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HAS THE GREEN REVOLUTION DESTABILIZED FOOD PRODUCTION?: SOME EVIDENCE FROM BANGLADESH

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I. INTRODUCTION

FOODGRAINS are the most important wage goods in the LDCs and the income elasticity of demand for food is very high, probably of the order of 0.60 or higher [19, p. 572] [21, p. 65]. In the short run, changes in relative food prices materially alter the real incomes of individuals on low monetary incomes [24, p. 1]. With technological change in the production of foodgrains (the Green Revolution), the supply of foodgrains has possibly become more variable and their prices more unstable. For example, it is commonly believed that yields from High-Yielding Varieties (HYVs) are more variable than those from the local varieties (see, for example, [23]). In the LDCs this can have important welfare consequences for low-income earners and increase fluctuations in incomes received by grain producers.

Foodgrain production is central to the agricultural economy of Bangladesh. Rice and wheat together occupy over 83 per cent of gross cropped area [26]. Bangladeshi agriculture mainly involves a rice monoculture. About 80 per cent of the total area is cropped with rice. In recent decades, a steady improvement in overall agricultural production has occurred due mainly to a moderate increase in the production of rice and a spectacular boost in the production of wheat [34, p. 75]. However, agricultural production in Bangladesh remains erratic because of considerable climatic variability from year to year. Floods and droughts cause extensive crop damage in Bangladesh [7, 1984–85 edition, p. 303]. Fluctuations in domestic production are accompanied by fluctuations in imports of grains [3].

This paper analyzes data on the variability of Bangladeshi foodgrain production and considers the possible role of the new technology (the Green Revolution) in moderating or accentuating fluctuations in production and yield. In the discussion, the main focus is on the aggregate supply of foodgrains (rice and wheat). This paper first of all briefly reviews the relevant literature and contents that the methodologies adopted by the authors of some recent studies (e.g., [15] [23]) suffer from serious shortcomings, can lead to misleading conclusions and be a source of faulty policy advice. It then presents and applies an alternative methodology in order to determine and outline trends in the variability of

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Bangladeshi foodgrain production and yield over time. Factors are then considered which may explain the observed underlying trends in the variability of foodgrain production in Bangladesh.

II. TECHNOLOGICAL CHANGE AND INSTABILITY OF PRODUCTION AND YIELD: A BRIEF REVIEW OF LITERATURE

The question of stability and adaptability of crops has been discussed at theoretical and empirical levels. Studies include such as those by Evenson et al. [13], Finlay and Wilkinson [14], and Tisdell [33]. Evenson et al. point to the need to draw a distinction between (a) *stability* of a genotype, that is, its changing performance with respect to environmental factors over time and (b) *adaptability,* that is, its performance with respect to environmental factors that change across locations. Evenson et al. express concern that new HYVs of crops could increase yield variability in developing countries and recommend more research into crops with a view to reducing such variability.

Recent studies of Indian agriculture [15] [16] [23] found evidence of increased instability in agricultural production following the introduction of modern agricultural technology.[1] Hazell goes so far as to conclude that "production instability is an inevitable consequence of rapid agricultural growth, and there is little that can effectively be done about it" [15, p. 10].

In our view, the studies by Mehra [23] and Hazell [15] are subject to two methodological limitations. First, these studies measure production stability or lack of it around a line of "best fit." As Ray points out, "any inference regarding changes in the pattern of growth and instability in production will be greatly influenced by the choice of mathematical function, the selection of which cannot be left alone to the statistical criteria of best fit" [29, p. 463].[2] Furthermore, while their studies compare the variability of one period with that of another, they do not consider whether variability itself shows any tendency to increase or decrease within a period of specified duration. Ray's own study suffers from similar inadequacies in that it compares "the instability in production over different periods under the assumption of stationary mean and variance in the year-to-year changes in the components of production index" [29, p. 463].

Secondly, both Hazell and Mehra assume arbitrary cutoff points. Furthermore, they do not seem to have a consistent rule for dropping observations for "unusual" years. Probably both Mehra and Hazell were justified in dropping observations relating to 1965/66 and 1966/67 because of severe drought during those years. As Hazell points out, "catastrophes of this kind are sufficiently rare and severe that they can be considered as separate phenomena from the more usual year-to-year fluctuations" [15, p. 13]. Mehra argues that "the mid-1960s witnessed two

[1] Some earlier studies [32] [28] indicated causal connection between agricultural development and instability in agricultural output growth in India. For evidence of increased yield variability in cereal grain see Barker, Gabler, and Winkelmann [10].

[2] See also Rudra [30] for further discussion on various functional forms for estimating growth rates.

drought years (1965/66 and 1966/67) of such unusual severity as to significantly alter the variance for any period in which they are included, thus casting doubts about the validity of the conclusions" [23, p. 10]. On closer examination of the foodgrain production data presented by Sawant [31, p. 476] one can identify two worst years during the period 1967/68 to 1977/78 which corresponds to the second period designated by Mehra [23] and Hazell [15]. In 1972/73 Indian foodgrain production dropped by over 8 million tonnes from the previous year's production. It was even worse in 1976/77 when the decline was 10 million tonnes from the production of 1975/76. Apart from 1965/66 and 1966/67 no other year between 1950/51 and 1977/78 saw such an absolute decline in foodgrain production in India. The seriousness of the problem can also be seen if one considers the yields of the two major foodgrains (rice and wheat) which together constitute over 70 per cent of all foodgrains during the period 1967/68 to 1977/78 [16, p. 13]. Using data from Joshi and Kaneda [20, p. A3], one can identify a few bad years in terms of yields per hectare. During 1972/73 wheat yield fell by 109 kilograms per hectare from the 1971/72 level of 1,380 kilograms. In 1973/74 it dropped even further (to 1,172 kilograms per hectare). For rice, 1972/73 was not as bad as it was for wheat. But during 1974/75 rice yield dropped to 1,045 kilograms per hectare from the previous year's 1,151 kilograms. The worst year for rice during the second period must be 1976/77 when rice yield fell to 1,088 kilograms from 1,235 kilograms in 1975/76. Overall, of course, 1972/73 and 1976/77 remain the two worst years during the second period. To be consistent one would have expected these two years to be dropped from the analysis of the second period. In that case, one would perhaps end up with a different picture to those emerging from the studies by Mehra and Hazell.

