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Private investments in modern food storage

An economic feasibility analysis for private investments in modern food storage and potential public sector roles in promoting such investments

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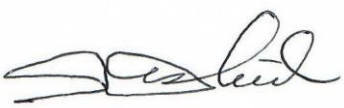

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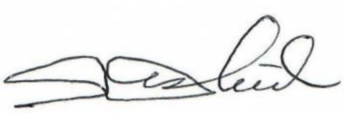


ACRONYMS AND ABBREVIATIONS

BADC	Bangladesh Agricultural Development Corporation
BAU	Bangladesh Agricultural University
BBS	Bangladesh Bureau of Statistics
BDT	Bangladesh Taka
BIHS	Bangladesh Integrated Household Survey
CO_2	Carbon dioxide
CPI	Consumer Price Index
CV	Coefficient of Variation
DAM	Department of Agricultural Marketing
DG Food	Directorate General of Food
FPMU	Food Planning and Monitoring Unit
GHG	Greenhouse gas
IFPRI	International Food Policy Research Institute
IFPRP	Integrated Food Policy Research Program
JV	Joint Venture
KG	Kilogram
KW	Kilowatts
LSD	Local Supply Depot
MFSP	Modern Food Storage Facilities Project
MT	Metric tons
PE	Polyethylene
PFDS	Public Foodgrain Distribution System
PMU	Project Management Unit
PSU	Primary Sampling Unit
PVC	Polyvinyl chloride
UIUC	University of Illinois at Urbana-Champaign

EXECUTIVE SUMMARY

Unprecedented growth in rice production in Bangladesh over the last four decades has outpaced the capacity of post-harvest operations, resulting in substantial grain losses. While production technology has changed dramatically over time, there has been relatively little private investment in transforming storage capacity in the country.

This paper explores the lack of widespread private investment in improved grain storage and examines the potential for public support to stimulate greater private sector investment in modern storage. We calculate the returns to investment in bulk grain silos and hermetic cocoons that could upgrade warehouse storage, and calculate the grain loss that conversion to those technologies would prevent. We then assess the public support that would be required to trigger private investment in modern storage systems.

Our analysis shows that storage in jute bags in warehouses or homes outperforms the modern technologies in terms of financial returns at observed prices. Our analysis further shows that given the observed price changes during the harvest and post-harvest periods from 2008 to 2018, cocoon and silo storage as well as conventional warehouse storage were unprofitable in most years and on average overall. Although seasonal variation in market prices for paddy is sometimes pronounced, the pattern of the variation is not sufficiently large or consistent to make paddy storage reliably profitable. Conventional warehouse storage implied an average loss of BDT 2,877/MT/season over the 20 seasons considered. Use of modern storage methods would have implied average losses of BDT 3,200/MT/season to BDT 4,950/MT/season, depending on technology used.

These results imply that a public sector co-investment on the order of BDT 300/MT would be required to trigger a shift from conventional to modern storage by traders or millers. This shift would imply a reduction in grain loss of 30kg to 80kg per MT stored for a public cost of BDT 3.75 to BDT 10.00 per kilogram of loss avoided. To make it profitable for intermediaries to provide commercial storage services to farmers who currently store on-farm would require a much larger co-investment of about BDT 3,200/MT stored, implying BDT 40 to BDT 106 per kilogram of loss avoided.

Removal of import tariffs on storage technologies or realization of a price premium for silo-stored or hermetically stored grain could be sufficient to encourage millers to adopt modern storage, but would be inadequate to trigger increased off-farm storage as an independent activity. There is anecdotal evidence of a price premium for paddy that has been stored using improved technology. Existence of such a premium could significantly reduce public support needed to trigger private investment in improved storage.

I. INTRODUCTION

Bangladesh succeeded in tripling its grain production in the last four decades, but the country performs poorly in grain conservation, with an estimated 10% of its cereal lost during post-harvest operations (Majumder et al. 2016; Bala 1997). High post-harvest losses impose financial harm on economically vulnerable smallholder farmers who dry and store the largest share of the country's grain. Due to poor post-harvest processing and storage capabilities, these smallholder farmers incur crop losses that reduce national food availability and diminish their own incomes. Smallholders sell a large share of their production at the harvest season, but they hold more than half of their grain in their homes in the expectation of higher market prices in subsequent months and in order to provide for home consumption. Poor household storage facilities result in deterioration in the quantity and quality of grain as it becomes susceptible to molds, fungal growth, and attacks from pests causing farmers to lose three percent to eight percent of the stored grain by weight (Bari, 2015; Hossain 2020). These losses tend to be higher for grain harvested during the wetter months associated with Boro and Aus harvests. Physical storage loss coupled with quality deterioration lead to lower monetary value of stored grain, encouraging greater sales at harvest which contributes to depressed harvest-time prices.

Off-farm storage could provide a way to use modern storage technology to lower losses while giving flexibility in the timing of sales. There are multiple possible models for off-farm storage. For example, a service provider could offer access to drying and storage facilities for paddy for a fee, with stored paddy remaining the farmer's property, or an intermediary could buy the grain and dry and store it for later resale. Regardless of the contracting arrangement, a technically efficient and competitive private sector offering drying and storage services might reduce storage losses while smoothing seasonal price fluctuations by keeping grain off the market when prices are low at harvest and releasing it as prices rise. However, current practices at husking mills and private warehouses often offer similar technical performance to household storage in terms of losses experienced and do not provide storage services to growers.

This paper explores whether commercial storage using improved technology could be profitable in Bangladesh based on intertemporal arbitrage related to seasonal price variation. The paper assesses whether grain storage is financially viable as an economic activity and whether use of modern off-farm storage technologies allow stockholding at lower cost, including physical losses, than methods currently in practice. Results indicate that despite high losses, use of jute sacks in homes or simple warehouses for periods of up to four months competes favorably with the modern technologies under consideration in terms of financial returns. Results indicate that typical seasonal patterns of price variation offer little scope for profitable storage under any technology considered. Rather, stockholding by commercial operations such as automatic mills is a cost associated with other business activities and is not financially attractive in its own right. Results suggest that modest policy changes could trigger conversion from conventional warehouses to hermetic storage or silos by millers, but significant financial support from the government would be required to stimulate private investment in stockholding as a commercial activity given current prices and technical options.

The next section explains the data and methodology used. Section III presents information on paddy production and stocks held by different stakeholders and seasonal variation of paddy prices in Bangladesh. Section IV reviews potential storage technologies that are suitable for commercial stockholding in the country. Section V presents a financial feasibility analysis of private storage services, and Section VI concludes with consideration of policy interventions that could trigger investment in modern storage technologies and reduced post-harvest loss.

II. METHODOLOGY AND DATA

This analysis of the profitability of commercial paddy storage in Bangladesh uses data from a range of sources covering monthly market prices, costs of alternative storage technologies, and grain losses using those technologies. A survey of millers and traders as well as discussion with key informants[1] indicated very little use of large-scale modern storage facilities among private agents in Bangladesh at this time. For this reason, the analysis relies heavily on simulation and field testing to assess costs and likely returns to stockholding, rather than financial or other data from current stockholders. Requisite data for the analysis include cost information for various storage methods, production and storage data, and data on monthly grain price movements to calculate the private returns to stockholding.

Data on seasonal rice equivalent paddy production were obtained from the Bangladesh Bureau of Statistics (BBS), and prices in regional markets are reported by the Department of Agricultural Marketing (DAM) of the Ministry of Agriculture.[2] Data on storage losses, installation and operational costs of hermetic cocoons and conventional warehouse storage come from a field study conducted by a research team from the Bangladesh Agricultural University (BAU). Cost data for silo construction and relevant technology installation are from a feasibility study of the Ministry of Food, Bangladesh (2019). We estimate the financial feasibility of different storage methods by calculating the profit or loss associated with use of each method under different rates of storage loss and monthly price increase. Calculated profits or losses associated with observed seasonal price movements for last 20 seasons reveal the returns that private investors would have obtained under each storage method. Results suggest the scale of public co-investment that would be required to make private participation likely.

A large share of private stocks of grain are held by smallholder farm households. Household stocks of paddy and rice have been estimated using data from the Bangladesh Integrated Household Survey (BIHS) administered by the International Food Policy Research Institute (IFPRI) in 2018-19. BIHS is a nationally representative panel survey of rural households, covering more than 6,500 households in 325 primary sampling units (PSUs) or villages, allocated across seven divisions of Bangladesh. Data from a smaller household survey conducted by IFPRI in 2017 are used to estimate the monthly paddy sale by farm households. Calculating national stockholding relies on estimates of consumption based on HIES 2016 data and imports, public procurement and public distribution taken from the Food Planning and Monitoring Unit (FPMU) Database.

In estimating the stocks of paddy and rice for households, millers and traders we first estimate the total private rice stocks for each month using the following formula:

$$Total\ stocks_m = Stocks_{m-1} + Prod_m + Imp_m - Consm_m + Dist_m - Proc_m$$

Where:

$Total\ stocks_m$ = Total monthly stocks by the private actors;

$Prod_m$ = Monthly rice equivalent paddy production;

Imp_m = Total monthly rice import;

[1] Key informants are listed in Appendix Table A.4.

[2] This analysis considers the returns to storage of paddy, based on seasonal variation in paddy prices. DAM data on rice prices summarized in Appendix Table A.2 show less seasonal variability than paddy prices. Conducting this analysis using rice prices would suggest lower financial returns to storage than the results given in this analysis.

$Cons_m$ = Total monthly rice consumption;

$Dist_m$ = Total monthly public rice distribution;

$Proc_m$ = Total monthly public rice procurement; and

m = monthly index

To estimate the household level stocks, disaggregated by farm and non-farm households, we apply the following formula:

$$Total\ hh\ stocks_m = \sum_i (Avg\ stocks_{i,m} * Total\ HH_{i,m})$$

Where:

$Total\ hh\ stocks_m$ = Total monthly household stocks;

$Avg\ stocks_{i,m}$ = Average household stocks;

$Total\ HH_{i,m}$ = Total number of households;

m = month index; and

i = farm and non-farm households

We assume that non-farm rural and urban households stock rice in same proportion in every month. Our estimation of the $Avg\ stocks_{i,m}$ comes from the BIHS survey data.

To estimate the monthly stock held by millers and traders, we apply the following residual method:

$$Millers\ and\ Traders\ stocks_m = Total\ stocks_m - Total\ hh\ stocks_m$$

III. STORAGE AND PRICES IN THE BANGLADESH PADDY MARKET

The scope for private investment in improved grain storage depends on the current distribution of storage services across improved and conventional methods: the smaller the share of grain currently stored using modern methods the greater the potential scope for improvement. The pace of private investment in improved storage capacity depends on the expected return to delayed sales, which is largely based on recent inter-seasonal price variation. This section reviews patterns of production and storage in Bangladesh, examining the roles of smallholders, private intermediaries and the public sector in order to confirm that there is a large share of production that could move from conventional to modern storage. An analysis of historical market prices of paddy is then used to reveal the nature of seasonal price patterns which suggest the potential to profitably invest in improved technology.

Production seasonality and grain storage

The need for storage in a country is related in part to the frequency of harvest seasons. The duration and volume of intra-annual stockholding will tend to be greater when harvests are less frequent, as is the case in countries with a single crop season per year. Given multiple harvests per year in Bangladesh (Aman, Boro and Aus), storage periods are shorter than in other settings, but the seasonality implies harvests during relatively rainy periods, which can challenge post-harvest management and contribute to high storage losses.

Table 1 presents annual rice equivalent paddy production in Bangladesh from the 2008-09 cropping year (November to October) to 2017-18. Over those 10 years, paddy production in Bangladesh increased almost every year and reached 36 million tons in 2017-18. Among the three cropping seasons, Boro is dominant contributing 54% of the total domestic rice output, followed by Aman (39%) and Aus (7%). The dominant cropping season varies across regions of the country. As shown in Appendix Figure A.1, Aman is the most important crop season in the Barishal division, and almost as important as the Boro crop in the Chittagong, Khulna and Sylhet divisions. This production pattern implies relatively short storage durations compared to many other settings.

