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Seed industry and seed policy reforms in Bangladesh: impacts and implications

RESEARCH ARTICLE

Deepthi Elizabeth Kolady^a and Md. Abdul Awal^b

^aAssistant Professor, Department of Economics, South Dakota State University,
P.O. Box 2236, 1150 Campanile Ave, Brookings, SD 57007, USA

^bChief Scientific Officer, Planning and Evaluation Division, Bangladesh
Agricultural Research Council, Farmgate, Dhaka 1215, Bangladesh

Abstract

High population density in Bangladesh implies that agricultural productivity improvement is key to ensure food security. This raises the need for increased research and development investment in the agricultural sector. Although Bangladesh has enacted various seed policy reforms since 1990s to attract the private sector, the seed sector in Bangladesh still remains less developed and relies heavily on imports for the supply of quality seeds. Unlike in Bangladesh, the seed policy reforms in India contributed to the development of a competitive seed industry in India. In this study, we examine the characteristics of seed sector in Bangladesh, conduct a comparative analysis of seed policy reforms in Bangladesh and India, and empirically examine the effect of Bangladesh seed policy reforms on cereal crops' productivity. Results from the study have implications for seed industry stakeholders and policy makers in developing countries, particularly in designing strategies and policies for seed industry development.

Keywords: seed sector, private sector, R&D investment, food security, India

JEL code: O13, Q12, Q13, Q16, Q18

^①Corresponding author: deepthi.kolady@sdstate.edu

1. Introduction

Bangladesh is one of the most densely populated countries in the world with very high levels of food insecurity. Agriculture sector is the major source of livelihood for about 48% of the Bangladesh population. This high pressure on land in Bangladesh implies that achieving productivity growth in agriculture is critical for attaining food security in the country. There is strong empirical evidence on the positive effects of development and adoption of improved crop varieties or cultivars on increased agricultural productivity (Alston and Venner, 2000; Evenson and Gollin, 2003; Fernandez-Cornejo, 2004). However, annual agricultural research and development (R&D) spending levels in Bangladesh have shown an erratic trend since its peak in 2000 (Stads *et al.*, 2014). This highlights the importance of attracting private sector R&D investment into Bangladesh agriculture and seed sector.

While the public sector is the dominant player in the seed sectors of self-pollinated crops such as rice and wheat, where farmers can save and use the seeds in the upcoming cropping seasons, private sector is the major player in the maize seed segment, an open-pollinated crop, dominated by hybrids in the South Asia region. There is evidence that potential yield progress of wheat and rice are getting slower in the region compared to that of maize (Fischer *et al.*, 2014). Hence, there is a push to bring private sector investments, especially with the advances in fields such as molecular biology and biotechnology, into rice and wheat crop segments in countries such as Bangladesh and India, to address food security concerns (Spielman *et al.*, 2014). However, geographical differences in the rates of adoption and diffusion of improved cultivars and its contribution to agricultural productivity suggest that R&D of improved cultivars alone will not contribute to increased agricultural productivity, a seed industry that increases farmers' access to improved and quality seeds is essential. Available evidence suggests that in addition to the market demand, technology solutions and supportive policy environment are essential for the development of a robust and competitive seed industry (Gerpacio, 2003; Kolady *et al.*, 2012; Morris *et al.*, 1998).

Like in many other countries in the region, the seed sector in Bangladesh was highly regulated in the 1970s and 1980s. It was not until the early 1990s that the state control over the seed industry began to loosen in Bangladesh. Unlike in India, where the seed policy reforms were aimed at developing an active seed sector with strong R&D investment and research portfolio, the reforms in Bangladesh focused on promoting private seed enterprises in seed marketing and distribution, regulating seed quality for domestically produced seeds, and facilitating seed imports into the country. Because of this, most of the R&D investment in the seed sector still occurs in the public sector and the seed industry remains less developed in Bangladesh. This raises the questions such as whether the differences in performance of seed industries in Bangladesh and India can be attributed to the differences in the policy and institutional environments within which seed industries operate in these two countries, whether depending on import for quality and improved seeds is a reasonable and sustainable strategy for the private sector in relatively smaller markets such as Bangladesh, and what are the impacts of such a strategy on crop productivity. It is to be noted here that there are concerns about private sector participation into seed sector, especially into seed segments of staple food crops. In general, these concerns arise from issues related to seed quality, pricing, and control over seeds (Murugkar *et al.*, 2007). These concerns make policy makers' decision on whether to allow private sector participation into seed sector much more difficult.

The objectives of our study are three fold: first, analyze the major characteristics of the seed sector in Bangladesh; second, examine the seed policy reforms in Bangladesh and conduct a comparative analysis of seed policy reforms in Bangladesh and India; and third, empirically examine the impact of seed policy reforms on cereal crops' productivity in Bangladesh and compare these results with already available evidence from India. Results from the study will be of value for policy makers and various seed industry stakeholders including managers in the following ways: (1) provide insights on seed market dynamics, seed industry structure, and competition that will be of value in management and investment decisions; (2) highlight the huge untapped potential for seed business in Bangladesh; (3) highlight the major seed policies in the country

and its implications for various stakeholders; and (4) provide insights on policy options worth pursuing to improve the seed sector and crop productivity to address food security concerns.

