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Changing Patterns of Variability in Cereal Prices and Production

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The substantial growth in world cereal production of the past two and one-half decades has been accompanied by a widening band of variability around the trend. Although each trough in production has been consistently higher than in all previous downturns, the probability that aggregate production can fall substantially below trend has increased since the 1960s.

Increased variability in world cereal production implies even larger-than-average increases for many countries. To secure their consumption and to moderate domestic price fluctuations, these countries may need to stockpile more grains or depend more on world markets. However, storing food is expensive, and world markets have become more risky as variability in world cereal production increases.

Increased variability in national cereal production tends to destabilize national income, particularly in poorer countries where agriculture is the predominant sector. This effect will be reinforced if a country's cereal production is positively correlated with fluctuations in world prices. Its effects on the welfare of farmers and poor consumers is less predictable, however, depending on such factors as the way in which domestic production and prices are correlated, the possibilities of substitution between commodities, especially in demand arising from government intervention policies, and so forth (see Sahn and von Braun 1985; Walker forthcoming; and chapter 6 of this volume).

Variability in world cereal prices also increased markedly in the 1970s. Structural shifts in demand and changes in U.S. storage policies were probably the main causes, but increased production variability and the domestic price policies of many industrialized countries were also important (Myers and Runge 1985; Blandford and Schwartz 1983; Josling 1980). By stabilizing prices for consumers, these countries essentially exported much of the variability in their domestic production. Since the volume of cereals traded in the world market is only about 15 percent of total production, a relatively small increase in production variability of major exporters can induce a much larger increase in world price variability.

The following analysis documents the changes in the variability of world cereal prices and production since the 1960s and, by use of a variance decomposition procedure, identifies the main components of the increase in production variability.

CHANGES IN THE VARIABILITY OF CEREAL PRICES

Using available data on farmgate cereal prices from selected countries,[1] price variability is measured in two time periods: 1961–71 and 1974–81. This partitioning usefully coincides with structural shifts that occurred in world cereal markets. The years 1972 and 1973, when major structural adjustments occurred in world and many domestic cereal markets, were omitted from the analysis. Their inclusion would have exaggerated the changes in variability that have since occurred.

Since all the price data obtained were in nominal (or current) prices, many of the series showed strong trends over time. These may arise from trends in real (deflated) prices as well as from general inflationary forces, and separating the two effects is difficult. Fortunately, for the purposes of this chapter, it is possible to avoid the thorny problem of constructing relevant price deflators and simply to detrend the data directly. It is only necessary to analyze fluctuations in prices around trend. Even if the data were deflated, it might still be necessary to detrend the resultant real prices.

Separate trend regressions were run for 1961–71 and 1974–81. In most cases linear equations gave excellent fits, but where nonlinearities were apparent, quadratic functions were used. The residuals, centered on the mean prices for each period, became the primary data for analysis.

Table 3.1 shows the changes in the variability of world prices and of domestic farmgate prices for selected countries. These countries represent a range of agricultural policy regimes as well as providing a broad geographical coverage. Price variability, as measured by the coefficient of variation, is much higher in world markets than in the domestic markets of most countries. The coefficients of variation of world cereal prices for the two periods increased 400 percent for wheat, 59 percent for rice, and 67 percent for maize. Patterns of increase were similar in the United States,

1. The data were obtained mostly from FAO sources. These are *Agricultural producer prices 1961–70*, the 1982 *Producer yearbook*, and the 1982 *Statistics on prices received by farmers*. Price data for India for the years 1961 to 1968 were obtained from various issues of *Agricultural prices in India*, published by the Ministry of Agriculture. The world prices used are as follows: *wheat*, U.S. No. 1 (No. 2 prior to 1974), soft red winter, f.o.b. Atlantic ports; *rice*, 5% broken, milled, f.o.b. Bangkok; *maize*, no. 2 yellow, f.o.b. Gulf ports. These prices are published by the World Bank in *Commodity trade and price trends* (1985).

Table 3.1 Changes in the coefficients of variation of world and national cereal prices, 1961–71 to 1974–81

	Wheat		Rice		Maize	
	1961–71	1974–81	1961–71	1974–81	1961–71	1974–81
World	4.05	20.50	17.76	28.16	7.37	12.35
France	3.02	2.41			2.51	4.27
U.S.	15.03	20.20	2.56	20.29	7.98	16.77
Mexico	2.92	5.47			7.60	10.03
India	9.89	7.20	22.36	11.10		
Japan	3.37	8.39	13.50	4.24		
Canada	7.37	20.06				
Turkey	2.67	25.48				
F. R. Germany	2.92	3.00				
U.K.	2.68	4.78				
Italy	2.53	3.43				
Pakistan	7.84	8.11				
Argentina	24.58	50.17			23.15	33.05
Brazil			13.75	18.69	5.04	26.07
Yugoslavia					18.07	14.00
Kenya					10.91	10.00
Burma			2.54	0.66		
Philippines			12.57	4.17		
Colombia			14.05	9.32		

Canada, and Argentina, which have grain markets relatively open to international trade. Many other countries were successful in using domestic policies to contain or reduce the variability of domestic farmgate prices, despite the increased turbulence in world markets. The EEC countries were particularly successful in this respect, as were Japan, India, Pakistan, Burma, the Philippines, Colombia, Kenya, and Yugoslavia.

Tables 3.2, 3.3, and 3.4 show the changes in inter-country price correlations for wheat, rice, and maize. Countries that maintain open grain markets for international trade would be expected to have positive price correlations with both the world price and domestic prices of other trading countries.

In fact, however, only Pakistan and Italy had statistically significant and positive correlations between their domestic wheat prices and the world wheat price during 1961–71. These correlations became negative in 1974–81, when only the United States and Canada had significant positive correlations with the world wheat price. Similarly, very few countries had statistically significant and positive correlations between their domestic rice or maize prices and the corresponding world prices, and there is no indication of any widespread shift toward more positive correlations between the two periods.

