Articles and Notes

Changing Variability in Cereal Production in Australia

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As part of a review of changing patterns of variability in cereal production around the world, the situation in Australia is examined both by major cereal crops and by State in which they are grown. The Australian results are generally consistent with those found in parts of both the industrial and developing world. There has been a tendency for production and especially yields to become both somewhat more variable as assessed by the dimension-free measure, the coefficient of variation, and more covariate between producing regions. The two post-World War II sub-periods examined are dominated, respectively, by tall (traditional) and short (modern) cultivars suggesting that there may be a causal link between cultivar used and relative yield variability.

1. Introduction

Evidence has accumulated on tendencies for variability of cereal yields and production to increase over recent decades (Hazell 1985, Anderson and Hazell 1989). The essentially unexploited data on variability in Australia provide an opportunity to consider the Australian situation, and to examine some of the effects of different levels of geographic aggregation on variability in the grain growing sector, particularly with regard to any changes that have taken place over the past four decades. Such information on variability and its tendencies has not been readily available to industry and government authorities in Australia, and the present paper represents an initial attempt to enter this void and to provide information that may be useful in policy debate and research.

An approach frequently used (*e.g.* Hazell 1982, 1984, 1985) has been to break the period of observation into two sub-periods, each consisting of sufficient observations to enable some inferences about any observed changes in patterns of variability. In most of the previous studies, the break point between the periods has been in the mid-1960s, in order to correspond broadly with the major adoption of modern (*i.e.* mainly semi-dwarf or short-stemmed, stiff-strawed fertiliser-responsive, and photoperiod-insensitive) varieties that have been a feature of the "green revolution" in Asia and elsewhere, at least in so far as wheat and rice are concerned. In the following analysis, somewhat later break points are used because of the lateness of the adoption of modern cultivars in Australia relative to the mid- to late-1960s for much of Asia. Only since the mid 1970s have semi-dwarf varieties of wheat been widely grown in Australia (Brennan 1986).

The overall Australian situation with regard to variability in yield and production (*i.e.* area times yield) of cereals, and to a lesser extent average performance of these indicators, is broached in section

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2 of this paper. In this context, the sensitivity of our results relative to the sub-periods of observation is briefly examined in section 2.1. The overview at the national level is concluded in section 2.2 with a brief discussion of sources of changes in average levels of production of Australian cereals.

National-level analysis is the subject of section 3. This deals mainly with statistical decompositions of the variance of production of individual cereals and their aggregate. The decomposition partially identifies various sources of change, including changes in area and yield variability. One of the important sources of co-variation between different elements of the whole cereal sector and a particular aspect of this, namely co-variation of crop yields for a given crop between different States, is addressed in section 3.1.

The focus of the paper then shifts to one very important State-crop combination, namely N.S.W. wheat. Over the past 40 years, wheat production has accounted for more than two-thirds of Australia's cereal production. Until recently, New South Wales was Australia's foremost wheat producing State, typically accounting for about 35 per cent of national production (Australian Wheat Board 1981). As has been observed:

> ...fluctuations in N.S.W. critically affect the Australian total, and a dampening of these fluctuations would have a significant impact in terms of total wheat production (Australian Wheat Board 1981, p. 5).

A more disaggregated study within a State level rather than at national and State levels may throw new light on the variability of Australian wheat production. This is pursued in section 4 with subsections addressed, respectively, to yield and production variability, yield variability and spatial correlations, yield variability and geographical distribution, and yield variability and the use of modern cultivars. The paper is then briefly concluded in section 5.

2. The Australian Situation in General

A summary of variability measures for the two arbitrary sub-periods chosen for Australia since the early 1950s through to the mid-1980s is reported in Table 1. Here the data mostly relate to total production of the designated six major grains. The overwhelming importance of wheat in the Australian cereal sector is evident from the data on mean levels of production. Not only is wheat of considerable historical significance but it has also been the source of major growth in the cereal sector over the period of observation. Barley is a significant alternative crop whilst the other crops are comparatively minor in terms of their aggregate levels of production.