Table 1: Annual paddy production (million metric tons rice equivalent)

Crop year	Aman	Boro	Aus	Total
2008-09	11.61	17.81	1.71	31.13
2009-10	12.21	18.34	2.13	32.68
2010-11	12.79	18.62	2.33	33.74
2011-12	12.80	18.67	2.16	33.63
2012-13	12.90	18.78	2.33	34.01
2013-14	13.02	19.01	2.33	34.36
2014-15	13.19	19.19	2.29	34.67
2015-16	13.48	18.94	2.13	34.55
2016-17	13.66	18.01	2.71	34.38
2017-18	13.99	19.58	2.78	36.35

Source: Bangladesh Bureau of Statistics (BBS).

The Boro harvest occurs from late April into early June, Aus harvest occurs in August and September, and the Aman harvest is in November and December (Dorosh, Getnet and Smart 2017). Since rice consumption in Bangladesh is essentially stable through the year, this production pattern implies that high volumes of grain must come into storage in May and December to be drawn down continuously over the next 4 to 5 months. The Government of Bangladesh procures and stores grain which is distributed primarily through the public food distribution system (PFDS). This public storage amounts to 5 to 10% of the rice stored, leaving the private sector with 90% or more of the burden of storage. On-farm storage by producers accounts for a large share of private sector stockholding.

Private stockholding

Private stockholders include farm households, millers, and traders. The patterns of storage differ across these groups, with households demonstrating greater seasonal variation in storage volumes. Table 2 presents average monthly stockholding by different types of agents across three years for which data are available. In each year, households are the most prominent stockholders, followed by traders and millers with the public sector playing a smallest role. In 2010-11, the household share of the total monthly average stocks of paddy and rice was 46%, which jumped to 54% in 2013-14. In 2017-18 the share of total monthly average stocks held in households fell to 47%, which still made them the single largest source of stocks of rice and paddy in the country. On the other hand, traders and millers have reduced their share of total monthly stock from 47% of the total in 2020-11 to 36% in 2013-14 and 44% in 2017-18.

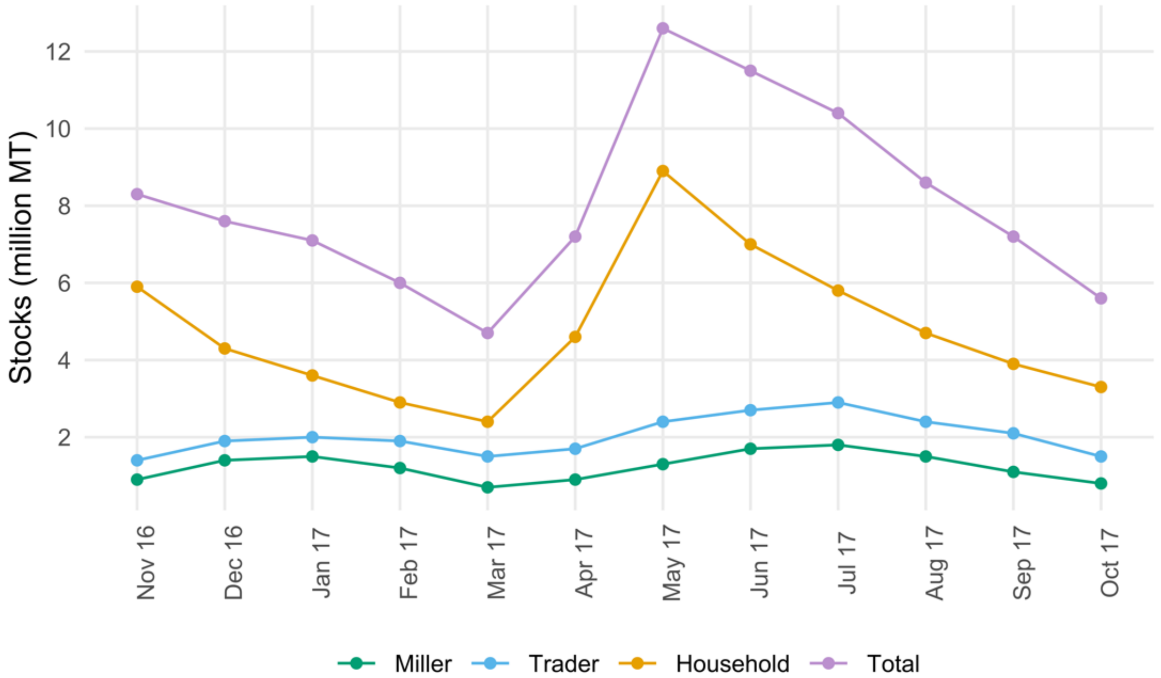
Table 2: Estimated average monthly private and public rice stock in Bangladesh (million metric tons)

Stock level	2010-11	2013-14	2017-18
All Households	4.49 **(46%)**	4.69 **(54%)**	5.16 **(47%)**
Rice Farm Households	3.62 (37%)	3.89 (45%)	3.45 (31%)
Non-Rice Farm Households	0.87 (9%)	0.80 (9%)	1.71 (16%)
Traders/Millers	4.54 **(47%)**	3.08 **(36%)**	4.87 **(44%)**
Total Private Stocks	9.03 (93%)	7.77 (90%)	10.03 (91%)
Total Public Stock	0.73 (7%)	0.86 (10%)	0.95 (9%)
Total Stock	**9.76**	**8.63**	**10.98**

Source: Dorosh et al. 2019 (2010-11 and 2013-14). 2018-19 figures from BIHS. Percent of total in parentheses.

Figure 1 shows the monthly average stock of rice and paddy held by different stockholders for the cropping year 2016-17 as reported in Dorosh et al (2019). The total private stock fell to minimum levels in March and October, coinciding with the immediate pre-harvest months for the Boro and Aman crops respectively. Stocks reached a peak in May when the Boro harvest was active. The stocks had another peak in November, the harvesting month for Aman. The Aus harvest appears to be too small to be perceptible in these data. Households held the majority of the stock and display sharp seasonal changes in stock levels. Traders and millers, on the other hand, maintained more consistent levels of stock in every month. These data suggest that the storage needed to ensure smooth consumption through the year is provided primarily by smallholder producers, with traders and millers storing enough to maintain steady utilization of their capacity. Individuals owning storage capacity confirmed that they generally view storage as an element of some other enterprise, such as milling, rather than a stand-alone activity.

Figure 1: Disaggregated miller, trader, household and total private stocks, 2016-17



Source: Dorosh et al., 2019.

The limited use of modern storage silos by millers and traders is indicated in data on commercial stockholding in Table 3. These data are from the 2018 Millers and Traders Survey implemented by IFPRI in 2018. The data show that in general traders and millers with semi-automatic or husking mills hold very limited stocks, rarely over 100 MT of paddy and rice combined in any given month. These volumes are too low to justify storage in a bulk silo and suggest keeping only sufficient stock-holding volumes to maintain milling operations or trade flows. Automatic mills hold larger stocks, but rarely over 1000 MT of paddy and rice combined in any given month and rarely over 500 MT of either paddy or rice. These stocks are consistent with the volume of grain milled in the operations. The data in Table 3 and Figure 2 suggest that most milling and trading operations find it preferable to maintain a steady flow of grain by purchasing paddy through the year that other agents (e.g., farmers) have stored. If grain storage at mills were significantly more efficient than on-farm storage, one might expect greater purchases by mills at harvest and greater seasonality in stockholding by mills. The absence of such stockholding may reflect the similarity in costs associated with storage in mill facilities and farm households.

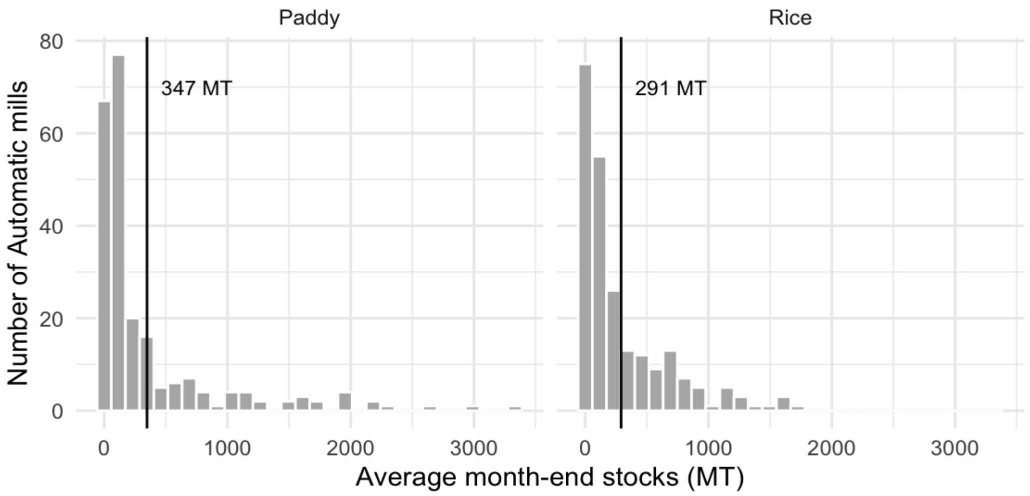
Table 3: Average monthly grain stockholding (MT) by operation type

	Automatic mills		Semi-automatic mills		Husking mills		All mills combined		Traders	
Month	**Paddy**	**Rice**	**Paddy**	**Rice**	**Paddy**	**Rice**	**Paddy**	**Rice**	**Paddy**	**Rice**
Nov 2016	403	184	33	20	26	16	46	25	4.12	6.98
Dec 2016	402	287	31	33	28	21	47	36	5.06	8.46
Jan 2017	396	299	49	39	36	22	56	38	4.72	10.19
Feb 2017	366	265	62	35	50	15	68	30	3.71	10.26
Mar 2017	323	176	90	22	51	6	70	17	1.9	8.59
Apr 2017	245	198	48	24	32	12	45	23	2.46	8.88
May 2017	371	280	32	40	19	27	38	42	5.17	10.8
Jun 2017	424	417	31	50	43	33	60	55	6.23	12.2
Jul 2017	415	459	41	55	55	33	71	58	5.68	13.51
Aug 2017	380	377	44	56	58	26	72	47	3.24	13.08
Sep 2017	334	311	55	49	60	14	73	34	3.18	12
Oct 2017	286	217	47	37	40	6	53	21	2.21	9.29
Average	362	289	47	38	42	19	58	35	3.97	10.35
N, sample	**230**		**237**		**326**		**793**		**471**	**291**
N, weighted	**1,130**		**3,058**		**18,465**		**22,653**		**211,250**	**91,922**

Source: IFPRI Millers and Traders Survey 2018.

Note: Paddy quantity has not been converted to rice equivalent. Rice retailers are excluded. Average stocks are estimated using survey weights.

Figure 2: Distribution of stockholding volumes at automatic mills



Source: See Table 3.

Considering the automatic mills, which are the most likely operations to invest in modern silos, the volume of rice stored is nearly as great as the volume of paddy and follows a slightly different seasonal pattern. The need to store both paddy and rice in separate bins and on a slightly different calendar means that it is unlikely to achieve full capacity in two seasons each year. Because agents are not likely to be at full capacity in both seasons, investors must expect to spread fixed costs of investment over a volume of grain that is less than the technical maximum capacity.

In aggregate, the largest amount of stockholding is undertaken by farmers. Table 4 indicates durations that farm households hold stocks from the two major cropping seasons. A large portion of the Aman harvest is held for three months. Around 36% of the harvest that is not consumed on farm is sold in the harvesting months (November – December), 30% in January, 20% in February, and around 12% in March. We see somewhat more harvest-time sales at the Boro harvest where over 60% of production is sold in May and June (the harvesting months), and around 30% of the harvest sold in July through October. Because household storage methods tend to allow considerable exposure to pests and moisture, the large volume of grain held on farm implies grain losses that could be avoided through commercial storage in modern facilities. Furthermore, the relative concentration of Boro harvest sales in a single month (June) compared to Aman harvest sales which are evenly spread over December through February may suggest pressure to sell harvests coming in rainy months when drying and storage on farm could be especially constrained.