Table 3.2 Intercountry correlations between wheat prices, 1961–71 and 1974–81

	World	France	U.S.	Mexico	India	Japan	Canada	Turkey	F. R. Germany	U.K.	Italy	Pakistan
France												
1961–71	0.37	1.00										
1974–81	−0.29	1.00										
U.S.												
1961–71	0.22	0.81***	1.00									
1974–81	0.95***	−0.38	1.00									
Mexico												
1961–71	0.21	−0.78***	−0.67**	1.00								
1974–81	−0.49	0.53*	−0.31	1.00								
India												
1961–71	−0.19	0.41	0.25	−0.59**	1.00							
1974–81	0.50	0.29	0.60*	0.39	1.00							
Japan												
1961–71	0.00	0.10	0.14	−0.19	0.36	1.00						
1974–81	−0.59*	−0.39	−0.55*	−0.04	−0.58*	1.00						
Canada												
1961–71	0.38	0.26	0.40	0.11	0.05	0.32	1.00					
1974–81	0.97***	−0.46	0.97***	−0.46	0.50	−0.44	1.00					

Turkey												
1961–71	−0.01	0.20	0.42	−0.09	−0.52*	−0.12	0.15	1.00				
1974–81	−0.58*	0.76**	−0.54*	0.73**	0.26	−0.19	−0.64**	1.00				
F. R. Germany												
1961–71	0.24	−0.33	−0.44*	0.60**	−0.36	−0.05	0.36	0.24	1.00			
1974–81	−0.42	0.60*	−0.50	0.21	−0.17	−0.38	−0.54*	0.73**	1.00			
U.K.												
1961–71	−0.13	0.17	0.03	−0.07	−0.27	−0.84***	−0.22	0.43*	0.13	1.00		
1974–81	−0.25	0.15	−0.46	−0.44	−0.47	0.41	−0.34	−0.15	−0.02	1.00		
Italy												
1961–71	0.64**	0.02	0.14	0.47*	−0.30	0.10	0.86***	0.13	0.57**	−0.19	1.00	
1974–81	0.24	0.50	0.07	−0.06	0.47	−0.14	0.16	0.18	−0.06	0.38	1.00	
Pakistan												
1961–71	0.54**	0.35	0.28	0.07	0.13	0.36	0.86***	0.09	0.57**	−0.23	0.81***	1.00
1974–81	−0.69**	0.41	−0.53*	0.84***	−0.10	0.07	−0.68**	0.64**	0.43	−0.40	−0.44	1.00
Argentina												
1961–71	0.37	0.62**	0.26	−0.43*	0.60**	0.28	0.20	−0.33	0.04	−0.18	0.08	0.56**
1974–81	−0.58*	0.86***	−0.54*	0.81**	0.23	−0.13	−0.68**	0.84***	0.49	0.05	0.18	0.70**

Note: ***, **, and * indicate correlation coefficients that are significantly different from zero (one-tail tests) at the 1%, 5%, and 10% confidence levels, respectively.

Table 3.3 Intercountry correlations between rice prices, 1961–71 and 1974–81

	World	U.S.	India	Japan	Brazil	Burma	Philippines
U.S.							
1961–71	−0.58**	1.00					
1974–81	0.55*	1.00					
India							
1961–71	−0.17	0.62**	1.00				
1974–81	0.70**	0.33	1.00				
Japan							
1961–71	0.67**	−0.69***	−0.67**	1.00			
1974–81	−0.02	−0.21	0.20	1.00			
Brazil							
1961–71	0.03	0.72***	0.52*	−0.40	1.00		
1974–81	−0.24	−0.07	0.26	0.23	1.00		
Burma							
1961–71	0.44	−0.22	0.29	0.41	−0.24	1.00	
1974–81	0.39	0.22	0.42	0.02	−0.54*	1.00	
Philippines							
1961–71	−0.40	0.18	−0.41	−0.03	0.13	−0.55**	1.00
1974–81	−0.44	−0.66**	0.16	0.30	0.60*	−0.38	1.00
Colombia							
1961–71	0.56**	−0.64**	−0.60**	0.94***	−0.45*	0.49*	0.04
1974–81	−0.04	−0.19	0.05	0.93***	0.06	−0.11	0.27

Note: ***, **, and * indicate correlation coefficients that are significantly different from zero (one-tail tests) at the 1%, 5%, and 10% confidence levels, respectively.

Table 3.4 Intercountry correlations between maize prices, 1961–71 and 1974–81

	World	France	U.S.	Mexico	Brazil	Argentina	Yugoslavia
France							
1961–71	0.63**	1.00					
1974–81	−0.24	1.00					
U.S.							
1961–71	0.59**	0.46*	1.00				
1974–81	0.80***	−0.30	1.00				
Mexico							
1961–71	0.33	0.21	−0.18	1.00			
1974–81	−0.21	0.06	−0.47	1.00			
Brazil							
1961–71	−0.25	−0.03	−0.06	−0.35	1.00		
1974–81	0.07	−0.19	−0.01	0.63**	1.00		
Argentina							
1961–71	−0.32	−0.60**	−0.30	0.14	0.00	1.00	
1974–81	−0.22	0.31	−0.71**	0.77**	0.26	1.00	
Yugoslavia							
1961–71	0.48	0.41	−0.16	0.27	0.03	−0.15	1.00
1974–81	−0.12	0.04	−0.62**	0.54*	0.13	0.90***	1.00
Kenya							
1961–71	0.21	−0.02	−0.23	0.23	0.34	0.31	0.69**
1974–81	−0.56*	−0.38	−0.63**	0.69**	0.47	0.45	0.37

Note: ***, **, and * indicate correlation coefficients that are significantly different from zero (one-tail tests) at the 1%, 5%, and 10% confidence levels, respectively.

There were more substantial changes in patterns of collinearity between prices of different crops than between prices of the same crop among countries (tables 3.5, 3.6, and 3.7). World prices became much more collinear between crops. The correlation between world maize and rice prices increased from −0.62 in 1961–71 to 0.79 in 1974–81. Similarly, the correlations between world rice and wheat prices increased from −0.13 to 0.82, and from 0.30 to 0.89 for maize and wheat. Not surprisingly, these changes were accompanied by increases in the correlations between the prices of different cereals among countries. The number of significant and positive price correlations between rice and corn increased from 7 in the first period to 15 in the second (table 3.5), while those between rice and wheat rose from 15 to 23 (table 3.6). There was little change in the number of significant and positive price correlations between maize and wheat (table 3.7).

