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The impact of floods on the adoption rate of high-yielding rice varieties in Bangladesh

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Abstract

This paper analyses econometrically the impact of floods on the rate of adoption of high-yielding varieties (HYVs) of rice in Bangladesh. It uses a small model combining a modified logistic adoption function with a model of the process generating expectations errors by the farmers which encompasses most other expectation hypotheses. Using pooled cross-section and time-series data at the district level, the econometric results show a significant negative impact of expected flood damage on the HYV adoption rate of 'aman' rice. Moreover, it is shown that the adoption of HYV 'boro' rice is governed by essentially the same equation.

1. Introduction

In a land-scarce economy like Bangladesh, a significant increase in food production can only result from the diffusion of modern agricultural technologies. Although there exists some possibility of substituting food crops for non-food crops, they are very limited. Rahman (1986) presents econometric supply functions for a very large number of crops in Bangladesh, showing the importance of technical progress in determining the supply of the main food crops. The so-called 'Green Revolution' implies the adoption of high-yielding varieties (HYVs) of rice, and the use of fertilizers and irrigation (Bray, 1986).

Bangladesh is, together with Thailand, one of the countries where the rate of adoption of HYV rice is the lowest among the main Asian rice producers (Bera and Kelley, 1990). Although HYVs were introduced in this country in 1968 (dry-season or 'boro' rice) and in 1970 (monsoon-season or 'aman' rice) (Hossain, 1989), adoption is still relatively limited, especially for the latter variety (see below).

One can distinguish two major strands in the literature trying to identify the main constraints preventing farmers from increasing their adoption rate. The first one emphasizes the availability of complementary inputs, while the second one brings out the role of risk. They are briefly surveyed in the next section. The present paper belongs to the second strand, and presents an econometric analysis of the negative impact of the risk of floods on the adoption rate of HYVs.

Section 3 presents the simple model which is used in the following sections to estimate the impact of expected flood damage on the rate of adoption of HYVs for 'aman' rice (Section 4) and 'boro' rice (Section 5). The process generating expectations errors is modelled carefully, with an

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equation which encompasses most widely used expectations hypotheses as special cases (rational expectations, adaptive expectations, etc.).

2. Review of the literature

2.1. The two strands of the literature

The first strand in the literature emphasizes the availability of the complementary inputs. Kashem (1987) points to human capital, suggesting that education is the binding constraint. This result is opposed by Hossain (1989), who finds a negative impact of education on the adoption of modern varieties, after controlling for many variables, in a cross-section study. Hossain (1986) and Rahman (1983) emphasize the provision of irrigation services as a factor with a positive influence on the adoption rate. Boyce (1986) enlarges this concept, and uses that of 'water control', which encompasses flood protection, irrigation and drainage. However, his results point to irrigation as the dominant factor.

The other strand of this literature, which does not exclude the principle of the previous one, puts the emphasis on risk, with special reference to the risk of floods. HYVs are regarded as being more risky than local varieties, as they require more initial investment by the farmer (fertilizer etc.), while they are less resistant to agro-climatic shocks. At the theoretical level this strand of the literature is not completely foreign to the previous one, as it emphasizes the shortage of one particular complementary input, namely insurance services. Nevertheless, it is useful to distinguish these two strands of the literature as they point to two different types of policies, which are not in fact mutually exclusive. The first one favors the development of irrigation, public or private, while the second one emphasizes flood protection. The latter is by nature a collective or public action, whereas this is not the case with the former, which can take either form (Bray, 1986). The feasibility of flood control in Bangladesh has been hotly debated recently. After the 1987 and 1988 'centenary floods', there was renewed interest in the possibility of controlling floods in this country. A 'megaproject' (Boyce, 1990) was put forward by a French engineering consortium, the cost of which was estimated between \$5.2 and \$10.1 billion for construction (in 1989), with subsequent recurrent operation and maintenance costs estimated at \$160–180 million per annum. It was severely criticized on economic, political, and environmental grounds. Boyce (1990) reports on these criticisms, and advocates a more pragmatic and more labor-intensive approach involving the farmers. The French project has been largely abandoned and replaced by a piecemeal approach, with the profitability of each piece of embankment appraised case by case. Moreover, the emphasis is now put on flood control, rather than flood protection, in order to let the farmers benefit from 'barsha' (normal flooding), which plays a useful role in maintaining the fertility of the soil, and to protect them against 'bonna' (abnormal flooding), which is very harmful. A full-blown evaluation of this set of issues lies outside the scope of this paper.