Measuring variability in an easy, informative and non-controversial way is probably impossible (Anderson and Hazell 1989, Ch. 1). Here we base the statistical analysis on the residuals left after removing systematic trends from time series (Hazell 1982, 1984), and analyse two summary measures of variability, namely an absolute measure, the variance, and a relative measure, the coefficient of variation (cv). While aspects of both measures are reported in Table 1, for this study the key data concern the cvs of detrended production levels. These are high in absolute magnitude *cf.* cvs reported for the U.S.A. and India by Hazell (1984), and for other major regions and countries by Hazell (1985). The cvs of Table 1 do not reveal a consistent picture. The two major grains have smaller production cvs in the second period. The only increases in cv of seeming significance are those for rice and maize production, while the cv for sorghum decreases. These, however, are minor cereals in the Australian context although they feature increasingly variable areas sown.

Table 1: Changes in the Mean and Variability of Cereal Production (and Yield) in Australia 1951/2-1970/1 to 1971/2-1984/5[a]

	Average production			Coefficient of variation of production (and yield)			Variance F ratios[a] (second period/first)		
	First period kt	Second period kt	Change per cent	First period	Second period[a]	Change per cent	Production	Area sown[b]	Yield[b]
Wheat	7,212	13,029	81	0.29 (0.16)	0.25 (0.23)	-14 (44)	2.36	0.14	2.42
Barley	1,109	3,166	185	0.28 (0.18)	0.25 (0.20)	-11 (11)	6.39*	3.62*	1.52
Oats	1,087	1,266	16	0.28 (0.19)	0.36 (0.17)	29 (-11)	2.40	4.63*	1.31
Sorghum	263	1,106	321	0.58 (0.19)	0.26* (0.17)	-55 (-11)	3.34*	5.03*	1.33
Rice	150	537	258	0.10 (0.12)	0.21* (0.13)	110 (8)	62.34*	58.21*	1.17
Maize	153	164	7	0.11 (0.10)	0.31* (0.15)*	182 (50)	7.98*	16.42*	3.80*
Total	9,976	19,268	93	0.22 (0.15)	0.23 (0.20)	5 (33)	4.13*	0.45	2.33

[a]An asterisk denotes that the cv or variance in the second period is significantly different from that of the first period at the 5 per cent level (see Appendix). This convention is also adopted for significance tests reported in following tables. The tests are two-tailed so that for the F test here, for instance, based on 20 observations in the first period and 14 in the second (higher variance) period, computed values of the variance ratios are compared with the upper 2.5 per cent critical value of F, namely $F(13,19) = 2.68$.

[b]Ratios for area and yield are presented for information although data on their period averages are, for the sake of brevity, not reported here.

2.1 Sensitivity of results to changing period of observation

Since the sample sizes involved in these sets of statewide data are small it must be asked whether the findings presented are robust with respect to the particular sub-periods identified for contrast. If the results were sensitive to arbitrary partitions of the data, it would substantially undermine the value of the analyses reported here.

Sensitivity is addressed by presenting a few data for the most important crop--wheat--where different sub-periods have been used for comparison at the national level. Data are first presented by States for the cvs (and their standard normal statistics, see Appendix) of detrended yields in Table 2, along with F tests on the corresponding variance ratios between the periods. In this instance, there is a strong degree of correspondence between the significant increases in variability according to the two very different measures (cv and variance) and tests (Z and F). However, the economic significance of the increases (or decreases) in either absolute or relative variability is not at all clear.

Table 2: Coefficients of Variation and their Test Statistics, and Variance Ratios of Detrended Wheat Yields by State, and for Australia for Differently Defined Sub-Periods[a]

Region	Coefficient of Variation		Z^c	F^d
	Period 1	Period 2		
N.S.W.	0.32	0.36	0.44	1.83
Victoria	0.20	0.37	3.04*	4.73*
Queensland	0.28	0.40	1.51	2.42
S. Australia	0.26	0.37	1.50	2.19
W. Australia	0.19	0.20	0.19	1.16
Tasmania	0.17	0.42	5.23*	6.42*
Aust. (20,10)[b]	0.17	0.25	1.69	2.55
Aust. (16,16)	0.21	0.25	0.75	2.09
Aust. (20,14)	0.16	0.23	1.77	2.42

[a]For the first seven rows of the table the periods are defined over the seasons 1955/6 - 1974/5 and 1975/6 - 1984/5, respectively. For the penultimate row, 1950/1 - 1965/6 and 1966/7 - 1981/2, respectively (*cf.* Table 4), and for the final row, 1951/2 - 1970/1 and 1971/2 - 1984/5 respectively, the latter repeating some elements of the first row of Table 1.