CHANGES IN WORLD CEREAL PRODUCTION

Production variability for cereal crops is measured for 1960/61 to 1970/71 and 1971/72 to 1982/83.[2] This split:

(a) corresponds to speculated changes in yield variability that are possibly associated with the green revolution, usually regarded as occurring around 1970 in many developing countries;

(b) corresponds broadly with the dramatic increases in price variability in the early 1970s; and

(c) more pragmatically, gives roughly equal sample sizes from the available data.

Year-to-year fluctuations in areas sown and yields of each crop in each country reflect the separate influences of long-term and short-term sources of variation. By assuming an independent and deterministic long-term trend in each variable, the area and yield data for each crop and country were detrended by regression analysis. The residuals, centered on the mean areas or yields for each period, became the primary data for analysis.

Quadratic equations were chosen because they do not assume a deterministic part to any relation between the variance of the dependent variable and time. Also, unbiased and efficient estimates of the variances and

2. The production analysis in this chapter is limited to the major cereal crops of wheat, maize, rice, barley, millet, sorghum, oats, and a residual crop comprising rye and mixed cereals. Only cereals grown for grain are considered, and no distinction is made between grains utilized for human and for livestock consumption.

Data on the production and area sown of each crop by country were obtained from the U.S. Department of Agriculture for the period 1960/61 to 1982/83. For the purposes of this analysis, the 34 most important cereal-producing countries (excluding the People's Republic of China) were selected, and all other countries were combined into a single residual country.

Table 3.5 Intercountry correlations between maize and rice prices, 1961–71 and 1974–81

	Maize price							
Rice price	World	France	U.S.	Mexico	Brazil	Argentina	Yugoslavia	Kenya
World								
1961–71	−0.62**	−0.59**	−0.33	0.11	0.24	0.75***	−0.54**	−0.12
1974–81	0.79***	0.16	0.79***	−0.30	−0.24	−0.30	−0.29	−0.81***
U.S.								
1961–71	−0.07	0.00	−0.07	−0.65**	−0.15	−0.32	0.23	0.02
1974–81	0.43	−0.27	0.82***	−0.41	−0.13	−0.83***	−0.88***	−0.38
India								
1961–71	−0.29	−0.11	0.21	−0.97***	0.26	−0.28	−0.28	−0.42
1974–81	0.82***	−0.38	0.62**	0.18	0.14	0.04	0.12	−0.22
Japan								
1961–71	−0.26	−0.27	−0.25	0.61**	0.01	0.68**	0.00	0.32
1974–81	−0.34	0.21	−0.38	0.69**	0.02	0.55*	0.38	0.36
Brazil								
1961–71	−0.46*	−0.33	−0.47	−0.60**	0.00	0.19	−0.09	−0.03
1974–81	0.03	−0.34	0.00	0.72**	0.95***	0.27	0.16	0.59*
Burma								
1961–71	−0.45*	−0.44*	0.11	−0.27	0.27	0.29	−0.21	−0.10
1974–81	0.29	−0.41	0.34	−0.52*	−0.69**	−0.30	0.03	−0.36
Philippines								
1961–71	0.40	0.33	−0.41	0.35	0.05	−0.03	0.87***	0.71
1974–81	−0.06	−0.16	−0.53	0.82***	0.58***	0.84***	0.79***	0.69**
Colombia								
1961–71	−0.19	−0.31	−0.18	0.49*	0.20	0.65**	0.11	0.52*
1974–81	−0.37	0.41	−0.46	0.65**	−0.10	0.57*	0.30	0.32

Note: ***, **, and * indicate correlation coefficients that are significantly different from zero (one-tail tests) at the 1%, 5%, and 10% confidence levels, respectively.

Table 3.6 Intercountry correlations between rice and wheat prices, 1961–71 and 1974–81

	Rice price							
Wheat price	World	U.S.	India	Japan	Brazil	Burma	Philippines	Colombia
World								
1961–71	−0.13	0.08	−0.33	0.11	0.19	−0.46*	0.85***	0.70
1974–81	0.82***	0.65**	0.60*	−0.53*	−0.24	0.43	−0.48	−0.55*
France								
1961–71	0.47*	0.12	0.14	0.14	0.49*	0.01	−0.04	0.04
1974–81	0.00	−0.68**	0.08	0.29	0.20	−0.47	0.68**	0.39
U.S.								
1961–71	0.28	0.29	0.22	−0.11	0.47*	−0.02	0.01	−0.18
1974–81	0.78**	0.60*	0.71**	−0.41	−0.22	0.64**	−0.42	−0.50
Mexico								
1961–71	−0.59**	−0.16	−0.50*	0.01	−0.53**	−0.32	0.55**	0.06
1974–81	−0.16	−0.71**	0.22	0.70**	0.20	0.17	0.61*	0.53*
India								
1961–71	0.87***	−0.54**	−0.14	0.64**	−0.14	0.52*	−0.50*	0.63**
1974–81	0.72**	0.16	0.96***	0.32	0.15	0.41	0.23	0.21
Japan								
1961–71	0.17	0.09	0.13	0.35	−0.04	0.72**	−0.01	0.57**
1974–81	−0.40	0.10	−0.59*	0.44	−0.21	−0.04	−0.37	0.49