Various aspects of the risk implied by HYVs have been studied in the literature. Murshid (1987) shows that the new technology increases risk significantly, approximating this effect by the instability of production. On the other hand, Alauddin and Tisdell (1988) oppose the idea that the green revolution has entailed an increased variability of food output in Bangladesh. Parikh (1989) and Shahabuddin (1989) have provided useful analyses of the effect of risk on the peasants' behavior, including that of HYV adoption. One difficult point in this line of research is the measurement of risk as perceived by the farmers.

2.2. Use of cross-section data

In general, the relationship between the rate of adoption of HYVs and risk is more easily analyzed using cross-section data than using time-series data. The reason for this is that for time-series analysis one needs an assumption about how the perceived risk changes over time as new information unfolds. Then any test performed within this framework is contingent upon the validity of the assumed mechanism of risk perception. For cross-section data, using for example district-level data, one can overlook this element to some extent, as one can relate the objective agro-climatic risk of each district to the rate of adoption of HYVs which prevails in it. Then, if one assumes that farmers do not perceive risk with any bias, a behavioral interpretation can be given to the results.

However, some care must be taken when interpreting the district-level cross-section relation between lower risk and higher adoption of HYVs, as effects other than pure technical choice by the farmers are involved, and they complicate this relationship. For example, less risky districts are more densely populated, as peasants tend to move away from excess exposure to floods and droughts in order to improve their safety, but population pressure has been shown to have a positive impact on labour productivity and adoption of HYVs by increasing the demand for intensification of cultivation (Chaudhuri, 1981; Boyce, 1989; Hossain, 1989). There is two-way causation in this process, with higher productivity in addition to relative safety attracting migrants, thus increasing population pressure, which in turn enhances the incentive for productivity increase. Therefore, the effects of relative safety, higher productivity, and higher population density are intertwined in cross-section data. To avoid a 'chicken and egg' type of problem here, one needs to determine what is exogenous and what is endogenous. Risk is probably exogenous in the short run, unless one assumes that an increased population leads to increased protection against agro-climatic risk (polderization, etc.).

2.3. Use of time-series data

Bera and Kelley (1990) have provided an interesting time-series analysis of this problem. The need for such an analysis is brought out in their paper by scrutiny of the historical record of adoption of an HYV of 't-aman' rice (transplanted 'aman' rice). The adoption path was subjected to a drastic downwards shift after the 1974 floods. This suggests that a learning process was at work at that time, with new information on the relative degree of exposure to the risks of floods of modern varieties vis-à-vis traditional ones being provided by the 1974 experience. This assumption is relatively well supported by the data. These results suggest that no expansion of new technology is possible in Bangladesh unless a major change in the risk of crop damage occurs. They are thus implicitly supportive of the policy of flood control.

However, their paper raises three questions. The first one is related to the quality and quantity of the data. They use only 15 annual data points, between 1971 and 1985, for their econometric estimation. Moreover, some doubts have been expressed in Dhaka to the present author about the reliability of the time series on the adoption rate of an HYV of 't-aman' rice (notably by Mahabub Hossain, in a private conversation). Fears are expressed that the downwards shift of the adoption path after 1974 might be due to the fact that the adoption rate was grossly overestimated before that date, for policy reasons. The newly independent Bangladeshi Government was perhaps trying to benefit from an 'announcement effect' by claiming that a higher adoption rate than the actual one had been achieved at that time. According to this view, the data would be more reliable after 1974, although another policy-induced shift might be feared after 1977, when General Zia Ur Rahman became president.

Second, their model does not seem to apply at all to the adoption of HYVs of 'boro' rice, although this probably offers some interesting prospects for development. They provide no econometric analysis showing any direct impact of floods on adoption of HYVs of this type of rice. Such an impact is tested and rejected in the cross-section analysis performed by Parikh (1989) on survey data. This is perhaps due partly to the fact that the rate of adoption of HYVs of 'boro' rice is already much higher than that of 'aman' rice (Hossain, 1989), leaving less room for significant differences among farmers.