2. Background

2.1 Characteristics of Bangladesh seed sector

Based on the seed production practices and technology used, Bangladesh seed sector can be classified into the following two segments: (1) formal system where seeds are produced following certain production procedures and practices, and (2) informal system where seeds produced do not follow any specific production procedures, but subjected only to farmers' own evaluation, comprising mainly of farmer saved seeds. According to the data available from the Seed Wing of the Ministry of Agriculture, during 2012-13 the formal system supplied only 40% of the total demand for rice seeds and 34% of the demand for wheat seeds as opposed to the 79% of the demand for maize seeds (Seed Wing, 2014). This statistic suggests that the majority of the rice and wheat farmers in Bangladesh still rely on farmer saved seeds for crop production and highlight the huge untapped potential for seed business in the country.

The implicit assumption supporting formal seed system is that in the informal system, farmers rely on poor selection methods and processing techniques and lack proper storage facilities which will result in poor quality seeds, particularly in terms of genetic purity and germination. Although there are studies challenging this assumption (Biemond *et al.*, 2013; Bishaw *et al.*, 2012), interaction with public and private sector stakeholders in Bangladesh suggest that poor quality seeds from the informal seed system is an important challenge that needs to be addressed to ensure food security in the country.

The formal seed system of Bangladesh is comprised of public and private sectors, and non-governmental organizations (NGOs). The seed markets in the formal system are categorized into two groups based on the regulatory status: notified/controlled crops and non-notified crops. Rice, wheat, potato, jute, and sugarcane are the notified crops that are considered important in terms of food and national security and seed segments of these crops are highly regulated. Private sector faced restrictions in the use of new genetic material and accessing public varieties and breeding lines of these crops. Additionally, private sector had to pay levies on seed imports for all notified crops and had to undergo time consuming and onerous registration process where the companies pay a fee to the government to conduct performance tests to decide whether or not to allow each cultivar. All other crops are classified as non-notified crops and private sector faced no restrictions in the use of new genetic material and relatively less restrictions in the importing, registering, and marketing of seeds of non-notified crops (Ahmed *et al.*, 2012). Because of this, overall, public sector is the major player in the seed segments of notified crops and private sector dominates the seed segments of non-notified crops.

2.2 Public sector

In the public sector, plant breeding is primarily conducted by research institutions under the Bangladesh National Agricultural Research System (NARS) and agricultural universities. Although, Bangladesh Agricultural Research Institute (BARI) has the mandate for research and technology generation for the all the crops, Bangladesh Rice Research Institute is the key institution responsible for the development of improved rice varieties. The Bangladesh Institute of Nuclear Agriculture under the Ministry of Agriculture has the mandate for germplasm improvement in crops through application of advanced tools such as mutation breeding.

Once the breeders' seeds are developed, Bangladesh Agricultural Development Corporation (BADC), a state owned enterprise, takes the responsibility of seed multiplication and distribution. The BADC has about 7,500 seed dealers, and 72,000 contract seed growers for producing certified seed and about 16 processing and storage facilities (Seed Wing, 2014; USDA FAS, 2014a). Although, BADC's main focus is notified crops, it has expanded into non-notified crops as well. The seeds marketed and distributed by the BADC are subsidized

as it does not cover the full costs of production, processing, marketing, and distribution (Ahmed *et al.*, 2012). The Seed Certification Agency (SCA) is responsible for certification of breeder and foundation seeds.

2.3 Private sector

Restrictions on the use of new genetic material, levies on seed imports, and subsidized seeds from BADC prevented the emergence of private seed sector in the country. Until early 1990s, the number of private companies was limited in Bangladesh and those present were focused on marketing and distribution of seeds of non-notified crops, particularly in the vegetable sector. For example, in the late 1980's, the private sector supplied only about 5% of the total requirement for seed in the country (Ahmed *et al.*, 2012). Currently there are over 150 private seed companies and 17,500 registered seed dealers in Bangladesh. However, only ten of these companies have own R&D activities which are primarily focused on hybrid seeds of vegetables, maize, and rice (USDA FAS, 2014a). The companies without own R&D investments choose one or more of the following approaches for marketing and distribution: (1) rely on the NARS for breeder seeds for seed multiplication and distribution; (2) import seeds; and (3) import parental lines for domestic production of hybrids. Additionally, only a very few companies have own seed testing facilities. While the majority of the small and medium size companies focus on marketing of seeds of high yielding varieties vegetables and potato, the large companies focus on hybrid seeds of vegetables, rice, and maize.