Table 4: Household monthly paddy sales (% of total sales)

Crop year	Aman	Boro
January	29.8	0.0
February	20.0	0.2
March	12.1	0.1
April	0.7	6.7
May	0.0	18.1
June	0.1	45.6
July	0.1	15.2
August	0.0	9.5
September	0.0	2.0
October	1.8	2.6
November	6.4	0.0
December	29.1	0.1
Total	100	100

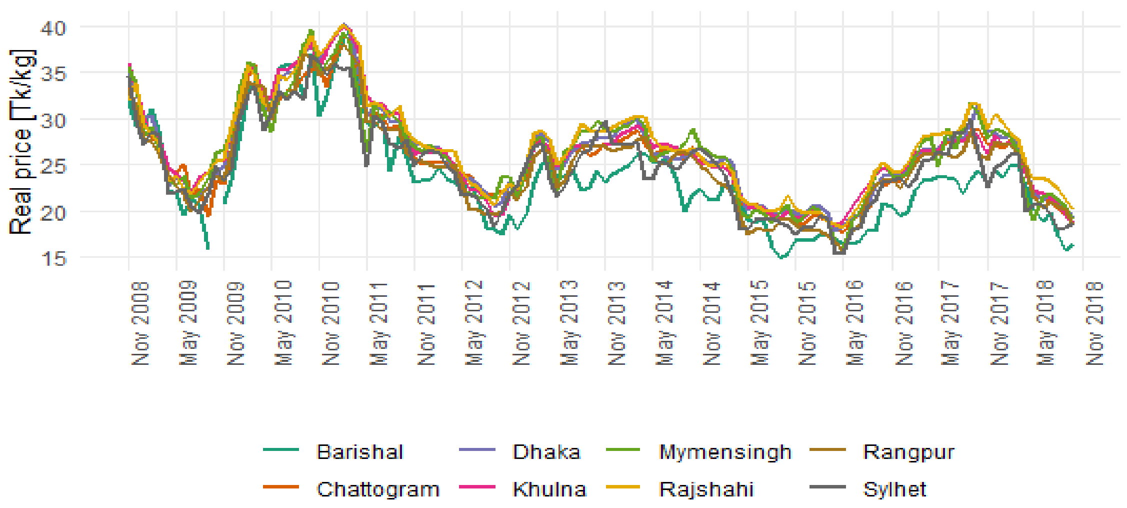
Source: IFPRI short survey 2018, N = 283.

Common storage technologies used by farmers include jute bags, plastic bags, plastic drums, motka, dole and other containers made of natural and permeable materials (Bala et al, 1992; Alam et al 2007). Because of their durability, low cost, and availability, jute gunny bags with capacity of 40 to 100 kilograms, remain the most commonly used storage method among farmers. When such bags are used indoors the on-farm system can approximate storage in a simple warehouse. Polypropylene plastic bags are also widely used in on-farm grain storage. With a storage capacity of 40 to 50 kilograms, plastic bags became popular for their light weight, low price, and widespread availability. Neither jute sacks nor plastic bags offer protection from moisture or pest infestation. Many farmers also use traditional storage technologies such as dole, and motka. In recent years, plastic drums that can be closed with lids have become popular for on-farm storage. Plastic drums last for several years and provide better protection from moisture and pest infestation than the other methods described here but have small capacity and do not seal sufficiently to fully prohibit infestation. All these on-farm techniques may be supplemented with chemical pesticides, but their use is uneven. Overall, only a small share of the country's grain is stored in modern silos or other improved systems, leaving considerable room for technical improvement in storage performance.

Trends and seasonality in market prices of paddy

Review of historical data on market prices for paddy and rice can suggest whether seasonal price movements have been sufficiently large and consistent to offer a return to private investment in modern storage. Because rice is critically important to people's diets and the nation's economy, the government of Bangladesh endeavors to keep the prices for rice and paddy stable at levels that ensure a return to farmers and affordability for consumers. Whether the existing level of price volatility is consistent with profitable storage can be assessed through examination of returns to storage.

Figure 3: Movement of average wholesale price of coarse and medium grain paddy, 2008-2018



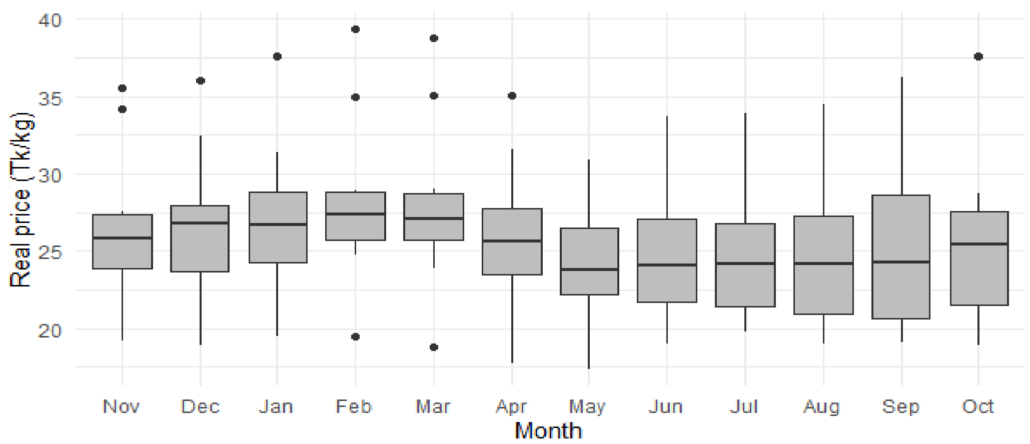
Source: Nominal prices from Ministry of Agriculture, Department of Agricultural Marketing (DAM). Real prices calculated using the consumer price index (BBS), 2017-18.

Note: Data are averages of weekly observations from 68 markets.

Figure 3 presents monthly average wholesale prices for coarse and medium grade paddy in the eight divisions of Bangladesh from 2008 to 2018. The monthly average prices are based on weekly observations from 68 markets around the country. The plot shows a decreasing trend of the real prices over the 11 years period, with significant fluctuation of prices across and within the years. For example, the prices reached as high as BDT 40/kg around February in 2011 and fell to BDT 15/kg in September 2015, and then doubled to BDT 30 over the next two years. In addition to inter-annual variation, the data show seasonal variation in prices. Each of the four pronounced price troughs in 2009, 2012, 2015, 2018 encompass the Boro harvest season in May of the year. Prices tend to increase in subsequent months and then fall again in November at the harvest of the Aman crop. This pattern, however, is not equally pronounced or even apparent in every year. Whether they conform to the pattern of price declines at the Boro and Aman harvest or not, the price dynamics manifest themselves consistently across the eight divisions, indicating that markets are well integrated over space. The impression of spatial price integration is confirmed in formal analysis in Minot et al (2020).

Figure 4 presents a boxplot distribution of paddy prices aggregated over all markets in the data set and over 11 years shown in Figure 3. These data reveal the pattern of seasonal price variability on average over the time period. The average price hits its minimum in May, with the Boro harvest, and increases in subsequent months until it reaches the peak in October, just before the Aman harvest. The increase in average prices in the months following the Boro harvest appears modest, but there is a clear increase in variability of prices during the June-October period as shown in the lengthening of the boxes in the plot. In November average prices fall but not as low as in May, and then remain flat for next two months. The average prices increase again in February and March, falling at the start of the Boro harvest in April. Prices show greater variation in the pre-harvest months of the Aman crop, as seen in the growing spread between the 25th and 75th percentile of prices in September and October.

Figure 4: Monthly variation of wholesale price aggregated over 11 years (2008 – 2018)



Source: See Figure 3.

Note: For each month, the horizontal bar represents the mean over 11 years of data for the markets covered and the box indicates the range from the 25th percentile to the 75th percentile of the distribution of observed monthly prices.

Although Figure 4 reveals a tendency for lower harvest-time prices on average, the pattern does not appear consistently over the years. Table 4 shows observed average monthly price changes in the months following each Aman and Boro harvest from 2008 through 2018. In contrast to expectations, the data show negative price changes during the post-harvest months for many seasons. For example, the paddy price declined by BDT 6.78/kg over the five months starting at the Aman harvest in November 2008 and ending in April 2009, implying an average monthly decline in prices of 8.1%. We observe similar negative changes in market prices in the months following harvest in years 2010-11 (Boro and Aman), 2011-12 (Boro and Aman), 2013-14 (Boro), 2014-15 (Boro and Aman), and 2015-16 (Aman). Among the seasons-years with positive price changes, the average monthly increases range from 0.4% (2013-14 Aman) to 6.1% (2015-16 Boro). For the seasons-years with negative average price changes, monthly rates of decline ranged from -0.1% to -8.1%.

The monthly average price changes in Table 5 suggest the maximum costs that could be profitably absorbed in storage activities. To be profitable, the monthly cost of storing Aman paddy up to the Boro harvest would have to be less than the rate shown in the first column. Similarly, the costs of storing Boro paddy up to the Aman harvest would have to be lower than the rate shown in the second column. The costs of storage include the working capital cost on the value of the grain stored, storage losses, and operating and capital costs of storage facilities. If the cost of capital were 0.75% per month (9% annually), any period for which the average price increase was less than 0.75% would imply a financial loss even if operating costs and physical losses were zero. The data suggest that there have been periods (e.g., 2009-10, 2012-13, 2015-16, and 2016-17) during which storage might have been highly profitable and other periods (e.g., 2008-09, 2010-11, 2011-12, 2014-15, 2017-18) during which it would likely be loss making.

Table 5: Average monthly price change over post-harvest months for Boro and Aman seasons

Crop year	Aman Postharvest [Nov-April] (%)	Boro Postharvest [May-Oct] (%)	Annual [Nov-Oct] (%)
2008-09	-8.1	0.9	-3.2
2009-10	4.5	3.8	3.6
2010-11	-0.4	-1.9	-2.5
2011-12	-1.1	-2.4	-2.2
2012-13	3.3	2.6	1.7
2013-14	0.4	-0.1	-0.5
2014-15	-4	-0.1	-2.5
2015-16	-1.6	6.1	1.9
2016-17	2.3	1.6	1.7
2017-18	-2.6	-2.9	-3.4
Average	-0.73	0.76	-0.54

Source: Calculated as average of monthly real price changes using deflated DAM data for coarse and medium paddy.

Note: Prices are monthly averages of weekly data from 68 markets.

As long as Bangladesh produces the bulk of its rice, a high level of stockholding is needed to ensure continuous availability for consumption. As the pattern of seasonal price variation has not indicated consistent positive returns to storage, household storage cannot currently be a viable commercial activity and trader and miller storage will be limited. At least in many years, smallholders will face economic losses by storing for future sale, but without commercial storage options available, they are left to bear the burden of stockholding. The next sections review technologies that might reduce the costs of storage and encourage more off-farm stockholding which could ultimately further reduce seasonal price variation as well as post-harvest losses.

IV. OFF-FARM STORAGE SYSTEMS: SILOS, COCOONS, AND WAREHOUSE STORAGE

Current stockholding patterns suggest that much of the country's grain is stored using methods that imply high storage losses, with little use of modern technologies. There are a number of technical options for off-farm storage, including bulk storage in climate-controlled silos, use of jute sacks in warehouses and use of jute sacks within hermetic cocoons. Most off-farm storage operations in South Asia rely on jute bags stored in warehouses. Storage in warehouses requires a capital investment in facilities and operating costs including costs of labor, bags, and insecticides. Though effective in controlling pest attacks, the use of synthetic insecticides also comes with increased costs, risk of health hazards due to toxic residues, and environmental contamination (Kumar and Kalita 2017). Moreover, difficulty controlling climate in warehouses can lead to variation in humidity and moisture content, which may allow quality deterioration and food safety risks. On-farm storage is similar to warehousing in the use of jute sacks and possibly insecticides, but may rely on plastic, earthen or woven bins, all of which are subject to moisture variation. Modern systems can reduce losses and pesticide application and may be financially viable if they imply cost reduction compared to conventional methods. This section considers the financial viability of investment in 5,000 MT silos and investment to upgrade warehouse storage by introducing hermetic cocoons within existing structures.