Third, they do not explicitly model the way farmers perceive risk, and the way this perceived risk changes over time. Their treatment of this question is at best allusive.

2.4. Outline of the paper

The present paper offers some partial answers to these three questions. First, it uses a panel of pooled time-series and cross-section data at the district level for analysing the impact of floods on the adoption rate of 't-aman' rice. More precisely, 21 annual observations for 21 districts [1] are used. This approach thus tries to mitigate the problem of the potential heterogeneity of the time-series data, referred to above, by taking advantage of the assumed strength of the cross-section data. Moreover, it provides a much larger sample than the one used by Bera and Kelley (1990). It includes both some pre-independence data and the 'centenary flood' years 1987 and 1988, and this should reduce the weight in the sample of the suspect years between independence and 1974.

Second, it provides a model which shows some direct influence of floods on adoption of HYVs of both 'aman' and 'boro' rice. It is shown econometrically that the adoption rate for 'boro' is basically governed by the same equation as that for 't-aman', which is itself negatively affected by floods. This equation is an extension of the standard logistic function, which has been often used in models of technological diffusion (Gomulka, 1990). Bera and Kelley (1990) also use an extension of this function in their study referred to above. In addition, we analyze the impact of the relative price of local and HYV rice on the adoption rate of HYVs of 'boro' rice. We have only been able to perform this analysis on a sub-sample for which data on this relative price were available.

Third, we offer an explicit model of the way farmers perceive risk as a function of the share of the land planted with each type of rice that is expected to be affected by flooding. This model is both simple and versatile, as it allows various alternative assumptions to be tested as special cases.

The next section presents the rationale for the modified logistic function used below to describe the behavior of the rate of adoption of HYVs. We combine it with a fairly general model of the generation of expectation errors, which encompasses rational expectations and adaptive expectations as special cases. The resulting model provides a framework for testing the impact of floods on the adoption of HYVs of rice which is not overly restricted by a particular assumption regarding expectations formation.

3. Modified logistic adoption function

The logistic function is often used as a starting point for modelling the diffusion of new technology (e.g. Gomulka, 1990). The basic intuition behind this diffusion process is that the rate of adoption of a new technique is proportional to the relative gap between the maximum possible adoption rate and the current one. Then one may add to this basic model various variables which are liable to speed up or slow down the diffusion process. This is the basic format used by Bera and Kelley (1990) in their study referred to above. We also use it here, after some modification aimed at bringing out the impact of expected flooding on the adoption rate.

3.1. Adoption function

In this function, r denotes the current rate of adoption of the HYV, and r^* denotes the maximum possible value of this adoption rate. Then R is an index of the rate of adoption relative to its maximum possible value, defined as $R = \log(r/(r^* - r))$. R is an increasing function of r, and a decreasing one of r^*. We define f as the percentage of the area planted with the type of rice under study ('aman' or 'boro') which is damaged by flooding. The expected value of f is denoted by f^*. We then postulate that for any district at any point in time, the adoption index R is governed by the following linear relation:

$$R = a + bt - cf^* + v \tag{1}$$

where a is any constant, b and c are positive constants, t is a time trend, and v is a white noise.

[1] Chittagong, Chittagong Hill Tracks, Comilla, Noakhali, Sylhet, Dhaka, Faridpur, Jamalpur, Kishoreganj, Mymensingh, Tangail, Barisal, Jessore, Khulna, Kushtia, Patuakhali, Bogra, Dinajpur, Pabna, Rajshahi, Rangpur.

We can easily check that under this assumption, given f^*, the adoption rate r evolves according to the mechanism described above:

$$\mathrm{d}\log r/\mathrm{d}t = b(r^* - r)/r^* \quad (2)$$

In words, this means that the growth rate of the adoption rate is proportional to the percentage gap between the current value of the adoption rate and its maximum possible value.

The inclusion of f^* in Eq. (1) is meant to take account of the fact that the adoption rate is smaller, at any point in time, the higher the fraction of the planted area that is expected to be flooded. The impact of this variable is smaller, the closer the adoption rate is to its maximum possible value ($\mathrm{d}\log r/\mathrm{d}f^* = -c(r^* - r)/r^*$). Obviously this expected value is unobservable, and we need to postulate a process for generating expectations.