It seems likely that the findings of both Mehra [23] and Hazell [15] are sensitive to changes in cutoff points and to their decisions to delete certain observations. This gains some support from recent study by Hazell [17]. In that study, Hazell compares instability in world cereal production between two periods, viz., 1960/61 to 1970/71 and 1971/72 to 1982/83 and also examines instability in cereal production in different regions of the world, e.g., in South Asia, in India. When comparing the instability of cereal production between the two periods for India, he does not drop observations for 1965/66 and 1966/67. Nor does he drop the observations for 1972/73, 1976/77, or 1979/80 when total foodgrain production fell by a huge 22 million tonnes [31, p. 476]. When no observations are dropped from either period, one finds that the coefficient of variation of cereal production in India decreases by 29 per cent [17, p. 150] during the second period (1971/72 to 1982/83) as compared to the first (1960/61 to 1970/71) whereas the earlier studies by Mehra and Hazell indicated a rise in the coefficient of variation. Thus the assumption of arbitrary cutoff points and inconsistency in deletion of observations can lead to conflicting results.[3]

[3] A recent study [18, p. 80] extending Hazell's analysis to 1983/84 and without dropping any observations from either period finds that the period of new technology (1967/68 to 1983/84) is associated with a lower production and yield variability compared to the

As will be seen, the analytical framework employed in this paper does not measure instability around an arbitrarily fitted trend line nor does it delete observations nor assume arbitrary cutoff points. However, it enables us to identify particular phases during which variability tends to increase, decrease, or remain more or less stationary. In our initial analysis, our cutoff points are decided on the basis of the patterns that emerge from the observed behavior of variability over the years. In subsequent analysis, to examine the behavior of variability within the periods of traditional and modern technologies and make a comparison between the two periods, cutoff points are adjusted so as to coincide with customary or accepted points of technological change. Thus both considerations are covered by our analysis.

III. METHODOLOGY

Two measures of variability—absolute and relative—are employed in this analysis. Absolute variability is measured in terms of standard deviation while the coefficient of variation provides a measure of relative variability. We first of all derived annual indices of relevant variables, e.g., production using the average of the triennium ending 1977/78 as the base. For yield, the weighted average of yields for the years 1975/76 to 1977/78 has been used as the base. The degree of variability has been measured in terms of a five-year moving average of the relevant indices. The variance for each period is that away from the moving average and for the preceding five years, that is, the five years on which the moving average is based. This enables us to get a series of values of average indices of yield and production as well as standard deviations and coefficients of variation during the period 1947/48 to 1984/85. Foodgrain production and yield indices and cropping intensity figures[4] for Bangladesh for the years 1947/48 to 1984/85 are presented in Table I.

IV. EMPIRICAL OBSERVATIONS: BEHAVIOR OF VARIABILITY OVER TIME

Table I sets out the absolute and relative variability of production and yield of all foodgrains. A few observations seem pertinent. First, there seems to be little time trend in both absolute and relative measures of variability. Secondly, absolute production variability seems to increase initially and then appears to stabilize albeit with occasional minor fluctuations. Relative production variability increases at first and then seems to decline over time. Thirdly, both absolute and relative measures of yield variability show initial increases and then tend to stabilize if not decline.

These aspects come into sharper focus when one plots these observations

earlier period (1949/50 to 1966/67). However, other limitations of the Hazell study apply to the Jain et al. study.

[4] Intensity of cropping is defined as the ratio of gross cropped area (i.e., the area actually cultivated plus the area cultivated more than once during the year) to net cultivated area (the area cultivated only once during the year) expressed in percentage terms.

TABLE I

MEAN VALUES, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION OF PRODUCTION AND YIELD OF ALL FOODGRAINS, 1949/50 TO 1982/83

Year	Production				Yield				Cropping Intensity	
	Index	Mean	Standard Deviation	Coefficient of Variation	Index	Mean	Standard Deviation	Coefficient of Variation	Index	Mean
1947/48	52.75				70.74				130.19	
1948/49	60.06				78.79				131.01	
1949/50	57.78	56.64	2.79	4.93	75.44	73.50	3.80	5.17	127.69	129.21
1950/51	57.49	57.58	1.75	3.04	73.29	73.45	3.84	5.23	127.79	127.47
1951/52	55.11	58.48	3.56	6.10	69.23	72.65	2.70	3.72	129.38	129.87
1952/53	57.46	58.82	3.56	6.05	70.50	71.78	2.24	3.12	131.44	130.61
1953/54	64.56	57.32	5.37	9.36	74.80	70.20	3.39	4.83	133.08	130.44
1954/55	59.46	59.12	5.92	10.01	71.06	72.62	5.91	8.14	131.36	129.91
1955/56	50.02	59.53	5.84	9.81	65.40	73.51	5.85	7.96	126.94	129.16
1956/57	64.09	57.46	5.43	9.45	81.34	72.62	5.94	8.18	126.73	127.94
1957/58	59.51	58.86	6.80	11.55	74.96	74.40	6.65	8.94	127.68	127.40
1958/59	54.24	63.78	7.64	11.98	70.34	78.67	6.27	7.97	127.00	128.47
1959/60	66.45	65.80	8.97	13.63	79.98	80.41	8.12	10.10	128.69	129.29
1960/61	74.59	67.60	8.26	12.23	86.75	81.62	7.53	9.23	132.27	130.26
1961/62	74.21	73.13	6.05	8.27	90.02	86.29	5.84	6.77	130.81	131.59
1962/63	68.51	76.03	5.50	7.23	81.02	88.38	4.79	5.42	132.52	132.89
1963/64	81.91	77.31	5.81	7.51	93.68	88.86	4.71	5.30	133.65	133.79
1964/65	80.96	77.28	5.83	7.54	90.42	87.64	5.10	5.82	135.23	135.14
1965/66	80.97	81.29	5.14	6.32	89.14	89.86	3.71	4.13	136.76	137.55
1966/67	74.04	82.81	6.36	7.68	83.96	89.92	3.80	4.23	137.54	139.62
1967/68	88.54	85.26	7.68	9.01	92.09	90.35	3.98	4.41	144.57	142.75
1968/69	89.54	86.40	7.30	8.45	94.00	90.42	3.96	4.38	143.98	143.84