Grain silos

Climate controlled silos avoid problems associated with humidity in warehouses and can allow some scale economies in handling grain. Because they may not seal out all pests, fumigation is commonly used to protect grain in silos from insect damage and grain losses tend to be extremely low. However, silos require a large capital investment and their orientation to bulk grain handling may be inconsistent with existing transportation, handling and marketing systems, creating specific challenges. This financial feasibility analysis for bulk grain silos is based on the technical specifications outlined by the Ministry of Food (2019) in a feasibility report for the construction of steel silos for grain storage. The ministry report prepared a budget for constructing 200 steel silos in 186 Upazilas. Each silo consists of 3 bins, each with a capacity of 1,670 MT, for a total of 5,000 MT storage capacity. In addition to the storage space, the silos include other facilities such as grain drying, cleaning, processing, temporary storage, all of which are needed to ensure functionality of the storage complex. The budget includes the expenses for the land acquisition, machinery purchase and installation, necessary human resources, site management, maintenance operations, and all necessary civil works.

Our financial feasibility analysis for the bulk grain silos uses two investment categories: (a) technology purchase and silo construction expenses, and (b) power/electricity installation expenses. These two items constitute 93% of the total budget. The expenses include the cost for three steel storage bins, grain dryers (16MT/hour capacity), digital weighing scales (60 MT), receiving pit for each bin (8-10MT/pit/hour), cleaning capacity (16MT/hour), processing bins (80 MT/bin), chain conveyor systems, bucket elevators, truck-loading systems with required chain conveyor and accessories set up, electrical and central control system (OTM). Expenses here also include the cost to acquire and develop with necessary civil works 0.392 acres of land. Power/electricity installation costs include purchase of electronic equipment and tools required for installing an electricity sub-station with the capacity of 11 KW (kilowatts) electricity. These investment costs as well as operating costs on a per MT basis are outlined in Table 6.

Table 6 presents three possible scenarios for costs of storage with silos. In all scenarios we assume that grain is stored for 4 months following each of two harvests per year. Specific parameters are listed in Appendix Table A.1. The first scenario assumes 100% capacity utilization, meaning that twice per year the silo is filled to 5,000 MT and then drawn down so that 10,000 MT are stored per year. The second scenario (80% capacity) assumes that an average of 4,000 MT is stored per season, for 8,000 MT annually. This calculation assumes that rigidities in management make it difficult to maximize use of capacity in all storage bins, given the mix of paddy, rice and other grains. The third scenario assumes 80% capacity and also allows for 10% cost over-runs due to unforeseen challenges. These scenarios suggest a minimum cost of storage in silos of about BDT 4,600/MT over a 4-month period. Fixed costs represent the bulk of this expense (BDT 3,375) and variable costs are dominated by the interest charge on grain, based on an annual rate of 9% applied over 4 months to the cost of paddy at harvest time. If we assume less than full capacity in operations, fixed costs rise to BDT 4,175/MT and total costs rise to about BDT 5,400/MT over the 4-month storage period.

Table 6: Cost of stockholding in 5,000 MT silo (2019, 4 months following harvest)

All items per MT per season unless noted as "Full"	**100% Capacity Utilization**	**80% Capacity Utilization**	**80% Capacity & 10% Cost Overage**
Full purchase price of technology (BDT) free of tariff	275,017,500	275,017,500	302,519,250
Full Power/electricity installation/equipment	3,231,000	3,231,000	3,231,000
Full Interest and depreciation (9%) per season	15,999,231	15,999,231	17,580,639
Average capacity used (MT paddy)	5,000	4,000	4,000
Interest and depreciation on equipment & silo per MT	3,200	4,000	4,395
Fixed cost per MT per season	**3,375**	**4,175**	**4,570**
Labor: drying, loading, security and management	305	305	305
Pesticides, fuel and electricity	325	325	325
Working capital	30	30	30
Interest charge on purchase of 1 MT paddy at 18.75/kg held for 4 months	563	563	563
Variable cost per MT per season	**3,375**	**4,175**	**4,570**
Total cost per MT (excluding storage losses)	**4,598**	**5,398**	**5,793**
Storage loss rate (four months)	0.0010	0.0010	0.0010
Storage losses (kg)	1	1	1
Value of storage losses at sales price (25.49/kg)	25	25	25
Total cost per MT of 4 months storage including value of lost paddy	**4,623**	**5,423**	**5,818**

Source: Authors' calculations.

Note: A full set of assumptions and parameters related to these calculations is provided in Appendix Table A.1.

Hermetic cocoons

Hermetic storage in cocoons or silo bags provides an option to modernize warehouse storage. Hermetic storage refers to the use of containers that place an airtight barrier between the grain and outside atmosphere (Omondi et al, 2011; Ben et al 2006; Navarro, 2006). A GrainPro Cocoon, for example, consists of two halves made of Polyvinyl chloride (PVC) or other plastics that are joined together with an air-tight zipper and can enclose bagged grain. The high carbon dioxide concentration inside the airtight container creates an inhibitory atmosphere for the insects and aerobic microorganisms, controlling pests without chemical treatment. In addition to preventing the grains from pest attacks, hermetic storage also controls moisture and maintains the quality of the grains over long periods. Hermetic bags and cocoons ranging in capacity from less than 50 kg to over 300 MT are now available on the market and may be filled with bulk grain or with grain that has been bagged in jute sacks or other containers. Cocoons and silo bags have varying degrees of durability against tears and damage from sunlight. Experimental studies comparing the effectiveness of cocoon storage technology with storage in jute sacks in Bangladesh found the cocoon technology highly effective in preventing pests, stabilizing moisture content, and maintaining germination rate (Alam et al. 2009). Cocoons with 30 MT capacity have been piloted for seed storage by the Bangladesh Agricultural Development Corporation (BADC) in Madhupur, Tangail.

The limited use of improved storage for rice or paddy by private agents restricts the possibilities for using agents' experience as a basis for calculating costs. Instead, we rely on field testing and measurement of technical performance of paddy storage in jute sacks in cocoons in warehouses or open air over the Aman and Boro post-harvest periods in 2019-2020. Field testing by researchers from the Bangladesh Agricultural University (BAU) gathered technical information for five technologies examined here:[3]

1. *Polyvinyl Chloride (PVC, 1,050g/m^2) Cocoon Indoors*, which involves storing jute sacks of paddy in GrainPro PVC Cocoons in a protected setting in a warehouse. For simplicity, we calculate the cost estimates based on a single five-ton cocoon bag (actual capacity 3.6 tons bagged paddy), but results are expected to be generalizable to larger cocoons.

2. *Polyvinyl Chloride (PVC, 1,050g/m^2) Cocoon Exposed*, which involves installing the five-ton GrainPro PVC cocoon on a concrete foundation under open air. Open air treatment avoids the warehouse costs but may affect storage losses and equipment durability.

3. *Polyethylene (PE, 97.5 g/m^2) Cocoon Indoors*, involves storing jute bags in a light-weight hermetic plastic shell. This less durable shell must be kept indoors and has a 2-year product life, compared to 15 years for the PVC cocoons. The field trail used a five-ton PE cocoon and larger versions with 50 MT capacity are available on the market.

4. *Jute Indoors* involves storing paddy using jute sacks in a warehouse or other protected setting. This method can be considered representative of current practice in small mills and in many households in Bangladesh, in which the home itself may serve as a warehouse.

5. *Jute Exposed* involves storing jute sacks of paddy in the open air, which commonly occurs in mills and households.

The cost data for each technology has been converted to per ton of paddy per season assuming two seasons a year (Boro and Aman). Parameters for the cost calculations, reported in Appendix

[3] The field testing was conducted by researchers from the Department of Agricultural Mechanization, Bangladesh Agricultural University on site at a mill near Mymensingh (Moti Auto Rice Mill, Shyamgonj, Netrakona). The test covered two additional cocoon treatments which performed less well than those discussed here.

Table A.1 and Table 7, are obtained from the BAU field study described above. The field study collected technical information on storage losses over 4 months following the 2019 Aman and 2020 Boro harvests. Parameters other than rates of storage loss are constant across Boro and Aman. The results shown in table 6 reflect loss rates following the Aman harvest. Costs differ widely between the heavy-duty PVC cocoon and the lightweight PE version of the cocoon. The PVC cocoon has annualized fixed costs per MT that are similar to those of the silo. While the silo requires a much larger investment, its investment costs are spread over a longer time frame (40 years as opposed to 15) and over a larger volume of grain. The fixed costs per ton stored in the PVC cocoon come to over BDT 4,500/MT/season. The PE cocoon, which lasts only 2 years, has much lower fixed costs per MT per season than the PVC cocoon or silo. Variable costs are equivalent for each cocoon technology and are similar in total to those of the silo, as the interest charge on stored grain represents a large share of these costs. Grain losses are slightly higher for the cocoons than for the silo but are inconsequential in financial terms. Comparison of results in tables 5 and 6 indicate that total costs per MT stored are higher for the PVC cocoon than for any of the scenarios for silos. However, the costs associated with the PE cocoon, which must be kept in a protected environment like a warehouse, are lower than any of the silo storage scenarios.

Table 7: Cost of stockholding in 5 MT cocoon (2019, 4 months following Aman harvest)

All items per MT per season unless noted as "Full"	PVC Cocoon Indoors	PVC Cocoon Exposed	PE Cocoon Indoors
Full purchase price of technology (BDT) free of tariff	145,850	145,850	19,783
Full import tariff (28.9%)	42,150	42,150	5,717
Full Power/electricity installation/equipment	-	-	-
Full Interest and depreciation (9%) per season	14,727	14,727	7,523
Average capacity used (MT paddy)	3.6	3.6	3.6
Interest and depreciation on equipment & silo per MT	4,091	4,091	2,090
Warehouse space, platforms, and jute sacks per MT	712	490	712
Fixed cost per MT per season	**4,803**	**4,581**	**2,802**
Labor: drying, loading, security and management	606	606	606
Pesticides, fuel and electricity	-	-	-
Working capital	27	27	27
Interest charge on purchase of 1 MT paddy at 18.75/kg held for 4 months	563	563	563
Variable cost per MT per season	**1,196**	**1,196**	**1,196**
Total cost per MT (excluding storage losses)	**5,999**	**5,777**	**3,998**
Storage loss rate (four months)	0.0064	0.0070	0.0020
Storage losses (kg)	6	7	2
Value of storage losses at sales price (25.49/kg)	153	178	51
Total cost per MT of 4 months storage including value of lost paddy	**6,152**	**5,955**	**4,048**

Source: Authors.

Note: A full set of assumptions and parameters related to these calculations is provided in Appendix Table A.1.

Conventional warehouse storage

Table 8 presents a cost analysis of stockholding with jute bags in conventional warehouses or in homes. This stockholding approach implies low capital and operating costs, but relatively high costs through storage losses. Use of jute sacks with no hermetic shell implies fixed costs of less than BDT 1,000/ton/season. The variable costs are approximately BDT 1,200/ MT for each technology. Loss rates are much higher for conventional storage, especially if jutes bags are exposed to weather. However, at observed prices, the conventional storage offers much lower total cost, even including the cost of lost grain, than the silo or cocoon technologies at least for Aman harvest paddy. Higher grain losses for the Boro harvest may lead to higher overall costs, as discussed below. The warehouse conditions can be considered as similar to storage indoors in a farmer's home, with the distinction that the warehouse fee is zero for the in-home scenario. Similarly, exposed jute storage will have the same technical specifications whether it occurs at a commercial facility or a farmer's home.

Table 8: Cost analysis of conventional warehouse or on-farm storage: 2019 (Aman harvest)

All items per MT per season unless noted as "Full"	Jute bags in Warehouse	Jute bags in Home	Jute bags Exposed
Warehouse space, platforms, and jute sacks per MT	712	212	212
Fixed cost per MT per season	**712**	**212**	**212**
Labor: drying, loading, security and management	606	550	550
Pesticides, fuel and electricity	139	139	139
Working capital	3	21	21
Interest charge on purchase of 1 MT paddy at 18.75/kg held for 4 months	563	563	563
Variable cost per MT per season	**1,311**	**1,273**	**1,273**
Total cost 4 months of storage per MT	**2,023**	**1,485**	**1,485**
Storage loss rate (four months following Aman)	0.0370	0.0370	0.0820
Storage losses (kg)	37	37	82
Sale price BDT/kg: April 2020, Mymensingh	25.49	25.49	25.49
Value of storage losses at sales price	**943**	**943**	**2,090**
Costs of storage including value of lost paddy/MT	**2,967**	**2,428**	**3,575**

Source: Authors.