[b]Bracketed pairs are numbers of years in the period contrasts.

[c]The approximately standard normal test statistic for the constancy of cv from first to second period (see Appendix).

[d]F statistic for variance ratio (*cf.* Table 1, footnote a).

A feature of these national-level contrasts is the consistency of the indicators of change and values of cv in the second period. On the basis of this very casual test, it is suggested that the results are somewhat insensitive with respect to the period of observation. The observational split in the main data dissection of Table 2 is designed to match fairly closely the stages in adoption of modern semi-dwarf wheat cultivars which have predominated in the second period. The issue is taken up in more specific detail in section 4 but, from the present results, it seems that the tendency to increasing variability may not be critically dependent upon modern cultivars themselves (*cf.* the similarities between the data of Table 2 and those of Table 4 below). Two other effects are, however, confounded in the main dissection, namely the imposition of production quotas in 1969-70 and a major drought in eastern Australia in 1982-83. The methods used here do not permit these effects to be disentangled.

2.2 Changes in average levels of production

As a prelude to the more detailed examination of variability in section 3, changes in average production levels are briefly examined. In a manner analogous to that used in section 3 for the decomposition of the variance of a product, the mean of a product of two random variables can similarly be decomposed into key components (Hazell 1982). This type of analysis is used in Table 3 to indicate the major components of change in the average levels of production of cereals in Australia in the periods under review. The sub-periods selected for comparison here represent a compromise between a desire to have a recent period with a preponderance of relatively modern cultivars and a desire to include in this necessarily short period a number of observations sufficient to provide an opportunity for any findings to have statistical significance. In contrast to the observational split for wheat in the upper part of Table 2, with the several crops involved in Table 3 there is no such clear basis for splitting the data, and thus the compromise split used here is arbitrary.

Table 3: Components of Change in the Average Production of Cereals in Australia 1951/2 - 1970/1 to 1971/2 - 1984/5 (per cent)[a]

	Wheat	Barley	Oats	Sorghum	Rice	Maize	Total Cereals
Change in mean yields	13.6	5.1	174	6.3	-0.5	756	14.4
Change in mean areas	77.8	86.1	-57	77.8	100.1	-433	77.4
Change in area-yield covariances	0.2	0.2	4.2	-2.2	0.7	-54	0.2
Change in interaction term	8.4	8.6	-21.2	18.2	-0.3	-169	8.0
Contribution to change in mean production of total cereals	62.6	22.1	1.9	9.1	4.2	0.1	100.0

[a]Components of change estimated by the method of Hazell (1982).

The major contributor to changing mean levels of production is the change in area sown. This result holds for the two major grains and also for those others where the decomposition procedure worked satisfactorily in the sense that the non-partitionable interactions are relatively small. The decomposition of the components for oats and maize appears not particularly informative, given the large negative interaction between changes in mean yield and mean area. The role of changing area in the changes in production comes as no great surprise, given the previous studies of the responsiveness of farmers to favourable economic conditions (Anderson 1974, Fisher 1975, Griffiths and Anderson 1978, Sanderson, Quilkey and Freebairn 1980).

From the perspective of generally increasing production between periods noted in Table 1, the question arises as to whether such increases in production have been accompanied by increasing variability in production, especially when variability is measured in a relative sense through the cv. Some observers (*e.g.* Bureau of Meteorology 1967) noting, for instance, the westward expansion of the wheat industry in N.S.W. and the analogous eastward developments in Western Australia, have speculated that these changes might lead to increased variability of production. Investigations of this question for N.S.W. (Anderson 1979, Brennan and Spohr 1985) have not revealed any such observable effect. This particular question is examined in section 4.3.

