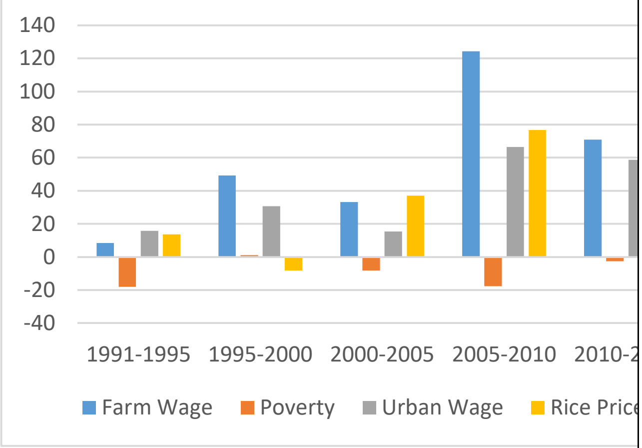
Technical Appendix **8**



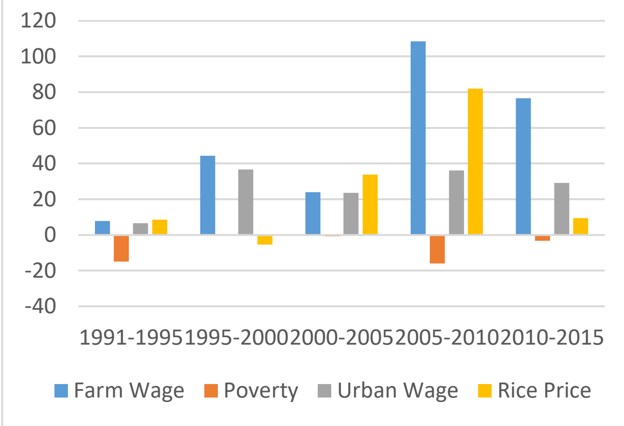
Dhaka



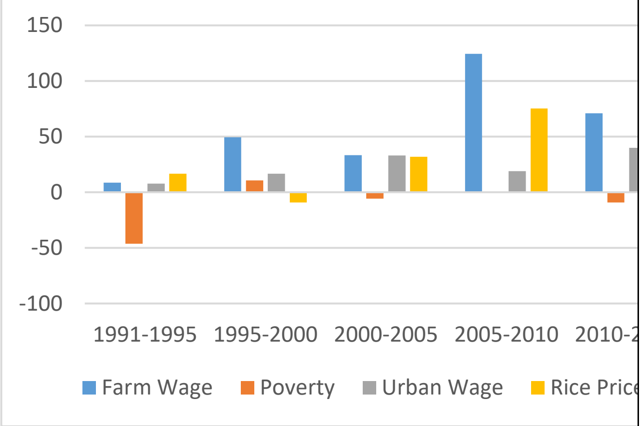
Barisal



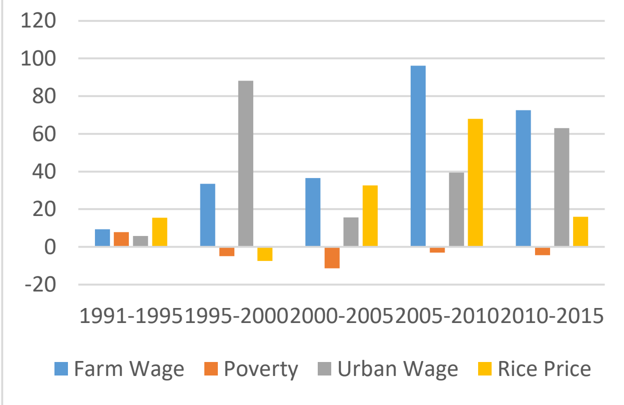
Rajshahi



Khulna



Sylhet



Chittagong

Figure 1: Percentage change of wages, prices and poverty; source: HIES from (1991 to 2015)

Technical Appendix **9**

Table 9: Summary of long- and short-run elasticities and labor demand

Magnitude	Long-run elasticities of farm wages							Pass-through (2008-2014) elasticities in the short run			Labor demand
Divisions	Rice	Industry	Construction	Break	Rice	Industry	Construction	Rice	Industry	Construction	Cultivated area
Dhaka	**+++**	**++++**	+		**++++++**	**++**	+		x	x	*****
Mymensingh	**+**	**+++++++**	**++**		**++++++++**	**+++++**	**+++++++**	x		x	****
Rajshahi	**++++++**	+	**+++++++**		+++++++	++++	**+++++**		x		********
Rangpur	**+++++**	**++**	**++++++**		++	**+**	**++++++**				*******
Khulna	**++++**	**+++**	**+++**		+	**+++++++**	**++++**		x	x	***
Sylhet	**++**	**+++++**	**+++**		++++	**++++++**	+++				*
Barisal	**+++++++**	**++++++**	**+++++**		+++	+++	++	x			**
Chittagong	**++++++++**	**++++++++**	**++++++++**		+++++	**++++++++**	++++++++				******

Note: "**+**" signs are arranged in ascending order (bold sign means significance at 1%-10%); "x" indicates significant transmission of the price shocks to farm wage; "*" indicates the area of rice cultivation in ascending order for Aman and Boro.

Technical Appendix 10

Table 10: Correlation between the number of service providers and service charge

Thana	Tractor	Power tiller	Thresher	VMP
Kishorgonj Sadar	-	0.110	0.394	-
Jashore Sadar	-0.195	0.068	-0.224	-
Bagmara	-0.520	0.005	0.013	-
Durgapur	-	-0.450	0.417	-0.0072
Shibgonj	-0.359	-0.110	-0.080	-