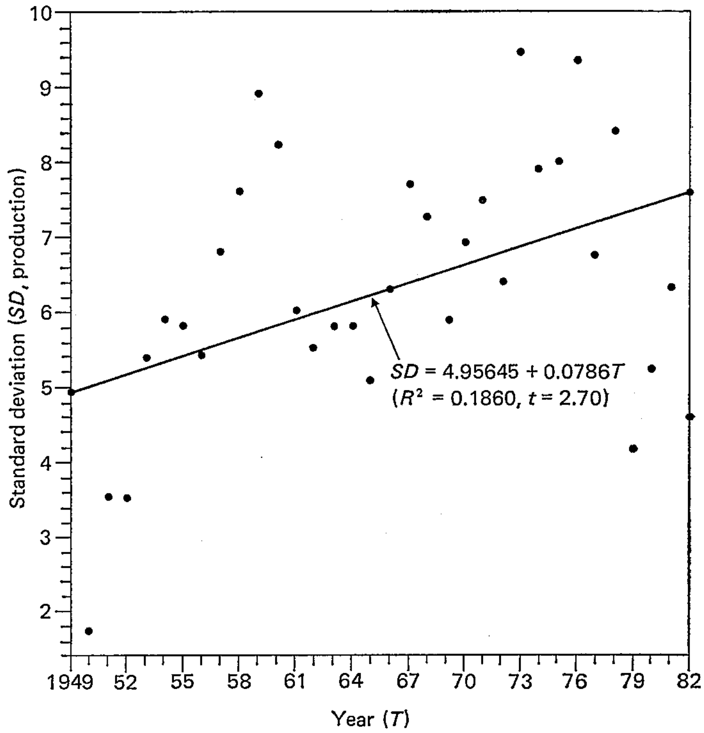
TABLE I (Continued)

Year	Production				Yield				Cropping Intensity	
	Index	Mean	Standard Deviation	Coefficient of Variation	Index	Mean	Standard Deviation	Coefficient of Variation	Index	Mean
1969/70	93.19	87.06	5.91	6.79	92.57	90.64	3.51	3.87	150.90	143.99
1970/71	86.66	85.01	6.96	8.19	89.46	88.86	4.67	5.26	142.19	142.94
1971/72	77.38	85.57	7.52	8.78	85.08	89.21	5.19	5.82	138.28	142.20
1972/73	78.26	84.46	6.44	7.63	83.17	89.09	5.10	5.73	139.34	139.88
1973/74	92.37	87.08	9.50	10.91	95.75	90.94	6.70	7.37	140.27	139.75
1974/75	87.64	90.07	7.90	8.77	92.01	92.98	5.98	6.43	139.29	140.44
1975/76	99.76	96.00	7.95	8.28	98.70	97.55	5.30	5.43	141.58	142.72
1976/77	92.31	99.28	9.35	9.42	95.28	99.31	5.96	6.00	141.74	145.29
1977/78	107.93	102.61	6.77	6.60	106.03	101.30	4.36	4.30	150.74	148.07
1978/79	108.79	105.67	8.42	7.97	104.52	103.45	5.31	5.13	153.10	150.49
1979/80	104.24	109.64	4.15	3.78	101.97	105.55	2.71	2.57	153.18	152.92
1980/81	115.07	111.59	5.27	4.73	109.46	106.32	3.35	3.15	153.71	153.70
1981/82	112.19	113.99	6.32	5.54	105.79	108.04	4.27	3.95	153.86	153.71
1982/83	117.67	117.90	4.57	3.88	109.85	111.18	4.46	4.01	154.66	153.46
1983/84	120.81				113.12				153.16	
1984/85	123.77				117.66				151.90	

Sources: Based on data from [5, pp. 1–2, 4–10, 12–15, 26–29] [7, 1979 edition, pp. 166–71, 340] [7, 1982 edition, pp. 232, 235–38, 240–41] [7, 1983–84 edition, pp. 218–19, 570, 690] [7, 1984–85 edition, pp. 301, 310] [8, 1979–80 edition, pp. 20–25, 30–31, 33–34, 36–37, 46–52] [8, 1983–84 edition, pp. 32–72] [9, p. 89] [12, pp. 40–41, 120] [25, pp. 31, 39, 42] [26, pp. 39, 47–50, 53] [35, Tables 2.5 and 2.6].

Notes: 1. Index numbers are constructed with the average of the triennium ending 1977/78 = 100.
2. Mean values are five-yearly moving averages of those index numbers.
3. Standard deviations are based on the corresponding five-yearly figures.
4. Coefficient of variation = (standard deviation / mean) × 100.