2.4 Non-governmental organization sector

Active participation of NGOs in seed production, marketing, and distribution, is another important characteristic of Bangladesh seed sector. For example, Bangladesh Rural Advancement Committee (BRAC), the largest NGO in the country, has its own R&D program for rice, maize, and vegetables. Most other NGOs primarily focus on marketing and distribution of seeds of non-notified crops. For the remainder of the paper, NGO sector is included as part of the private sector unless stated otherwise specifically.

3. Seed policy reforms in Bangladesh

The Seeds Ordinance 1977 was the first major seed law in the country after its independence in 1971. It specified what seeds must be regulated, recommended creation of seed certification procedures for notified seeds through the SCA, and empowered the government to develop rules to execute the Ordinance. The general intent of the ordinance was to set some seed quality standards in terms of germination and purity. However, the National Seed Board (NSB) used the Ordinance to create a list of allowed varieties for all crops grown in the country. The number of allowed varieties towards the end of 1980s was short and (with the exception of vegetables) identified almost entirely to the varieties developed and promoted by the public sector with assistance from international agricultural research centers such as International Rice Research Institute (Gisselquist and Srivastava, 1997). Through the Ordinance, the public sector became the dominant player in the seed sector, particularly for notified crops.

The liberalized market access to irrigation equipment during the end of 1980's expanded rice acreage and production in the country, particularly in irrigated conditions. The increased rice production motivated the government to encourage diverse crop production in the country. However, lack of availability of quality seeds was a major constraint for crop diversification. Additionally, public sector expertise was mainly focused on the notified crops. The diversification motive coupled with the concern related to the widening gap between the supply of and demand for quality and improved seeds, encouraged the Ministry of Agriculture to enact the National Seed Policy (NSP) in 1993 (Gisselquist and Srivastava, 1997; Ahmed *et al.*, 2012). The major recommendations of the NSP included: (1) public and private sector should be allowed to breed and import improved seeds; (2) seeds of non-notified crops should not require testing for registration; (3) seed companies that are registered with the NSB can acquire/purchase breeder and foundation seeds for seed multiplication; (4) BADC should eventually withdraw from marketing of seeds and should allow the private sector to use its processing and storage facilities; and (5) introduced the concept of Truthfully Labelled Seeds where public

and private sector can independently certify their own seeds and market them in labelled packages (USDA FAS, 2014b). According to the NSP, the government must recognize all cultivars by registering, before seed sale is permitted. The registration process gives credibility to the seed companies and its products and helps the government to screen out fake or fly-by-night seed operators from marketing low and/unknown quality seeds. For the notified crops, testing is required prior to registering where the companies pay a pre-determined fee to the government to test the performance of cultivars. For non-notified crops, testing by the government is not required for registering (Ar-Rashid *et al.*, 2012). Incorporating the recommendations from the NSP 1993, the Seeds Ordinance 1977 was amended in 1997 (The Seeds Amendment Act, 1997), 2005 (The Seeds Amendment Act, 2005), and 2007 (The Seeds Amendment Act, 2007). The Seed Rules 1998, was created to implement the Seeds Act 1997. The 2007 Act formulated the hybrid seed registration guidelines and encouraged the private sector and NGOs participation in hybrid seed sector. Although Plant Variety and Farmers' Right Act was proposed in 1998 to incentivize private sector R&D investment into agriculture, it is yet to be enacted (USDA FAS, 2014b).

Like in Bangladesh, India had a state monopoly in the seed sector until 1980s. State control over the seed sector began to loosen since 1980s with the following reforms in rules and regulations: (1) the Seed Control Order of 1983 that regulated the seed dealers through dealer licensing; (2) the Indian Industrial Licensing Policy of 1987 that de-reserved the Indian seed industry permitting large Indian companies to produce and sell seeds in India; (3) and the New Policy on Seed Development of 1988 which relaxed seed trade norms within the country, reduced import restrictions on germplasm for research, and encouraged foreign company participation in the seed industry. These seed sector specific policy reforms were followed by an economy-wide liberalization in 1991, which further opened up the seed industry and provided a conducive environment for the private sector R&D investment in India. Additionally, India enacted Plant Variety Protection and Farmers' Right Act in 2007 to incentivize innovation in agricultural research and development while protecting Farmers' Rights. Although initially the seed policy reforms in India focused on opening up the seed sector to private companies and regulating it for quality control purposes, upon participation of the private sector in the seed sector, the reforms incentivized the private sector to invest in R&D of new crop varieties. The private sector investments that leveraged the results of public sector R&D investments contributed to increases in crop productivity in crop segments such as maize and pearl millet in India (Kolady *et al.*, 2012).