Note: A full set of assumptions and parameters related to these calculations is provided in Appendix Table A.1.

V. FINANCIAL RETURNS TO OFF-FARM STORAGE

Financial returns to storage by technology at 2019 prices

Table 9 summarizes the financial feasibility analysis using loss rates observed for the Aman season harvest and observed market prices in Mymensingh in December 2019 (BDT 18.75/kg) and April 2020 (BDT 25.49) to calculate the procurement cost and sales revenue for stored paddy. This table includes two silo scenarios (100% and 80% capacity utilization). It does not include the indoor PVC cocoon, as the use of this system in open air offers lower cost than indoors. The PE cocoon in warehouse is also included. Using the 2019-2020 cost and price parameters from the field study, each of the storage technologies yielded a positive return, but the returns were lowest for the PVC cocoon and silo technologies. Profits per ton of paddy stored for the simulation of the 2019 Aman harvest were BDT 1,317 for the silo at 80% capacity, rising to BDT 2,117 if 100% capacity utilization were assumed. Because the total cost per ton using the PVC cocoon is higher than that of the silo, the estimated profit obtained from storage using an exposed PVC cocoon in the simulation of the 2019 Aman harvest is lower, at BDT 785/MT paddy. The polyethylene (PE) cocoon represents an incremental innovation over conventional warehouse storage in that it provides hermetic protection within a warehouse and presents lower costs that either the silo or the PVC cocoon. Based on the parameters for 2019 Aman harvest, storage using jutes sacks within the PE cocoon could yield greater profits that the silo or the PVC cocoon.

Table 9: Financial feasibility analysis of storage technologies: 2019 (Aman harvest)

All items in BDT/MT for 4 months storage period	5000 MT Silo (80% capacity)	5000 MT Silo (100% capacity)	PVC Cocoon Exposed	PE Cocoon Indoors	Jute Bags in Ware-house	Jute Bags in Home	Jute Bags Exposed
Fixed cost of storage per MT per season	4,175	3,375	4,581	2,802	712	212	212
Variable cost of storage per MT per season	1,223	1,223	1,196	1,196	1,311	1,273	1,273
Storage cost per MT	5,398	4,598	5,777	3,998	2,023	1,485	1,485
Cost per MT including paddy purchase	24,148	23,348	24,526	22,747	20,773	20,235	20,235
Storage loss rate (four months following Aman harvest)	0.0010	0.0010	0.0070	0.0020	0.0370	0.0370	0.0820
Net paddy for sales after stor-age losses (kg)	999	999	993	998	963	963	918
Total revenue/MT stored (based on sales volume)	25,465	25,465	25,312	25,439	24,547	24,547	23,400
Total profit/MT stored	**1,317**	**2,117**	**785**	**2,691**	**3,774**	**4,312**	**3,165**
4-month paddy price increase to breakeven (BDT/kg)	5.42	4.63	5.95	4.04	2.82	2.26	3.29
4 month % paddy price in-crease to breakeven	29%	25%	32%	22%	15%	12%	18%

Source: Authors.

Note: Paddy purchase at BDT18.75/kg, observed market price in Mymensingh in December 2019. Sales price of BDT 25.49/kg based on observed price in April 2020, discounted at 2% for inflation over 4 months. 8% monthly real price increase, implying a 35.9% price increase over the period. A full set of assumptions and parameters related to these calculations is provided in Appendix Table A.1.

Storage losses are negligible under the silo and cocoon technologies in both the Aman and Boro post-harvest periods. By contrast, the paddy that was warehoused in jute bags suffered 3.7% losses in grain weight while the grain stored in exposed jute sacks suffered 8.2% losses following the Aman harvest. Recorded losses over the four months following the Boro harvest came to 5.3% of paddy in jute sacks in a protected warehouse and exceeded 11% for paddy in exposed jute sacks. These loss rates experienced in the field test are similar to those reported elsewhere in the literature (Alam et al, 2007; Bari, 2015; Hossain, 2020). Despite the high storage losses associated with conventional technologies, the projected profits from stockholding following the 2019 Aman harvest in traditional jutes bags indoors or outdoors are substantially higher than the profit from the modern storage technologies. The calculated profits come to BDT 3,744 per ton when stored in a warehouse, BDT 4,312 when stored in a protected in-home space, or BDT 3,165 when stored outdoors (Table 9). Even using the higher loss rates associated with the Boro harvest, profits from conventional storage in warehouses exceed those calculated for improved technologies and the profitability of storage in exposed jute bags is comparable to that calculated for the PE cocoon, the most financially viable of the modern systems (Table 10).

Table 10: Financial feasibility analysis of storage technologies: 2020 (Aman harvest)

All items in BDT/MT for 4 months storage period	5000 MT Silo (80% capacity)	5000 MT Silo (100% capacity)	PVC Cocoon Exposed	PE Cocoon Indoors	Jute Bags in Warehouse	Jute Bags in Home	Jute Bags Exposed
Fixed cost of storage per MT per season	4,175	3,375	4,581	2,802	712	212	212
Variable cost of storage per MT per season	1,223	1,223	1,196	1,196	1,311	1,273	1,273
Storage cost per MT	5,398	4,598	5,777	3,998	2,023	1,485	1,485
Cost per MT including paddy purchase	24,148	23,348	24,526	22,747	20,773	20,235	20,235
Storage loss rate (four months following Boro harvest)	0.0010	0.0010	0.0070	0.0020	0.05	0.05	0.10
Net paddy for sales after storage losses (kg)	999	999	993	998	950	950	900
Total revenue/MT stored (based on sales volume)	25,465	25,465	25,312	25,439	24,216	24,216	22,941
Total profit/MT stored (Boro harvest)	**1,317**	**2,117**	**785**	**2,691**	**3,443**	**3,981**	**2,707**
4-month price increase to breakeven (BDT/kg)	5.42	4.63	5.95	4.04	3.12	2.55	3.73
4 month % price increase to breakeven	29%	25%	32%	22%	17%	14%	20%

Source: Authors.

Note: All cost parameters and prices are held as in Table 6. Boro season loss rates are applied. These loss rates show negligible seasonal variation in cocoon and silo systems. A full set of assumptions and parameters related to these calculations is provided in Appendix Table A.1.

At observed prices for the period in question, the modern systems had increased costs for which the reduced paddy losses did not fully compensate. Even though the storage losses are much higher using conventional storage methods, the high costs of modern storage technologies compared to the low value of avoided grain losses result in low return on investment in these technologies. If in-home storage using jute bags indoors is comparable to warehouse storage in terms of technical outcomes, it competes favorably with off-farm storage using available technologies. These simulation

results favoring conventional storage reflect the relatively low value of the paddy that is lost using conventional storage, given the parameters from the 2019-2020 field tests.

The cost of PVC and PE cocoons used in the financial analysis includes a 28.9% import tariff. Table 11 and Table 12 report the results of a financial analysis if the cocoons are priced at the tariff-free price that might prevail given a tariff waiver or local production. Removing this import tariff would increase the profit to BDT 1,702/MT for the PVC cocoon (exposed) and BDT 3,160/MT using the PE cocoon. The returns to the use of the PE technology imported free of tariff are comparable to those achieved through conventional warehousing in jutes sacks (BDT 3,774/MT and BDT 3,443/MT for Aman and Boro, respectively) and exceed those of exposed jute bags for the Boro harvest. These results suggest that some private agents currently storing in warehouses or open air could profitably invest in PE cocoons, if they were available free of import duty or manufactured locally at a price near the duty-free rate.

Table 11: Financial feasibility analysis of storage technologies, 2019 Aman season loss rates: Tariff-free costing of cocoon technology

All items in BDT per MT per season	5000 MT Silo (80% capacity)	5000 MT Silo (100% capacity)	PVC Cocoon Exposed	PE Cocoon Indoors	Jute Bags in Ware-house	Jute Bags in Home	Jute Bags Exposed
Fixed cost of storage per MT per season	4,175	3,375	3,664	2,333	712	212	212
Variable cost of storage per MT per season	1,223	1,223	1,196	1,196	1,311	1,273	1,273
Storage cost per MT	5,398	4,598	4,860	3,529	2,023	1,485	1,485
Cost per MT including paddy purchase	24,148	23,348	23,610	22,279	20,773	20,235	20,235
Total revenue/MT stored (based on sales volume)	25,465	25,465	25,312	25,439	24,547	24,547	23,400
Total profit/MT stored (Aman harvest)	**1,317**	**2,117**	**1,702**	**3,160**	**3,774**	**4,312**	**3,165**
4-month price increase to breakeven (BDT/kg)	5.42	4.63	4.88	3.55	2.82	2.26	3.29
4 month % price increase to breakeven	29%	25%	26%	19%	15%	12%	18%
Total profit/MT stored with 5% quality premium	**2,590**	**3,390**	**2,968**	**4,432**	**3,774**	**4,312**	**3,165**

Source: Authors.

Note: All cost parameters and prices are held as in Table 6. Aman season loss rates are applied. These loss rates show negligible seasonal variation in cocoon and silo systems. A full set of assumptions and parameters related to these calculations is provided in Appendix Table A.1.

Table 12: Financial feasibility analysis of storage technologies, 2019 Boro season loss rates: Tariff-free costing of cocoon technology

All items in BDT per MT per season	5000 MT Silo (80% capacity)	5000 MT Silo (100% capacity)	PVC Cocoon Exposed	PE Cocoon Indoors	Jute Bags in Ware-house	Jute Bags in Home	Jute Bags Exposed
Fixed cost of storage per MT per season	4,175	3,375	3,664	2,333	712	212	212
Variable cost of storage per MT per season	1,223	1,223	1,196	1,196	1,311	1,273	1,273
Total cost 4 months of storage per MT	5,398	4,598	4,860	3,529	2,023	1,485	1,485
Total cost per MT including paddy cost	24,148	23,348	23,610	22,279	20,773	20,235	20,235
Total revenue/MT stored (based on sales volume)	25,465	25,465	25,312	25,439	24,216	24,216	22,941
Total profit/MT stored (Boro harvest)	**1,317**	**2,117**	**1,702**	**3,160**	**3,443**	**3,981**	**2,706**
4-month price increase to breakeven (BDT/kg)	5.42	4.63	4.88	3.55	3.12	2.55	3.73
4 month % price increase to breakeven	29%	25%	26%	19%	17%	14%	20%
Total profit/MT stored with 5% quality premium	**2,590**	**3,390**	**2,968**	**4,432**	**3,443**	**3,981**	**2,706**

Source: Authors.

Note: All cost parameters and prices are held as in Table 6. Boro season loss rates are applied. These loss rates show negligible seasonal variation in cocoon and silo systems. A full set of assumptions and parameters related to these calculations is provided in Appendix Table A.1.

There is some evidence that modern storage preserves grain quality in ways that result in higher sales prices. The simulations so far assume that paddy stored in conventionally warehoused jute bags and in modern systems fetch the same price when sold. Shukla (2020) reports that hermetically stored grain sold in markets in Bihar State India at a premium of up to 10% based on enhanced quality preservation.[4] Anecdotal reports from key informants suggests a similar premium may exist for paddy stored in modern systems in Bangladesh. As the final line of Table 11 and Table 12 shows, with a 5% premium at sale of stored paddy, the PE technology would yield higher returns than the conventional use of jute sacks for four months of storage following either the Aman or the Boro harvests (BDT 4,432/MT compared to BDT 3,774/MT or BDT 3,443/MT). A silo operating at full capacity could offer similar returns to conventional storage if the 5% premium is realized in the market. Thus, if markets in Bangladesh recognize a quality difference in hermetically stored grain and if cocoons were available duty free, we would expect some private mills and traders who store for multiple months would adopt the technology. Silos may also be attractive to agents who can maintain full capacity and see a premium for silo-stored grain. This conversion to modern storage would imply a reduction of storage losses of 3 to 5 percent on the share of national production stored by these actors (about 45%) that is held for multiple months.

