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Assessing the Impact of Rice Price Stabilization Policies in Bangladesh
Results from a Stochastic Spatial Equilibrium Model

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Abstract

Rice plays a central role in the diet in Bangladesh and as a source of income for farmers. Although Bangladesh has largely liberalized international trade in rice, it maintains a public food distribution system to stablize prices, distributing an average of 2 million tons of rice per year at a cost of almost US$ 800 million per year. This study explores whether alternative policies could achieve similar stabilization at a lower cost. It uses a stochastic spatial-equilibrium model of rice markets to simulate monthly prices in eight regions of the country. Stochastic shocks are used to simulate fluctuations in regional production, replicating historical patterns at the region-season level, as well as inter-regional correlation in production shocks. It also simulates fluctuation in world rice prices, mimicking the mean, variance, and serial correlation of historical wholesale prices of rice in Delhi. Public procurement and distribution follow historic averages by month and region. Private storage is represented by a simplified version of rational expectations models, in which net storage is a non-linear function of availability in the previous month.

One set of simulations tests alternative levels of distribution, finding that cutting distribution to 1 million tons would have minimal effects on the level of rice price stability. Another set of simulations tested different import tariff levels, including the baseline rate of 25%[1]. We find that lower tariffs result in both lower rice prices and less price instability, as world rice prices tend to be more stable than local prices. Simulating a buffer stock with different price bands shows that a narrow band can achieve high price stability but at a high fiscal cost. A 20 T/kg (USD 0.26/kg) price band generates similar price stabilization at a lower cost compared to current policy. However, it is difficult to set the "right" purchase and sale price, and many simulations result in exhausting reserves or reaching warehouse capacity. An adaptive buffer stock, in which the price is adjusted as the stock runs too low or too high, solves some of these problems. In general, the study finds that current procurement and distribution patterns do not match well with the regional and monthly patterns of surplus and deficit, possibly reflecting multiple and conflicting goals of the public food distribution system.

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[1] The import tariff rate was 25% in 2016, the year of calibration, but it changes regularly in response to international prices and policy priorities of the government.

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1. Introduction

Price instability is a fact of life. In a market economy, domestic prices change in response to changes in supply, consumer preferences, policy, world prices, and other factors. Crop prices tend to be particularly volatile because harvests occur only once or a few times per year and because the size of the harvest varies due to weather, prices, and other factors. For internationally-traded commodities, volatility in world prices can be another source of instability in domestic prices.

At the same time, most people are risk averse, meaning they are willing to accept a lower average income in exchange for an income flow with less variability. Evidence of this can be found in the demand for various types of insurance, the fact that risky investments must offer higher rates of return, the fact that employers must pay higher wages for dangerous or short-term jobs relative to safer and more stable positions with similar skill requirements, and the fact that households use savings to maintain stable consumption in the face of fluctuating income.

Low-income food-deficit households are particularly vulnerable to changes in food prices in general and staple grain prices, in particular. This is because staple foods represent a significant share of the expenditure of low-income households, so price changes have a larger effect on the purchasing power and standard of living of these households. Similarly, households that depend on the sale of agricultural commodities are sensitive to instability in agricultural prices.

Thus, it is not surprising that various governments pursue policies to reduce food price instability. The most common strategy is for the government to purchase grain during the harvest and sell it during the off season, maintaining public reserves of grain for emergency use and other periods of scarcity. For example, the Food Corporation of India purchases and distributes roughly 60 million tons of rice and wheat each year (Rashid et al., 2007; FCI, 2017). In Indonesia, the Bureau of Logistics (BULOG) plays a similar role, managing rice imports and distributing more than 3 million tons of subsidized rice through a program called RASKIN (Fernandez, 2015, Rashid et al., 2007). The Ministry of Food in Bangladesh has responsibility for the procurement, storage, and distribution of rice and wheat throughout the country. And in sub-Saharan Africa, grain marketing boards in Kenya, Malawi, and Zambia buy and sell maize and other staples to manage food prices.

At the same time, the costs of managing public procurement and distribution of food grains can be high. The Food Corporation of India receives annual budget support amounting to more than US$ 10 billion per year (FCI, 2017). In Indonesia, the RASKIN rice distribution programme costs US$ 1.7 billion per year (Fernandez, 2015). Given the scale of these programs, it is important to evaluate the benefits they generate.

This paper examines rice price stabilization in Bangladesh and uses a model to simulate the impact of alternative policies on rice price stability. The paper is divided into five sections. After this introduction, we provide some background on food price stabilization, including sources of price instability, international patterns, instability in Bangladesh, and the economics of public grain reserves. The third section discusses the methods used to design and run the simulation model. The fourth section describes the results of the simulations, focusing on the patterns of rice price stability. The final section summarizes the results and discusses the implications for stabilization policy.

2. Background

2.1. International patterns in grain price instability

Domestic food price changes can be the result of changes in demand or changes in supply. A shift in domestic supply may be caused by changes in the cost of production, changes in the price of competing crops, changes in policy (e.g. fertilizer subsidies), or weather-related variation in yields. A shift in food demand may be caused by changes in income, changes in the price of competing foods, or changes in policy (e.g. food price subsidies). Changes in international prices can influence both the supply of imported food and the international demand for domestic food, thus affecting domestic prices. Since consumer demand is relatively stable over time, most of the variation in food prices is related to changes in domestic supply and/or changes in international prices.

Table 1 shows the coefficient of variation (CV) and adjusted CV for wholesale rice prices in various countries, based on data from the FAO Food Price Monitoring and Analysis database[2] (FAO, 2024). Because the original prices are expressed in US dollars, the inflationary time trend is small, and there is little difference between CV and adjusted CV.

The adjusted CV for medium rice prices in Dhaka wholesale markets is 13.6%. This indicates that rice price instability in Bangladesh is relatively low, below the international average of 16.8%. The adjusted CVs of other prices range from 7.9% in Ecuador to 30.6% in Thailand. There are no obvious patterns by region or by importer/exporter status.

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[2] The coefficient of variation is defined as the standard deviation divided by the mean, which is sometimes expressed as a percentage. The adjusted coefficient of variation is the CV of a detrended variable.

Table 1. Price instability in wholesale rice markets

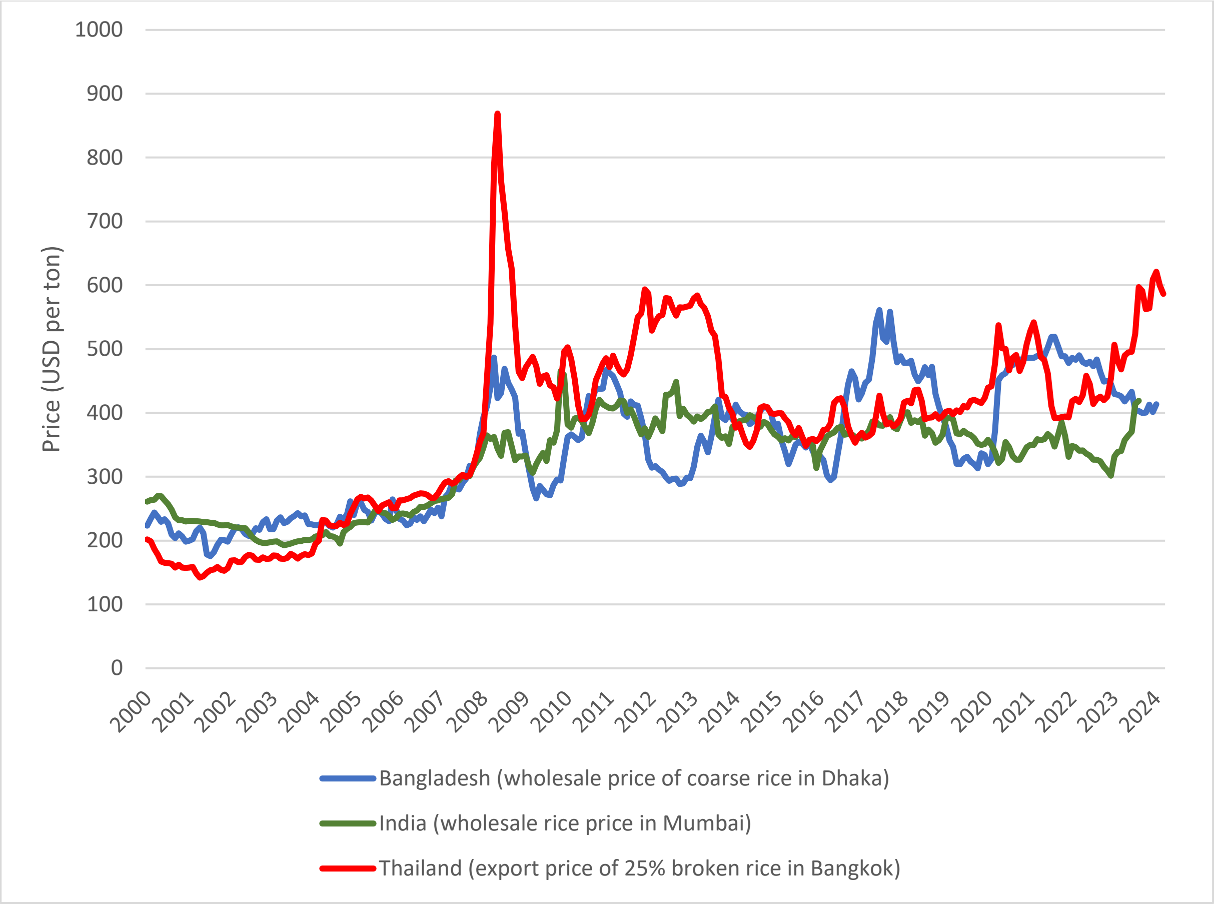
Country	Market	Rice type	Coefficient of variation	Adjusted coefficient of variation
Ecuador	Quito	Long grain	11.6	7.9
Dominican Rep.	Santo Domingo	First quality	9.8	9.2
Myanmar	Yangon	Emata, ehyv-fq	12.6	10.7
Bolivia	La Paz	First quality	11.5	11.0
Viet Nam	An Giang	20% broken	15.3	13.0
Panama	Panama City	First quality	15.0	13.1
Honduras	San Pedro Sula	Second quality	14.1	13.2
Nigeria	Lagos	Imported	13.5	13.4
Bangladesh	Dhaka	Medium	13.9	13.6
Mali	Bamako	Local	13.7	13.7
India	New Delhi	Unspecified	26.5	14.2
Peru	Lima	Milled, superior	18.5	14.7
Nicaragua	Managua (oriental)	First quality	25.5	14.8
Philippines	Metro Manila	Regular milled	33.3	15.0
Brazil	National Average	Paddy	15.5	15.1
Guatemala	Guatemala City	First quality	23.8	15.1
Rwanda	Kigali	Unspecified	16.8	15.5
Uruguay	National Average	Grade 1	27.4	16.4
Niger	Niamey	Imported	17.0	16.9
Cambodia	Phnom Penh	Mix	19.9	17.8
El Salvador	San Salvador	Unspecified	19.1	18.4
Burkina Faso	Ouagadougou	Imported	18.8	18.6
Uganda	Kampala	Unspecified	22.7	19.0
Tanzania	Dar es Salaam	Unspecified	24.7	20.5
Ghana	Accra	Local	27.3	22.0
Mexico	Mexico City	Morelos	27.9	22.4
Colombia	Bogotá	First quality	37.4	23.8
Djibouti	Djibouti	Belem	24.9	24.5
Italy	National Average	Paddy, Arborio Volano	29.1	28.8
Thailand	Bangkok	25% broken	39.6	30.6
Mean			20.9	16.8
Median			19.0	15.1

Source: Authors' analysis of FAO price data (FAO, 2024).

2.2. Patterns of grain price instability in Bangladesh

In Bangladesh, rice prices are strongly influenced by international prices. Figure 1 compares the wholesale price of coarse rice in Dhaka with two benchmark international prices: the Mumbai wholesale price of rice and the Thai price of 25% broken rice, all expressed in US dollars per ton. From 2000 to 2007, the Bangladesh rice price tracked the Indian and Thai prices quite closely. During the 2007-08 food crisis, all three prices spiked, the price in Thailand the most, in Bangladesh less so, and in India the least. Since 2010, the three prices have diverged, at times moving in the opposite direction, but they generally remained within USD 100-200 of each other.