The seed policy reforms in India allowed the private sector participation in all crop segments at all levels. Unlike in India, the reforms in Bangladesh did not specify anything about the import of germplasm by the private sector for research and development in notified crops. The restrictions that still remain for the private sector participation in Bangladesh include the mandatory performance testing by the government prior to the marketing and distribution of seeds of notified crops and the marketing challenges faced by the continued supply of subsidized seeds through BADC. One major exception of these restrictions was when food security concerns forced the government to permit four private sector companies to import 2,200 metric tons of hybrid rice seeds for the 1998-99 *boro* season to make up the shortage of rice seeds after the 1998 flood (Hossain *et al.*, 2003). Since then, despite being a notified crop, private sector is a major player in certain segments of rice seed sector (see below). While the strength of enforcement of India's PPV&FR Act and its impact is not very clear at this point in time, interactions with industry stakeholders suggest that the Act is expected to help address the information asymmetry between farmers and seed retailers and thus help the Indian seed industry by preventing fake seed companies and dealers from exploiting the farmers (Spielman *et al.*, 2016). Lack of such a regulation in Bangladesh is a concern for private sector companies who are investing in R&D activities for crops such as high yielding varieties of rice.

4. Impact of seed policy reforms in Bangladesh

4.1 Conceptual framework

Although, the effect of seed policy reforms on private R&D investment was minimal or none, the reforms indeed had positively influenced the private sector participation in the seed distribution and marketing of certain crop segments. The reforms contributed to an increase in the number of companies importing seeds from a very limited number focusing on vegetable seeds prior to 1993 to about 150 companies focusing on a broad range of crops during 2013-14 (USDA FAS, 2014a). Compared to the very limited market share prior to the reforms, in 2011-12 the private sector accounted for 94, 89 and 21% of proportion of commercial seeds distributed in the country for maize, vegetables, and *boro* rice, respectively. The effect was evident not only in seed distribution, but also in registration of new cultivars (most of which were imported). For example, the number of registered cultivars increased from a very limited number during 1971-1993 to 1064 during 1994-2012 for vegetables, and to 98 for maize (Naher, 2014). It is interesting to note that while the private sector registered 76 rice hybrids (mostly from imports) during 2000-2010, the public sector registered only five rice hybrids during that period (Ar-Rashid *et al.*, 2012).

Nevertheless, these aggregate figures above do not reveal the differences in private sector's response to seed policy reforms between and within crop segments. Additionally, what is less clear is whether the reforms contributed to increases in crop productivity. An understanding of the characteristics of various crop segments is necessary to understand the factors influencing differences in private sector response to seed policy reforms and its impact on crop productivity.

4.2 Cereal seed sector in Bangladesh

Rice accounts for more than 75% of gross cropped area, 92% of the annual grain production, and 94% of the cereals consumed in Bangladesh (BBS, 2010). Hence increasing rice yields, to maintain a stable price, is essential to ensure food security in the country. Rice cultivation in Bangladesh fall into the following three seasons: *aus/kharif 1* (mid-March to mid-July); *aman/kharif 2* (June to December); and *boro/rabi* (mid-November to mid-May). While *aman* is a rain fed crop, *boro* and *aus* are grown mostly under irrigated conditions.

Prior to the reforms, BADC was the sole supplier of quality seeds for all rice segments (Gisselquist and Srivastava, 1997). Although rice seeds suited for *boro* rice were available from China prior to 1993, due to its regulated status, the private sector was not allowed in the rice seed markets. Since *boro* and *aus* rice are grown mostly under irrigated conditions, farmers prefer purchasing quality seeds of these crops each year instead of using farmer saved seeds. Expansion in the irrigated rice area, particularly for *boro* and *aus* rice, created a steady market demand for quality seeds and attracted private sector participation into these segments during the post reform period. As mentioned previously, even with the reforms, the government allowed the private sector to import rice hybrid seeds from China only when the floods caused a shortfall in supply of quality seeds for rice during the 1998/99 season. The yield benefits of hybrid seeds are attributed to the hybrid vigor achieved by the crossing of two distinct parental lines. In contrast to seeds of traditional/modern high yielding varieties, hybrid seeds loose its hybrid vigor for each of the generations when seeds are reused compelling farmers to purchase new seeds every year. Thus hybrids act like a biological form of intellectual property and attract private sector participation into it. Most of the rice hybrids are for *boro* rice. Currently, there are a couple of private sector players investing in the R&D of new hybrid rice varieties. *Aman* varieties are long duration type and mostly grown under rain fed conditions. Since most of the farmers rely on farmer saved seeds for *aman* season there is less demand for seeds from the market. Hence participation of private seed companies is very limited in the *aman* seed segment, even after the reforms.

Wheat is the second most important cereal crop in the country. The area under wheat is declining over the years, mainly due to the expansion in maize area. Hence, the potential seed market for wheat is relatively

low compared to rice and most of the farmers rely on farmer saved seeds for production of subsequent crops. Because of these reasons private sector participation in the wheat seed market is very limited.