Fig. 1. Absolute Production Variability: Standard Deviation of Aggregate Foodgrain Production, 1949/50 to 1982/83



against time. Figure 1 plots standard deviation (absolute variability) of production. One can identify visually, two distinct phases (the first phase 1949–60, that is, 1949/50 to 1960/61 and the second phase 1961–82, that is, 1961/62 to 1982/83). Up to the early 1960s standard deviation of production shows a strong tendency to increase. In order to make quantitative comparison of change in behavior of absolute production variability we estimated three regression lines with time (T) as the explanatory variable. These are presented as equations (1), (2), and (3) for the corresponding periods in Table II. Figure 1 illustrates equation (3) for the whole period. Equation (1) clearly indicates a strong time trend in standard deviation in terms of both explanatory power and statistical significance. Equation (2) shows no trend in absolute variability during the later phase. The estimates are poor both in terms of R^2 and t-value. Equation (3) provides a similar picture even though R^2 is marginally higher and the coefficient is statistically significant. Overall there seems to be some tendency for the standard deviation to increase. This can also be seen by comparing the average values of standard deviation of production over the two periods. These are 5.49 and 6.67 respectively. Thus the absolute production variability seems to have risen to a higher level. This is probably influenced by some natural and political

TABLE II

TRENDS IN FOODGRAIN PRODUCTION AND YIELD VARIABILITY (STANDARD DEVIATION AND COEFFICIENT OF VARIATION) FOR DIFFERENT PHASES DIVIDED ACCORDING TO PLOTS 1–4, 1949–82

Equation	Period	Intercept	Coefficient	R^2	t-value
		Standard deviation: production			
(1)	Phase 1 (1949–60)	2.22141	0.5944	0.9158	10.43***
(2)	Phase 2 (1961–82)	6.47154	0.0188	0.0073	0.38[a]
(3)	Entire Period	4.95645	0.0786	0.1860	2.70***
		Coefficient of variation: production			
(4)	Phase 1 (1949–60)	4.31184	0.8544	0.8806	8.59***
(5)	Phase 2 (1961–82)	8.60583	−0.1126	0.1731	2.05**
(6)	Entire Period	8.92703	−0.0572	0.0527	1.33[a]
		Standard deviation: yield			
(7)	Phase 1 (1949–60)	2.60628	0.4692	0.7720	5.82***
(8)	Phase 2 (1961–82)	4.82103	−0.0143	0.0090	0.43[a]
(9)	Entire Period	4.92177	−0.0042	0.0009	0.17[a]
		Coefficient of variation: yield			
(10)	Phase 1 (1949–60)	3.85838	0.5496	0.7232	5.11***
(11)	Phase 2 (1961–82)	5.66596	−0.0657	0.1299	1.73**
(12)	Entire Period	6.81343	0.0706	0.1391	2.27**

*** Significant at 1 per cent level.
** Significant at 5 per cent level.
[a] Not significant.

factors such as drought, flood, and the War of Liberation in the early 1970s which might have increased variability. But for all these factors, the average absolute production variability might be of the same order of magnitude during either phase. In any case, one would anticipate a rise in standard deviation on account of the substantial rise in the absolute level of production.

Figure 2 plots coefficient of variation (relative variability) of production against time. One can identify two similar phases in its behavior to those for absolute variability of production. However, there is a difference in that relative variability has declined to lower average value. It has fallen from an average of 9.01 for the first phase to 7.42 for the second. To facilitate quantitative comparisons, we estimated equations (4), (5), and (6) by least squares linear regression and have illustrated equation (6) in Figure 2. Equation (4) corresponds to the first phase and shows that variability has a strong tendency to increase during phase 1. The strong explanatory power and high t-value lend clear support to this claim. However, there is dramatic change in the behavior of relative variability when one considers equation (5) which relates to the second phase and equation (6) which relates to the entire period. Even though the signs seem to indicate a declining trend over time one should note the poor quality of the estimates both in terms of R^2 and t-values. In view of this one needs to be wary. There is no clear simple downward trend but a fortiori no upward trend is apparent.

Fig. 2. Relative Production Variability: Coefficient of Variation of Aggregate Foodgrain Production, 1949/50 to 1982/83

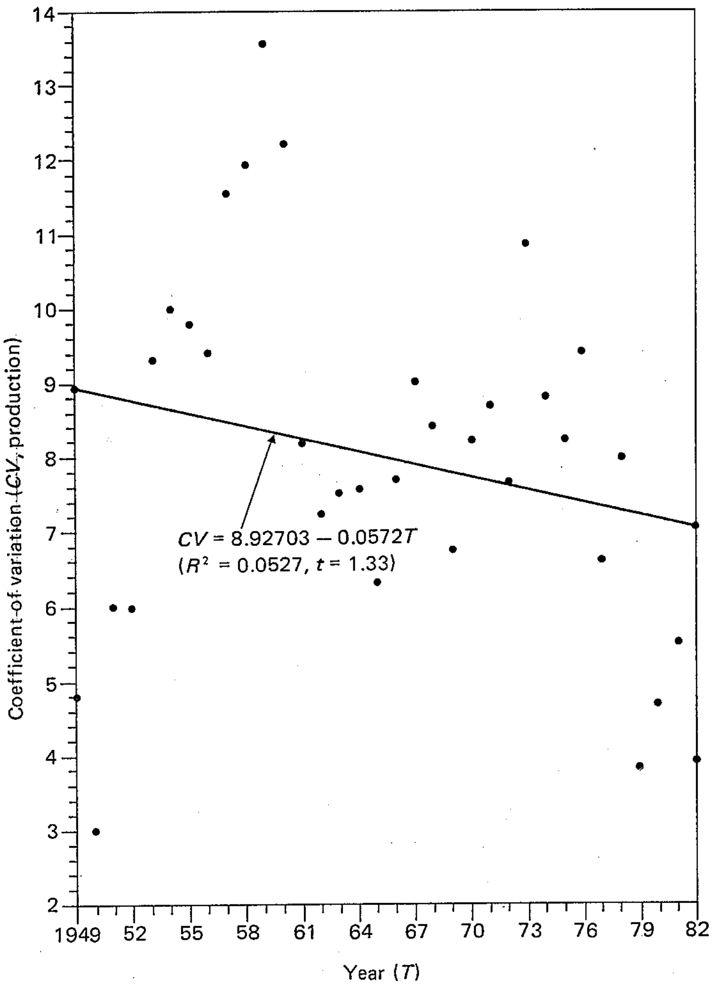


Figure 3 depicts the behavior of absolute yield variability over the years. Overall no time trend can be established. But two distinct phases can be identified. First, absolute yield variability increases during the period up to the early 1960s and falls to lower values on average during the second period. The average value of the standard deviation of yield falls from 5.18 in phase 1 to 4.67 in phase 2. The behavior of absolute variability can be placed into a pattern by considering the estimated regression equation in Figure 3 and equations (7), (8), and (9) which relate respectively to the first and second phases and the entire period.