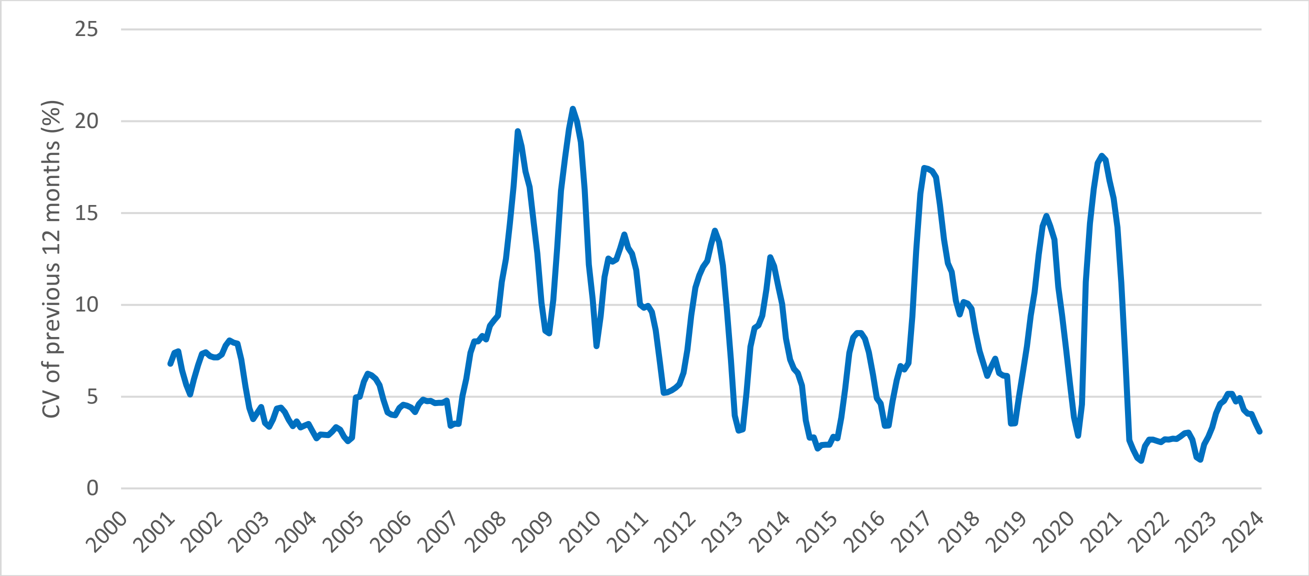
Figure 1. Rice prices in Bangladesh, India, and Thailand



Source: FAO (2024).

We can measure changes in grain price instability. Figure 2 shows changes in rice price instability, measured by the CV of the real wholesale price of coarse rice in Dhaka over the previous 12 months. In other words, each point measures the standard deviation of the previous 12 months of prices as a percentage of the average price over the previous 12 months. The CV of rice prices ranged from just 2% to over 20%. The period of greatest rice price stability over this period occurred between 2003 and 2007 and again since 2022, when the CV was below 5% for most months. The highest points of price instability occurred in April 2007 and June 2008 during the global food crisis of 2007-08. During most of this period, however, the CV of wholesale rice prices was less than 10%, which is low by international standards.

Figure 2. Moving coefficient of variation (CV) of Dhaka wholesale coarse rice price



Source: Analysis by authors using data from FAO (2024).

2.3. Economics of public grain reserves

Economic arguments for public grain reserves focus on ways in which the government may be able to improve the performance of private agents in stabilizing prices. There are at least four types of economic justification for public grain reserves, most of which rely on some type of market failure.

The first possible economic justification is market power. If a group of grain traders were able to collude, they could make monopoly profits at the expense of society. To do this, they would need to control a large share of the storage capacity, to agree to act together, and enforce this agreement on each other. The agreement would involve storing *less* than what they would in a competitive market, thus lowering the harvest price and raising the off-season price, which increases the returns from storage. This is not an easy task, given the large number of traders and millers, the risk of “cheating” (agents who store more than agreed to), and the possibility that farmers or other agents will store grain in response to the increased profitability.

The second possible justification is imperfect information. If the government has better information about future market conditions, they could do a better job of knowing how much needs to be stored for future needs. This argument was probably more persuasive in the 1960s and 1970s when private markets and communication infrastructure were less developed than it would be today (Rashid et al, 2008).

The third rationale is economies of scale in storage. If large-scale public grain storage costs less than private grain storage, this would be a possible justification for maintaining public grain reserves (Newberry, 1989). This argument has been undercut by studies showing that public grain storage tends to have higher costs than storage in the private sector.

Fourth, public grain storage could be justified by the absence of insurance and futures markets that consumers and farmers could use to hedge against risk associated with unstable prices. When markets are "missing", the outcome of competitive markets is not necessarily optimal. In this situation, public-sector efforts to stabilize rice prices, including grain reserves, could be justified as a second-best solution (Newberry and Stiglitz, 1981: 207).

Finally, public reserves to stabilize grain prices may be justified on the grounds of equity. Poor consumers tend to spend a large share of their budgets on staple grains and are risk averse. The government may have an interest in grain price stabilization to protect poor households from food insecurity (Turnovsky et al, 1980). As mentioned above, competitive private-sector grain storage does not eliminate price instability, so the government may take measures to further stabilize prices.

Regardless of economic arguments, political pressure is often brought to bear during periods of extreme prices. Consumers lobby for intervention when grain prices spike, and farmers may protest during gluts when prices are low (Islam and Thomas, 1994; Poulton et al, 2006). Wright and Cafiero (2011) make the point that "governments are pressured by power consumers to force traders who have accumulated grain to surrender stocks to the government… to limit 'speculation' in grain markets… Anticipation of such treatment discourages private storage in times of plenty, for distribution at a high price in time of need."

Even if private traders are not accused of hoarding, the operation of public grain reserves to stabilize prices will reduce the incentive for private traders to store grain. In effect, public grain reserves tend to displace some private storage activity. This displacement raises the possibility that public grain stocks may actually increase food price instability. This could occur if the public stocks are not managed well so that they are less effective in smoothing grain availability than the private stocks they displaced would have been.

Arguments against public grain reserves often focus on the high cost of managing them, the potential for corruption or favoritism in procurement and/or distribution of grain, and the fact that government agencies managing the reserves may be slow to respond to evolving market conditions. Procurement and distribution decisions are often subject to intense political pressure from farmers lobbying for higher grain prices and/or consumers demanding lower prices. Sometimes, governments concede to both groups, paying above-market prices and selling at below-market prices, resulting in operating losses and fiscal costs to taxpayers (Newberry and Stiglitz, 1981; Rashid et al., 2008).

2.4. Research on storage and public grain reserves

Economic research to simulate the operations of public grain reserves focuses on the case of buffer stocks, which have clearly defined rules for buying and selling stocks. A buffer stock is usually represented as defending a price floor by being willing to buy unlimited quantities at that price and defending a price ceiling by being willing to sell unlimited quantities at that price. These operations keep the market price in the band between the two prices.

A key contribution to the study of grain storage under uncertainty was made by Gustafson (1958), who developed an approach to identify optimal storage rules given stochastic harvests. This approach only worked, however, when supply was assumed to be perfectly inelastic. Wright and Williams (1982) extended this analysis to take into account the case where supply responds to market prices. Williams and Wright (1991) provided a comprehensive analysis of the impact of buffer stock operations in the context of competitive price-sector trade with rational expectations. They found that the market price rarely stays in the center of the band; instead, it is often "challenging" the price ceiling or the price floor. Because private storage is less profitable, there is more price volatility near the price ceiling as a result of the buffer stock, though of course the buffer stock eliminates the risk of the price exceeding the ceiling. Furthermore, there is no long-term tendency for sales and purchases to offset each other. Their simulations show that the costs will eventually grow unsustainably.

Gouel and Jean (2013) expand this model to take into account international trade. They assume a market for a storable commodity in a small open economy where world price is given, per-unit transport is constant, consumers are risk averse, and domestic food price volatility is driven by both stochastic output shocks and a stochastic world price. The optimal trade policy to stabilize prices in the absence of storage consists of subsidizing imports when availability is low and the taxing of exports when both availability is bountiful and the world prices are high. By combining trade policy and public grain storage, the price of grains is significantly more stable than in the absence of these policies. However, the redistribution of benefits between producers and consumers is large compared to the efficiency gains. In addition, the effect of these policies on international trade, if implemented by many countries, would exacerbate grain price spikes in world markets.

The choice of price band has major implications for the fiscal cost, the necessary storage capacity, and the impact on the food prices. One important dimension of the buffer stock rules is the width of the price band. A wide price band would limit purchases or sales to cases of serious shortages or a large surplus. Thus, government intervention in the market would only occur every few years. The cost and storage requirements would be relatively small, but the degree of price stabilization would also be modest. It would reduce inter-annual price instability but leave seasonal cycles largely unaffected. A narrow price band would have the opposite effect, increasing the degree of stabilization but at a higher cost and with more frequent intervention.

Another dimension of the buffer stock rules is the level of the price band. If the price band is set too high relative to the market price, the buffer stock will be purchasing more often than it is selling, resulting in the accumulation of larger stocks each year. Storage capacity or budget constraints will eventually prevent further purchases, making it impossible to continue defending the floor price. Conversely, if the price band is set too low, the buffer stock will be selling more often than it is buying. Eventually, the stock will be exhausted, and it will be impossible to continue to defend the ceiling price.

Because of uncertainty regarding the “normal” market price, it is often recommended that buffer stocks use a moving average of the previous 3-5 years as the mid-point for the price band (Knudsen and Nash, 1990). However, simulations by Williams and Wright (1991) suggest that it is very difficult to defend a price band with a finite budget. Eventually, the government will not be able to “defend” the price band, at which point the market price will become erratic.

Finally, there is the issue of whether the price band is the same across all buying stations or not. If all stations are defending the same price band (pan-territorial pricing), it will reduce or eliminate the incentive for private traders to move grain from one location to another. Depots in surplus zones will be paying above-market prices and will be forced to purchase the entire surplus. Meanwhile, in deficit zones, the depots will be selling at below-market prices, so they will be forced to supply large quantities of grain. The buffer stock becomes a grain marketing parastatal, responsible for all grain transport from surplus to deficit zones. Furthermore, the grain transport will be done at a loss because the price difference will often be less than the cost of transport, particularly if the band is narrow.

Alternatively, if each station sets a different price band, it would be possible to maintain incentives for private traders to move grain from deficit to surplus zones. To achieve this, the mid-points of the price bands would have to be set according to the normal market price in each location. This means that the price difference between locations would be large enough to motivate private traders to handle transport in normal years.

The above is an idealized view, in which the buffer stock has one objective (price stabilization) and makes purchases and sales based on a clearly defined price band. The actual operation of public food reserves is more complicated, as discussed below.

2.5. Public grain reserves in Bangladesh

Since independence in 1971, Bangladesh has moved progressively from a government-managed grain market to one in which markets play a much larger role. In the 1970s and 1980s, Bangladesh operated a grain rationing system in urban and rural areas, combined with numerous restrictions on private sector grain trade. A number of studies in the 1980s demonstrated both the high cost of the grain rationing system, and the fact that much of the grain was “leaked” to non-poor households. In the late 1980s and early 1990s, Bangladesh removed restrictions on internal movement of grain, phased out the rural rationing program, and legalized the private-sector imports of rice and wheat. The combination of social safety net programs and private-sector grain imports are credited with the successful response to the extensive 1998-9 floods (Ali et al, 2008).

Bangladesh maintains a system of public procurement of rice and wheat, a network of public warehouses, and open market sales of grain. However, the procurement price is not a floor price in that the government does not attempt to "defend" the price by purchasing all available grain at those prices. Similarly, the open market sales are limited in quantity, so they do not represent an effective ceiling price. Although some research has questioned the economic rationale for price stabilization (Goletti, 2000), there is political support for continued public grain procurement and open-market grain sales.

Various studies have attempted to study the impact of price stabilization. Building on the work of Ahmed and Bernard (1989), Shahabuddin (1991) presented a model for rice and wheat price stabilization in Bangladesh. This model was used to estimate the volume of domestic procurement and open market sales of food grains that are needed to support prices during the harvest seasons and accommodate the prices during peak seasons with a fixed price ceiling for price stabilization. Using a fixed floor (procurement) price and a fixed ceiling (sales) price, the results indicate that most procurement would take place in the *aman* and *boro* harvests. The model indicated that there was hardly any seasonality displayed in the ration (monetized) distribution of food grains. The offtake in rice and wheat, which comprised for nearly 60% of the sales by the Public Food Distribution System (PFDS) and roughly 7% of the market supply, acted as a cushion for market rice prices in Bangladesh. On the other hand, open market sales of rice showed notable seasonality in the model, specifically in the lean season where higher prices were predicted, versus the harvest season where low prices were predicted. One limitation of the model, however, is that the model assumes that the government is fully responsible for price stabilization, with no role for the private sector.

Dorosh and Haggblade (1997) use a partial-equilibrium model to simulate the impact of potential food-aid monetization which would shift poverty assistance away from food-for-work (FFW) programs with in-kind deliveries of wheat to a cash-for-work (CFW) program. Food aid would be monetized (sold at market prices), and cash transfers would be provided to beneficiaries. The results indicate that the program would improve beneficiary welfare and reduce commodity handling costs which have the potential to lead to an increase in available funding for development and poverty-alleviation programs. Replacing the FFW program with a monetized CFW program would alter the seasonality of wheat prices, lowering lean season prices and raising harvest season prices which would greatly benefit poorer households.

In an analysis on the value of price stabilization and the management of public food grain stocks in Bangladesh, Goletti (2000) says that demand for government price stabilization is in decline. He argues that price stabilization in Bangladesh has provided very small microeconomic benefits, undeterminable macroeconomic benefits, and negligible effects on poverty. Seasonal and inter-year price fluctuations have diminished because of significant growth of the *boro* rice harvest, and the expanded activity of private traders who are motivated to import grains during domestic shortfalls. However, price stabilization and the scale of public intervention remain important politically, rather than economically. He argues that 700,000 to 800,000 tons would be sufficient for emergency needs. At these stock levels, there would be an estimated savings for the public food program of about $130 million per year.