Maize, unlike rice and wheat, is a non-notified crop making it easier for the private sector to enter the maize seed market. Although private sector was active in the maize seed sector from early on, the rapid increase in demand for hybrid seeds since late 1990s attracted many companies into the sector. Recent estimates suggest that about 90% of the demand for hybrid seeds is met through imports, particularly from India (Oxfam, 2013). While most of the private sector companies rely on imports of seeds or parental lines, some private sector companies and BRAC have their own R&D programs for hybrid maize (Ali *et al.*, 2008). The BARI started its own research program in hybrid maize in mid 1990s and released its first hybrid in 2001.

It is clear from the above discussion that the NSP of 1993 attracted private sector participation into *boro* and *aus* segments of rice and maize seed markets. Figure 1 compares the percentage changes in yield levels for rice, wheat, and maize before and after the NSP of 1993. It is evident from Figure 1 that the segments with strong private sector participation (*boro*, *aus*, and maize) experienced substantial increases in yield levels during the post-reform period. On the contrary, the percentage change in yield levels decreased for *aman* rice and wheat, the two segments dominated by the public sector during the post-reform period. Thus, the results in Figure 1 suggest a positive correlation between private sector participation in the seed markets and yield increases at farm-levels. What is less clear is whether the private sector participation led to improved crop yields for these crops after controlling for other factors that might influence yields. We address this question empirically in the following section.

4.3 Empirical model

Here we examine whether the NSP of 1993 contributed to a structural change in the yield levels for *aus* and *boro* rice and maize, evidence of which would indirectly suggest positive effects of policy reforms on crop productivity and encourage private sector participation in the seed industry. Our hypothesis here is that crop segments that attracted private sector participation would exhibit increases in on-farm yields during the post-reform periods. We test this hypothesis by examining yields since 1971 for rice and maize, and comparing them with wheat yields. The empirical model used in the study follows the general approach of Kolady *et al.* (2012).

$$\text{Log}Y_{it} = a_0 + a_1\text{PIRRIGAREA}_{it} + a_2\text{RAINFALL}_t + a_3\text{PRICE}_{it-1} + a_4\text{UREAPRICE}_t + a_5\text{YRHARVEST}_{it} + a_6(\text{DPOLICY}_t * \text{YRHARVEST}_{it}) + e_{it} \quad (1)$$

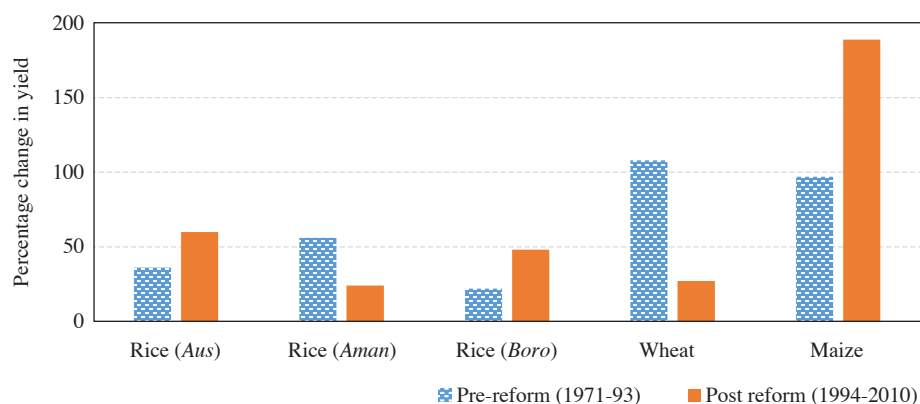


Figure 1. Percentage change in yields of rice, wheat, and maize in Bangladesh, 1971-2010 (based on BBS data from various years).

$PIRRIGAREA_{it}$ denotes the proportion of area under irrigation of crop i in year t .

$RAINFALL_t$ denotes the average annual rainfall in year t .

$PRICE_{it-1}$ denotes the real farm harvest price of crop i in year $t-1$, obtained by deflating the farm harvest price by the consumer price index. Crop-specific data on variable input use and irrigation that might influence yields are not available. However, as suggested by Pray and Ramaswami (2001), we include lag values of real farm harvest prices as a proxy for farmers' perception on crop profitability that might influence farmers' variable input use. The implicit assumption here is that farmers in developing countries, who still lag behind in getting timely information on current and potential market information, rely on previous year's market prices in deciding the crop acreage and input use for the current period.

$UREAPRICE_t$ denotes the real value of fertilizer price paid by farmers for urea, one of the most commonly used and highly subsidized fertilizer in Bangladesh, in year t . Since crop-specific data on fertilizer use that could influence yield is not available, we include real values of national level fertilizer prices in the model to capture changes in the amount of fertilizer (urea) used by farmers over the years. Our assumption here is that there is an inverse relationship between fertilizer price and its use in year t .

$YRHarVEST_{it}$ denotes the year of harvest of crop i in year t . Year is included as a trend variable. Additionally, we expect it to address some of the omitted variable issues we discuss below.