Fig. 3. Absolute Yield Variability: Standard Deviation of Aggregate Foodgrain Yield, 1949/50 to 1982/83

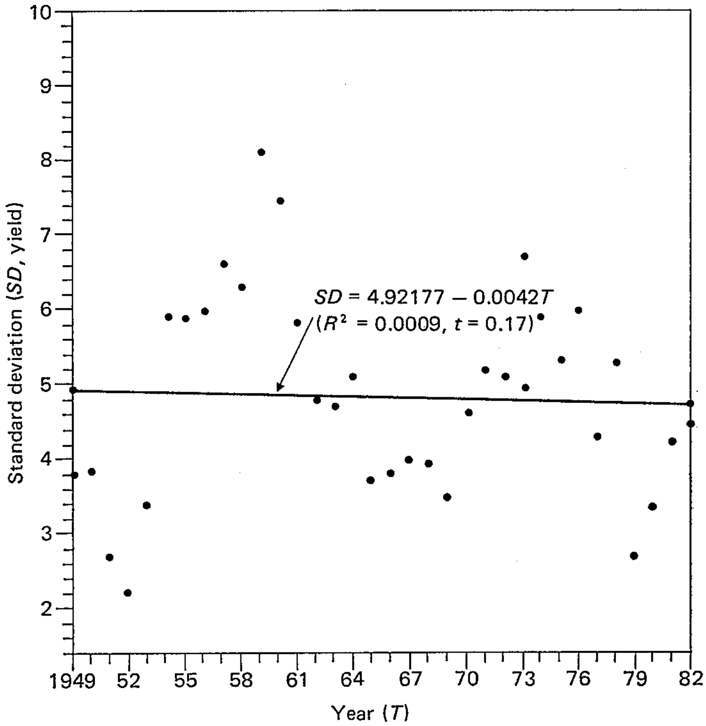
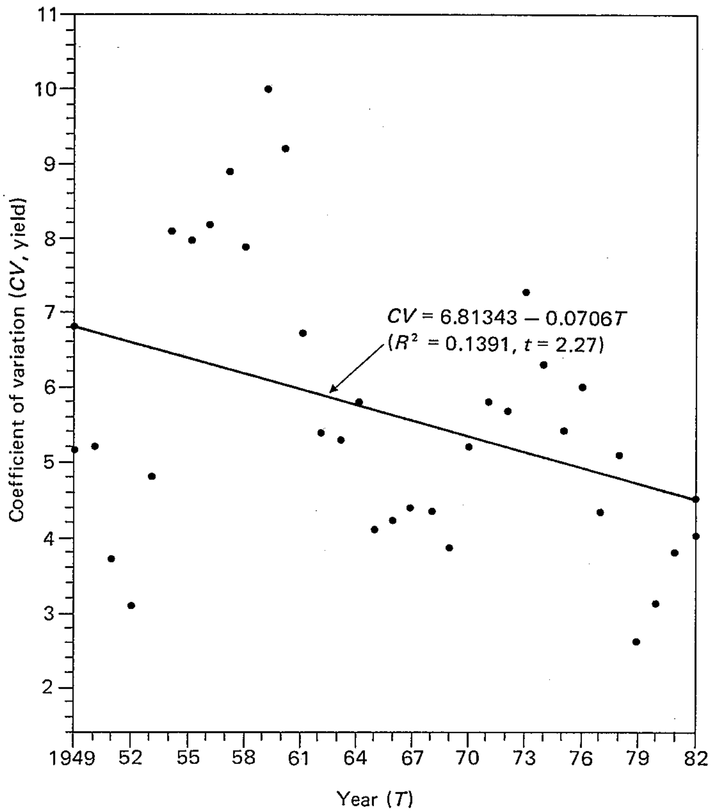


Figure 4 plots relative yield variability over time. It follows a similar pattern to that for absolute variability. Little trend is apparent in the overall period. However in phase 1, there is a strong tendency for relative yield variability to increase with only a very weak tendency for it to decline in the second phase. On average, it is lower during the second phase than the first phase. It falls from an average of 6.86 to an average of 4.97. Regression equations (10), (11), and (12) (graphed in Figure 4) indicate pattern in relative yield variability over time. These are respectively for phase 1, phase 2, and the overall period.

In terms of the above analysis of absolute and relative production and yield variability, there is little evidence to suggest that variability has increased in the second phase compared with the first phase. Indeed, especially if one takes into account the unprecedented drought and flood of 1972 and 1974 respectively and political factors like the War of Liberation of 1971, the second period seems to be associated with a somewhat greater production and yield stability than phase 1. Why does the apparent break occur in variability? Mostly, we suggest, because the second period, 1961/62 to 1982/83, corresponds to the commencement of introduction of new technology *to control* agricultural production. Increased

Fig. 4. Relative Yield Variability: Coefficient of Variation of Aggregate Foodgrain Yield, 1949/50 to 1982/83



irrigation and fertilizer use followed later by introduction of HYVs occurred during the second phase, as distinguished here.