Dorosh and Shahabuddin (2002) examine the causes of grain price instability in Bangladesh, arguing that it is primarily the result of fluctuations in production, due to floods and droughts. According to their analysis of rice price data over 1970s-1990s, the annual fluctuations in nominal prices of rice in Bangladesh were more stable in the 1980s compared to the 1970s. However, in the 1990s fluctuations in rice prices increased. Agricultural seasonality remains an issue among the poorer populations; vulnerable households can slip into poverty temporarily, and those who are poor experience more hardships. The ratio of seasonal peak price to trough price showed a gradual decline over time, with the most significant decline occurring between the 1980s and 1990s.

Before liberalization of the private rice trade in 1994, government imports and stock policies were the two factors most responsible for determining rice prices. As a result, the Bangladesh market was partially protected from world market fluctuations. After liberalization, domestic rice prices of the 1990s were below import parity levels. Over 1970-2000, world prices of rice became more stable as the volume of world trade increased. Bangladesh domestic rice prices were relatively as stable in the 1990s. Bangladesh rice prices (in local currency terms) were marginally more stable than international (Thai) prices, but less stable than Indian prices.

Through trade liberalization, the import parity price sets a ceiling on domestic prices. Del Nino et al (2001) show that private-sector imports were instrumental in stabilizing rice prices in Bangladesh for 1997/98 as well as 1998/99 after major rice production shortfalls. The reason that prices did not rise any further during this time was that competitive private-sector importers were able to import the grain necessary to meet domestic demand. While private sector imports have provided stable prices, one cannot rule out the need for rice stocks. The sales of subsidized government imports can avoid price spikes caused by domestic production shortfalls combined with high international prices.

Similarly, Dorosh (2001) analyzes trade liberalization and its effects on food security and price stabilization. Because of the late 1990's rice production shortfalls, Bangladesh's private sector importers relied heavily on Indian rice harvest imports in order to alleviate Bangladesh's food security problems. Dorosh (2001) raises the question of whether the private sector and international markets can be relied on as a source of food grain. The analysis shows that there is low correlation among Indian and Bangladesh rice harvests. Nonetheless, one cannot completely rule out the possibility of India and Bangladesh having poor harvests in the same year. He recommends that the Bangladesh government prepare itself for such a situation. In this case, rice imports would most likely come from Thailand which would come at a higher cost than if imported from India. For these reasons, continued government support of private import trade is essential. Because of trade liberalization in both

India and Bangladesh, large-scale trade took place and private sector importers were able to help to prevent a food crisis in the late 1990s.

Brennan (2003) developed a model of Bangladesh grain markets that government intervention takes place in the context of competitive storage by private-sector agents using rational expectations. The paper examines the effect of private storage, government subsidization of storage, and government imposition of a price ceiling on the distribution of market prices over time. The key findings from this analysis were that the more inelastic the demand, the greater the incentive to store, which led to lower prices in times of oversupply and higher prices in times of shortage. In turn, the increase in storage under inelastic demand led to a higher consumption stability. The reverse was found to be true for more elastic demands, which lowered the incentive to store and increased the variability of consumption. She also found that government stockholding tends to displace private sector storage because the price ceiling reduced the incentive for private-sector storage during periods of lower production. In general, price ceiling methods were found to be unfavorable due to the large amount of stock that the government would need to hold, the government's infrequent participation in the market, and overall variability in prices. The option of public subsidization of private sector storage would be a cheaper alternative for stabilizing rice prices, but this policy does not always prevent price spikes. If the goal is to protect poor urban consumers by preventing extreme price peaks, then buffer stock schemes with a price ceiling are a better choice than the subsidization of private storage. One limitation of this study is that the model assumes a closed economy, meaning that there are no grain imports or exports. As discussed above, grain imports have proven to be an effective way to prevent price spikes at no fiscal cost.

Rashid et al (2005) reviews the benefits associated with grain market liberalization, particularly the legalization of private-sector grain imports. Until the early 1990s, the government of Bangladesh maintained a monopoly over international grain trade, and restrictions on the movement of grains by the private sector. Concessional credit to government operations and preferential access to transportation were also used to discourage private-sector trade. The government paid higher import prices for grain than the private sector, even when the government's imports were much greater than those of the private sector.

Allowing private grain trade and stabilizing grain prices around the international parity price in Bangladesh had a large payoff. The savings associated with the addition of private-sector imports were an estimated 3.22 million tons of grain over the ten-year time span of 1992/93-2001/02 which is roughly $422 million USD. In addition, liberalization contributed to an overall decline in the annual public distribution of rice and wheat. Price stability was not threatened by reforms which were accomplished through the PFDS. Because of these savings, Bangladesh has been able to allocate additional resources to development and anti-poverty projects. In general, investments in agricultural productivity, roads, education, and safety net programs are considered a better investment than price stabilization (Rashid et al, 2005; Ali et al, 2008).

3. Methods and data

3.1. Description of the Bangladesh Rice Market Model

To study the impact of policy alternatives on rice price stability, we develop a stochastic spatial-equilibrium monthly model of rice markets in Bangladesh. As a spatial-equilibrium model, it represents markets in the eight Divisions of Bangladesh. Flows of rice between Divisions are determined endogenously depending on spatial arbitrage. In other words, rice flows from one Division to another whenever the difference in prices is large enough to justify the cost of transporting rice from one to the other.

The model simulates the markets for rice in Bangladesh. We focus on rice because it is the most important food item in the Bangladesh diet, accounting for 66% of the caloric intake (FAO, 2023). Furthermore, as a staple grain, rice is particularly important for food security in a country where 24.5% of the population lives below the poverty line. Rice also accounts for the vast majority of food stocks held by the government of Bangladesh.

Although spatial equilibrium models of agricultural markets are relatively common, the Bangladesh Rice Market Model is distinct in three ways.

- First, the model incorporates stochastic production shocks, in that it simulates random variation in rice production, replicating historical patterns in terms of the degree of variation in production in each of the three seasons and each Division as well as correlations across Divisions in the size of the harvest.
- Second, the model simulates random shocks in international prices, based on the historical patterns of price volatility in the New Delhi wholesale rice market. This allows us to compare the stability of rice prices under a policy of free trade, where local markets are subject to international volatility, and various levels of import restrictions, where local markets are partially insulated from international markets but subject to instability due to domestic supply shocks.
- Third, it is a monthly model, to make it more useful to policymakers. Most spatial-equilibrium models are comparative-static models (without a time dimension) or annual stochastic. Making the model monthly implies the need for decision rules for how much rice the private sector and the Ministry of Food decide on changes in stocks.

To simulate the impact of alternative policies on rice price stability, we run the model for 200 years. We are not forecasting rice markets over time, but rather repeating the current year 200 times to determine the long-run average level of rice price stability[3]. The model is designed and implemented using the General Algebraic Modeling System (GAMS). GAMS is a language designed to represent systems of equations with indexes to

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[3] For example, the coefficient of variation (CV) of the rice price varies considerably as the number of years increases up to around 150 years. By 200 years of simulation, the estimate of the CV has converged and additional years of simulation have little effect on the estimate.

represent multiple regions, commodities, and time periods. The IFPRI Bangladesh Rice Market Model is composed of ten sets of equations. The details of the model and the ten equations are provided in Appendix A.

3.2. Data used to calibrate the model

To make the Bangladesh Rice Market Model accurately represent grain markets in Bangladesh, we need to calibrate it using data on production, consumption, prices, the cost of transportation, and the cost of storage in Bangladesh. In general, the model is calibrated to represent production, consumption, and prices from 2016 because household survey data from 2016 is an important source of data. However, for stochastic variables, we calibrate the model using variation over the ten-year period from 2007 to 2016.

For consumption, we use estimates of per capita rice consumption in urban and rural areas of each Division from the 2016 Household Income and Expenditure Survey (HIES). These numbers are converted to Division-level aggregate consumption by using population estimates from the 2011 Population Census and assuming 1.0% annual growth in population between 2011 and 2016. We assume that the demand curve for rice is constant over the 12 months of the year, though the quantity of rice consumed will vary by month depending on market prices and it will vary across Divisions according to the consumption patterns in the HIES.

For production, we use rice production estimates from the Bangladesh Bureau of Statistics (BBS). Because of the unusual shortfall in boro rice production in 2017, we use production in calendar year 2016 rather than the agricultural year 2016-17. Because rice production is one of the stochastic variables in the model, we need estimates of the variability in rice production over time by season and by Division. We use the detrended coefficient of variation of rice production by season and by Division over the period 2007-2016.

In analyzing rice production patterns in Bangladesh, we did not find any correlation over time, that is, between the size of the aman rice harvest and the subsequent boro harvest. However, there is cross-Division correlation in the rice harvest for each season, as shown in Table 2. The table shows that most of the correlations are positive, but less than half are statistically significant (as indicated by the asterisks). The highest correlations are in the boro season between Dhaka and Mymensingh and between Dhaka and Barishal. A few pairs show negative correlations, such as the aman season rice production of Rangpur and Khulna.

Table 2. Cross-Division correlation of rice production by season

	Barishal	Chattogram	Dhaka	Khulna	Mymensingh	Rajshahi	Rangpur	Sylhet
Boro season								
Barishal	1.00							
Chattogram	0.76 ***	1.00						
Dhaka	0.91 ***	0.64 **	1.00					
Khulna	0.85 ***	0.67 **	0.70 **	1.00				
Mymensingh	0.77 ***	0.44	0.92 ***	0.64 **	1.00			
Rajshahi	0.84 ***	0.67 **	0.84 ***	0.49	0.73 **	1.00		
Rangpur	0.52	0.42	0.46	0.39	0.48	0.54 *	1.00	
Sylhet	0.58	0.13	0.83 ***	0.33	0.89 ***	0.64 **	0.37	1.00
Aus season								
Barishal	1.00							
Chattogram	0.24	1.00						
Dhaka	-0.21	0.26	1.00					
Khulna	-0.11	0.85 ***	0.10	1.00				
Mymensingh	0.64 **	0.45	-0.18	0.38	1.00			
Rajshahi	0.86 ***	0.01	-0.30	-0.16	0.74 ***	1.00		
Rangpur	-0.81 ***	0.14	0.13	0.57 *	-0.19	-0.66 **	1.00	
Sylhet	-0.29	-0.58 *	0.41	-0.56 *	-0.42	-0.19	0.05	1.00
Aman season								
Barishal	1.00							
Chattogram	0.64 **	1.00						
Dhaka	0.72 **	0.84 ***	1.00					
Khulna	-0.60 **	0.00	-0.04	1.00				
Mymensingh	0.59 *	0.59 *	0.73 **	0.02	1.00			
Rajshahi	-0.28	-0.06	-0.14	0.29	-0.26	1.00		
Rangpur	0.88 ***	0.42	0.51	-0.69 **	0.59 *	-0.62 **	1.00	
Sylhet	0.49	0.93 ***	0.80 ***	0.16	0.63 **	-0.25	0.35	1.00

Source: Bangladesh Bureau of Statistics.

Note: *** significant at the 1% confidence level.
** significant at the 5% confidence level.
* significant at the 10% confidence level.

The production shocks in the model replicate the historical variability of rice production in each Division and each season, as well as the correlations across Divisions within each season. We did this by producing a Choelesky decomposition of the variance-covariance matrix of cross-Division harvests for each season. This matrix can convert a vector of standard normal random variables into a vector of random variables that replicate both the standard deviation of harvests by season and Division and the cross-Division correlation of harvests.

To convert season production estimates into monthly production estimates, we use data from the 2013-14 Bangladesh Integrated Household Survey on the monthly distribution of each of the three rice harvests. Because of the need for time to dry, we shifted the timing forward by two weeks to represent the flow of the new harvest onto the market.

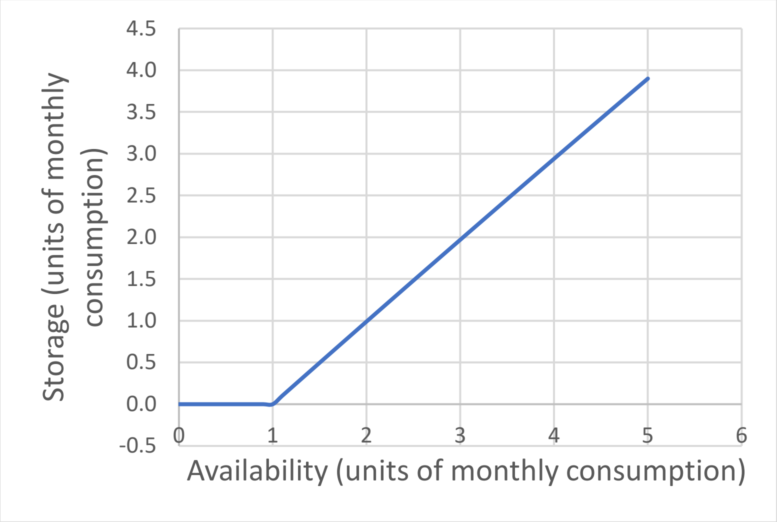
International trade in rice is negligible in most years, with imports accounting for less than 1% of production in 2013 (FAO, 2023). In 2016, imports were 0.49 million tons, so this is used as the base level.

We need to reconcile rice production, consumption, and net trade estimates. Expressed in rice equivalent, national rice production in 2016 (according to the Bangladesh Bureau of Statistics) plus net imports (according to the FAO) are significantly greater than rice consumption (according to the 2016 Household Income and Expenditure Survey). This is probably the result of post-harvest losses, animal feed, industrial use, and consumption outside the home. Thus, the HIES consumption estimates in each Division were scaled up proportionally so that national consumption is equal to national production plus net imports. Thus, consumption should be interpreted to include all uses: human consumption, animal consumption, industrial use, and losses.