$DPOLICY_t$ is the dummy variable representing the policy change with value 0 if $t < T$ and 1 if $t \geq T$ (where T is the year of policy change).

The policy variable is introduced into the empirical model with a lag to reflect the time required for firms to respond to the policy change. As discussed earlier, instead of promoting investments in national level research, the seed policy reforms encouraged private sector to engage in marketing of publicly developed high yielding modern varieties of rice (short duration varieties of *aus* and *boro*), and imports of hybrid seeds (*boro* rice and maize). Starting a seed distribution and marketing program relying on imports or public sector R&D is relatively easy compared to starting a breeding and research program from the scratch. For example, if the private sector was involved in marketing of publicly developed high yielding varieties (*aus* and *boro* rice) or imports of seeds, the response time needed is very short. However, due to the differences in the regulated status of the crops and market size, private sector's response to the seed policy reforms vary between and among crop segments. Although due to the non-regulated status private sector was active in the maize seed market from early on, it was the rapid expansion in maize area in the late 1990s that attracted many more companies into the import of hybrid maize seeds. Unlike maize, rice and wheat are notified crops with strong public sector R&D investment. Hence the reforms provided the private sector quick opportunities to either import seeds or to use domestically developed public sector seeds for marketing and distribution. However, as mentioned previously, market demand for quality seeds was limited to *boro* and *aus* segments of rice. Hence, private sector focused on these segments instead of *aman* rice or wheat. Thus the time taken by the private sector to respond to the policy change vary by the crop segment, market demand, and technology (hybrid versus high yielding variety). Under these circumstances, relying on one particular time period as the policy response lag may not be appropriate. To address this concern we test the hypothesis of structural change in the yields by taking two, four, six, eight, and 10 years as policy response lags since 1993. For example, the policy dummy variable takes the value of 1 for all years since 1995 (under the two-year lag), for all years since 1997 (under the four-year lag), for all years since 1999 (under the six-year lag), for all years since 2001 (under the eight-year lag), and for all years since 2003 (under the 10-year lag). Instead of introducing the policy variable an intercept dummy we are including it as slope variable by interacting it with the trend variable $YRHarVEST_{it}$. We interpret a positive and significant sign on the interaction variable $DPOLICY_t * YRHarVEST_{it}$ as suggestive of a structural change in the yield level since the passage of policy reforms.

One of the reviewers has mentioned that use of a modelling approach such as distributed-lag model that allows for changes to take place over multiple years would have been better than our approach adopted here to account for the effect of policy lag. We agree with the reviewer that the distributed-lag model would have been a better approach. However, given that our sample size is relatively small with only 40 years of observation makes it difficult to employ a distributed lag model spreading over 10 years or so. The reviewers have also highlighted that our empirical model may be mis-specified as it does not take into account all the factors that would have influenced crop yield such as extension services, public investment, roads, tillage practices, cultivars, etc. We agree that there are other farm, farmer, and contextual factors that might influence crop yields. As highlighted in our data section below, lack of crop specific panel data at farm level is a major constraint for this type of analysis. By including the trend variable, we try to capture many of the omitted variables such as other policy changes happening in the economy and agriculture sector, improvements in public infrastructure such as roads and public R&D investment, etc. As pointed out by one of the reviewers, without a natural experiment, it will be hard to resolve the issue of omitted variable bias.

4.4 Data

Crop specific panel data at farm, district, or state levels on agricultural production practices reflecting yields, input use, and market prices are not available from Bangladesh for the study period starting 1971. One notable exception is the Bangladesh Integrated Household Survey (BIHS)-2011-2012, which collected data on plot-level agricultural production practices. Availability of BIHS like data for the study period would have addressed some of the omitted variable bias issues discussed above. While BIHS data will not be of use for the present study, this is an important effort to collect necessary data for similar studies in future. Due to the lack of availability of farm level panel data relevant for our study, we use national level data for the period 1971-2010. We used various secondary sources for data collection: Bangladesh Bureau of Statistics (BBS), Year Book of Agricultural Statistics (various years) for yields, proportion of irrigated area, price of urea, harvest prices, and rainfall; BBS and Bangladesh Bank (various years) for data on consumer price index. Harvest prices for maize was not available for many years since 1971 due to the less demand for crop prior to late 1990s. Hence we have not included harvest prices in our estimation of the maize yield model. Diagnostic tests were conducted to examine for the presence of autocorrelation, unit roots, and heteroscedasticity. To address the issue of serial correlation, the model was estimated using Prais-Winsten (AR1) regression.