Canada								
1961–71	−0.16	−0.04	−0.49*	0.23	−0.30	−0.14	0.36	0.30
1974–81	0.81***	0.75**	0.63**	−0.43	−0.21	0.54*	−0.57*	−0.49
Turkey								
1961–71	−0.39	0.36	0.44*	−0.57**	0.10	−0.05	0.03	−0.58**
1974–81	−0.34	−0.66**	0.15	0.56*	0.66**	−0.47	0.92***	0.49
F. R. Germany								
1961–71	−0.38	−0.37	−0.41	0.06	−0.62**	−0.18	0.36	0.20
1974–81	−0.53*	−0.59*	−0.17	−0.11	0.68**	−0.75**	0.80***	−0.11
U.K.								
1961–71	−0.08	−0.08	0.05	−0.30	−0.01	−0.42*	−0.25	−0.53**
1974–81	−0.18	0.09	−0.55*	−0.04	−0.34	−0.47	−0.14	0.32
Italy								
1961–71	−0.45*	0.03	−0.55**	0.04	−0.26	−0.47*	0.73***	0.15
1974–81	0.63**	0.26	0.36	0.33	0.06	−0.33	−0.02	0.48
Pakistan								
1961–71	0.04	−0.25	−0.54**	0.39	−0.28	−0.10	0.46*	0.50*
1974–81	−0.56*	−0.89***	−0.22	0.39	0.21	−0.02	0.57*	0.22
Argentina								
1961–71	0.72***	−0.40	−0.37	0.66**	0.15	0.12	0.11	0.66**
1974–81	−0.28	−0.84***	0.01	0.54*	0.15	−0.23	0.79**	0.58*

Note: ***, **, and * indicate correlation coefficients that are significantly different from zero (one-tail tests) at the 1%, 5%, and 10% confidence levels, respectively.

Table 3.7 Intercountry correlations between maize and wheat prices, 1961–71 and 1974–81

	Maize price							
Wheat price	World	France	U.S.	Mexico	Brazil	Argentina	Yugoslavia	Kenya
World								
1961–71	0.30	0.41	−0.26	0.23	0.28	0.17	0.70***	0.69***
1974–81	0.89***	−0.22	0.92***	−0.59*	−0.18	−0.59*	−0.45	−0.76**
France								
1961–71	−0.17	−0.21	−0.03	−0.27	0.15	0.58**	−0.15	0.11
1974–81	0.06	0.56*	−0.44	0.61*	0.31	0.87***	0.70**	0.08
U.S.								
1961–71	−0.12	−0.32	−0.15	−0.29	0.13	0.28	−0.05	0.05
1974–81	0.87***	−0.41	0.89***	−0.56*	−0.24	−0.56*	−0.32	−0.65**
Mexico								
1961–71	0.53**	0.56**	−0.01	0.60**	−0.23	−0.48*	0.62**	0.24
1974–81	−0.21	0.05	−0.53*	0.59*	0.08	0.81***	0.88***	0.34
India								
1961–71	−0.56**	−0.52*	−0.10	0.03	0.45*	0.57**	−0.55**	0.04
1974–81	0.76**	−0.17	0.47	0.24	0.04	0.23	0.29	−0.27
Japan								
1961–71	−0.27	−0.48*	−0.08	−0.26	0.39	0.36	0.26	0.55**
1974–81	−0.82***	0.23	−0.40	0.00	−0.33	−0.16	−0.31	0.27

Canada								
1961-71	0.53**	0.06	0.19*	−0.38	−0.07	0.14	0.47*	0.61**
1974-81	0.82***	−0.33	0.96***	−0.60*	−0.22	−0.69**	−0.53*	−0.70**
Turkey								
1961-71	0.52*	0.21	0.42	−0.35	−0.22	−0.24	0.20	−0.27
1974-81	−0.17	0.09	−0.55*	0.93***	0.63**	0.90**	0.76**	0.62*
F. R. Germany								
1961-71	0.85***	0.46*	0.50*	0.42*	−0.10	−0.05	0.44*	0.34
1974-81	−0.13	−0.01	−0.44	0.60*	0.81***	0.56*	0.48	0.56*
U.K.								
1961-71	0.36	0.44*	0.43*	0.08	−0.50*	−0.18	−0.36	−0.68**
1974-81	−0.34	0.58*	−0.31	0.00	−0.25	0.00	−0.31	0.02
Italy								
1961-71	0.71***	0.34	0.09	0.46*	−0.03	−0.06	0.73***	0.74***
1974-81	0.38	0.61*	0.27	0.31	0.10	0.19	−0.14	−0.38
Pakistan								
1961-71	0.53**	0.00	0.15	0.39	0.07	0.46*	0.47*	0.75***
1974-81	−0.51*	0.02	−0.73**	0.43	0.17	0.71**	0.83***	0.48
Argentina								
1961-71	−0.22	−0.43*	−0.27	0.19	0.19	0.94***	−0.09	0.45*
1974-81	−0.23	0.34	−0.73**	0.70**	0.14	0.99***	0.91***	0.39

Note: ***, **, and * indicate correlation coefficients that are significantly different from zero (one-tail tests) at the 1%, 5%, and 10% confidence levels, respectively.

covariances of the detrended variables are easily obtained from the variance-covariance matrix of the residuals.

For more reliable estimates of long-term trends, the regressions were fitted to the full-time series in each country. The assumption of a homoscedastic error term is not appropriate when both periods are combined in this way, so a generalized least squares estimation procedure was used (Hazell 1984). The residuals were subsequently divided into two periods and their period means adjusted to zero before centering on the mean areas and yields for each period.

Estimates of detrended production for each country were obtained from the relevant products of the detrended area and yield series. When calculated this way, the means of these production series typically differ by less than 1 percent from the means of corresponding original data.

Table 3.8 shows the changes in world cereal production from 1960/61 to 1970/71 and 1971/72 to 1982/83.[3] Total world cereal production increased 37 percent, or 305 million tons, with wheat and maize accounting for one third each. Rice accounted for 12 percent of the total increase, barley 18 percent, and sorghum and millets for the rest. Production of oats and other cereals (rye and mixed cereals) declined moderately.

The coefficient of variation of total world cereal production rose from 2.8 percent to 3.4 percent between the two periods, an increase of 22 percent. The variance of total cereal production increased 178 percent. The F ratio of 2.78 is significant at the 10 percent confidence level. Both area and yield variability also increased, although only the F ratio for yields is statistically significant at the 10 percent level.

A useful policy measure of the increase in production instability is the probability that production will fall 5 percent or more below trend in each year (Valdés and Konandreas 1981).