Domestic trade occurs when the gap in prices between two Divisions exceeds the full cost of shipping rice between the two. We used data on transportation cost and distance in the rice trader survey to estimate a relationship between cost and distance. This was combined with estimates of the road distance between each pair of Division capitals. The result was an unrealistically low cost of transport between Divisions, probably because the survey data did not include the cost of loading, unloading, profits, and risk premia. We scaled up the transport kilometer costs using the maximum price difference between Mymensingh (a consistent rice surplus Division) and Dhaka (a consistent rice deficit Division), yielding transport costs that reflect the maximum price differences between Divisions.

To represent private storage behavior, we assume that private agents who store rice (including farmers, traders, and millers) follow a storage decision rule, where the amount stored is a function of the availability, defined as production, net inflows, and net imports in a given month and Division. The function is shown in the figure below. Private sector storage is also subject to a maximum level of six times monthly consumption, reflecting limits on storage capacity.

Figure 3. Private-sector storage decision rule



The function has a horizontal linear section and a quadratic section, where the line is sloped upward and is almost linear. In the linear section, if availability is less than average monthly consumption, storage is zero. If availability is greater than average monthly consumption, storage is a quadratic function of availability, close to but slight less than the surplus (availability minus average monthly consumption). The quadratic function is designed to pass through three points, described in the table below.

Table 3. Description of storage rule function

Section	Availability	Storage	Explanation
Linear section	$A < D_0$	$S = 0$	If availability is less than average monthly consumption, nothing is stored since there is no surplus
Quadratic section	$A = D_0$	$S = 0$	If availability is equal to average monthly consumption, nothing is stored since there is no surplus
	$A = 2 \times D_0$	$S = 0.99 \times D_0$	If availability is equal to double the average monthly consumption, 99% of the surplus is stored, leaving $1.01 \times D_0$ for current consumption
	$A = 3 \times D_0$	$S = 1.97 \times D_0$	If availability is equal to triple the average monthly consumption, 98.5% of the surplus is stored (1.97/2.00 = 0.985) leaving $1.03 \times D_0$ for current consumption

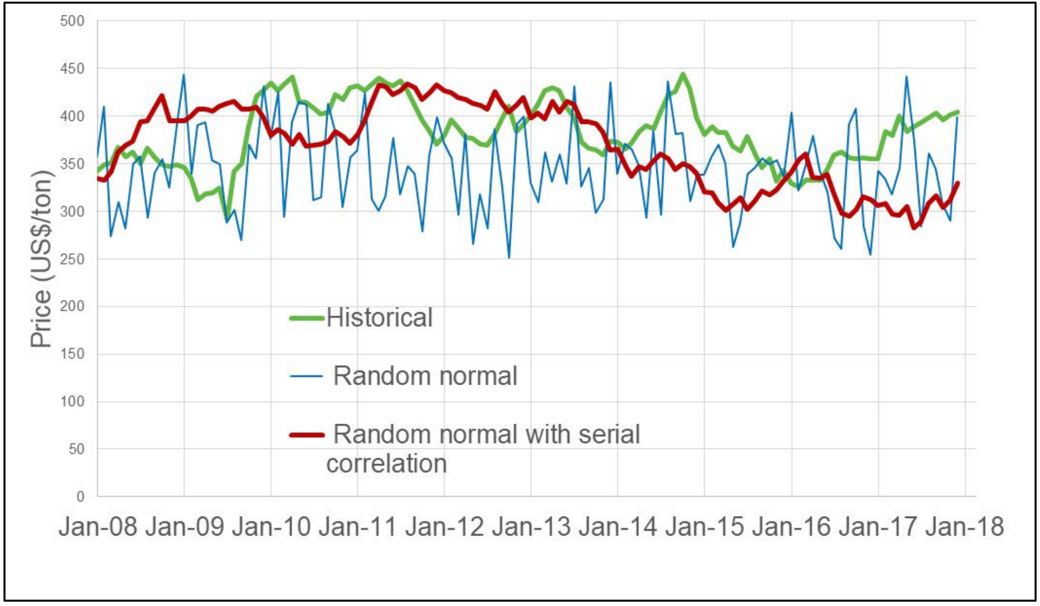
This is approximately consistent with temporal arbitrage. For example, if availability is double average consumption, then 99% of the surplus is stored until the next period. This means consumption is $1.01 \times D_0$ in the current period and $0.99 \times D_0$ in the next period. With our demand elasticity of -0.68, this 2% decrease in the quantity available for consumption will result in a 2.94% increase in price. Estimates of storage costs vary but are in this range. For example, Brennan (2003) estimates that the physical cost of storage is about 0.5% per month, but the financial cost is about 1.5% per month but can be much higher, so the total cost of storage would be around 2% per month. The average price of medium rice on the wholesale markets rises about 5.5% per month over July-October, after the Boro harvest and before the beginning of the Aman harvest. This suggests that the actual costs of storage, including risk premia, may be higher than 3% per month.

The model also simulates public procurement, storage, and distribution of rice. In the baseline simulation, we use the historical pattern of government procurement and distribution by Division and by month over 2014-2018. For procurement, we have information on the monthly procurement and the procurement by Division, allowing us to estimate the proportion of annual procurement that occurs in each month and Division. For distribution, we only have the monthly composition, so we assume that the distribution by Division is in proportion to rice consumption. Again, this generates a percentage by month and by Division of annual rice distribution. In this alternative, we assume that the quantities procured and distributed are fixed across years, as are the geographic and monthly patterns.

We also adopt several alterative simulations by a) varying the quantity procured and distributed each year, b) by altering the monthly and Divisional pattern to improve price stabilization but keeping the pattern fixed over the years, and c) by switching to a buffer stock operation in which the government defends a floor price by buying unlimited quantities and defends a price ceiling by selling unlimited quantities at that price. These simulations will be described in more detail in Section 4.

Imports in each year of the simulation will vary depending on domestic production and international prices, both of which vary stochastically. We use the wholesale price in New Delhi to represent the stochastic behavior of international prices. The green line in Figure 4 shows the historical wholesale price of rice in New Delhi from January 2008 to December 2017. Over this time, the average was US$ 382 per tonne and the monthly standard deviation was 33.96, implying a coefficient of variation of 8.9%. However, if we generate a random normal variable with this mean and standard deviation, the result is the blue line in Figure 4. Although the coefficient of variation is the same in the historical (green) and random (blue) series, they look quite different because the historical series shows strong serial correlation. In other words, the price in any given month is strongly correlated with the price in the previous month. We use a regression analysis to estimate current price as a function of the lagged price to estimate the degree of serial correlation. We use the lagged coefficient and the standard error of the regression to construct a simulated New Delhi wholesale price which replicates the average value, the standard deviation, and the degree of serial correlation. An example is shown in the red line in Figure 7. It is not intended to follow the trend over 2008-2017, but rather to follow the same statistical patterns.

Figure 4. Wholesale price of rice in New Delhi, historical and simulated



Source: Authors' analysis of data from FAO (2024) and simulated data.

As noted above, we assume Bangladesh is a "small country" in rice markets, meaning that the volume of imports has a negligible effect on international (New Delhi) prices.

The import parity price for each Division is calculated as the New Delhi price plus the cost of transporting rice from New Delhi to the border, any import taxes, and the cost of transporting from Khulna to each Division. Similarly, the export parity price for each Division is the New Delhi price minus the cost of transporting from the border to New Delhi minus any export taxes minus the cost of shipping from each Division to Khulna.

4. Results

4.1. Baseline scenario

The baseline scenario describes a set of assumptions that make the model replicate the current situation. It is used to compare the outcome from the current set of policies with the simulated outcome under a different set of policies. As described earlier, the Bangladesh Rice Market Model simulates the behavior of rice markets in Bangladesh for each month and in each of the eight Divisions.

The base scenario makes the following assumption about rice policy:

- The government procures and distributes 2 million tons of rice per year, reflecting recent historical trends.
- The patterns of public rice procurement and distribution follow the average historical pattern for 2007-2018 by month and by Division.
- The import tariff rate on rice is 25%.

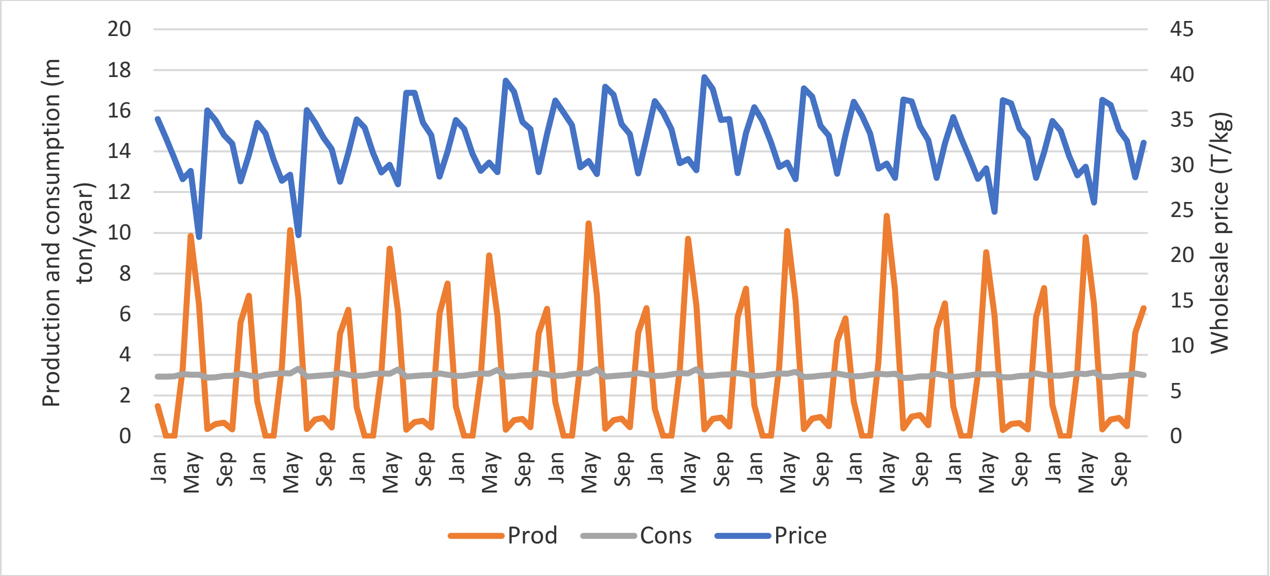
The simulation is run for 200 years in order to obtain the long-run average tendencies for each variable. We measure the long-run tendencies of each key variable in terms of the average value and the coefficient of variation (CV). As described above, the coefficient of variation is our measure of rice price instability.

The results over the full 200 years cannot easily be presented in a graph, so we present most of the results in tables. However, Figure 5 gives a sample of the first ten years of the simulation to illustrate the patterns. The graph shows rice production and rice consumption (on the left axis) and rice prices (on the right axis). Rice production (the orange line) varies tremendously, going from close to zero in February and March months to around 9 million tonnes in May. The tallest peaks represent the Boro harvest, the smaller peaks represent the Aman harvest, and the Aus is barely visible in between the two. It is worth noting that the size of the peaks varies from year to year, corresponding to random differences in the size of the annual harvest and in the size of the harvest in each season. This variation replicates the historical patterns of rice production in Bangladesh.

Rice prices (the blue line) vary from about 25 T/kg to 45 T/kg (0.33 to 0.59 USD/kg) over the ten-year period. The model simulates wholesale rice prices for each Division, and this price is the average of the eight Division prices. Prices move in response to domestic supply shocks (annual, seasonal, and Divisional) and shocks in the international price. In general, it is highest in March and October, just before the Boro and Aman harvests, respectively, and it is lowest in June and November, just after those two harvests.

Rice consumption (the grey line) is relatively flat, fluctuating between 2.8 and 3.1 million tonnes per month. This reflects the preference and needs of consumers for relatively stable levels of caloric intake and hence rice consumption.

Figure 5. Sample of 10 years of results for rice production, consumption, and price

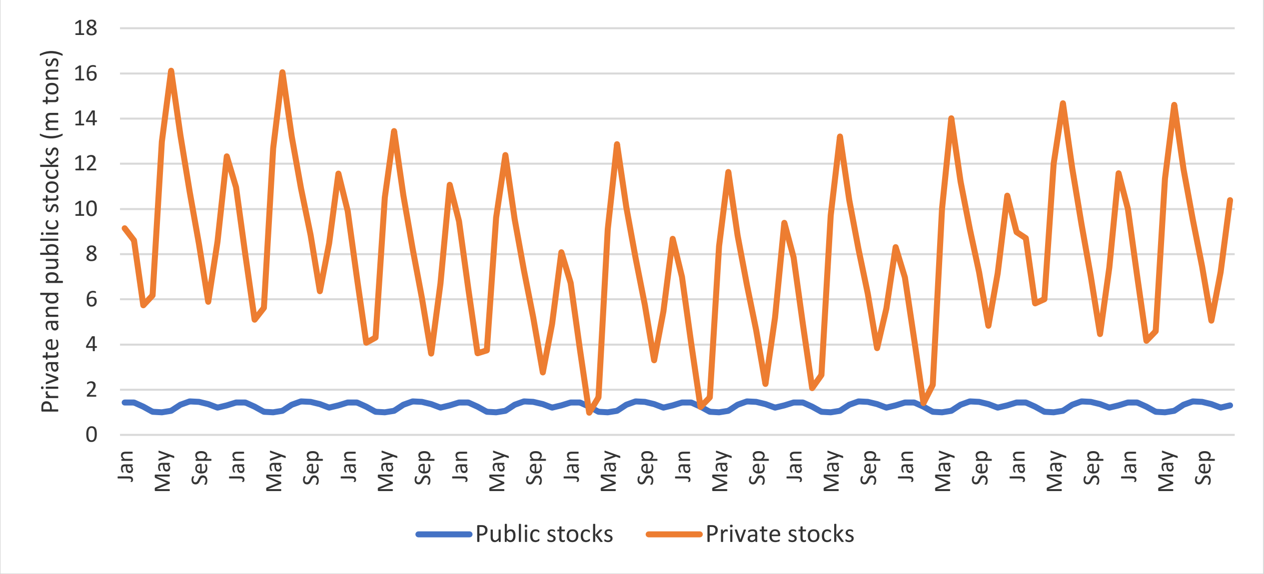


Source: Simulations using the IFPRI Bangladesh Rice Market Model.