5. Results and discussion

In this section we present the estimation results of yield models of rice, maize, and wheat. As explained earlier, we have estimated the empirical model with various policy response time lags (two, four, six, eight, and ten years lag since 1993). The demand for maize increased only in the late 1990s with a substantial increase in the area since 1999 which attracted more and more private companies into the marketing and distribution of maize hybrids. Hence, looking for structural change in maize yield level prior to 1999 will not be appropriate. To simplify the presentation of results and for better comparison across crops, we present the results of yield models of rice and wheat with four years of policy response lag, and for maize with six years of policy response lag in Table 1. Results in Table 1 show that there are differences in the significance levels of the coefficient of the interaction term $DPOLICY_t * YRHARVEST_{it}$. Crop-wise estimation results of yield models with all other policy response lag years are presented in Supplementary Tables S1-5.

Since our econometric model controls for factors which might affect the crop yield, such as irrigation, rainfall, fertilizer price, and produce price, we take the positive and statistically significant coefficients of the policy response variables for *aus* and *boro* rice as supporting evidence of the hypothesis that there is a structural change in yield levels of crops with greater potential for appropriation and demand since the NSP of 1993. The coefficient of the interaction term for *aus* rice is significant starting from the two-year policy response lag (Supplementary Table S1). This might be because private sector focused on marketing the publicly developed high yielding varieties (HYVs), meaning the response time needed for the industry to react to NSP was short. Since farmers' access to HYVs improved shortly after NSP that might have resulted

in realization of higher farm level yields for *aus* rice. However, the non-significance of the policy interaction term in later years for *aus* and *boro* rice raises concerns (Supplementary Tables S1 and S3) and suggests that increased R&D investments is required to achieve and sustain growth in yield levels. Unlike *aus* or *boro* rice, the coefficient of the interaction term $DPOLICY_t * YRHARVEST_{it}$ is not significant for *aman* rice (Table 1). The non-significance of the interaction term for *aman* rice supports our alternative hypothesis that the policy reforms did not contribute to any structural change in the yield levels for crop segments such as *aman* rice which do not provide greater appropriability or market potential for the private sector.

As mentioned earlier, the demand for maize increased since late 1990s with a proportionate increase in maize area and private sector participation. The positive and statistically significant coefficient of the slope variable (Table 1) on policy supports our hypothesis that the NSP attracted strong private sector participation into the maize hybrid seed market with positive implications on maize crop productivity. The non-significance of the coefficient on the policy response variable with shorter time lags (Supplementary Table S4) reflects the less demand scenario for maize until the late 1990s. However, as in the case of *boro* rice, the non-significance of the coefficient of the interaction term with 10-year policy lag (Supplementary Table S4) raises concerns.

As in the case of *aman* rice, results from wheat yield model in Table 1 and Supplementary Table S5 show non-significant slope coefficients for the policy response variable. This lends support to our alternate hypothesis that due to the lack of appropriability and reduced market demand for wheat seeds, private sector participation is limited in the wheat sector and hence there is no structural change in its yield levels.

In summary, we find positive evidence to our hypothesis that the NSP of 1993 encouraged private sector participation into the crop segments such as *boro* and *aus* rice and maize, which have greater appropriability and market potential and contributed to positive structural changes in the yield levels for these crops and no such effect is evident for other crops such as wheat and *aman* rice. However, there are differences in the results from our study using national level data from Bangladesh and that of Kolady *et al.* (2012) from India. The India study focused on the response of maize, pearl millet, rice, and wheat sectors to the seed policy reforms since late 1980s and its impact on crop productivity. In the India study, there was no structural change in the yield trends for self-pollinated crops of rice and wheat, while there were positive and

Table 1. Estimation results of yield models of rice, maize, and wheat 1971-2010, Bangladesh.¹

Variable	<i>Aus</i> rice	<i>Aman</i> rice	<i>Boro</i> rice	Maize	Wheat
Dependent	Log yield	Log yield	Log yield	Log yield	Log yield
% of irrigated area	7.1×10^{-3} (1.3×10^{-1})	-7.2×10^{-3} (1.3×10^{-2})	-2.0×10^{-3} (1.9×10^{-2})	-1.9×10^{-2} (1.2×10^{-2})	$8.6 \times 10^{-3***}$ (2.7×10^{-3})
Rain fall (mm)	3.9×10^{-5} (3×10^{-5})	3.6×10^{-5} (3.5×10^{-5})	1.3×10^{-6} (2.7×10^{-5})	-2.7×10^{-4} (1.6×10^{-4})	3.0×10^{-5} (4.0×10^{-5})
Real harvest price(t-1) Taka/ton	1.7×10^{-5} (1.1×10^{-1})	1.9×10^{-5} (1.0×10^{-5})	1.2×10^{-6} (1.2×10^{-5})		-5.8×10^{-6} (2.0×10^{-5})
Real price of urea (Taka/ton)	5.2×10^{-6} (3.3×10^{-6})	-2.3×10^{-6} (4.1×10^{-6})	-7.0×10^{-7} (4.1×10^{-6})	-2.2×10^{-5} (2.7×10^{-5})	$1.9 \times 10^{-5**}$ (9.0×10^{-6})
Harvest year	$1.3 \times 10^{-2***}$ (4.1×10^{-3})	$1.5 \times 10^{-2***}$ (3.9×10^{-3})	$1.3 \times 10^{-2**}$ (1.4×10^{-3})	4.8×10^{-2} (3.9×10^{-2})	1.4×10^{-2} (9.9×10^{-3})
Harvest year* policy dummy	$5.3 \times 10^{-3***}$ (1.4×10^{-3})	2.3×10^{-3} (1.7×10^{-3})	$3.1 \times 10^{-3**}$ (1.4×10^{-3})	$3.4 \times 10^{-2***}$ (1.2×10^{-2})	-2.5×10^{-3} (4.2×10^{-3})
Constant	$-4.7 \times 10^{-1***}$ (1.2×10^{-1})	-1.1×10^{-2} (1.1×10^{-1})	$7.1 \times 10^{-1***}$ (2.0×10^{-1})	6.3×10^{-1} (6.2×10^{-1})	-3.1×10^{-1} (2.3×10^{-1})
Policy lag (years)	4	4	4	6	4
Number of observations	39	39	39	40	39