A difficulty in calculating these probabilities is that the distribution of possible production outcomes for individual years is not known; there is only a single observation for each year. However, from the detrending procedure used, estimates of the variance of production around trend are available for each of the two periods. By assuming that the variance of production remains constant for all years within a period, the average probabilities can be obtained.[4] This probability was 3.5 percent for 1960/61 to 1970/71 and increased to 6.8 percent for 1971/72 to 1982/83.

3. The People's Republic of China is excluded from all calculations because of the extraordinary disruption of production in the early 1960s and subsequent periods.

4. Let detrended production in year t be denoted by $\hat{Q}_t = \bar{Q} + e_t$ where $\bar{Q}$ is the period mean and e_t is the deviation from the mean that year. Then the probability of a shortfall of 5 percent or more below trend is derived from $\Pr\{\bar{Q} + e_t \leq 0.95\,\bar{Q}\} = \Pr\{e_t/\sigma_e \leq -0.05\,\bar{Q}/\sigma_e\}$, where σ_e is the standard deviation of e_t. Assuming e_t is approximately normally distributed, the desired probability can be obtained from tables for the cumulative normal distribution.

Table 3.8 Changes in the mean and variability of world cereal production, 1960/61–1970/71 to 1971/72–1982/83[a]

Cereal	Average production: First period	Average production: Second period	Average production: Change	Coefficient of variation of production: First period	Coefficient of variation of production: Second period	Coefficient of variation of production: Change	F ratios: Production	F ratios: Area sown	F ratios: Yield
	(metric tons)			(percent)					
Wheat	253,454	352,982	39.3	5.46	4.83	−11.5	1.52	0.34**	1.64
Maize	210,074	317,303	51.0	3.29	4.41	34.0	4.08**	1.65	4.17**
Rice	119,971	155,031	29.2	3.97	3.80	−4.3	1.52	2.45*	0.88
Barley	95,283	150,997	58.5	4.81	7.50	55.9	6.18***	3.13**	3.28**
Millets	19,705	21,381	8.5	7.78	7.66	−1.5	1.14	2.22	0.69
Sorghum	40,159	53,386	32.9	4.75	5.70	20.0	2.55*	1.08	2.10
Oats	49,033	47,595	−2.9	11.30	5.35	−52.6	0.21***	0.07***	4.42**
Other cereals	41,404	35,231	−14.9	4.57	9.33	104.2	2.95**	0.36*	3.61**
Total cereals	829,087	1,133,908	36.8	2.76	3.06	21.7	2.78*	2.22	2.69*

Note: ***, **, and * indicate statistically significant F ratios (one-tail tests) at the 1%, 5%, and 10% confidence levels, respectively. The first period is from 1960/61 to 1970/71; the second period is from 1971/72 to 1982/83.

[a] Does not include China.

Table 3.8 also shows that the sizeable increases in world wheat and rice production were not accompanied by a significant increase in variability. In fact, the coefficients of variation declined from 5.5 to 4.8 percent for wheat and from 4.0 to 3.8 percent for rice. Production variability increased substantially for maize, barley, and other cereals but declined for oats.

There is little observable relationship between a country's performance in increasing cereal production and the changes in production variability (table 3.9). The correlation across countries between the percentage change in average production and the change in the coefficient of variation of production is in fact −0.15. This is not significantly different from zero at the 10 percent confidence level.

How robust are these results? The question is particularly relevant since there were only eleven years in the first period and twelve in the second. There is a danger that extreme years may determine the results, depending in which period they are assigned.

Ten-year moving averages for the mean and, after (in this case) linear detrending, the standard deviation and the coefficient of variation of production were calculated, and the results are reported in table 3.10.

Absolute variability around the trend has increased quite consistently over the years, so our previous result is not due to the particular periods chosen. The coefficient of variation has also trended upward in a similar manner, though it peaked in the early 1980s and there has been a modest gain in relative stability since then. The probability of a 5 percent shortfall below trend in world cereal production followed a similar pattern and has diminished a little since the early 1980s. But the probability of a shortfall is still much higher than in the 1960s.

METHOD OF FURTHER ANALYSIS

To analyze the components of change in the mean and variance of world cereal production, a variance decomposition procedure is used, as reported in Hazell (1982, 1984). There are four sources of change in average production. Two parts arise from changes in the mean yield and mean area. These "pure" effects arise even if there are no other sources of change. There is also an interaction effect between changes in the mean yield and the mean area, and a further effect arises from changes in the covariability of areas and yields.

The variance of total cereal production consists of the sum of the following four types of production variances and covariances: individual crop variances within countries, intercrop covariances within countries; intercountry covariances within crop; and covariances between different crops in different countries. The change in each of these production variances and covariances can be further decomposed into the following ten parts: change in mean yields, change in mean areas, change in yield variances and covariances, change in area variances and covariances, change in area-yield covariances, interaction between changes in mean yields and mean areas, interaction between changes in mean areas and yield variances, interaction between changes in mean yields and area variances, interaction between changes in mean areas and yields and changes in area-yield covariances and change in the residual (Hazell 1984).

The first five sources of change are "pure" effects, the next four are interaction effects which occur because of simultaneous changes in all the constituent parts, and the last term is a higher-order term which is typically small and of little importance.

COMPONENTS OF CHANGE IN WORLD CEREAL PRODUCTION

Increases in mean yields account for 72 percent of the increase in world cereal production, and area expansion accounts for 22 percent (table 3.11). Yield improvements were even more important in expanding the production of wheat and were more important than area expansion in increasing the production of maize, rice, and millet. Area increases were more important for barley.

Table 3.12 shows the results from the decomposition of the change in the variance of world cereal production. The rows in the lower half of this table correspond to four groups of production variances and covariances delineated. The first six columns correspond to six of the ten sources of change for a production variance and covariance listed above, while the seventh is the total of the four types of interaction terms. All entries in the table are expressed as a percent of the change in the variance of total cereal production; hence rows and columns sum to 100 percent.

The row sums in table 3.12 show that 34 percent of the increase in the variance of world cereal production is attributable to increases in the production variances of individual crops within countries. Wheat, maize, and barley account for nearly all of this increase. The remaining 66 percent is due to increases in production covariances, and of these the most important are between crops, both within and between countries. Changes in intercountry covariances within crops turn out to be only 5 percent of the total variance increase.