One of the main functions of the Bangladesh rice marketing system is to redistribute rice from periods of surplus (harvest months) to periods of deficit (non-harvest months). In other words, it must convert a highly unstable flow of rice production into a stable flow of rice for consumption. The graph illustrates the magnitude of this challenge.

The stable flow of rice for consumption is only possible because large quantities of rice are put into storage during harvest months and taken out of storage during the deficit months. Figure 6 illustrates the quantities in storage each month during ten years of the 200-year base scenario simulation. Public stocks (the blue line) vary between 1.0 and 1.5 million tonnes, while private stocks vary from 2 million tonnes to 16 million tonnes.

Figure 6. Sample of 10 years of results for public and private stocks

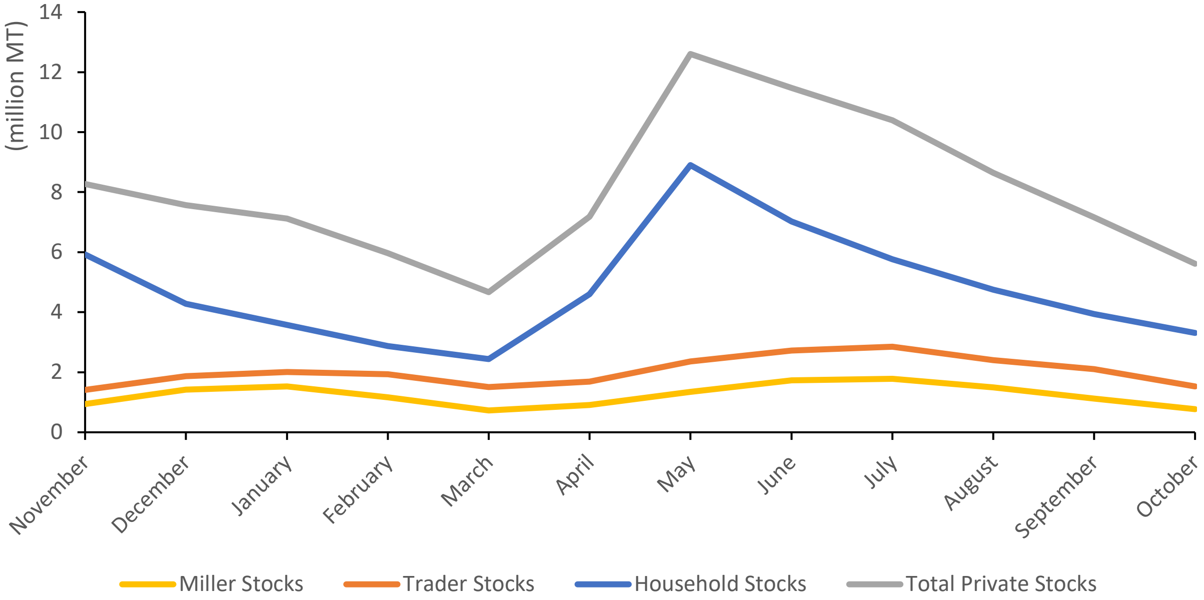


Source: Simulations using the IFPRI Bangladesh Rice Market Model.

Although the patterns shown in the graph are simulations from the model, they replicate the historical patterns closely. In the case of public stocks, they follow the average historical pattern over 2007-18 in terms of distribution and procurement by month and by Division each year. In the case of the private-sector storage, they are consistent with the volumes of rice that must be stored to redistribute rice from the harvest months to the rest of the year. They are also roughly consistent with the patterns of private storage estimated from the 2018 Bangladesh Miller and Trader Survey as shown in Figure 7. According to that survey, private stocks of rice in 2017-2018 varied from 4.7 million tonnes in March to 12.6 million tonnes in May. The simulated private-sector stocks have a wider range (1 to 16 million tonnes) than the measured private stocks, but this is expected given the fact that the simulation results cover ten years while the measured stock refers to just one 12-month period. One interesting result from the Miller and Trader Survey is that more than 60% of private-sector rice storage is carried out by households rather than by millers and traders.

The main results of the base scenario are shown in Table 4. The first two columns of statistics show the historical pattern, including the average value and the coefficient of variation (CV), that is, the standard deviation expressed as a percentage of the mean value. Most of the historical patterns refer to the most recent decade for which data are available, but there is some variation, as explained in the notes under the table. The second two columns represent the average and CV from a 200-year simulation using the Bangladesh Rice Market Model.

Figure 7. Estimated size of private stocks by month



Source: Dorosh et al., 2019 based on 2018 Bangladesh Miller and Trader Survey.

The first three rows show statistics for rice production in each of the three rice harvests in Bangladesh, while the fourth row shows the statistics for annual production. It is clear that the baseline simulation generally replicates the historical pattern, though there are some differences. For example, the model is slightly (1%) higher in terms of annual rice production and somewhat higher (5%) in terms of the variability of annual rice production.

We cannot compare consumption with historical data because the Bangladesh Household Income and Expenditure Survey (HIES) collects information on direct human consumption, while the model uses a broader definition that includes animal feed, industrial use, and post-harvest loss.

The average value of historical net imports over 2008-17 is about 0.7 million tonnes per year, which is matched (to the nearest 0.1 million tonnes) by the average in the baseline scenario. Simulated import volatility (calculated with monthly data) is higher than historical volatility, though both are quite high because they act as a shock absorber for variation in production. For example, a 5% shortfall in production can result in a 1.7 million tonne gap, which, if met with imports, would result in imports that are more than double the annual average.

The historical fiscal cost of rice operations is based on the revised budget for just one year, 2018-19, so we cannot calculate the standard deviation. The simulated fiscal cost is based on simulated quantities purchased, stored, and sold and the actual per ton costs from 2018-19. As shown in the table, the historical and simulated average costs are quite close.

The revenue from the import tariff on rice is calculated as 25% of the value of imported rice. We do not have information on the historical value of import revenue, but the simulated revenue should be as accurate as the simulated rice import volume.

Finally, the last line of the table shows the historical and simulated patterns in wholesale rice prices. The simulated average price over the eight Divisions and 200 years is 0.44 USD/kg (33.4 T/kg), which is quite close to the average historical price of medium wholesale rice prices in the eight Divisions over 2007-2018, 0.44 USD/kg (33.5 T/kg). Furthermore, the CV of simulated monthly rice prices is 13.3%, which is almost identical to the CV of historical monthly rice prices, 13.3%. In calibrating the model, we gave high priority to closely replicating the average and CV of rice prices because the focus of this report is on price stability.

Table 4. Main results of base scenario

	Historical pattern		Baseline scenario simulation	
	Average	CV	Average	CV
Rice production in Boro season (m tons/year)	18.9	4.7	19.3	6.2
Rice production in Aus season (m tons/year)	2.1	9.0	2.1	9.5
Rice production in Aman season (m tons/year)	13.7	5.5	13.8	6.9
Rice production (m tons/year)	34.7	4.0	35.2	4.2
Rice production (m tons/month)	2.9	--	2.9	106.0
Rice consumption (m tonnes/year)	--	--	35.9	2.6
Imports (m tons/year)	0.7	192.8	0.7	683.7
Exports (m tons/year)	0.0		0.0	4596.8
Private rice stocks (m tons)	7.8	40.2	5.8	60.6
Public rice stocks (m tons)	1.3	12.9	1.3	12.9
Fiscal cost of rice PFDS (milion USD/year)	401	--	399	4
Revenue from rice tariff (million USD/year)	--	--	--	--
Wholesale price of medium rice (USD/kg)	0.44	0.17	0.43	0.17

Source: Simulations using the IFPRI Bangladesh Rice Market Model. Historical average rice production based on data from the Bangladesh Bureau of Statistics for the agricultural year 2016-17, while the CV of rice production is based on data from 2006-07 to 2016-17. Historical data are not available for monthly rice production and monthly rice consumption. Historical data on average rice imports is from the FAO (2023b) for the years 2007-2018, while the CV of monthly imports is based on the same period. Historical average and CV on private rice stocks come from the IFPRI Millers and Traders Survey for 2016-17 (Dorosh et al, 2020). The historical fiscal cost of the PFDS for rice operations is from the 2018-19 revised budget for rice operations, assuming 1.3 m tonnes average rice stocks and 2.0 m tonnes of annual purchases and sales. The data are for just one year so we cannot calculate a historical CV. The price data from the Bangladesh Bureau of Statistics for the period 2007-18. The CV is calculated as the average CV across the eight Divisions, where each CV is calculated as the standard deviation of Division-level prices as a percentage of the Division-level mean price. US dollar figures are calculated using 76.9 Taka/USD, the rate prevailing on 30 June 2016.

4.2. Simulations of changes in scale of PFDS

In this section, we describe the results of a set of simulations in which we vary the quantity of rice purchased and distributed by the Public Food Distribution System (PFDS). In the baseline scenario, the government purchases and distributes 2 million tonnes each year, allocated across months and Divisions according to the average proportions over the period 2007-18. In other words, the procurement and distribution vary across months and Divisions, but is constant from one year to the next. In these simulations, we vary the quantity purchased and distributed each year from 0 to 4 million tonnes. All other assumptions remain the same as in the base scenario, as do the production shocks and the variation in international rice prices. In other words, any differences in the outcomes in these scenarios is the result of changing the quantity of rice purchased and distributed by the PFDS. As before, the simulation is run for 200 years (2400 months) to obtain the average values of each indicator as well as the level of rice price instability, measured by the coefficient of variation (CV) of the wholesale rice prices.

Table 5 shows the results across the five scenarios with different levels of government procurement and distribution. Note that the third simulation, with 2 million tonnes per year, is the base scenario. The first five rows show that the average rice production and consumption are virtually unaffected, as we would expect. Rice imports vary between 0.7 and 1.6 million tonnes. Imports are highest in the first scenario with no rice procurement, suggesting that without the PFDS, rice imports would play a larger role in stabilizing rice prices. The average wholesale rice price varies by just 0.03 USD/kg (2.2 T/kg) across the five scenarios.

The main differences across scenarios are the rice stocks and the fiscal cost. Of course, the public rice stocks (the average amount in storage in a given month) rise from 0 if there is no rice procurement or distribution to 2.6 million tonnes if the government purchases (and distributes) 4 million tonnes per year. Also, as expected, the fiscal cost of the program depends on both the average volume in stock and the quantity purchased and distributed each year. It rises from 0 to almost USD 800 million per year, with the cost being roughly proportional to the volume purchased (and sold) each year. More surprisingly, the average private-sector rice stocks also increase, rising from 4.5 million tonnes with no public stocks to 8.3 million tonnes.

The last row shows the coefficient of variation (CV) of wholesale rice prices, the measure of price instability. The first column indicates that, in the absence of public rice procurement and distribution, the CV would be 12.5%. With one million tonnes of annual procurement (and distribution), the CV declines slightly to 12.0%. As the scale of public procurement and distribution increases from 1 to 4 million tonnes per year, the level of price instability rises from 12.0% to 19.5%.

Why does expanding public procurement and distribution beyond 1 million tonnes per year increase price instability? In these simulations, we assume a fixed proportion of total procurement and distribution occurs in each month and each Division. Small interventions may nudge the price toward the average, while larger interventions may push the price beyond the average level, thus increasing price instability. For example, every March, the model allocates 2.5% of the annual distribution to Dkaha. In the second scenario, the annual distribution is 1 million tonnes, so Dhaka would receive 25,000 tonnes each March. Since March prices in Dhaka tend to be higher than average, this will push them down and reduce price instability. But under the scenario with 4 million tonnes being distributed, Dhaka would receive 100,000 tonnes in March, which would probably push Dhaka prices below the average, thus increasing price variation. In other words, this effect is partly due to our assumption of fixed proportions allocated to each Division and month. Later, we simulate alternative ways of allocating public rice stocks.