[4] Shukla, 2019 reports results of a field experiment in India that suggested at 10% premium for maize stored in hermetic bags compared to maize stored in jute after 3 months in storage. Casual observations of the authors indicate similar a premium for paddy in Bangladesh.

Retrospective scenarios

The figures in Table 9-12, reflecting storage of Aman and Boro paddy in Mymensingh in 2019-2020, suggest opportunities for profitable storage when there is a wide swing in seasonal prices as experienced that year. However, none of the storage systems would generate a positive financial return given the average seasonal price movements in Bangladesh over the 2008-2018 period. Based on the cost data in tables 5, 6 and 7, in order for storage for a 4-month period using jute sacks in a conventional warehouse to be profitable, the paddy price would need to increase by at least BDT 2.82/kg, or 15% over four months following Aman harvest. The required price increase for a profit using the PVC cocoon, PE cocoon or silo was 32%, 22% and 25%, respectively (BDT 5.95, BDT 4.04 and BDT 4.63 per kg, respectively) (Table 13).

If the PVC and PE cocoons were available at the duty-free cost, the breakeven price increases for paddy fall to 26% and 19%, respectively. If the paddy stored in a hermetic cocoon or silo received a 5% premium at sale, the storage in PE cocoons could be profitable as long as paddy prices rose by 14% over four months after harvest and silo storage would be profitable with a 15% seasonal price increase. Inter-seasonal price increases have often been well below these breakeven rates, suggesting that none of the storage technologies described in the tables would be consistently profitable. The average price increases over the four months following these 10 Aman harvests (5.85%) and 10 Boro harvests (3.1%) seasons were below the level required for profitable stockholding with any of these systems (Table 13).

Table 13: Average paddy prices by season, 2008-09 to 2017-18

Season	Crop year	Purchase price (at harvest)	Sale price (4 months after harvest)	Observed price change (BDT)	Observed price change (%)
Aman	2008-09	33.3	27.4	-5.9	-17.8
	2009-10	26.0	35.0	9.0	34.7
	2010-11	35.8	38.8	3.0	8.4
	2011-12	26.1	25.4	-0.7	-2.7
	2012-13	22.0	27.8	5.8	26.5
	2013-14	27.5	29.1	1.6	5.8
	2014-15	25.2	23.8	-1.3	-5.3
	2015-16	19.0	18.8	-0.3	-1.3
	2016-17	23.4	26.5	3.1	13.0
	2017-18	27.5	26.7	-0.8	-2.9
	Average	**26.6**	**27.9**	**1.4**	**5.9**
Boro	2008-09	23.2	23.8	0.5	2.3
	2009-10	32.3	36.9	4.6	14.3
	2010-11	30.6	28.6	-2.0	-6.4
	2011-12	23.0	20.4	-2.6	-11.2
	2012-13	24.5	27.3	2.7	11.1
	2013-14	26.3	25.9	-0.4	-1.6
	2014-15	19.8	19.4	-0.5	-2.5

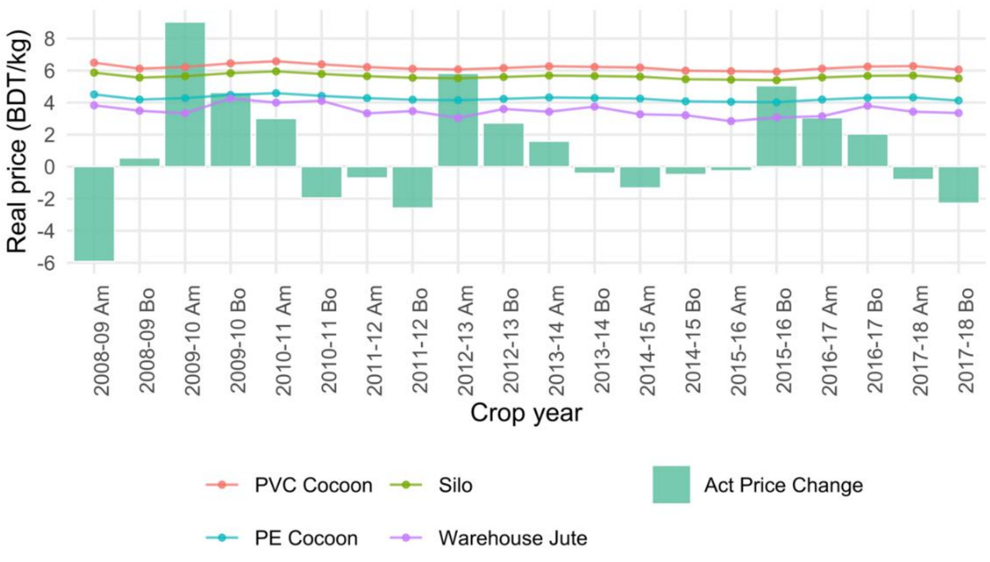
	2015-16	18.2	23.2	5.1	27.8
	2016-17	26.9	28.9	2.0	7.6
	2017-18	21.6	19.3	-2.3	-10.6
	Average	**24.6**	**25.4**	**0.7**	**3.1**
Average		**25.6**	**26.6**	**1.0**	**4.5**

Source: Ministry of Agriculture, DAM.

Note: Average of monthly prices for coarse and medium paddy deflated at consumer price index. Observed November and June prices are purchase price for Aman and Boro, respectively.

Figure 5 compares observed seasonal price changes with the minimum price increase required for commercial storage to at least break even (achieve zero profit) using cocoons (PVC and PE), silos, or jute sacks in a warehouse over the Boro and Aman seasons for the 10 crop years starting in 2008-2009. The figures assume tariffs are paid on cocoon technology and there is no price premium for quality associated with hermetic storage. Storage is profitable when the observed price difference exceeds the required price difference for the given technology. Because the interest charge on stored grain is a significant share of costs and is affected by the paddy price itself, the breakeven prices vary slightly with year-to-year changes in prices. The figure demonstrates that out of the twenty seasons, the conventional indoor storage technology would yield profit for only in five seasons (Aman and Boro 2009-10, Aman 2012-13, Boro 2015-16, and Aman 2016-17). On the other hand, the PE cocoon would yield a profit in four of those five seasons, the silo in two seasons and the PVC cocoon in only one (Aman 2009).

Figure 5: Observed vs. break-even price margin (in real prices BDT/kg) by Boro and Aman season: 2008-17



Source: Authors.

Note: Dashed lines represent the price increase required over the 4 months following harvest to recover storage costs and losses using each technology. The actual price change (shown with the bar column) was calculated by subtracting the harvest month price from the price observed 4 months after the harvest. All prices deflated to real values.

Results thus far indicate that the financial returns to seasonal stockholding using improved storage technology are at best similar to the returns from the conventional use of jute sacks in warehouses or other structures. Moreover, considering seasonal price movements over the 2008/09-2017/18 period, none of the storage technology options could be profitably exploited as an independent commercial activity. Investment in additional storage capacity using these technologies does not appear to be privately profitable, given observed patterns in price movement. To understand the level of public support required to make improved storage technology commercially viable, this section revisits past price patterns while considering the costs of alternative storage methods.

Table 15 presents the profits associated with each storage technology considered given the average price spread observed in each Boro and Aman season from 2008 through 2017 and storage loss rates for Boro and Aman seasons. The results indicate that the PVC cocoon technology would not have been profitable in any of the last 10 Boro seasons and in only one Aman season and that the average loss would have exceeded BDT -4,600/MT paddy stored from Aman harvests and would have reached BDT -5,250 for storing after Boro harvests. Duty free import of the PVC cocoon would not substantially improve its profitability (Appendix Table A.3). The PE cocoon performs only slightly better, being profitable in four seasons of these 20 seasons with average losses of BDT -2,910 for Aman harvest storage and losses of BDT -3,472/MT for Boro harvest storage for an average of BDT -3,191/MT/season. These average losses fall by roughly BDT 400/MT if duty free import had been available. Silo storage (80% capacity) would reach breakeven only in two seasons out of the 20 considered and would yield average financial losses of BDT -4,288 and BDT -4,852 for Aman and Boro harvest storage, respectively, averaging about -4,557/MT/season. At 100% capacity the silo generates about BDT 800/MT/season more, reducing losses to an average of BDT -3,757/MT/season (Appendix Table A.3). The frequency of storage generating profit is similarly low for conventional jute bag technologies, in home or in warehouse, with average losses on the order of BDT -1,745/MT following Aman harvest and BDT -4,008/MT following Boro harvest for an average of BDT – 2,877/MT/season.

As Table 15 indicates, if purchased duty free, the PE cocoon used in a warehouse would imply average losses to storage of BDT -2,794/MT, making it BDT 83/MT less unprofitable than conventional warehouse storage. All other modern technologies are more unprofitable than conventional storage, unless a price premium is secured.

Table 14: Per ton profit and loss estimation for observed price changes over 4 months following harvest

Season	Crop year	Observed price change (%)	PVC Cocoon	PE Cocoon	PE Cocoon tariff free	5000 MT Silo (80% capacity)	Jute bag in warehouse
Storage loss rate (Aman/Boro)			0.1%/0.1%	0.1%/0.1%	0.1%/0.1%	0.02%/0.02%	3%/10%
Aman	2008-09	-17.78	-12,160	-10,381	-9,984	-11,759	-9,200
	2009-10	34.73	3,001	4,780	5,177	3,408	5,739
	2010-11	8.42	-3,316	-1,537	-1,140	-2,906	-686
	2011-12	-2.68	-6,724	-4,945	-4,548	-6,324	-3,707
	2012-13	26.51	-80	1,699	2,096	321	2,868
	2013-14	5.79	-4,477	-2,698	-2,301	-4,075	-1,565
	2014-15	-5.28	-7,323	-5,544	-5,147	-6,925	-4,260
	2015-16	-1.31	-6,054	-4,275	-3,878	-5,660	-2,844
	2016-17	13.01	-2,894	-1,115	-718	-2,493	92
	2017-18	-2.91	-6,867	-5,088	-4,691	-6,466	-3,888

	Average	**5.85**	**-4,689**	**-2,910**	**-2,513**	**-4,288**	**-1,745**
Boro	2008-09	2.33	-5,394	-3,615	-3,218	-4,996	-3,991
	2009-10	14.34	-1,589	190	587	-1,181	-1,489
	2010-11	-6.38	-8,109	-6,330	-5,933	-7,708	-7,188
	2011-12	-11.24	-8,503	-6,724	-6,327	-8,108	-6,766
	2012-13	11.09	-3,257	-1,478	-1,081	-2,856	-2,201
	2013-14	-1.56	-6,440	-4,661	-4,264	-6,040	-5,253
	2014-15	-2.47	-6,319	-4,540	-4,143	-5,924	-4,480
	2015-16	27.82	-732	1,047	1,444	-334	726
	2016-17	7.59	-4,009	-2,230	-1,833	-3,607	-3,118
	2017-18	-10.56	-8,161	-6,382	-5,985	-7,767	-6,319
	Average	**3.10**	**-5,251**	**-3,472**	**-3,075**	**-4,852**	**-4,008**
Average		**4.54**	**-4,957**	**-3,191**	**-2,794**	**-4,557**	**-2,877**

Source: Price data from DAM.

Note: Profits/losses based on costs in Table 6-Table 8. Results for PVC Cocoon tariff free and silo at 100% capacity utilization are shown in Appendix Table A.3.

Table 15 summarizes key results from Table 14 and includes profits if a price premium is secured for well-stored grain. The generally negative profits in Table 15 mean that if private actors consider past seasonal price patterns as indicative of future prospects, investment in improved storage to expand stockholding capacity as an independent business activity is unlikely without some form of government support.

Table 15: Comparative returns to alternative storage technologies

	Average profit (BDT/MT)		
Storage technology	**Aman**	**Boro**	**Total**
5000 MT Silo (80%)	-4,288		-4,852
PE Cocoon	-2,910	-3,472	-3,191
PE Cocoon (Duty free)	-2,513	-3,075	-2,794
Jute Bags in Warehouse	-1,745	-4,008	-2,877
5% premium on selling price*			
5000 MT Silo (80%)*	-2,892	-3,584	-3,222
PE Cocoon*	-1,515	-2,206	-1,860
PE Cocoon (Duty free)*	-1,118	-1,809	-1,463
Jute Bags in Warehouse	-1,745	-4,008	-2,877

Source: Calculated from Table 14.