3.2. Expectations formation

Although many assumptions have been used in the literature on expectations formations, it is fair to say that two hypotheses have played a dominant role, namely the adaptive expectations hypothesis and the rational expectations hypothesis. We adopt a more general approach here by postulating an expectations generation process which encompasses these two polar hypotheses as special cases. As illustrated notably by Ravallion (1987), it is more fruitful to model the process generating expectations errors than the process generating the expectations themselves. His approach is extended below as we postulate a different process for generating expectations errors.

We assume that expectations errors are generated by the following process:

$$f - f^* = e + g(f - f_{-1}) + h(f_{-1} - f^*_{-1}) \quad (3)$$

where e is white noise, g and h are constant parameters, and the subscript -1 denotes a 1-year lag. Depending on the values taken by the parameters g and h, Eq. (3) can generate various types of expectations formation processes. We can see immediately that if $g = h = 0$, this process reduces to the rational expectations hypothesis, which assumes that expectations errors are generated by a white noise, independently of the information available at the time of the formation of expectations.

If g is strictly positive, the expectations error is affected by the change in the variable to be forecast from its value at the previous date. This captures the intuitive idea that it is easier to predict the level of a variable which changes little than that of a variable subjected to wide swings. If h is strictly different from zero, then expectations errors are auto-regressive. This coefficient can be positive or negative depending on whether the error dynamics is monotonic or oscillatory.

Another interesting special case is when $g = h > 0$. Then, Eq. (3) reduces to

$$f - f^* = e + g(f - f^*_{-1}) \quad (4)$$

In this case, expectation errors are affected by the deviation of the flooded area from its previously expected value. There is some sluggishness in the formation of expectations, which is governed in this case by the following process:

$$f^* - f^*_{-1} = (1 - g)(f - f^*_{-1}) - e \quad (5)$$

If $1 > g = h$, this process means that f^* is an 'underpredictor of change' in the flooded area when the result is different from the one that was previously expected. The direction of change is correctly predicted, but not its amplitude, which is underestimated. If $g = h > 1$, then f^* predicts a change in the wrong direction when f deviates from its previously expected value. This case is fairly odd, but can be encompassed by our model Eq. (3).

The classic adaptive expectations hypothesis results from the restriction $g = 1 > h$. Then Eq. (3) can be simplified and rearranged to yield the following expectations generation process:

$$f^* - f^*_{-1} = (1 - h)(f_{-1} - f^*_{-1}) - e \quad (6)$$

This is the standard adaptive expectation mechanism, augmented with a white noise.

The final meaningful special case to be considered, although it is not very exciting, is the case of static expectations, which occurs when $g = h = 1$. Then one gets

$$f^* = f^*_{-1} - e \quad (7)$$

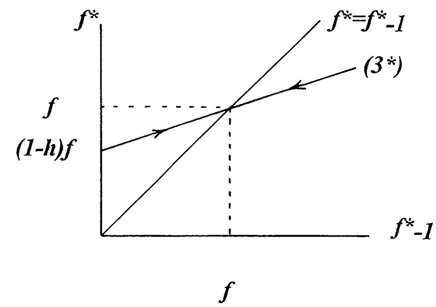

Fig. 1. Expectations dynamics.

Rigorously speaking, unless e is identically zero for all states of nature, the case described by Eq. (7) should be called random walk expectations rather than static expectations. However, we use the latter, which sounds more familiar.