Table 5. Simulation of the impact of changing the scale of rice PFDS

	Volume of public procurement & distribution per year				
	0 million tonnes	1 million tonnes	2 million tonnes	3 million tonnes	4 million tonnes
Rice production in Boro (m tons/year)	19.0	19.2	19.3	19.3	19.4
Rice production in Aus (m tons/year)	2.2	2.2	2.1	2.1	2.0
Rice production in Aman (m tons/year)	13.0	13.4	13.8	14.0	14.1
Rice production (m tons/year)	34.2	34.7	35.2	35.4	35.6
Rice production (m tons/month)	2.9	2.9	2.9	3.0	3.0
Rice consumption (m tonnes/year)	35.8	35.8	35.9	36.2	36.5
Imports (m tons/year)	1.6	1.1	0.7	0.9	1.1
Exports (m tons/year)	0.0	0.0	0.0	0.1	0.2
Private rice stocks (m tons)	4.5	4.7	5.8	7.3	8.3
Public rice stocks (m tons)	0.0	0.6	1.3	1.9	2.6
Fiscal cost of rice PFDS (milion USD/year)	0	200	399	599	798
Revenue from rice tariff (million USD/year)	136	94	56	68	91
Wholesale price of medium rice (USD/kg)	0.44	0.44	0.43	0.42	0.41
Price instability (CV of wholesale price in %)	12.5	12.0	13.3	16.2	19.5

Source: Simulations using the IFPRI Bangladesh Rice Market Model.

4.3. Simulations of changes in rice import tariff

This section describes the results of five simulations in which the import tariff on rice varies from 0% (no tariff) to 40%. As discussed above, the import tariff on rice affects the import parity price. The import parity price is the international price of rice plus the cost of transporting to markets in Bangladesh, including the cost of any import tariffs. In other words, it is the price above which it becomes profitable to import rice. In the base scenario, with a 25% tariff, the import parity price is around 0.52-0.59 USD/kg (40-45 T/kg), though this depends on the Division and the level of rice prices in New Delhi. When the tariff is 0%, the import parity price is lower, whereas an import tariff of 40% would raise the import parity price, making imports unprofitable except at high domestic prices.

Table 6 shows the average values of the main outcome indicators over the 200-year simulation for each tariff rate. As expected, the higher tariff rates increase the average price of rice from 0.40 USD/kg (30.4 T/kg) with no tariff to 0.44 USD/kg (34.1 T/kg) with a 40% tariff, a 12% price increase. The reasons the 40% tariff rate does not raise average prices 40% is that Bangladesh only imports rice occasionally. In most months and most Divisions, the domestic price is below the import parity price, so imports are not profitable. During these months, the import tariff rate has no effect on the domestic price. The tariff rate only affects prices during those occasional months where prices are higher than usual. Because of this, introducing a tariff of a given percentage (such as 40%) increases average prices by substantially less than that percentage.

As expected, taxing imports tends to reduce the level of imports. With no tariff, average imports over the 200 years of simulation are 2.5 million tonnes. Average imports fall to 0.9 million with a 20% import tariff and to 0.4 million tonnes with a 40% import tariff. This is because, with a 40% import tariff, the cost of imported rice is exceptionally high, so it is only worth importing when the domestic price is very high, such as when the boro or aman harvest is significantly below normal.

Private rice stocks tend to be higher when the tariff is low. Average private stocks are 9.5 million tonnes with no import tariff but decline to 5.2 million tonnes when the tariff is 40%. This is because stocks and imports are alternative ways of stabilizing prices. With high tariffs and lower imports, the price instability creates greater incentives for the private sector to hold stocks.

Table 6. Simulation of the impact of changing the rice import tariff

	Import tariff on rice				
	No tariff	10% tariff	20% tariff	30% tariff	40% tariff
Rice production in Boro (m tons/year)	18.8	19.1	19.2	19.3	19.3
Rice production in Aus (m tons/year)	2.1	2.1	2.1	2.1	2.2
Rice production in Aman (m tons/year)	13.4	13.6	13.8	13.8	13.9
Rice production (m tons/year)	34.3	34.8	35.1	35.3	35.4
Rice production (m tons/month)	2.9	2.9	2.9	2.9	2.9
Rice consumption (m tonnes/year)	36.6	36.3	36.0	35.9	35.8
Imports (m tons/year)	2.5	1.6	0.9	0.6	0.4
Exports (m tons/year)	0.1	0.0	0.0	0.0	0.0
Private rice stocks (m tons)	9.5	7.4	6.1	5.5	5.2
Public rice stocks (m tons)	1.3	1.3	1.3	1.3	1.3
Fiscal cost of rice PFDS (milion USD/year)	399	399	399	399	399
Revenue from rice tariff (million USD/year)	0	46	56	56	59
Wholesale price of medium rice (USD/kg)	0.40	0.41	0.43	0.44	0.44
Price instability (CV of wholesale price in %)	11.3	11.9	12.7	14.0	15.1

Source: Simulations using the IFPRI Bangladesh Rice Market Model.

Tariff revenue shows a non-linear relationship with the tariff rate: first it rises with a higher tariff, then it falls. Naturally, without a tariff, there is no tariff revenue. When the tariff is raised to 10% and 20%, the tariff revenue rises significantly. But as the tariff rises to 30% and 40%, the revenue begins to plateau. Eventually, if tariffs are high enough, the declining volume of imports more than offsets the rising tax rate and tariff revenue declines.

The last row shows the coefficient of variation (CV) of the wholesale rice price. The level of price instability is lowest with no tariff and rises steadily as the tariff increases. With a 40% import tariff, the CV of rice prices is 15.1%. The reason for this pattern is that a high tariff rate increases the import parity price, thus raising the ceiling that imports place on domestic prices. In other words, a high tariff allows domestic prices to spike higher than they would with no tariff or a low tariff. Those spikes contribute to higher price instability and a higher coefficient of variation in prices.

4.4. Simulations of buffer stock operations

In this section, we consider the effect of managing the Bangladesh rice reserves as a buffer stock with price bands of different widths. As discussed in Section 2.5, a buffer stock is a system for managing stock to keep prices within a specific range (or band). A floor price (or buying price) and a ceiling price (or selling price) are set by the government. Whenever the market price falls to the floor price, the stock purchases as much as is needed to prevent the price from falling any further. Whenever the market price rises to the ceiling price, stocks are sold or distributed in whatever quantity is necessary to keep the price from rising further.

We run five buffer stock scenarios, varying the width of the price band, that is, the difference between the ceiling price and the floor price. The center of the price band must be carefully set. If the center is set too high, the buffer stock will buy frequently and eventually reach storage capacity. If it is too low, the buffer stock will sell more often and eventually exhaust its stock. Further complicating the task of setting the center is the fact that it varies depending on the width of the band. Because the distribution of prices is assymetric, a center that creates excess accumulation of stocks with one width may lead to excess depletion of the stock with a different width. This problem is particularly acute when the price band is narrow, which requires numerous purchases and distributions to keep prices within the band.

In fact, even after adjusting the band carefully, the buffer stock either completely depletes its stock or reaches the government storage capacity (set at 5 million tonnes in the model). In some simulations, it will do both over the course of the 200-year simulation. To address this problem, we designed the model to import rice if the buffer stock needs to distribute more rice than it has in storage. Likewise, if it needs to purchase more rice from the market than it has capacity for, it will export the excess rice. These government operations are included in imports and exports in the table. In addition, the fiscal cost of these operations is calculated as the difference between the Dhaka wholesale price and the appropriate import/export parity price. In other words, the per-tonne cost of government imports is calculated as the Dhaka import parity price (excluding import tariff) minus the Dhaka wholesale price, while the per-tonne cost of government exports is the Dhaka wholesale price minus the export parity price (excluding tariff). This estimate excludes administrative and loading costs, but it should capture the bulk of the cost. These costs are included in the Fiscal cost line of the table.

After some trial and error, we set the center of the band for the first two scenarios at 0.47 USD/kg (36 T/kg), the third at 0.48 USD/kg (37 T/kg), and the last two at 0.51 USD/kg (39 T/kg). The width of the band varies across scenarios from 10 T/kg to 50 T/kg (0.13 USD/kg to 0.65 USD/kg). Table 7 shows the floor and ceiling prices for each simulation.

Table 7. Floor and ceiling prices for the buffer stock simulation

	10 T/kg band	20 T/kg band	30 T/kg band	40 T/kg band	50 T/kg band
Floor or buying price (T/kg wholesale price)	31	26	22	19	14
Center of price band (T/kg wholesale price)	36	36	37	39	39
Ceiling or selling price (T/kg wholesale price)	41	46	52	59	54
Floor or buying price (USD/kg wholesale price)	0.40	0.34	0.29	0.25	0.18
Center of price band (USD/kg wholesale price)	0.47	0.47	0.48	0.51	0.51
Ceiling or selling price (USD/kg wholesale price)	0.53	0.60	0.68	0.77	0.70

Note: The US dollar values are calculated using an exchange rate of 76.9 Taka/USD, the rate prevailing on 30 June 2016.

Table 8 shows the average level of the main indicators for the five buffer stock simulations with different widths of the price band. Average rice production, consumption, and wholesale price vary little across the five scenarios. Normally, the narrow price band prevents the price from rising high enough to trigger rice imports. At the same time, the narrow band requires the buffer stock to make frequent interventions to keep prices within the band, increasing the chances of exhausting the buffer stock or reaching storage capacity. In fact, two-thirds of the imports in the 10 T/kg scenario are by the government to replenish the buffer stock. With a wider price band, such as 40 T/kg or 50 T/kg, prices are allowed to rise to import parity which triggers commercial imports, while interventions by the buffer stock are rare so there is little or no need for government imports and exports.

The average public rice stocks vary from 0.1 to 1.3 million tonnes. The low averages occur because the public stock is frequently close to empty and is being replenished with imports often. The highest average occurs with the widest price band – the band is so wide, that the market price never falls to the floor price (0.18 USD/kg or 14 T/kg) nor rises to the ceiling price (0.70 USD/kg or 54 T/kg). As a result, the buffer stock has no effect on the rice market and the public reserves remain at their original level of 1.3 million tonnes.

Table 8. Simulation of the impact of a buffer stock with different price bands

	Price bands				
	10 T/kg band	20 T/kg band	30 T/kg band	40 T/kg band	50 T/kg band
Rice production in Boro (m tons/year)	19.1	19.0	19.0	19.0	19.0
Rice production in Aus (m tons/year)	2.2	2.2	2.2	2.2	2.2
Rice production in Aman (m tons/year)	13.2	13.0	13.0	13.0	13.0
Rice production (m tons/year)	34.5	34.2	34.2	34.2	34.2
Rice production (m tons/month)	2.9	2.9	2.9	2.9	2.9
Rice consumption (m tonnes/year)	35.7	35.8	35.8	35.8	35.8
Imports (m tons/year)	1.2	1.6	1.6	1.6	1.6
Exports (m tons/year)	0.0	0.0	0.0	0.0	0.0
Private rice stocks (m tons)	4.3	4.4	4.5	4.5	4.5
Public rice stocks (m tons)	0.6	0.1	0.1	0.8	1.3
Fiscal cost of rice PFDS (milion USD/year)	603	390	112	68	105
Revenue from rice tariff (million USD/year)	25	69	113	135	136
Wholesale price of medium rice (USD/kg)	0.44	0.44	0.44	0.44	0.44
Price instability (CV of wholesale price in %)	8.2	12.4	14.0	14.5	14.5

Source: Simulations using the IFPRI Bangladesh Rice Market Model.
Note: The price bands are equivalent to 0.13 USD/kg, 0.26 USD/kg, 0.39 USD/kg, 0.52 USD/kg, and 0.65 USD/kg at the exchange rate of 76.9 T/USD prevailing on 30 June 2016.

The fiscal cost of the narrow band is the highest at USD 603 million per year. This is composed of three parts: the cost of maintaining the stocks, the cost of purchasing and distributing rice, and the cost of importing rice to replenish the stock (government exports are not needed at the price band selected). This is 50% higher than in the base scenario, which is equal to the PFDS operating costs in 2018-19. The next scenario has a 20 T/kg price band and costs USD 390 million, similar to the base scenario. The costs are lower because the PFDS intervenes less frequently in rice markets and maintains a lower stock. The remaining three scenarios have wider bands and cost USD 68-112 million per year. It might seem surprising that the 50 T/kg price band costs more than the 40 T/kg price band. This is because the cost of holding the 1.3 million tonnes of storage, which is never used in the 50 T/kg scenario, is higher than the cost of maintaining the smaller stock in the 40 T/kg scenario, in which a few distributions have partly depleted the stock.

In the first column of the last row, the CV of the wholesale price is just 8.2%, the lowest level of price instability across all the simulations done. As the price band widens, the price instability rises to 12.4%, then 14.0%, and then 14.5%. The latter two price bands have similar levels of price instability because they involve little or no intervention and simply allow domestic markets and commercial imports to maintain price stability. This is the same level of price stability as the first scenario in Table 8, with no rice procurement or distribution.

Table 8 shows the level of variability in the main outcome variables. Again, we are mainly interested in price stability. Not surprisingly, the narrow band yields a remarkably high level of price stability, the CV being just 6.9%. However, this price stability would require an unrealistically large budget and storage capacity, as discussed above. As the band expands from 20 T/kg to 50 T/kg, the degree of price instability rises slowly from 10.5 to 11.7%. The last two scenarios give almost the same level of price instability because in both cases, interventions to stabilize prices are rare.