The incremental impact of shifting from conventional storage in warehouses to cocoon or silo storage is summarized in Table 16. To encourage a business currently storing paddy in warehouses to shift to PE cocoons or silos would require reducing the financial losses associated with the PE cocoons by about BDT 315/MT/season or reducing the losses associated with an 80% capacity silo by about BDT 1,700/MT/season to match losses associated with conventional warehouse storage. If a PE cocoon is imported duty free, converting from conventional warehousing to use of the cocoon would reduce financial losses to storage by just over BDT 80/MT stored, with no additional public support. If silo-stored and hermetically stored grain secures a 5% price premium in the market, the cocoon technologies would be attractive to millers without additional government support and the silo at 80% capacity would require modest subvention (BDT 362/MT). Conversion from conventional warehousing to either hermetic cocoon or silo storage would avoid grain losses of about 64 kilograms per ton stored. A public investment of BDT 362/MT stored would therefore imply a cost of BDT 5.6 per kilogram of avoided paddy losses.

Table 16: Incremental effects of private investment in modern storage

	Without premium			With 5% premium on selling price		
	5000 MT silo (80% capacity)	**PE cocoon**	**PE cocoon (Duty free)**	**5000 MT silo (80% capacity)**	**PE cocoon**	**PE cocoon (Duty free)**
Differential with jute bag in warehouse (impacts of converting from warehouse)						
Incremental profit (BDT/MT)	-1,694	-315	82	-362	1,016	1,413
Loss avoided (KG/MT)	64.8	64	64	64.8	64	64
Cost of loss avoided (BDT/KG)	26.1	4.9	-1.3	5.6	-15.9	-22.1
Differential with home storage (impacts of expanded capacity for commercial storage)						
Incremental profit (BDT/MT)	-4,557	-3,191	-2,794	-3,222	-1,860	-1,463
Loss avoided (KG/MT)	79.8	79	79	79.8	79	79
Cost of loss avoided (BDT/KG)	57.3	40.4	35.4	40.6	23.6	18.5

Source: Calculated from Table 14.

Note: Storage loss rates as shown in Table 14.

To encourage service providers to enter into stockholding as a commercial activity, rather than an aspect of a milling or other business, would require larger co-investments to make stockholding profitable on average, rather than simply less unprofitable than conventional storage. Considering the simulated average losses from storage, additional finance on the order of BDT 2,800/MT/season and tariff free import would be required to attract private sector investment in hermetic storage using PE cocoons (absent any price premium for quality). This investment might reduce loss rates of 8% experienced on-farm and to near zero, saving 79 kilograms of paddy per ton stored at a cost of BDT 35 per kilogram of avoided paddy loss. If hermetically stored paddy sold at a 5% price premium compared to conventionally stored grain and cocoon technology were available at the duty-free price, then a public contribution of BDT 1,460/MT could trigger private investment in cocoons for the purpose of commercial storage, saving 79 kilograms per ton stored at a cost of BDT18.5/kg of avoided loss. As Table 16 shows, significantly higher levels of public support would be required to make expanded capacity for silo storage as a stand-alone commercial activity financially viable. Even with a 5% premium on silo stored paddy, financial losses of over BDT 3,200/MT would need to be offset, at a cost of over BDT 40 per kilogram of storage loss avoided through use of improved storage.

Non-market impacts and social costing

The financial analysis presented above ignores any non-market benefits from improved storage. By preventing gain losses, the use of improved storage technology ensures that environmental resources that are used in grain production are not wasted. Paddy production relies on the use of groundwater and contributes to greenhouse gas (GHG) emission. The social cost of lost grain includes the market value of that grain and also the value of groundwater usage and GHG emission that was associated with that grain, but not priced in the market.

Studies in the region (Mareseni et al, 2009; Yodkhum et al., 2017) suggest that producing a ton of paddy results in GHG emissions amounting to 0.28 tons CO_2 equivalent.[5] There is wide variation in the pricing of CO_2 across markets, but the World Bank's Carbon Pricing Dashboard data (https://carbonpricingdashboard.worldbank.org/map_data) as well as 2015 Carbon Dioxide Price Forecast (www.synapse-energy.com) suggest that a cost of $25/MT (BDT 2,125/MT) is reasonable. Thus, a kilogram of paddy can be considered to carry a social cost from greenhouse gas emission of BDT 0.60 in addition to its market price.

While producer costs and market prices reflect the cost of pumping water for paddy production, they do not include the intrinsic value of the water in the ground. Regional estimates of the value of groundwater vary widely, but review of (Beirkens et al, 2018) suggests a price of US$0.01/$m^3$ (BDT 0.85/m^3) for this context. Paddy production requires 2.5m^3 of water per kilogram (Bouman, 2008) implying that ground water use imposes a social cost of paddy of BDT 2.125/kg in addition to the market price.

The combined estimated costs from groundwater depletion and GHG emission suggest a social cost of paddy of BDT 2.725 above the market price. If every ton of paddy that is converted from warehouse to cocoon or silo storage avoids 64kg of loss, there is a BDT 174 benefit to the country in addition to any private benefits in the market. A movement of grain out of household storage and into modern systems would imply a reduction in loss of 80kg per ton stored, meaning a social gain of BDT 218 per ton stored in addition to the financial impacts shown in Table 16.

Returns to investment in modern storage including the social benefits derived from better use of groundwater and GHG emissions are reflected in Table 17. These results do not substantively change the implications of the findings from the financial analysis. Given the high degree of uncertainty in pricing of GHG and groundwater, these results should be treated as indicative, rather than definitive. They suggest that conversion from conventional off-farm storage to modern off-farm storage may pass a social benefit cost test, but expansion of off-farm storage in place of on-farm storage is unlikely to do so.

[5] The figure of 0.28 tons CO_2-equivalent per ton paddy is the average of the estimates for China, The Philippines, and Pakistan (0.21,0.17,and 0.36, respectively) reported in Maraseni T.N. et al. (2009) and the value of 0.39, reported by Yodkhum et al. (2017) for organic production in Thailand

Table 17: Incremental effects of private investment in modern storage: financial and non-market impacts

	Without premium			With 5% premium on selling price		
	5000 MT silo (80% capacity)	PE cocoon	PE cocoon (Duty free)	5000 MT silo (80% capacity)	PE cocoon	PE cocoon (Duty free)
Differential with jute bag in warehouse (impacts of converting from warehouse)						
Incremental profit (BDT/MT)	-1,694	-315	82	-362	1,016	1,413
Loss avoided (KG/MT)	64.8	64	64	64.8	64	64
GHG value in avoided loss (BDT)	39	38	38	39	38	38
Groundwater value in avoided loss (BDT)	138	136	136	138	136	136
Incremental profit plus values of GHG and groundwater (BDT/MT)	-1,517	-141	256	-185	1,190	1,587
Differential with home storage (impacts of expanded capacity for commercial storage)						
Incremental profit (BDT/MT)	-4,557	-3,191	-2,794	-3,222	-1,860	-1,463
Loss avoided (KG/MT)	79.8	79	79	79.8	79	79
GHG value in avoided loss (BDT)	48	47	47	48	47	47
Groundwater value in avoided loss (BDT)	170	168	168	170	168	168
Incremental profit plus values of GHG and groundwater (BDT/MT)	-4,339	-2,976	-2,579	-3,004	-1,645	-1,248

Source: Calculated from Table 14.

Note: Storage loss rates as shown in Table 14.

VI. IMPLICATIONS AND CONCLUSION

Rice production has consistently increased in Bangladesh over past three decades. The task of storing this increased volume so that it is available for consumers throughout the year falls largely to farm households. With limited access to services or technologies, farmers rely on traditional storage techniques which result in deterioration in the quantity and quality of grain, leading to storage loss as high as eight percent over an inter-seasonal storage period of 4 months. Providing access to modern drying and storage facilities would reduce storage losses and could serve to spread market activity more evenly through the year, moderating price volatility. This paper assesses the financial viability of modern off-farm storage technologies and compares them with conventional warehouse storage currently in practice.

Comparison of the costs of storage with the potential returns to sales up to four months after harvest suggests the following:

1. **Typical seasonal price increases do not compensate for the costs of storage using conventional or modern storage methods.** Over the 20 seasons considered in this study, the financial returns to storing paddy were negative on average and negative in most years, regardless of storage technology used. In order for a storage using the 5000 MT silo to break even financially, prices would need to increase by 25% during the 4 months following harvest. The PVC cocoon, PE cocoon, and conventional warehouse storage require price increases of over 30%, over 20% and 15%, respectively to avoid financial losses. In-home storage offers similar costs and returns as warehouse storage if producers have capacity within their house or sheds. Average seasonal price increases were 5.9% following Aman and 3.1% following Boro season, averaging prices across all districts over a four-month period.

2. **Modern storage technologies under observed prices yield lower financial returns than use of jute sacks in conventional warehouses or in the home.** The physical storage losses avoided through use of hermetic cocoons or modern silos do not compensate for the higher costs associated with these technologies, implying larger financial losses from these modern storage technologies than from conventional methods, under observed prices.

3. **Modern storage technologies could be less unprofitable than conventional storage if there is a sufficient price premium on silo-stored or hermetically-stored grain or if cocoons are available duty free.** Even under these conditions stockholding does not appear profitable as an independent activity. If these conditions held, however, one could expect conversion from conventional to improved storage by traders and millers with consequent reductions in post-harvest losses. We would not expect a shift from on-farm to off-farm storage or the expansion of commercial stockholding as an independent activity.

Taken together, these results suggest little scope for addressing storage losses through commercially provided off-farm storage based on observed market prices. Under the conditions reported here, a storage service provider is unlikely to be drawn into the sector and would be unlikely to be able to offer farmers a service that is financially superior to on-farm storage, from the farmer's perspective. Commercial storage has not been viable given costs and expected seasonal grain price movements. Observed tendencies for mills to only stock sufficient quantities to ensure throughput, leaving farmers to store a large volume of grain, is consistent with these calculations.

In current market circumstances, specialized private agents are unlikely to invest in storage provision, and farmers will continue to keep the bulk of storage under traditional storage methods despite the high storage loss rates of these methods. If there is a public interest in increasing storage to further diminish price volatility or to reduce grain losses, government could co-invest in storage or compensate storage providers. Based on monthly price volatility that prevailed on average from 2008-2017, a supplemental payment of approximately BDT 3,200 per ton stored would make storage a viable commercial activity using a PE cocoon in a warehouse for up to four months following harvest. A somewhat larger payment would be required if silos were used. If payment of BDT 3,200 per ton shifted paddy from low quality in-home storage facing 8% losses into modern storage, 80 kg of paddy could be saved from loss for every ton stored, implying a cost of over BDT 40 per kilogram of loss avoided.

An alternative to incentivizing increased storage by storage-service providers could be to encourage traders and millers to adopt silos or PE cocoons within existing warehouses without increasing their storage volumes. While a payment to entrepreneurs to stimulate increased private storage would need to make the storage activity profitable to have impact, a subsidy to encourage existing traders and millers to convert from conventional to modern technology would only need to make the modern technology less financially costly than conventional practice. Such conversion could reduce storage losses to near zero on grain stored in mills. As mills tend to store for shorter periods of time, their losses may be modest in the baseline and actual loss reduction would likely be lower than 3% in most cases. If PE cocoons were available at the tariff free price, the private agent's cost of PE hermetic storage per ton would fall below the cost of conventional warehouse storage. While expanded storage would remain unprofitable on average, it would become attractive to some actors to shift from current storage practice to reduce costs. Alternatively, an intervention to reduce the costs of using a PE cocoon by BDT 300/MT could trigger their adoption as an upgrade to conventional warehouses. Similarly, intervention to reduce the cost of silos by BDT 900/MT/season could be sufficient to incentivize conversion from warehouses to silos at 100% capacity utilization. If 80% capacity utilization is the operational limit for silo management, then BDT 1,700/MT/season would be required. In any of these cases, the conversion from conventional to modern storage would ensure that GHG and groundwater embodied in paddy would not be wasted. The social value of using these resources could justify a level of public support for investment in improved storage.