An attractive feature of the expectations generation process modelled by Eq. (3) is that it describes asymptotically rational expectations, provided that $h < 1$ (Stein, 1981; Stein, 1988). This expression means that f^* converges towards $f^* = f$ when the system is in long-run equilibrium, defined by $f - f_{-1} = e = 0$. Moreover, this convergence is monotonic provided that $0 < h < 1$, and this is a desirable property for the model. To check this point, note first that in the long-run equilibrium Eq. (3) becomes

$$f^* - f^*_{-1} = (1-h)(f - f^*_{-1}) \qquad (3^*)$$

One can see the analogy with the case of the 'underpredictor of change' Eq. (5). It is straightforward to check that the point where $f^* = f^*_{-1} = f$ is a stable stationary point of Eq. (3^*), given f. This can be done using Fig. 1. The 45° line is the locus where the expected value of f is stationary, with $f^* = f^*_{-1}$. Next, the long-run equilibrium dynamics of f^* is governed by Eq. (3^*), which is also represented in Fig. 1. Then, as represented by the arrows borne by the (3^*) line, f^* increases from one date to the next if $f^*_{-1} < f$, and decreases in the reverse case. Hence, provided that $0 < h < 1$, the expected value f^* converges monotonically to f.

3.3. Estimating equation

Therefore, Eq. (3) provides an encompassing framework in which most widely used assumptions about expectations formation, as well as a few less standard ones, can be tested as parameter restrictions. In order to do this, we substitute for f^* in Eq. (1). After using Koyck's transformation, the resulting equation can be rearranged to read

$$R = a' + b't + hR_{-1} - c(1-g)f - c(g-h)f_{-1} + ce + v' \qquad (8)$$

In Eq. (8) we have used the following notation: $a' = (1-h)a + hb$, $b' = (1-h)b$, and $v' = v - hv_{-1}$. This equation is a good test for the assumptions spelt out above. If $h = 0$, then the lagged endogenous variable is not significant. If $c = 0$, then neither the current flooded area nor its lagged value are significant. The same outcome occurs if $g = h = 1$, but in this case the trend term is insignificant, so we can discriminate between the case of static expectations and the case where the expected flooded area has no impact, provided b is not nil. If $g = 1 > h$ while $c > 0$, then the current value of the flooded area is not significant, while the lagged one is significant. This is the case of adaptive expectations. Conversely, if $1 > g = h$ while $c > 0$, then the current flooded area is significant, while the lagged one is not significant. This is the case of the 'underpredictor of change'.

It is worth emphasizing an attractive feature of our encompassing expectations formation approach: it enhances our ability to test the negative impact of the risk of flood on the rate of adoption of HYVs, because it does not make this test excessively contingent upon a specific expectations hypothesis.

We now turn to the econometric results concerning the rate of adoption of HYVs of 'aman' rice.

4. Adoption rate of HYV 'aman' rice

4.1. Data

The data used cover the period from 1968/1969, before independence from Pakistan in 1971, to 1988/89, for 21 districts. Some data were missing for one district, for which the corresponding years have been deleted. They have been collected from the *Yearbook of Agricultural Statistics of Bangladesh* (various issues). Note that this sample contains the 'centenary' floods of 1974, 1987 and 1988.

For measuring r, we have used the ratio of the area planted with HYV 'aman' rice to the total area planted with this type of rice. For constructing the dependent variable R, Bera and Kelley (1990) have been able to estimate r^* by non-linear methods. We have taken the simpler route of approximating r^* by the highest adoption rate reached during our sample period. The resulting measurement error should not have serious effects on the estimated equation, as it concerns the dependent variable. It should only affect the intercept and feed in the residuals, without biasing the estimated coefficients, but it is liable to entail some heteroscedasticity, as it is in fact increasing with r.

Similarly, the share of the area damaged by flooding is the ratio of the area planted with 'aman' rice which is damaged by flooding to the total area planted with this type of rice.

4.2. Econometric problems

As our sample has been built by pooling time-series and cross-section data, special attention had to be paid to some of the usual econometric problems raised by panel data. First, some fixed effects have been included in the equation. These are captured by including one dummy variable for each district, across the whole period. After appropriate testing, the non-significant district dummy variables have been deleted for the sake of parsimony.

Second, heteroscedasticity has been thoroughly tested using the simplified version of the famous Breusch and Pagan (1979) test presented in Pagan (1984). It turned out to be a very significant problem for ordinary least squares (OLS) estimation, so that the standard t-ratios could not be used for model selection as they are biased in this case. As is well known, heteroscedasticity does not bias the OLS estimation of the coefficients, but it biases the estimation of their standard errors. Therefore, we have used White's heteroscedasticity-consistent (WHC) t-ratios (White, 1980), instead of the usual ones, as the basis for an exclusion decision. It turned out in our selection procedure that these tests resulted in preferred equations which are quite different from the ones obtained by using the standard t-ratios. For technical reasons, we have not been able to take due account of the moving average process generating the random disturbance term v' in Eq. (8) [2].