The dominance of the production covariances arises for two reasons. First, they are far more numerous; for each r variances in the equations used, there are $r^2 - r$ covariances. Second, unless there are changing pat-

Table 3.9 Changes in the mean and variability of total cereal production by major countries, 1960/61–1970/71 to 1971/72–1982/83

Country	Average production			Coefficient of variation of production			*F* ratios			Probability of 5% shortfall below trend	
	First period	Second period	Change	First period	Second period	Change	Production	Area sown	Yield	First period	Second period
	(thousand metric tons)			(percent)							
1. U.S.	181,982	265,022	45.6	6.83	6.64	−2.8	1.97	1.24	8.23***	23.3	22.6
2. U.S.S.R.	138,436	180,952	30.7	12.16	14.26	17.3	2.35*	1.28	1.69	34.1	36.3
3. India	74,753	104,000	39.1	7.65	5.42	−29.2	0.97	0.65	0.92	25.8	17.9
4. Canada	29,991	40,033	33.5	17.07	10.66	−37.6	0.69	0.22***	0.44*	38.6	31.9
5. France	27,456	41,085	49.6	6.01	9.19	52.9	5.26***	1.58	4.30**	20.3	29.5
6. Indonesia	13,464	20,341	51.1	6.09	5.15	−15.4	1.62	0.74	2.89*	20.6	16.6
7. Brazil	16,500	26,149	58.5	5.19	8.87	70.9	7.25***	4.30**	2.47*	16.9	28.8
8. Argentina	17,186	23,764	38.3	11.80	14.04	19.0	2.72*	1.04	2.12	33.7	35.9
9. Mexico	10,487	15,571	48.5	7.03	11.10	57.9	5.58***	3.99**	3.40**	23.9	32.6
10. Turkey	12,932	18,363	42.0	7.06	9.71	37.5	3.80**	3.98**	3.45**	23.9	30.2
11. Australia	12,618	17,445	38.2	19.54	23.15	18.5	2.66*	1.65	1.67	39.7	41.3
12. Thailand	8,555	13,255	54.9	7.82	8.40	7.4	2.76*	3.00**	2.01	26.1	27.4
13. F.R. Germany	16,030	22,211	38.6	9.13	5.96	−34.7	0.82	3.24**	0.59	29.1	20.1
14. Bangladesh	10,544	12,861	22.0	7.21	5.03	−30.2	0.72	0.20***	1.05	24.5	16.1
15. Poland	8,373	13,135	56.9	9.21	9.29	1.0	2.52*	0.12***	4.00**	29.5	29.8

16. Romania	11,602	17,360	49.6	10.87	9.87	−9.2	1.83	0.80	2.17	32.3	30.5
17. U.K.	12,442	16,754	34.7	8.73	8.34	−4.5	1.66	0.33**	1.77	28.4	27.4
18. Italy	14,219	16,680	17.3	3.44	5.68	65.1	3.72**	5.50***	0.66	7.4	18.9
19. Pakistan	7,668	13,179	71.9	10.23	3.15	−69.2	0.28**	0.44*	0.27**	31.2	5.6
20. South Africa	7,499	11,999	60.0	20.37	19.69	−3.3	2.40*	2.63*	1.99	40.1	40.1
21. Yugoslavia	11,397	15,069	32.2	9.98	5.18	−48.1	0.47	0.74	0.57	30.9	16.9
22. Burma	4,933	6,537	32.6	9.88	7.68	−22.3	1.06	0.45	1.77	30.5	25.8
23. Japan	14,565	11,393	−21.8	6.01	9.31	54.9	1.45	4.27**	1.58	20.3	29.5
24. Vietnam	6,011	7,326	21.9	8.99	5.59	−37.8	0.58	1.26	0.41*	28.8	18.7
25. Hungary	7,342	12,115	65.0	10.08	6.05	−40.0	0.98	0.35**	1.39	39.9	20.3
26. Spain	9,291	13,676	47.2	8.09	13.86	71.3	6.37***	0.68	7.73***	26.2	35.9
27. Philippines	4,295	7,005	63.1	5.51	5.43	−1.5	2.56*	6.87***	0.77	18.1	16.1
28. Nigeria	7,793	8,491	9.0	11.68	5.05	−56.7	0.22***	0.16***	0.14***	33.4	25.5
29. Czechoslovakia	6,189	9,688	56.5	11.73	7.54	−35.7	1.01	0.07***	1.62	33.4	25.5
30. German D.R.	4,606	7,147	55.2	11.29	6.40	−43.3	0.78	1.18	0.65	33.0	21.8
31. Iran	4,955	6,508	31.3	8.29	9.24	11.4	2.15	1.00	3.88**	27.4	29.5
32. Bulgaria	5,429	7,706	41.9	10.27	7.47	−27.3	1.05	3.55**	0.72	31.2	25.1
33. South Korea	5,266	6,227	18.3	5.97	10.77	80.4	4.02**	0.96	7.76***	20.1	32.3
34. Egypt	5,789	7,109	22.8	4.95	2.67	−46.1	0.44*	0.23**	0.37*	15.6	3.1
35. Rest of world[a]	98,481	117,747	19.6	3.19	2.80	−12.2	1.10	0.47	0.75	5.9	3.8
36. Total world[a]	829,087	1,133,908	36.8	2.76	3.36	21.7	2.78*	2.22	2.69*	3.5	6.8

Note: ***, **, and * indicate statistically significant *F* ratios (one-tail tests) at the 1%, 5%, and 10% confidence levels, respectively.
[a] Does not include China.