Nevertheless, so far we have divided the entire period into two phases only on the basis of mathematical considerations as depicted by the plots in Figures 1–4. Even though the second phase (1961–82) can be broadly identified with the period of new technology and some elements of it (e.g., chemical fertilizers and modern irrigation) were introduced in the early 1960s, the new technological package in Bangladesh did not assume any real significance until the later part of the 1960s when HYVs of rice and wheat were introduced. Wide-scale adoption did not start until well into the 1970s. Thus, if one were to make inter-temporal comparison of trends in variability in foodgrain production and yield in the pre– and post–Green Revolution periods, a priori considerations would suggest that any of the years 1967/68 through 1969/70 is likely to provide a more clearcut dividing line. The following discussion concentrates on an examination of behavior of production and yield variability of Bangladeshi foodgrains by shifting the

TABLE III

TRENDS IN FOODGRAIN PRODUCTION AND YIELD VARIABILITY (STANDARD DEVIATION AND COEFFICIENT OF VARIATION) FOR DIFFERENT PHASES BASED ON TECHNOLOGICAL CONSIDERATIONS, 1949–82

Period	Intercept	Coefficient	R^2	t-value
		Standard deviation: production		
		Phase 1		
1949–66	3.90848	0.1976	0.3352	2.84***
1949–67	3.88921	0.2010	0.3801	3.23***
1949–68	3.92414	0.1951	0.4020	3.48***
1949–69	4.08182	0.1702	0.3542	3.23***
		Phase 2		
1967–82	7.93177	−0.1240	0.1478	1.56*
1968–82	7.87492	−0.1312	0.1382	1.44*
1969–82	7.90800	−0.1501	0.1476	1.44*
1970–82	8.37264	−0.2270	0.2790	2.06**
		Coefficient of variation: production		
		Phase 1		
1949–66	7.38922	0.1287	0.0615	1.02[a]
1949–67	7.45163	0.1177	0.0604	1.04[a]
1949–68	7.55777	0.1000	0.0508	0.98[a]
1949–69	7.78560	0.0641	0.0236	0.68[a]
		Phase 2		
1967–82	9.55162	−0.2840	0.4367	3.29***
1968–82	9.41238	−0.2995	0.4179	3.05***
1969–82	9.38783	−0.3312	0.4250	2.98***
1970–82	9.85643	−0.4312	0.5784	3.88***

dividing line between the two phases to the later part of the 1960s as may be more logical from technological considerations. As the Green Revolution is a continuous process a dividing line based on a single year may not realistically depict the behavior of variability between the two phases. Therefore, a series of dividing lines, starting with 1967/68 as the beginning of the second phase, are considered. The least squares regression estimates of the trend lines for the different phases based on the new dividing lines are presented in Table III.

A comparison of the behavior of absolute production variability (standard deviation) between the two phases clearly indicates that whereas the first period is characterized by an increasing tendency, the second period shows the opposite. The statistical quality of the estimates, however, is not very good especially in terms of explanatory power. Relatively speaking, the statistical quality of the estimates is much better in terms of explanatory power and statistical significance in the first period compared to the second. A similar behavioral pattern can be observed in the case of relative production variability. During the first phase it shows a *weak* rising trend while a *relatively* stronger tendency to fall is observed during the second. The explanatory power and statistical significance of the coefficients seem to improve as the dividing line is shifted forward.

TABLE III (Continued)

Period	Intercept	Coefficient	R^2	t-value
		Standard deviation: yield		
		Phase 1		
1949–66	4.28170	0.0857	0.0789	1.17[a]
1949–67	4.44679	0.0566	0.0396	0.55[a]
1949–68	4.58071	0.0343	0.0166	0.84[a]
1949–69	4.72519	0.0115	0.0021	0.20[a]
		Phase 2		
1967–82	4.82926	−0.0205	0.0084	0.34[a]
1968–82	5.03525	−0.0448	0.0341	0.68[a]
1969–82	5.29772	−0.0802	0.0924	1.11[a]
1970–82	5.76758	−0.1490	0.2863	2.10**
		Coefficient of variation: yield		
		Phase 1		
1949–66	6.12158	0.0264	0.0045	0.27[a]
1949–67	6.31775	−0.0082	0.0005	0.09[a]
1949–68	6.47057	−0.0336	0.0092	0.41[a]
1949–69	6.62892	−0.0586	0.0305	0.77[a]
		Phase 2		
1967–82	5.53114	−0.0891	0.1137	1.34[a]
1968–82	5.74233	−0.1213	0.1752	1.66*
1969–82	6.01043	−0.1662	0.2706	2.11**
1970–82	6.50207	−0.2484	0.5102	3.38***

*** Significant at 1 per cent level.
** Significant at 5 per cent level.
* Significant at 10 per cent level.
[a] Not significant.

An examination of the behavior of absolute and relative yield variability indicates much the same pattern as that of foodgrain production. In the first period, standard deviation of yield shows a *weak* rising tendency while a *weak* falling tendency can be observed in the second. The relative variability of yield shows a *weak* declining tendency in the first period and a *relatively stronger* tendency to fall in the second. The statistical quality of the estimates seem to show gradual improvement with a forward shift in the dividing line.

A comparison of the estimates set out in Table II with those of Table III, indicate that the rise in variability during the 1949–60 period is much stronger than in the case of the redefined first phases. By the same token, the fall seems to be stronger in the newly defined second phases compared to the 1961–82 period. Thus, irrespective of how one draws the dividing line between the two phases, that is, on observed mathematical grounds or on a priori considerations, the period associated with the new technology can in no way be identified with a period of rising variability in foodgrain production and yield. If anything, with the forward shift in the time cutoff points, both measures of variability show an increasingly stronger tendency to fall, that is, as the Green Revolution becomes more firmly established.

V. REASONS FOR THE OBSERVED BEHAVIOR OF VARIABILITY

From this paper, it can be seen that variability of foodgrain production and yield tended to increase in Bangladesh up to the early 1960s. After this period, there is evidence of a fall in variability and in some cases a downward trend in variability has become apparent. These changes have been associated with the introduction of new agricultural technology.