5. Results

Nevertheless, despite this obvious drawback, the estimated equation for 'aman' rice seems quite encouraging for the hypothesis under test.

$$R = -0.71 - 0.0008f + 0.58R_{-1} + 0.084t + \text{fixed effects} \quad (9)$$
$$(2.39) \quad (2.71) \quad (7.56) \quad (3.70)$$

$N = 385$, $R^2 = 0.68$, $F(6{,}379) = 158.90$, $BP-F(6{,}379) = 7.55$, $\text{Chow}-F(6{,}373) = 1.66$, $DW = 1.81$.

The figures in parentheses below the estimated coefficients are the WHC t-ratios. The insignificant variables according to this test have been deleted. In particular, most of the fixed effects are not significant, except for two districts. This shows a noticeable degree of behavioral homogeneity across districts with respect to the adoption of HYVs.

N is the number of active data points, R^2 is the standard coefficient of determination, showing here that Eq. (9) explains more than 68% of the variance of the adoption index R. $F(6{,}379)$ is the standard F-test, which tests whether all the coefficients from Eq. (9) are jointly nil. This assumption is rejected by a wide margin. BP-$F(6{,}379)$ is the simplified heteroscedasticity test from Pagan (1984), referred to above. It does reject the assumption of homoscedasticity, and

[2] MICRO–TSP would not handle it because of the characteristics of the sample, which includes too many gaps between each set of district data, notably because of the inclusion of the lagged endogenous variable.

this underlines the need for using the WHC t-ratios instead of the usual ones, as we have done above.

Chow-F(6,373) is the famous test of parameter constancy developed by Chow (1960). It has been computed by splitting the sample into two sub-samples with only one district difference between the two, in order to avoid splitting the data from the same district between the two sub-samples. It amounts to a comparison of the estimated residuals variance for these two sub-samples. It does not reject the assumption of parameter constancy, at the 5% level of significance. This confirms the diagnosis of sample homogeneity expressed above.

We have also presented the usual Durbin and Watson test (DW), although it is not very meaningful in the present setting because of the use of panel data. Note, however, that the number of inter-district 'jumps' in the sample is small compared with the number of pure time-series consecutive data points for the same district. There is one 'jump' and 19 or 20 consecutive data for each of the 21 districts. Hence, the DW test can be regarded as an approximation of a residuals autocorrelation test, which does not reject the assumption of serial independence, although admittedly this is not fully satisfactory. We have already noted above that a MA process should in fact be included in this equation, and that this could not be done for technical reasons. In view of all these test results, this omission is probably not a serious econometric problem in this application.

5.1. Interpretation of the results

We observe that the lagged dependent variable is significant in Eq. (9), and this is a rejection of the rational expectations hypothesis, within our framework. However, its estimated coefficient is significantly smaller than 1, so that the asymptotically rational expectations hypothesis is not rejected. Similarly, we observe that the current value of the flood damage variable is significant, while its lagged value is not. Addition of the latter value to this equation yields a WHC t-ratio of 1.62. The adaptive expectations hypothesis is thus rejected. As the trend term is significant, the static expectations hypothesis is thus rejected as well.

The lagged value of the flooded area is not significant, so that the restriction $g = h < 1$ is not rejected. This corresponds to the case of the 'underpredictor of change' analyzed above, where expectations errors are mainly affected by the deviation of the flood damage variable from its previously expected value. Note, however, that this case cannot be distinguished from a more encompassing case, that of being located in the neighborhood of the long-run equilibrium, as discussed above, but in our sample there seems to be enough variation in the flood damage variable, especially for the years of the 'centenary floods', to rule out such an interpretation of the results.