4.5. Simulation of adaptive buffer stock operation

In the previous section, we showed that a buffer stock with fixed floor and ceiling prices is quite likely to either accumulate large stocks trying to defend a floor price or exhaust its stock trying to defend a ceiling price, or possibly both. We saw that the appropriate center of the price band depends on the width of the price band. In addition, the center of the price band should be slightly higher than the average market price because of the assymetry of prices. Although the price bands we selected worked fairly well, it was necessary to try various alternatives before finding price bands that were successful in avoiding repeatedly fillng the public storage capacity or repeatedly exhausting the stock. Thus, one of the biggest constraints on adopting a buffer stock policy is setting an appropriate price band.

In this section, we give the results of an adaptive buffer stock policy, in which the floor and ceiling prices are adjusted periodically to reduce the risk of the government stock becoming exhausted or from reaching capacity. In particular, we start the buffer stock with the same floor and ceiling prices as before, but we adjust them as follows:

- If the national public rice stocks fall below 0.5 million tonnes, the floor and ceiling prices are increased by 0.2 T/kg (0.003 USD/kg).
- If the national public rice stocks rise above 3.5 million tonnes, the floor and ceiling prices are decreased by 0.2 T/k (0.003 USD/kg).

These adjustments help prevent the public rice stocks from being exhausted because, when the stocks fall below a threshold (0.5 million tonnes), the floor and ceiling prices are adjusted upward, creating more incentive to sell to the buffer stock and less incentive to buy from it. Likewise, if the stock becomes too large, the prices are adjusted downward, making it less attractive to sell to it and more attractive to buy from it.

Table 9 shows the results of the adaptive buffer stock for different price bands. Rice imports are 0.8 million tonnes with the narrowest band (the first scenario) but rise to 1.6 million tonnes in the two scenarios with the widest price bands. This is because the narrow band generally keeps the rice prices too low to justify rice imports. It would only be profitable to import rice if the ceiling price were adjusted upward over time and/or the international price were unusually low.

It is worth noting that the adjustment of floor and ceiling prices is not enough to avoid some government imports to replenish the public stocks and government exports to deal with an excess, particularly in the narrow-band scenarios. In the first scenario, the government accounted for one-third of the rice imports and all of the rice exports. The volume of government imports and exports necessary to replenish the stock declines as the price band gets wider and intervention is less frequent.

The average size of public rice stocks in the five scenarios ranges between 1.3 and 2.1 million tonnes. The adjustments in the floor price and ceiling price keep the average public stocks at roughly one-third capacity. In contrast, the fixed-price buffer stock kept public stocks close to zero because the price band was somewhat too low, and there was no mechanism to correct this.

The fiscal cost of the program declines from USD 470 million/year in the first scenario to USD 105 million/year in the last. This is because the narrow band requires more frequent intervention in the market to defend the price ceiling and price floor, as well as more government imports and exports to maintain the buffer stock. Of course, the smaller stocks imply lower fiscal costs of the program. The average fiscal cost for the 10 T/kg price band is USD 470 million/year, the highest among the five scenarios in the table. The cost declines as the price band gets wider, falling to USD 105 million/year with a 50 T/kg price band.

The first two scenarios are significantly less costly than the first two scenarios in the fixed-price buffer stock described in the last section, in spite of having larger public stocks on average. By adjusting the floor and ceiling price, the adaptive buffer stock reduces (but does not eliminate) costly imports and exports to rebalance the stock. On the other hand, the third and fourth scenarios are more expensive in the adaptive buffer stock, largely because they have larger average stocks. This is partly a function of having chosen a low price band which led to maintaining very low public stocks of rice. There is no difference between the fixed-price buffer stock and the adaptive buffer stock in the last scenario with the price band of 50 T/kg. This is because the band is so wide that market prices never reach the floor or ceiling price, so there are no interventions. Furthermore, the stock never reaches either threshold that would trigger an adjustment in the floor and ceiling price, so the two simulations give identical results.

The last row shows the coefficient of variation (CV) prices. Not surprisingly, the scenario with the narrowest price band (10 T/kg) shows very low-price instability, the CV of prices being 8.9%. This is almost as low as the CV of prices with the 10 T/kg price band under the fixed-price buffer stock (see Table 9). The adjustment of prices in the adaptive buffer stock adds a small margin to price instability but is significantly less costly.

As the band widens, the price instability increases somewhat, with the CV rising from 12.5% with the 20 T/kg price band to 14.5% with the 50 T/kg price band. As noted earlier, the 50 T/kg price band is essential the same as having no price band, so the price instability (CV=14.5%) reflects the level in the absence of any PFDS.

Table 9. Simulated impact of an adaptive buffer stock with different price bands

	Price bands				
	10 T/kg band	20 T/kg band	30 T/kg band	40 T/kg band	50 T/kg band
Rice production in Boro (m tons/year)	19.1	19.0	18.9	18.8	19.0
Rice production in Aus (m tons/year)	2.3	2.2	2.3	2.2	2.2
Rice production in Aman (m tons/year)	13.3	13.1	13.1	13.0	13.0
Rice production (m tons/year)	34.7	34.3	34.3	34.1	34.2
Rice production (m tons/month)	2.9	2.9	2.9	2.8	2.9
Rice consumption (m tonnes/year)	35.4	35.6	35.7	35.7	35.8
Imports (m tons/year)	0.8	1.3	1.3	1.6	1.6
Exports (m tons/year)	0.1	0.0	0.0	0.0	0.0
Private rice stocks (m tons)	4.1	3.9	4.0	4.2	4.5
Public rice stocks (m tons)	1.8	1.9	2.1	1.9	1.3
Fiscal cost of rice PFDS (milion USD/year)	470	278	185	169	105
Revenue from rice tariff (million USD/year)	37	96	119	139	136
Wholesale price of medium rice (USD/kg)	0.46	0.45	0.45	0.45	0.44
Price instability (CV of wholesale price in %)	8.9	12.5	13.8	14.2	14.5

Source: Simulations using the IFPRI Bangladesh Rice Market Model.
Note: The price bands are equivalent to 0.13 USD/kg, 0.26 USD/kg, 0.39 USD/kg, 0.52 USD/kg, and 0.65 USD/kg at the exchange rate of 76.9 T/USD prevailing on 30 June 2016.

5. Summary and conclusions

The objective of this report is to explore the impact of alternative policies on rice price stabilization in Bangladesh. In particular we study the effect of alternative rice import tariffs, of increasing and decreasing the scale of the rice PFDS program, of implementing a buffer stock policy with different price bands, and of implementing an adaptive buffer stock policy in which purchase and sale prices adjust to circumstances.

To accomplish this, we developed a stochastic spatial-equilibrium model of rice markets in Bangladesh, which simulates the interactions of the markets for rice in the eight Divisions of the country on a monthly basis. We run the model over 200 years to determine the long-run average levels of outcome indicators (such as rice prices), as well as the level of instability over time. Price instability in the model is based on stochastic (random) shocks to supply and stochastic variation in the international price. The production shocks are designed to replicate annual variation with serial correlation, the variation in production in each harvest in each Division, as well as cross-Division correlation in production. International prices are constructed to replicate the statistical patterns from an econometric analysis of the wholesale price of rice in New Delhi, including serial correlation.

The base scenario represents current rice policies, including a 25% import tariff, a PFDS that procures and distributes 2 million tonnes of rice per year, and a pattern of procurement and distribution across months and Divisions that follows the average quantities over 2007-2018. In general, the model replicates the average level of production, consumption, imports, public stocks, private stocks, and wholesale prices. In the case of variables for which we have estimates of the coefficient of variation (CV), the model also replicates historical patterns fairly well. For example, the CV of wholesale prices is 13.3% in the baseline scenario of the model and 13.3% in the historical data.

The baseline scenario provides three key findings:

- The current rice marketing system carries out a massive task of converting a highly unstable flow of rice production into a very stable flow of rice consumption. The model indicates that monthly rice production has a CV of 106%, but monthly consumption shows hardly any variability with a CV of just 2.6%.
- The stabilization of the flow of rice to consumers is possible because large quantities of paddy and rice are stored during harvest months for consumption later in the year. According to the model, the average quantity of rice in storage is 9.1 million tonnes, but it can rise to 18 million tonnes during the Boro harvest. Close to 90% of this quantity is stored by the private sector, including millers, traders, farmers, and consumers. According to the IFPRI Miller and Trader Survey, more than 60% of the private-sector rice storage is carried out by households rather than millers and traders.
- More generally, although the model is complex, with many moving parts, it is based on relatively simple rules: that rice will be imported when it is profitable, that rice will be transported from one region to another when the price difference exceeds the transportation cost, that rice will be stored when availability exceeds average consumption, and that greater supply will reduce prices. These simple rules, when combined with realistic production shocks, generate the level of price instability that we observe in the rice markets of Bangladesh.

5.1. Impact of changing the scale of rice procurement and distribution

One set of policy options we studied was to vary the scale of the government purchases and distribution of rice. In the base scenario, the PFDS buys and distributes 2 million tonnes per year. This is allocated among Divisions and over the months according to the historical averages over 2007-2018. This is a simplification of how the PFDS operates, but a good starting point for understanding its impact. The main findings of these simulations can be summarized as follows:

- We varied the quantity purchased (and distributed) by the PFDS from 0 to 4 million tonnes per year. The price instability was lowest at 1 million tonnes per year (12.0%), being higher with no PFDS and higher with 2 million tonnes or more.
- Given that the model simplifies the rules for allocating PFDS, we do not interpret this result to mean that 1 million tonnes is the optimal quantity of annual distribution. But it is important to note that a larger PFDS does not necessarily increase price stability. First, small distributions of rice may lower the off-season price toward the average, thus reducing price instability, but larger distributions may lower the price below the average, thus

adding to price instability. A similar argument applies to rice procurement. Second, PFDS procurement and storage displaces private sector storage to some degree. When the government purchases rice, there is less available for the private sector to purchase and greater risk in purchases given the possibility that government sales will make private storage unprofitable. The private sector is motivated only by buying when prices are low (surplus periods) and selling when prices are high (deficit periods), while the PFDS has multiple objectives. As a result, when the PFDS displaces private-sector storage, this does not necessarily reduce price instability.

- There is some evidence that the allocation of procurement and distribution of rice could be improved if the primary goal is to reduce price instability at a minimal cost. For example, Chapter 4 showed that June is one of the main months for rice distribution, but also one of the top months for rice procurement. In addition, rice procurement from high-price areas such as Dhaka could be reconsidered if the main objective is price stabilization.

5.2. Impact of alternative rice import tariffs

Rice import tariffs increase the import parity price, which serves as an automatic price ceiling on domestic prices. This is because if domestic prices rise above the import parity price, it becomes profitable to import rice, thus putting downward pressure on local prices. We would expect a higher ceiling to allow larger price spikes, thus increasing price instability. The model confirms this intuition. Below are the main findings from this set of simulations:

- A higher tariff implies higher rice prices and more price instability. With no import tariff, the average rice price is low (0.40 USD/kg or 30.4 T/kg), and rice price instability (as measured by the CV) is 11.3%. As the import tariff rises, so do the average price and the level of price instability. With a 40% tariff, the average price is 44 USD/kg (34.1 T/kg), and the CV is 15.1%.
- Higher tariffs do not increase domestic prices in the same proportion as the tariff. For example, a 40% tariff increased the average rice price just 11% in the model. This is because the tariff is only relevant in the locations and months when the domestic price is near the import parity price. Since Bangladesh is only an occasional rice importer, the tariff only occasionally affects the domestic price of rice.
- A higher tariff does benefit farmers, but the effect is relatively small. According to our simulations, a 40% tariff raises prices 11%, which increases rice production by just 3%.
- Finally, import tariffs raise tax revenue, but the relationship is non-linear. According to our simulations, a 40% tariff only raises 6% more tariff revenue compared to a 20% tariff. This is because the tariff reduces the volume of imports. At some point, higher tariffs reduce tariff revenue.

5.3. Impact of a buffer stock policy

A buffer stock policy attempts to keep prices within a specified range by purchasing as much as necessary to prevent the price from falling below the floor price and selling as much as necessary to avoid the price rising above the ceiling price. Buffer stocks were originally considered a straight-forward way to reducing price instability, but research by Newberry and Stiglitz (1981) and Williams and Wright (1991) showed that it is more difficult than it appears. In fact, simulations by Williams and Wright (1991) showed that it is very difficult to "defend" a price band with a finite budget.

We use the Bangladesh Rice Market Model to simulate a buffer stock policy in rice, using five different widths of the price band (the gap between floor and ceiling prices). The widths were 10 T/kg, 20 T/kg, 30 T/kg, 40 T/kg, and 50 T/kg. The main findings of this analysis are as follows:

- One of the most difficult aspects of implementing a buffer stock policy is determining the appropriate level of the price band. If it is too low, sales will exceed purchases and eventually the stock will be depleted. If it is too high, purchases will exceed sales and eventually the storage capacity will be reached. In some early simulations (before a capacity limit was added), public stocks would average 50 million tonnes. In others, it would reach unrealistically high levels and later fall to zero. To address this problem, we added an assumption that the government imports rice when the public stock is depleted and exports rice when the storage capacity (assumed to be 5 million tonnes) is reached.
- A narrow band is more difficult to defend, requiring frequent purchases and sales which make exhausting the stock or reaching storage capacity almost a certainty. At the other extreme, a very wide band may not impose any limitations on market prices, so it is effectively like not having a buffer stock policy. In our simulations, a 40 T/kg band rarely required any intervention, and a 50 T/kg band never did over the 200-year simulation.
- The center of the price band needs to be somewhat higher than the average market price. For example, the average price in our simulations was about 0.43 USD/kg (33 T/kg), but the center of the price bands had to be in the range of 0.47-0.48 USD/kg (36-37 T/kg) to avoid large scale imports or exports to rebalance the stock. The reason is that the distribution of prices is assymetric, with upward spikes being larger than downward ones. A price band centered on the average price will need to sell more frequently than it purchases, leading to depletion of the stock.
- The appropriate center of the price band depends on the width of the band. For example, in our simulations, we had to use a center at 0.47 USD/kg (36 T/kg) for the narrow 10 T/kg price band but raise the center to 0.48 USD/kg (37 T/kg) for the 20 T/kg price band.
- A buffer stock with a narrow band of 10 T/kg can reduce price instability to 8.2%, a remarkably low level, but it requires getting the price band right and it can be quite expensive. In our simulation, it cost about 50% more than the current policy, but many trial simulations led to much higher costs.