Table 3.10 Variability of world cereal production around linear trend for different periods[a]

Decade beginning	Average production	Standard deviation	Coefficient of variation	Probability of 5% shortfall below trend
	(million metric tons)			
1960/61	819	24.3	0.030	4.65
1961/62	837	20.7	0.025	2.17
1962/63	867	22.4	0.026	2.62
1963/64	890	24.1	0.027	3.22
1964/65	923	26.8	0.030	4.18
1965/66	946	31.2	0.034	6.55
1966/67	972	32.5	0.034	6.68
1967/68	1,001	34.3	0.035	7.21
1968/69	1,026	34.4	0.035	6.81
1969/70	1,057	40.0	0.037	9.01
1970/71	1,081	40.0	0.037	8.85
1971/72	1,108	40.1	0.036	8.38
1972/73	1,132	39.5	0.035	7.64
1973/74	1,159	38.5	0.033	6.68

[a] Does not include China.

terns of correlation, the sum of the production covariances should increase at about the same rate as the sum of the production variances.[5]

The part of the increase in the variance of total cereal production attributable to intercrop production covariances within countries increased proportionally more than the part due to the sum of the crop variances within countries. The *F* ratio was 42 percent larger. Similarly, the *F* ratio for the part of the variance increase due to production covariances between different crops in different countries was 86 percent larger. For these larger *F* ratios to have arisen, there must have been a loss in offsetting patterns of variation in production among crops within and between countries.

The column sums in table 3.12 show that 96 percent of the increase in the variance of world cereal production is directly attributable to changes in the variances and covariances of crop yields. Changes in yield variances within countries account for one-quarter of this increase, and most of this is attributable to increased yield variances for wheat and maize.

For most crops, increased yield variances account for the lion's share of their contribution to the variance of total cereal production. For example, when summed over countries, the increased production variances for

5. If x and y are random variables with variances σ_x^2 and σ_y^2, and if ρ is the correlation coefficient, then $\text{cov}(x, y) = \rho\sigma_x\sigma_y$. Assuming ρ is fixed, then the covariance will increase at a rate equal to the square root of the product of the rates of increase in the variances.

Table 3.11 Disaggregation of the components of change in the average of world cereal production, 1960/61–1970/71 to 1971/72–1982/83[a] (percent)

	Wheat	Maize	Rice	Barley	Millets	Sorghum	Oats	Other cereals	Total cereals
Change in mean yields	80.93	64.21	60.62	39.52	63.64	45.63	−528.09	−179.99	72.40
Change in mean areas	14.94	28.61	33.64	49.11	44.76	44.42	534.84	220.53	22.36
Change in area-yield covariances	0.19	0.09	−0.02	0.45	2.96	0.20	15.21	−1.08	0.14
Change in interaction term	3.95	7.08	5.77	10.93	−11.36	9.76	78.05	60.54	5.10
Contribution of crop to change in mean production of total cereals	32.65	35.18	11.50	18.28	0.55	4.34	−0.47	−2.03	100.00

[a]Does not include China.

Table 3.12 Disaggregation of the components of change in the variance of world cereal production, 1960/61-1970/71 to 1971/72-1982/83[a]

	Source of change							
Variance Component	Change in mean yields	Change in mean areas	Change in yield variances and covariances	Change in area variances and covariances	Change in area-yield covariances	Change in interaction terms	Change in residual	Row sums
Crop Variances								
Wheat	2.06	−2.38	5.27	−0.57	3.57	−0.49	0.15	7.61
Maize	6.67	1.94	17.16	−6.15	−5.01	−1.54	0.73	13.80
Rice	0.11	0.25	0.45	0.12	0.16	0.13	0.05	1.26
Barley	0.43	2.30	1.87	0.86	1.37	4.67	0.96	12.46
Millet	0.01	−0.01	0.04	0.01	0.06	−0.02	0.00	0.07
Sorghum	0.19	0.07	0.57	−0.23	0.12	0.07	−0.05	0.74
Oats	0.83	0.27	0.11	−1.25	−0.54	−1.06	−0.19	−1.85
Other	0.14	−0.15	0.00	−0.14	0.29	−0.77	0.06	0.36
Sum crop variances within countries	10.44	2.28	26.40	−7.36	0.01	0.99	1.70	34.45
Intercrop covariances within countries	0.97	4.48	36.68	−0.94	−9.38	1.89	1.65	35.35
Intercountry covariances within crops	0.09	1.61	11.49	−3.61	−4.40	−0.98	0.49	4.70
Covariances between different crops in different countries	2.75	0.85	21.36	19.13	−28.51	6.43	3.55	25.50
Column sums	14.24	9.22	95.93	7.22	−42.28	8.33	7.40	100.00

[a] Does not include China.

wheat account for 7.61 percent of the increase in the variance of total cereal production. Of this, 69.3 percent is due to increased yield variances. Yield variance shares for other crops are: maize, 124 percent, rice, 36 percent, millet, 57 percent, sorghum, 77 percent, and total cereals, 77 percent.

Changes in yield covariances are more important than changes in yield variances for the variability of world cereal production. However, part of the increase in the yield covariances is itself a direct consequence of increased yield variances. Part of it may also be due to changing correlations between crops and regions. To separate these effects it is useful to pursue the decomposition one step further.

Using the same kind of decomposition procedure as before, the change in a yield covariance between two periods can be decomposed into three terms (Hazell 1984): changes in yield variances alone, autonomous changes in the yield correlation, and the interaction between these terms.

For the world, only 6 percent of the 69.5 percent increase in the variance of total cereal production arising from changes in yield covariances is directly attributable to changes in yield variances. About 52 percent of the increase is attributable to changes in yield correlations alone, and the remaining 42 percent is due to interaction effects. The predominant correlation increases are between the yields of different crops in different countries. Increases in the intercrop yield covariances within countries were nearly all attributable to increased yield variances.

Table 3.12 also shows that changes in area-yield covariances reduced the variance of total world cereal production by 42 percent. Virtually all of this reduction can be attributed to a decline in area-yield correlations, the most important of which were between crop yields in one country with the sown areas of the same or different crops in other countries.

DISCUSSION

This analysis has identified three major components in the change in the variability of world cereal production since the 1960s: increased yield variances, an increase in correlations between the yields of different crops, and a decline in area-yield correlations, particularly between the crop yields in one country with the sown areas of the same or different crops in other countries. Additional research will be required to determine why these changes have occurred, but a number of hypotheses can be offered.