Our analysis does not support Hazell's earlier contention [15, p. 10] that increased yield instability inevitably accompanies rapid growth in agricultural production. In this context, Ray rightly points out that "certainly, with rapid growth, stability can be achieved if the environment for crop production is brought under human control. Even with a slower growth rate, production can be made more unstable by changing prices and other controllable factors. . . ." [29, p. 474]. Tables I and II indicate that the growth rates in both production and yield of foodgrains in Bangladesh are higher during the second period than the first. Yet there is no evidence of increased instability in either production or yield in the second period. One can see from Hazell [17, p. 150] that the coefficient of variation of rice production in South Asia which includes Bangladesh, Bhutan, Burma, Nepal, and Sri Lanka [17, p. 147] has declined by over 36 per cent between the two periods. Of these five countries Bangladesh alone produced nearly 54 per cent of rice in the region during the later period.[5] Given this relative weight of Bangladesh's share in the total production of rice in South Asia during that period, one might attribute some of the fall in variability to the fall in the Bangladesh rice production. Given the overwhelming importance of rice in total foodgrains in Bangladesh, this may have led to a reduction in the foodgrain production variability during the period 1971/72 to 1982/83.[6] This seems to be consistent with our findings.

Is it possible to be more specific about the factors associated with or responsible for the change in trend, if not the reversal of the trend, in variability of foodgrain production and yield in the second period as compared to the first? This may be possible by considering the sources of growth in foodgrain production in Bangladesh during the two periods.

In the period prior to the early 1960s marginal land was brought under cultivation due to increasing population pressure on existing cultivated land. Net cultivated area increased from about 8.0 million hectares in the late 1940s to about 8.5 million hectares in the early 1960s [12, p. 41]. During the first period

[5] The average production of rice in South Asia as defined by Hazell during 1971/72 to 1982/83 was 23,347,000 tonnes [17, p. 150]. Available sources (mentioned in the text) suggest the corresponding figure for Bangladesh to be 12,463,000 tonnes.

[6] The average share of rice in total foodgrain was more than 96 per cent during 1971/72 to 1982/83.

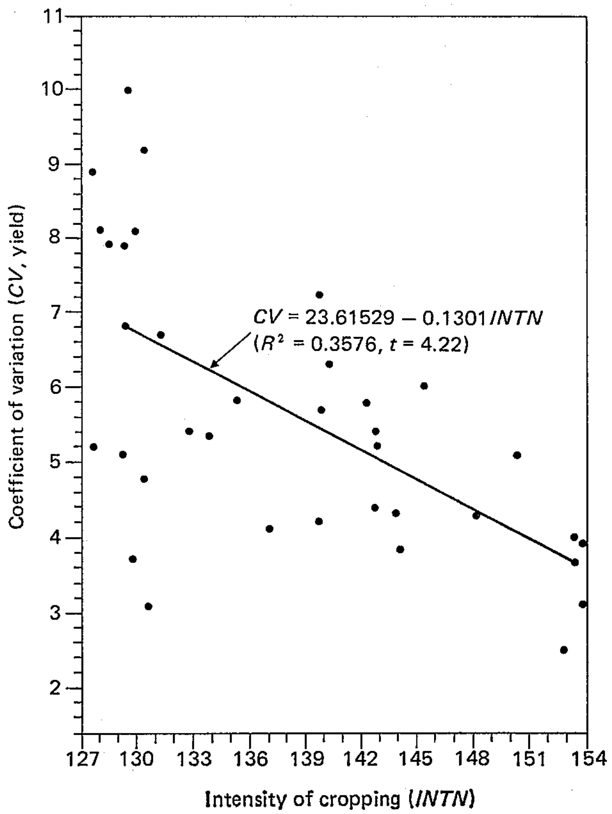
the cropping intensity remained stagnant at about 130 per cent. Foodgrain yield showed little tendency to increase and remained stagnant at around 920 kilograms per hectare. The foodgrain sector languished with a slow rate of growth and the primary source of this growth was the increase in net cultivated area. The upward trend in net cultivated area continued for a few years into the second period, when it reached a peak of 8.8 million hectares during the late 1960s. Throughout the entire period of the 1960s, cropping intensity increased slowly but steadily. During the later part of the second period, the net cropped area declined and by the first half of the 1980s it fell to around 8.6 million hectares [7, 1983–84 edition, pp. 218–19] [26, p. 39].

The increased instability during the period up to the early 1960s may be attributed in part to marginal land (of inferior quality) being brought under cultivation. The then available technology for foodgrain production did little to augment or preserve the fertility of the soil. However, why did variability not continue to increase during the 1960s even though some virgin land was still being brought under cultivation during that period? This may be the result of three factors at work. First, after new land is brought in for cultivation its quality seems to attain a certain degree of stability after a few years and farmers become more familiar with its qualities (a "learning-by-doing" factor). Furthermore, very risky marginal land may have been withdrawn from production once its poor qualities became apparent. This seems to have occurred after the 1960s. It is possible, therefore, that the new land that was brought in during the 1950s might have ceased to add to the variability during the second period any more than it did during the first. Second, the introduction of modern agricultural inputs like chemical fertilizers and irrigation at the beginning of the second period is likely to have to some extent helped maintain the fertility of existing land under cultivation. This may have compensated for any increased variability that may have resulted from the extension of the frontiers of cultivated land during the earlier part of the second period. Third, during the later part of the 1960s biological innovations like HYVs of rice and wheat were introduced. This made it possible to replace traditional rice cultivation by a whole range of new technologies. This had important implications in terms of higher productivity per unit area as well as greater choice and flexibility. Cultivated land that was once left fallow for a significant part of each year (for example, during the dry season) is now used for crops such as wheat and dry-season rice. The new technologies enabled the incidence of multiple cropping to increase.

The incidence of multiple cropping has increased significantly in recent years. For example, the area triple cropped (annually) expanded from around 480,000 to 649,000 hectares between the mid-1960s and first half of the 1980s [6, p. 113] [7, 1983–84 edition, pp. 218–19] [26, p. 39].[7] By the early 1980s the intensity of cropping rose to over 150 per cent. The growth of foodgrain production was more rapid during the second period compared to the first and the dominant source of this growth was the increase in yield per hectare [1].