Therefore, despite its shortcomings, Eq. (9) suggests that the risk of floods has a significantly negative impact on the rate of adoption of an HYV of 't-aman' rice in Bangladesh. Our panel data approach thus confirms, in a different context, the main result contained in Bera and Kelley (1990). This result is strengthened by the facts that we have used a much larger data set than theirs, and that the pooling of cross-section and time-series data mitigates the risk of data-heterogeneity involved in the pure time-series data. It also corroborates the cross-section results obtained by Parikh (1989) on survey data. However, contrary to the latter, we find that the rate of adoption of HYVs of 'boro' rice is generated by essentially the same equation as Eq. (9) above.

6. The adoption rate of HYV 'boro' rice

6.1. Some technical differences

As it grows during the dry season, 'boro' rice is not exposed to flood risk in the same way as 'aman' rice, which grows mainly during the monsoon season. 'Boro' rice is transplanted from mid-November to mid-February and harvested from mid-April to mid-June. Therefore, it depends crucially on irrigation and is only threatened by the early floods, which sometimes destroy part of the crop before the harvest. This type of rice covers only 25% of the total area planted with rice, but has the highest rate of adoption of HYVs, reaching 87% in 1988/89.

Conversely, 'aman' rice is transplanted from mid-June to mid-August, during the monsoon season, when the risk of floods is highest. Floods can thus either damage it by disturbing the newly transplanted seedlings, as in 1974 when a lot of plants were destroyed (Ravallion, 1987), or damage it later if the fields are flooded with water which is too deep. Some traditional varieties of 'aman' rice can resist flooding because their stems grow as the water level rises, and they can reach a height of about 2 meters. Unfortunately, however, the HYV of 'aman' rice cannot survive in these conditions.

Unless 'aman' rice is destroyed by a flood, it is harvested from November to January, so that it is also vulnerable to the risk of drought. It is the main crop in Bangladesh, covering 50% of the whole area planted with rice. The rate of HYV adoption is only 27%. Bera and Kelley (1990) suggest that this rate could not go much higher unless a major change in agro-climatic risk is achieved.

6.2. A similar adoption equation

Despite these technical differences, the rate of adoption of HYV 'boro' rice is governed by an equation which is similar to Eq. (9). The flood damage variable is measured according to the same principle as that for 'aman' rice used above, but its numerator and denominator now concern 'boro' rather than 'aman'. Similarly, the adoption index R is constructed as above, with the data concerning 'boro' instead of 'aman'.

The same econometric problems as those described above were encountered, so that we again use two district dummy variables as the only significant 'fixed effects'. Moreover, we again base the model selection procedure on the WHC t-ratios instead of the usual ones, in order to take care of a heteroscedasticity problem. The preferred equation is

$$R = -0.69 - 0.00f + 0.69R_{-1} + 0.077t + \text{fixed effects} \quad (10)$$
$$(2.68) \quad (3.59) \quad (7.40) \quad (4.45)$$

$N = 429$, $R^2 = 0.67$, $F(6,423) = 168.96$, $BP - F(6,423) - 5.03$, $\text{Chow} - F(6,417) = 1.20$, $DW = 1.34$.

The results are very similar to those found in Eq. (9) except for the fact that the DW test, with all the uncertainty which surrounds its use in the present setting, as emphasized above, seems to detect some residuals autocorrelation. Here again, the test based on WHC t-ratios rejects the rational expectations hypothesis, and the adaptive expectations favored by this econometric exercise are those which correspond to the 'underpredictor of change' described above, including its property of convergence to a long-run equilibrium. Here again, the impact of expected flooding is significant, while only two district dummy variables turned out to be significant, and they are not the same as those in Eq. (9).

Therefore, it seems that the simple model comprising Eq. (1), describing the rate of adoption as a modified logistic function augmented with the expected flood damage variable, and Eq. (4), describing the 'underpredictor of change' process generating expectations errors about the flooded area, is a useful one for analysing the Bangladeshi adoption rate data. We have been able to go one step further in the case of 'boro' rice by adding to Eq. (10) the impact of the relative price of local and HYV rice. [3]

6.3. The effect of the relative price

HYV rice and local varieties of rice are not perfect substitutes from the consumer point of view. The local varieties are preferred by Bangladeshi consumers. Therefore, one can expect that the relative price of the two types of

[3] Unfortunately, we have not been able to get hold of the corresponding series for 'aman' rice, but according to some local experts (Salauddin Ahmad and M. Asaduzzaman), the price difference between local and HYV 'aman' rice is not very significant.

rice significantly affects the rate of adoption of HYVs versus local varieties. Unfortunately, we have not been able to get hold of these data for the whole sample. Some dates, as well as some districts, are missing.