¹ Values in parentheses denote standard errors. *** and ** indicates that the coefficients are significant at 1 and 5% levels, respectively.

statistically significant structural changes for maize and pearl millet for all the periods of policy lags they have considered. While our results of wheat model are similar to those from India, there are some differences in results for rice and maize. In our study, we find positive and statistically significant structural changes for *aus* and *boro* rice with shorter policy lag periods while no such effect is visible for longer policy lag periods or for *aman* rice. It has to be noted that the India study did not have a sub-category level analysis for rice. Because of the dominance of state seed corporations in the rice and wheat seed segments in India, private sector participation in the marketing and distribution of seeds was negligible for these segments. With the seed policy reforms, private sector in India initially focused on crops such as maize, pearl millet, and vegetables for which hybrid seeds were readily available domestically from the public sector. Later, when more technology and market opportunities became available, private sector started to invest in R&D of these hybrid crops. In other words, even with the reforms, rice and wheat segments remained less attractive for private sector relative to hybrid crop segments in India. Unlike in the India case, there was no public sector driven hybrid research program in Bangladesh during the time of reforms. Additionally, BADC was not able to meet the demand for quality seeds for *boro* and *aus* rice, the largest seed market in the country. So the seed policy reforms attracted private sector participation into *boro* and *aus* rice segments with relatively strong market demand. This increased supply and adoption of quality seeds contributed to the structural change in yield levels for these rice segments. The coefficient of the policy interaction variable was significant for all models considered for maize in the India study. However, such a strong and long-term effect is not visible for maize in Bangladesh. As reported earlier, this could be due to the differences in the nature and scope of private sector participation in maize segments between these two countries.

6. Conclusions and policy implications

It is clear from our analysis that there is a huge potential for seed business in Bangladesh and attracting private sector participation into the seed industry is important to improve farmers' access to quality seeds, an important step in addressing food security concerns in the country. Results from our study show that the NSP of 1993 attracted private sector participation into importing, marketing, and distribution of seeds of crop segments with more market demand and appropriability in Bangladesh. Findings from our study imply that private sector participation in the seed sector, even if it is confined mainly to marketing of publicly developed improved varieties or marketing of imported seeds can contribute to increased crop productivity in farmers' fields. However, comparative analysis of results from our study and that of a similar study from India suggests that there are limitations to this strategy, most importantly, to sustain the yield gains at farmers' fields in the long term. Hence, relying only on import for quality seeds will not be a viable strategy for the private sector to increase their market share. Investment in R&D aimed at developing new crop varieties which can withstand biotic and abiotic stresses is critical to increase its competitiveness and market share.

In Bangladesh, with the exception of hybrid rice, policies to attract private sector R&D investments are lacking. Policy initiatives such as the removal of restrictions on private sector access to the public sector germplasm, removal of the mandatory performance testing of the private sector developed new cultivars by the government, enforcement of the proposed Plant Variety Protection Act, and provision of a level playing field for the private sector in the seed markets by preventing BADC from supplying seeds at subsidized price might attract more private sector R&D investment into crop segments with better appropriability. A competitive seed industry with strong R&D component will increase farmers' access to quality seeds and contribute to long-term productivity growth at farmers' fields with positive implications on food security and social welfare.

Supplementary material

Supplementary material can be found online at <https://doi.org/10.22434/IFAMR2017.0061>.

Table S1. Estimation results of *aus* rice yield model with various policy lags, 1971-2010, Bangladesh.

Table S2. Estimation results of *aman* rice yield model with various policy lags, 1971-2010, Bangladesh.

Table S3. Estimation results of *boro* rice yield model with various policy lags, 1971-2010, Bangladesh.

Table S4. Estimation results of maize yield model with various policy lags, 1971-2010, Bangladesh.

Table S5. Estimation results of wheat yield model with various policy lags, 1971-2010, Bangladesh.

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