- A 20 T/kg price band generated a rice price CV of 12.4% at a fiscal cost of USD 390 million per year. In other words, it achieves a greater level of rice price stability at a cost equal to the current PFDS program.

5.4. Impact of an adaptive buffer stock policy

In response to the practical problem of setting a price band that will not result in depleting the stock or over-accumulating the stock, we developed an adaptive buffer stock simulation, in which the price band adjusts to the level of stocks. When stocks decline to 0.5 million tonnes, the ceiling price and floor price are increased by 0.003 USD/kg (0.2 T/kg). Likewise, then public stocks rise to 3.5 million tonnes, the ceiling and floor prices are decreased by 0.003 USD/kg (0.2 T/kg). We used the same five price bands as in the fixed-price buffer stock scheme discussed above. There were several main findings:

- The adaptive buffer stock reduces the frequency of depletion and over-accumulation but does not eliminate them completely. Sometimes, the price does not respond quickly enough to avoid exhausting the public stock or reaching storage capacity.
- The simulation of a 10 T/kg price band with the adaptive buffer stock achieve a CV of 8.9%, almost as stable as the fixed-price buffer stock with the same band, but at a fiscal cost that is more than 20% lower.
- Alternatively, the simulation of the 20 T/kg price band with the adaptive buffer stock resulted in a CV of 12.5% at a cost of about USD 278 million/year, again achieving greater price stability at a lower cost compared to the current PFDS policies, as simulated by the model.

5.5. Implications for reducing price instability

The results of this report suggest that it is possible to reduce price stability without increasing costs or to reduce costs without exacerbating price volatility. In particular, the following conclusions identify a path toward more cost-effective price stabilization policies.

- Simply expanding the size of the quantities of rice purchased and distributed under the PFDS will not necessarily reduce rice price stability in Bangladesh. The model shows that expanding the scale of the program without changing the allocations across Divisions and months can actually increase price instability. This is partly because a larger public stock displaces private grain storage and may be less effective in smoothing grain availability over time.
- It would be worth exploring ways to improve the allocation of rice distribution and rice procurement to focus it on the objective of price stabilization. For example, the government could avoid purchasing rice from high-price regions like Dhaka and avoid distributing it in low-price markets. In addition, it could avoid distributing and procuring rice in the same month, as appears to be happening in June. This might require separating the safety net function of the PFDS from the price stabilization function, so that each can focus on a single objective.

- The simulations show that reducing or eliminating rice import tariffs is an effective way of reducing rice price instability. According to the simulations, eliminating the 25% import tariff on rice would reduce price instability (CV) from 13.3% to 11.3%. It would also imply a loss of roughly USD 56 million/year in tariff revenue, but this is less expensive than alternative ways of achieving the same level of price stability.
- A more aggressive approach to reducing rice price instability would be to consider adopting a buffer stock policy, in which decisions to purchase and distribute rice are based only on the level of market prices. If implemented poorly, the buffer stock could be quite costly or ineffective. Because of uncertainty regarding the appropriate level of the center of the price band, it would probably be preferable to establish an adaptive buffer stock, where the floor and ceiling prices are adjusted in response to the national level of stocks. More specifically, as stocks get low, buying and selling prices are adjusted upward, and as stocks approach warehouse capacity, then these prices are adjusted downward.

Although there is certainly room for improvement, it should be recognized that the current system, involving efforts by both the public and private sector, is already quite successful in converting a highly unstable flow of rice production into a stable flow of rice to consumers, in keeping price instability to a relatively low level by international standard, and establishing an integrated, national rice market, which allows the burden of adapting to local shocks to be shared across the country.

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Appendix A. Equations in the model

The Bangladesh Rice Market Model consists of ten blocks of equations, which is written in GAMS (General Algebraic Modeling System) and solved using Mixed Complementary Programming (MCP). Not all ten equations are used in every simulation. For example, the buffer stock buying price and selling price constraints are only used in simulations that assume the public food distribution system is operated as a buffer stock for rice. MCP finds solutions that satisfy a set of equalities and inequalities, where the inequalities must be linked to a complementary variable that becomes positive when the inequality constraint is binding. For example, spatial arbitrage is expressed as an inequality in which the difference between prices in different markets must be less than or equal to the cost of transportation between the markets. In this case, the complementary variable, which only becomes positive if the inequality is binding, is the volume of goods transported between the markets. The ten equations are described below.

Demand for rice

Rice demand in each Division is a function of the retail price, which is calculated as the wholesale price plus a fixed margin. The demand function in double-log, meaning that the price elasticity is constant throughout the range of price and quantity. The price elasticity of demand is -0.68, based on econometric analysis in Yunus and Shahabuddin (2013). This means that if the price of rice rises by 10%, the demand for rice will decline by 6.8%. Normally, one would expect that a staple food that has few substitutes would have a price elasticity of demand of -0.3 to -0.4. However, we use -0.68 partly because of econometric evidence to support it and partly because it results in rice price stability that is similar to the historical level (CV=13%). The demand function does not vary across months.

$$\boldsymbol{log(D_r) = Da_r + \varepsilon_d * log(PW_r) + MARG_r} \qquad \textbf{(1)}$$

where:
r = region
D = Quantity demanded (million tons)
ε_d = elasticity of demand
PW = Wholesale price (Taka per kg)
$MARG$ = Margin between producer and consumer prices in Taka per kg

Supply of rice

The supply of rice in each region is a function of the producer price four months prior and a stochastic shock. Like the demand function, the supply function uses a double-log specification, meaning that the supply elasticity is constant. The producer price is calculated as the wholesale price minus a fixed margin. The supply elasticity is

0.3, based on supply elasticities that have been estimated econometrically for Bangladesh (Yunus and Shahabuddin, 2013).

The production shock is a normally distributed random number. The production shocks in the model replicate the historical variability of rice production in each Division and each season, as well as the correlations across Divisions within each season.

These calculations provide a stochastic production for each Division and each season in the simulation, but since the model is monthly, we need to allocate the production for each season into months. We used data from the Bangladesh Integrated Household Survey, which collected information on the share of harvest occurring each month. We shifted the market availability of the rice forward by two weeks to allow time for drying the rice.

$$\boldsymbol{log(S_r) = Sa_r + \varepsilon_s * log\left(PW_{t-4,r} - MARG_r) + log(1 + SSHOCK_r)\right)} \qquad \textbf{(2)}$$

where:
r = region
S_r = Quantity supplied (million tons)
ε_s = elasticity of supply
PW_{t-4} = 4 month lagged wholesale price (Taka per kg)
$MARG$ = Margin between producer and consumer prices in Taka per kg
$SSHOCK$ = Independent random supply shocks (normal with 0 mean seasonal & regional sd)

Commodity balance and prices

The third set of equations in the model ensures that the inflows are equal to outflows in each month and each Division. Inflows include production, shipments from other regions, imports, net reductions in private stocks, and net reductions in public stocks. Outflows include consumption, shipments to other regions, exports, net increases in private stocks, and net increases in public stocks.

$$S_r + \sum_{r2} TQ_{r2,r} - \sum_{r2} TQ_{r,r2} + IMP_r - EXP_R + (STOCKLAG_r - STOCK_r) + \\ (GSTOCKLAG_r - GSTOCK_r) + GSALES_r - GPURCH_r = D_r \qquad \textbf{(3)}$$

where:
$TQ_{r,r2}$ = Transported quantity (million tons) from region r to region $r2$
IMP = Imports (million tons)
EXP = Export (million tons)
$STOCKLAG$ = Lagged private stock (million tons)
$STOCK$ = Private stock (million tons)
$GSTOCKLAG$ = Lagged public stock (million tons)
$GSTOCK$ = Public stock (million tons)
$GSALES$ = Government distribution (million tons)
$GPURCH$ = Government procurement (million tons)

Relationship among prices

A fourth set of equations ensures that the rules of spatial arbitrage are followed. In other words, the wholesale price in each Division plus transportation costs to another Division must be greater than or equal to the price in the second Division. Here, we define transportation costs broadly to include all costs related to shipping rice from one Division to another, including a normal profit margin and a risk premium that to offset the risks associated with the trade (theft, spoilage, adverse price changes, and so on). This equation has a complementary relationship with the trade flow between the two Divisions. This means that if the inequality is non-binding (the price plus transportation cost is greater than the other price), the commodity flow will be zero. Alternatively, if the inequality is binding (the price plus transportation costs equals the other price), the commodity flow can be positive. The economic intuition is that we would not expect any flows unless the price difference is large enough to justify the shipment. This set includes 57 equations, since each of eight Divisions has a price relationship with each of the other seven Divisions.

$$PW_{r1} + TC_{r1,r2} = PW_{r2} \tag{4}$$

where:
TC = Transport cost (Taka per kg)

Availability of rice

The fifth set of equations simply define "availability", which is used in the private-sector storage decision function. Availability is the sum of rice production, net shipments into the region, net imports, and carry-over private-sector rice stocks.

$$A_r = S_r + \sum_{r2} T\,Q_{r2,r} - \sum_{r2} T\,Q_{r,r2} + STOCKLAG_r + IMP_r + EXP_r \tag{5}$$

where:
A = Availability

Private-sector storage

Another set of equations defines the level of private-sector rice stocks carried over into the next month. It is a non-linear function of rice availability, defined above. The function is an approximation of the rational expectations storage decision rules that come out of the Williams-Wright competitive storage model. While the details of the storage rule vary depending on the elasticity of demand, the variability in stochastic supply, and the cost of storage, all storage rules take a similar form, where storage is equal to zero if availability is less than the average level of consumption, but as availability increases beyond this level, storage rises with a slope of close to 1. In other words, almost all availability beyond what is needed for current consumption is stored.

$$STOCK_r \geq MIN(STOCKMAX_r,\ PRSRa_r * A_r^2 + PRSTb_r * A_r + PRSTc_r) \qquad \textbf{(6)}$$

where:
$STOCKMAX$ = Private storage capacity (million tons)
$PRST$ = Coefficients on private storage function ($S = a * A^2 + b * A + c$)

Buffer stock buying price

The seventh set of equations only applies when we are simulating a buffer stock, in which the government keeps prices within a price band by buying or selling enough rice to "defend" the band. This equation simply requires the wholesale rice price in each Division to be greater than or equal to the government procurement price. This inequality is linked to government procurement, where if the inequality is binding (an equality), then government purchases are positive. If the inequality is not binding, then government procurement is zero.

$$PW_r \geq GPROCPRICE \qquad \textbf{(7)}$$

where:
$GPROCPRICE$ = Government procurement price

Buffer stock selling price

Again, the eighth set of equations also only applies when we are simulating a buffer stock. In this equation, the wholesale rice price is required to be less than or equal to the government selling price. Again, if the inequality is binding (meaning that the wholesale price is equal to the government sale price), then government sales are positive. If it is not binding (meaning the price is less than the sale price), then government sales are zero.

$$GSALEPRICE \geq PW_r \qquad \textbf{(8)}$$

where:
$GSALEPRICE$ = Government sales price

Import parity price

The import parity price is the price at which it becomes profitable to import rice. It is equal to the foreign wholesale price, converted to Taka, plus the cost of transporting to Bangladesh including any import tariffs. We assume that Bangladesh is a "small country" in world rice markets, meaning that the international price of rice is not influenced by the volume of imports to Bangladesh. Since most rice imports come from India, we use the New Delhi wholesale price of rice to calculate the import parity price. The import parity price differs across Divisions because the cost of transportation from the Indian border differs. This set of equations says that wholesale prices in each Division must be less than or equal to the import parity price for that Division. The equation is linked to the import volume, in that imports are zero if the local price is less than import parity and import volume can be positive only if the local price is equal to the import parity price.

$$((PWND + TCND) * (1 + MTAX) - TCBK) * \frac{ER}{1000} - TC_{khulna,r} \geq PW_r \qquad \textbf{(9)}$$

where:
$PWND$ = Lagged wholesale price in New Delhi (USD per ton)
$TCBK$ = Transport cost from border to Khulna (USD per ton)
ER = Exchange rate (T per US$)

Export parity price

The last set of equations require the local price in each Division to be greater than or equal to the export parity price, which is the wholesale price in the foreign market (New Delhi in this case) minus the cost of transporting it there. In Bangladesh, the export parity price is close to zero, so this equation is very rarely binding and hardly ever generates rice exports.

$$PW_r \geq PWND - TCBK * \frac{ER}{1000} - TC_{r,khulna} \qquad \textbf{(10)}$$

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