It is straightforward to extend the model in Section 3 in order to include the impact of the relative price, as this enters the equation in exactly in the same way as the trend term does. Let q denote the relative price of the local rice in terms of HYV rice. Then the preferred equation is

$$R = -0.001f + 0.92R_{-1} + 0.09t - 0.98q \qquad (11)$$
$$\quad (2.42) \qquad (9.68) \qquad (4.90) \quad (3.50)$$

$N = 242$, $R^2 = 0.70$, $F(5{,}237) = 188.70$, $BP - F(5{,}237) = 21.60$, $\text{Chow} - F(5{,}232) = 0.98$, $DW = 1.56$.

There are two main differences between Eqs. (10) and (11). First, the relative price effect is significant, as expected: when the relative price of the local varieties rises, diffusion of the HYV slows down. Second, there is no intercept in this equation. In addition, it can be seen that the coefficients of t and R_{-1} are higher in Eq. (11) than in Eq. (10). Nevertheless, this equation does not contradict the diagnosis found with the equations given above: the risk of flood is a significant determinant of the adoption rate of HYV.

7. Conclusion

In this paper we have analyzed the impact of the risk of floods on the adoption rate of HYVs of rice by Bangladeshi farmers, for the 'aman' and 'boro' seasons. Because of lack of data, we have not been able to perform the same exercise for the third type of rice grown in Bangladesh, namely 'aus' rice. This type appears to be dominated by traditional varieties, and does not seem to be regarded by specialists as offering the same development prospect as the other two. Moreover, its growing season overlaps that of 'boro' rice, so that a trade-off exists between the development of these two types of rice.

We have used a simple model based on a modified logistic adoption function. The new element included in this function is the share of the area planted in either type of rice which is expected by the farmers to be damaged by flooding. In order to test this hypothesis without making the results excessively contingent on the assumed expectations generating process, we have followed an encompassing approach. The equation generating expectations errors that we have hypothesized encompassed most of the hypotheses concerning the formation of expectations which have been used in the literature.

We have tested this model using a large sample made by pooling district-level cross-section data with time-series data covering 21 years. We found basically the same results for 'aman' and 'boro' rice. In both cases, we found a significant negative impact of the risk of flood on the adoption rate. Moreover, the three classic expectations hypotheses (rational, adaptive and static) have been rejected in favor of a process which we have called the 'underpredictor of change'. In this case, in addition to a white noise error, the expectation error is proportional to the change of the variable to be forecast from its previously expected level, but the factor of proportionality is smaller than one. There is some sluggishness in the process of expectations generation. Nevertheless, this hypothesis is consistent in this model with asymptotically rational expectations, as it does not prevent the expected flood damage variable from converging in the long run to an equilibrium value.

Therefore, it seems that an important ingredient for explaining agricultural development in Bangladesh is the level of risk of flood perceived by the farmers. We have seen that this perception plays a significant part in determining the rate of diffusion of the new technology for 'aman' and 'boro' rice. Note that our flood damage variable does not distinguish among the possible sources of flooding (river overflow, surface water, etc.). Therefore, our results do not bear directly on the issue of choosing between different flood protection systems (river embankment, draining, etc.). Moreover, the logistics specification adopted here suggests that the impact of the risk of flood on the rate of adoption is reduced by the passage of time as the latter comes closer to its maximum. The rate of return on any flood control project thus becomes smaller, the longer it takes to appraise it.

Obviously, this is not exclusive of the promotion of irrigation. On the contrary, that has been shown by many authors to play a crucial part in the development of 'boro' rice. As the adoption rate of HYVs is much higher for 'boro' than for 'aman' rice, it follows that given their respective HYV adoption rates, a faster development of 'boro' rice than of 'aman' rice increased the average rate of adoption of HYVs across these two crops. The question remains, however, to determine whether irrigation is more efficiently provided by public means or by private means, and what is the impact of flood risk on private investment in irrigation equipment, but these questions lie outside the scope of the present paper.

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