Given the importance of improved seed and fertilizer-intensive technologies in increasing yields in many countries, it is tempting to conclude that the increased yield variability is a direct consequence of the improved technologies. Indeed, under controlled (especially field trial) conditions, modern varieties typically have higher mean yields and variances than unimproved varieties. But their coefficients of variation are either lower or about the same. Recent evidence is available for winter wheat in the Great Plains of the United States (Peterson et al. forthcoming), and winter wheat and spring barley in Bavaria (Fischbeck forthcoming). Similar results seem to hold in farmer-managed trials, as shown for upland rice in the Philippines (Flinn and Garrity forthcoming) and for wheat and rice in India (Mruthyunjaya and Jha 1985). CIMMYT varieties of wheat and maize also seem to be more stable than available alternatives under experimental conditions when their performance across contrasting sites (environments) is compared (Pfeiffer and Braun 1985; Pham, Waddington, and Crossa 1985).

Apart from their greater absolute variability, there are a number of other reasons why modern varieties may have contributed to the greater variability observed in aggregate time series data for nations.

First, some of the early modern varieties associated with the international agricultural research centers proved to be susceptible to particular pests and diseases. Because of their high yields, these varieties were widely adopted in a very short time, and when pest and disease outbreaks occurred, these had a sizeable negative impact on farm and aggregate yields. This problem has been contained in recent years by the availability of a greater range of modern varieties, many of which have a wider range of resistance to pests and diseases (Coffman and Hargrove forthcoming; Duvick forthcoming; Holden 1985).

Second, modern varieties are more responsive to modern inputs. Some modern varieties seem to perform about as well as traditional varieties in poorer environments or under low input conditions, but their yields are much higher under favorable conditions and with greater application of inputs (Pfeiffer and Braun 1985; Pham, Waddington, and Crossa 1985). Consequently, if farmers adjust input use from year to year in response to changes in price signals, or in response to limited supplies of inputs, this may induce a much higher degree of yield variability in modern varieties. Such behaviorally induced yield variability may have become an important factor in some countries, and particularly in developing countries, where the greatly increased demand for the inputs that accompanied the green revolution outstripped the possibilities for adequate and timely supplies, given limited infrastructure and foreign exchange shortages (Jain, Dagg, and Taylor 1985). The problem may also have been aggravated by the sharp increases in the cost of fertilizers and other agrichemicals that accompanied the oil crises of the 1970s and by an increase in the variability of cereal prices in world markets.

A third reason why aggregate yields may have become more variable with the introduction of modern varieties is an increase in correlations among yields between regions (Hazell 1984; Walker forthcoming a). This again may be due to variations in input use, since farmers in the same or adjacent regions are likely to face the same prices and input shortages, thereby making similar adjustments in their use of inputs. The increased correlations may also be a consequence of the widespread adoption of relatively few varieties. As more farmers grow the same varieties, their yields may be becoming more synchronized because of a common susceptibility to the same kinds of pest, disease, and weather conditions.

Yields may also have become more variable because the production of some crops has expanded into more marginal and high-risk areas. The latter consideration has been particularly important in such countries as Brazil and Australia. While weather is an important factor in determining base-line levels of yield variability, Carter and Parry (1985) conclude that there is no indication that recent changes in cereal yield variability can be ascribed to climatic change. If anything, weather in some areas may have become less variable, e.g., in the cornbelt of the United States.

The broad increase in yield correlations among crops, both within and between countries, is likely associated with the broad increase in the correlations between cereal prices since the early 1970s. It is, however, difficult to determine whether greater correlation among cereal prices is due to changes in demand, such as increased substitution, or whether it in turn is a consequence of the more correlated yields. In either case, the effect could have been accentuated by the concurrent increase in the use of fertilizers and irrigation water. Farmers in more countries are increasingly responsive to price signals, and greater covariability in world prices would lead to greater and more synchronized variations in water and fertilizer application rates across crops and countries.

These factors may also explain the broad reduction in area-yield correlations between crops and countries. If price ratios in many countries move simultaneously in favor of particular cereals, not only might the land area allocated to these crops increase, but fertilizer and other yield-increasing inputs might be diverted from other crops.[6] This would lead to an observed negative relationship between the area sown to favored crops and the yield of the less favored crops. The effect could become quite pronounced if price ratios among crops fluctuate and as the use of fertilizers increases with improved varieties.

CONCLUSIONS

World cereals prices have become more variable since the early 1970s, which has led to corresponding increases in the variability of domestic

6. Even though the prices of different cereals have become more closely correlated, they still do not move in perfect unison. Thus there is still scope for changes in relative prices to favor one crop over another.

farmgate prices in some of the major cereal-exporting countries. However, many countries have successfully buffered their domestic prices from the increased volatility of world markets, and some have even been able to reduce the variability of domestic prices.

There is a surprising lack of collinearity between domestic and world cereal prices in many countries. Countries that buffer their domestic market prices apparently also shield their farmers from directional changes in world market prices. There does not appear to have been any significant change in these patterns of collinearity since the early 1970s.

On the other hand, a dramatic increase in the collinearity of world cereal prices between crops has been reflected in an increase in the correlation of domestic farmgate prices between crops, both within and among countries.

The growth in world cereal production from 1960/61 to 1982/83, largely due to improved yields, was accompanied by a more than proportional increase in the standard deviation of production. Increases in yield variances and a simultaneous loss in offsetting patterns of variation in yields between crops and countries were the overwhelming sources of the increase in production variability. More research is required before firm conclusions can be drawn about the cause of these changes in yields. An important factor may have been that the increased use of improved seed and fertilizer-intensive technologies since the 1960s has led to more variable and synchronized patterns of input use across crops and regions in response to changing prices. This effect may have been amplified by the sharp increase in the variability of world cereal prices since the early 1970s, and particularly by the increase in price correlations between crops. It does not appear that any inherently higher sensitivity of new technologies to environmental stress has been a significant cause.

Continued high levels of variability in world cereal prices seem likely. The United States is unlikely to return to its stockpiling policies of earlier years, and cereal imports by the U.S.S.R. remain unpredictable. World prices will also be affected by the levels of production variability now established. These factors, together with a continuing trend towards more input-intensive technologies, suggest that world cereal production and prices are likely to continue to become more variable in the years ahead.