[7] Such breakdowns are not available for individual years of the 1960s.

Fig. 5. Coefficient of Variation of Foodgrain Yield in Relation to Intensity of Cropping, 1949/50 to 1982/83



An increase in the incidence of multiple cropping can reduce the overall (annual) variability of production and a fortiori reduce the coefficient of variation of production. In Bangladesh the introduction of new technology has permitted the use of land for different crops of foodgrains over the whole year, e.g., its use for *kharif* (summer and wet season) foodgrains (*aus* and *aman* rice) and *rabi* (dry season) foodgrains (*boro* rice and wheat). Furthermore, within one season, land can be allocated between local and HYVs of the same foodgrain crop, e.g., local and HYVs of *aus* rice. When technological innovations reduce constraints on the use of a nonrenewable resource like land and allow the cultivation of two or more crops instead of only one crop during a year on the same plot of land, or different varieties of the same crop during the same crop season, the chance of a total crop failure considered annually can be reduced. The situation is akin to diversification of portfolios as a hedge against uncertainty [22] [4].

Let us now consider the impact multiple cropping might have had on the variability of yield. A casual observation at the relevant columns in Table I

TABLE IV

IMPACT OF INTENSITY OF CROPPING ON COEFFICIENT OF VARIATION OF YIELD IN DIFFERENT PHASES BASED ON PLOT 5 AND TECHNOLOGICAL CONSIDERATIONS, 1949–82

Period	Intercept	Coefficient	R^2	t-value
		Phase 1		
1949–60	95.69082	−0.6876	0.1107	1.12[a]
1949–66	46.21385	−0.3040	0.2464	2.29**
1949–67	39.27908	−0.2507	0.2622	2.46**
1949–68	35.53937	−0.2220	0.2809	2.65***
1949–69	34.80203	−0.2164	0.3210	3.00***
		Phase 2		
1961–82	20.82291	−0.1108	0.4060	3.70***
1967–82	31.67769	−0.1837	0.5807	4.40***
1968–82	33.10051	−0.1929	0.6288	4.69***
1969–82	34.10286	−0.1993	0.6687	4.92***
1970–82	35.73924	−0.2096	0.7681	6.04***
Entire period	23.61529	−0.1301	0.3576	4.22***

*** Significant at 1 per cent level.
** Significant at 5 per cent level.
[a] Not significant.

indicates that overall there is a tendency for the relative yield variability to decline with increase in the intensity of cropping. The relationship seems to be stronger toward the later part of the series. These aspects can be better illustrated by Figure 5 where the coefficient of variation of yield against intensity of cropping is plotted. The impact of multiple cropping on foodgrain yield variability in different phases comes into clearer focus if we consider the estimated regression equations involving the two variables. The statistical quality of the estimates pertaining to the second phase is consistently better than that of the earlier or the entire period. Furthermore, it seems to improve within the first phase as later year cutoff figures are used in regression estimates. During the second phase, significant improvement in the statistical quality of the estimates takes place when the cutoff point is shifted forward to include observations corresponding to the period whereby some progress has already been made with regard to the expansion of the HYV related technology.

Cropping intensity may be used as rough proxy for technological change in Bangladeshi agriculture. Irrigation, fertilizer, and HYVs all tend to increase multiple cropping. Because of complementarity between these inputs, one would expect a higher degree of multi-collinearity between them. In addition, the "learning-by-doing" factor would also contribute to reduction in relative variability of yields and production as experience with new technology proceeds.

The findings that emerge from the discussion surrounding Figure 5 and Table IV, are consistent with those in the preceding section. Thus the available evidence does not support the hypothesis that the Green Revolution has led to any increase in the variability in foodgrain production and yield, at least, in the case of Bangladesh. Indeed, we find some evidence to the contrary.

VI. CONCLUDING REMARKS

Recent studies (e.g., [15] [23]) suggest that the Green Revolution has been a source of increased variability of agricultural production. However, examination of Bangladeshi data suggest that the Green Revolution may have resulted in a reduction of relative variability of agricultural production and, therefore, the probability of a fall in yield and production a certain percentage below the trend may have been reduced.[8]

One of the most important impacts of the Green Revolution has been to increase the intensity of cultivation or cropping by increasing the incidence of multiple cropping, that is, the number of crops grown on cultivated land in each year. Even if variability should be higher during the original cropping period, the extra croppings in each year in most cases are likely to add stability in annual production and yield. Even though absolute variability might in some cases show a tendency to increase, increased (annual) average production and yield can bring about a decrease in relative variability. Increased usage of controlled complementary inputs like chemical fertilizers and irrigation might also have reinforced the moderating impact of multiple cropping. Because these factors have been significant in Bangladesh, the Green Revolution appears to have had a stabilizing influence on the relative variability of production rather than a destabilizing one.

One needs, however, to qualify our findings in two respects. First, our analysis is based on official data whose reliability and accuracy is not beyond question (see, for example, [11] [27]). But as there are no other comprehensive sources of information, we had to use official data keeping their limitations in mind. Secondly, the statistical quality of some of our estimates, while adequately casting doubts on earlier views or theses about trends in foodgrain variability, are not sufficient to establish the opposite views or theses. Nevertheless (taking account of the evidence, statistical or *otherwise*), the thesis cannot be lightly dismissed that the Green Revolution has reduced and is continuing to reduce, as it proceeds, the relative variability of foodgrain production and yield.

[8] In a separate study [2] applying Hazell's approach to Bangladeshi foodgrain data, no evidence of increased production and yield variability was found to be associated with the period of new agricultural technology. In fact relative production and yield variability and probability of yield or production falling say 5 per cent below the trend were found to be considerably lower in the post Green Revolution period.

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