As noted above, potential quality differentials from use of hermetic storage or silo storage may be sufficient to trigger conversion and loss reduction with no additional subsidy or with a much smaller subsidy. The existence of any price premium that can be secured through improved storage has not been confirmed through rigorous analysis and may be an important topic for additional research.

Potential actions to promote private investment in improved storage technology include:

1. Waiver of import tariffs on storage technology, such as PE cocoons, to encourage conversion and upgrading of warehouse facilities.

2. Identification of price premiums for grain traits associated with modern storage methods and communication of price premiums to stockholders to incentivize use of improved technology.

3. Evaluation of the social value of preserving grain from loss against the cost of subsidies that would be required to make commercial stockholding with improved technology profitable.

Overall, the implied paddy savings from improved off-farm storage appear small compared to the costs of holding that grain through modern technology as a commercial activity. The implication of this analysis that on-farm storage may be more economical than storage in silos, cocoons or warehouses, suggests that innovations in on-farm systems may have an important role to play in reducing loss and improving farmers' net income. Such technologies could include hermetic bags, or improved metal or plastic bins, among other devices. Access to proper drying technologies, either on farm or through a service provider model would remain a critical precondition for benefits of improved on-farm storage to be fully realized.

Even as storage conditions are critical to ensuring reduced postharvest loss and price volatility, inadequate drying facilities present an important bottleneck to improved postharvest management, especially for the Boro and Aus harvests. Off-farm storage services are unlikely to emerge given current costs and observed price movements. Increased capacity for off-farm drying could, however, be a promising mechanism for addressing losses. Since the benefit of drying is tied to the capacity to store in a moisture–controlled setting, the joint provision of drying and storage services may be an important direction for inquiry.

APPENDIX

Figure A.1: Annual paddy production and share of major cropping seasons by division

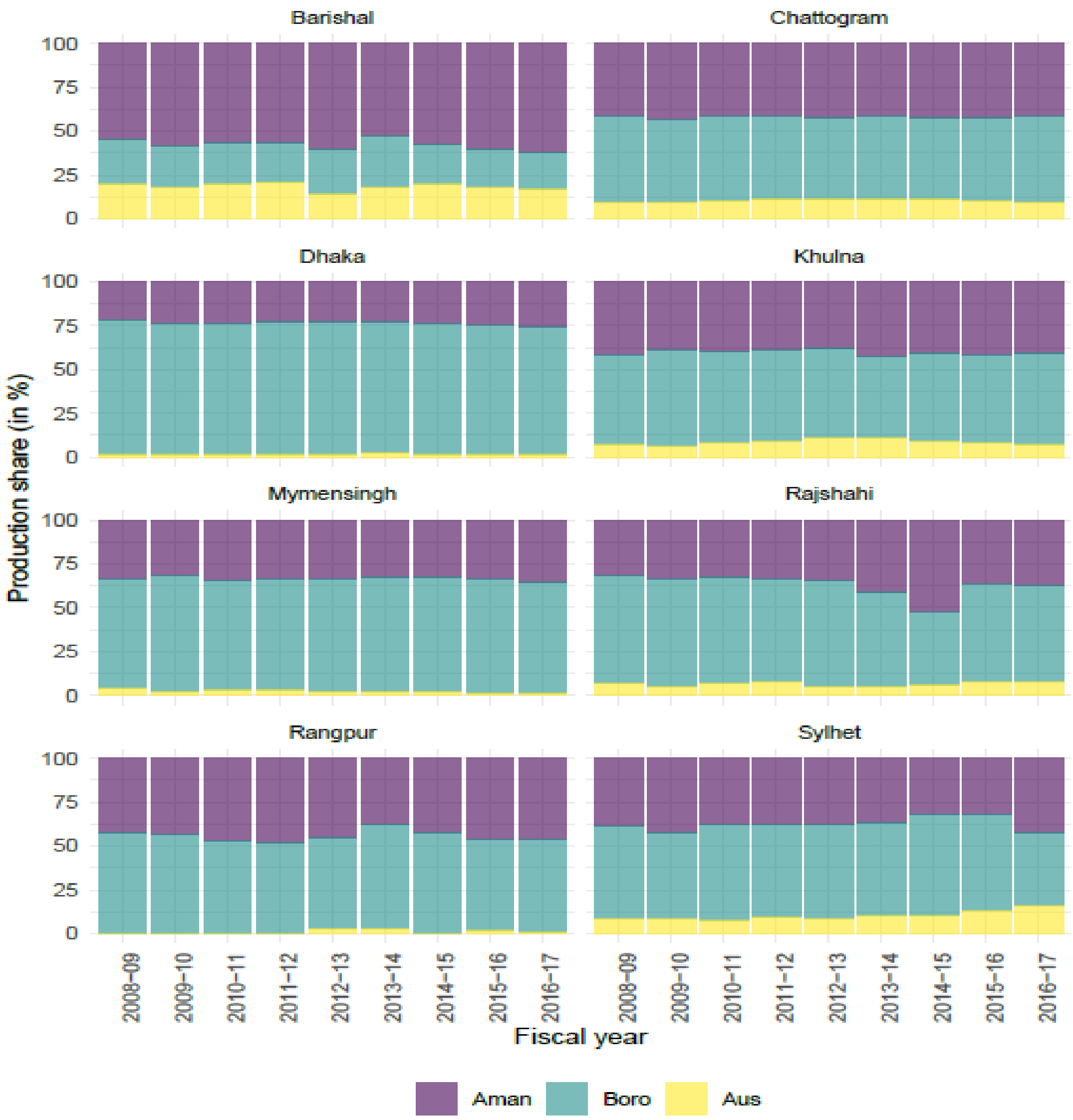


Figure 11: Rice eqv. paddy production (in '000 tinnes), division-wise

Source: Authors.

Table A.1: Parameters used for financial feasibility analysis

Parameters	PVC Cocoon Indoors	PVC Cocoon Exposed	5000 MT Silo	PE Cocoon in Warehouse	Jute in Warehouse	Jute Exposed
Life Expectancy of Technology	15	15	40	2		
Annual Interest Rate	0.09	0.09	0.09	.09	0.09	0.09
Number of Seasons/Year	2	2	2	2	2	2
Cost per Jute Bag (BDT)	80	80	80	80	80	80
Life Expectancy of Jute Bag	3	3	3	3	3	3
Storage Capacity Utilization (MT)	3.6	3.6	4,000-5,000	3.6	1	1
Labor Cost/Kg for Drying (BDT)	0.375	0.375	0	0.375	0.375	0.375
Labor Cost/Kg for Loading & Unloading (BDT)	0.175	0.175	0.175	0.750	0.175	0.175
Cost of platform for 5 Ton co-coon	2000	2000	0	2000	0	0

Source: Authors.

Table A.2: Annual average grain price (real) and Coefficient of Variation (CV)

Crop year (Nov-Oct)	Paddy		Rice	
	Average	CV (%)	Average	CV (%)
2008-09	26.07	16.21	45.74	15.42
2009-10	32.64	11.44	52.38	8.85
2010-11	33.37	12.28	55.65	8.79
2011-12	23.68	10.02	42.72	7.17
2012-13	25.55	8.19	43.71	5.98
2013-14	27.15	4.14	46.43	1.97
2014-15	21.8	12.01	39.59	8.03
2015-16	19.76	9.56	35.57	6.88
2016-17	26.29	7.07	45.22	7.93
2017-18	23.69	14.57	43.41	7.01
Average	**26.00**	**10.55**	**45.04**	**7.80**

Source: Authors' calculations using monthly price data from DAM.

Note: Prices are in real terms using CPI (base year Jun 2019).

Table A.3: Per ton profit and loss estimation for observed price changes over 4 months following harvest

Season	Crop year	Observed price change (%)	PVC Cocoon Tariff-free	5000 MT Silo (100% capacity)	Jute in home
Storage loss rate (Aman/Boro)			**0.1%/0.1%**	**0.02%/0.02%**	**3%/10%**
Aman	2008-09	-17.78	-12,025	-10,959	-9,162
	2009-10	34.73	3,136	4,208	5,777
	2010-11	8.42	-3,181	-2,106	-648
	2011-12	-2.68	-6,589	-5,524	-3,669
	2012-13	26.51	55	1,121	2,906
	2013-14	5.79	-4,342	-3,275	-1,527
	2014-15	-5.28	-7,188	-6,125	-4,222
	2015-16	-1.31	-5,919	-4,860	-2,806
	2016-17	13.01	-2,759	-1,693	130
	2017-18	-2.91	-6,732	-5,666	-3,850
	Average	**5.85**	**-4,554**	**-3,488**	**-1,707**
Boro	2008-09	2.33	-5,259	-4,196	-3,953
	2009-10	14.34	-1,454	-381	-1,451
	2010-11	-6.38	-7,974	-6,908	-7,150
	2011-12	-11.24	-8,368	-7,308	-6,728
	2012-13	11.09	-3,122	-2,056	-2,163
	2013-14	-1.56	-6,305	-5,240	-5,215
	2014-15	-2.47	-6,184	-5,124	-4,442
	2015-16	27.82	-597	466	764
	2016-17	7.59	-3,874	-2,807	-3,080
	2017-18	-10.56	-8,026	-6,967	-6,281
	Average	**3.10**	**-5,116**	**-4,052**	**-3,970**
Average		**4.54**	**-4,822**	**-3,757**	**-2,785**

Source: Price data from DAM.

Note: Profits/losses based on costs in Table 6-Table 8. At 100% capacity utilization, average profits for silo increase by approximately BDT 800/MT.

Table A.4: Millers contacted in key informant interviews

Name of the rice mill	Category	Address	Storage capacity (tons)
M/S Wahed Auto Rice Mill	Auto Rice Mill	Gonoi Mominakanda, Sherpur	2000
M/S Chandan Rice and Flour kal	Auto Rice Mill	Digharpar Road, Nouhata, Sherpur	15000
Fulpur Agro Industries	Auto Rice Mill	Phulpur Mymensingh Highway, Phulpur, Mymensingh	2000
Millers Limited	Auto Rice Mill	Shamvugonj, Mymensingh	1000
Kakoli Agro Industries Limited	Auto Rice Mill	Phulpur, Mymensingh	1840
Akbar Auto Rice mill	Auto Rice Mill	Western Market, Shamvuganj, Mymensingh	2400
New Arafat Auto Rice Mill	Auto Rice Mill	Gohalakanda, Shyamgonj, Purbadhala, Netrakona	1600
Jamuna Auto Rice mill	Semi-Auto Mill	Digharpar Road, Nouhata, Sherpur	3000
Jaker Auto Rice mill	Semi-Auto Mill	Hospital Road, Bazardi, Nakla, Sherpur	200
M/S Sakhina Mini Auto Rice Mill	Semi-Auto Mill	Jhinaigati, Sherpur	350
Fakir Auto Rice Mill	Semi-Auto Mill	Kodaldah Bazar, Ramchandrapur, Tarakanda, Mymensingh	2400
Pachvai Auto Rice Mill	Semi-Auto Mill	Cherag Ali, Anwarkhila, Phulpur, Mymensingh	720
M/S Shampa Auto Rice Mill	Semi-Auto Mill	Digharpar Road, Nouhata, Sherpur	2000
Moti Auto Rice mill	Semi-Auto Mill	Shyamgonj Bazar, Purbadhala, Netrakona	200
M/S S Rice and flour Mill	Husking Mill	Digharpar Road, Nouhata, Sherpur	120
Munshi Rice Mill	Husking Mill	Digharpar Road, Nouhata, Sherpur	200
Talukdar Rice Mill	Husking Mill	Gachtola Bazar, Tarakanda, Mymensingh	48
Juminar Rice mill	Husking Mill	Gopalpur, Char Barabila, Shamvugonj, Mymensingh	192
Cheragali Rice Mill	Husking Mill	Cherag Ali, Anwarkhila, Phulpur, Mymensingh	None
Pachtara Rice Mill	Husking Mill	Tarakanda Bazar, Madhupur, Mymensingh	48
Pachtara Rice Mill	Husking Mill	Tarakanda Bazar, Madhupur, Mymensingh	48

Source: Authors.

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