3. Cereal Yield Variability and Decomposition of Variability of Cereal Production

An overview of the variability of yields of major cereals at a State level is provided in Table 4. Here cvs are reported for the two periods for 23 crop-State combinations, as well as for total cereals and total Australian production. The span of data used is shorter than that used for wheat alone in Table 2 in order for a common span to be used for all the crops considered in Table 4. Comparing the pairs of cvs, it can be seen that nearly one-half of the State-crop pairs have increased in cv (although only four significantly so) whereas only three appear reduced in variability: sorghum in N.S.W., oats in South Australia and Western Australia, and barley in Western Australia (but only the latter being statistically significant). The other cvs do not seem to be noticeably changed.

In contrast to the above-noted findings of Anderson (1979), and Brennan and Spohr (1985), the relative variability of wheat yield has tended to increase in nearly all States (the exception being Western Australia) and barley yield variability has also increased in at least two of the major producing States (N.S.W. and Victoria).

Measures of yield variability at the State level conceal many different sources of variability operating in different localities, and it is clearly important to explore further regional decompositions (see section 4.1 below). Another insight can be gained by using the above-mentioned procedure of decomposition of observed variances, and results from this analysis are presented in Table 5 using data on the major crops' contribution to total cereal production in Australia. This table is not easily interpreted because of the cumbersome nature of the equation for the combined sources of yield and area variation in aggregate production consisting of several grains (Hazell 1982, Appendix 1). The data of Table 5 reveal all contributions as proportions of the change in the variance of total cereal production in Australia. The dominant effect of changing areas of wheat is again apparent (10.3 per cent) and the total contribution of wheat is also distinctively large (20.9 per cent). Other crop-specific effects are relatively minor. The small sum (23.2 per cent) due to increased production variability within States and crops is of the same order of magnitude as found in the U.S.A. and India (Hazell 1984). However, this result does imply that more than three-quarters of the increase in variance in total cereal production is due to increases in production covariances between States and crops. These covariance effects are mainly distributed between the interstate covariances within crops (30.2 per cent) and the covariances between different crops in different States (32.8 per cent).

Table 4: Coefficients of Variation of Detrended Yields by Crop and State - 1951/2 - 1970/1 and 1971/2 - 1984/5[a,b]

State	Wheat	Barley	Oats	Sorghum	Rice	Maize	Total Cereals
N.S.W.	0.31	0.23	0.31	0.36	0.12	0.10	0.28
	0.35	0.29	0.29	0.29	0.14	0.17*	0.30
Victoria	0.18	0.23	0.26				0.18
	0.33*	0.32	0.25				0.32*
Queensland	0.29	0.26	0.23	0.18		0.12	0.16
	0.35	0.24	0.30	0.18		0.19*	0.23
S. Australia	0.25	0.25	0.33				0.25
	0.32	0.29	0.27				0.30
W. Australia	0.18	0.30	0.15				0.16
	0.20	0.14*	0.12				0.18
Tasmania	0.16	0.12	0.17				0.12
	0.37*	0.12	0.21				0.12
Australia	0.16	0.18	0.19				0.15
	0.23	0.20	0.17				0.20

[a]Vertically paired couplets are, respectively, for the first (upper number) and second (number underneath) period.

[b]Asterisks denote significance (at the 5 per cent level) of differences in pairs of cvs based on the statistic

Thirty per cent of the total increase in variance is explained by the change in mean areas (second column sum). The second most important aggregate contributor is changes in yield variances and covariances (24.2 per cent). This result is consistent with a suggestion that modern varieties do exhibit greater covariance in production. What is not obvious is why this should be so. Clearly the climatic regime experienced in each period is a significant explanator of observations. However, notwithstanding the recent history of major droughts, there has not been any significantly different climatic experience over these periods (Hobbs 1988). Since Australian plant breeders have enthusiastically selected for drought tolerance and robust yielding characteristics (along with disease resistance and bread-making quality), there is no ready explanation from plant breeding for this apparent increase in the sensitivity of production to climatic and other effects. There is a need for further investigation of possible reasons for this finding.

Of the 24.2 per cent aggregate contribution to increased variance due to changes in yield variances and covariances, 11.2 per cent or nearly one-half is attributable to changing interstate yield

Table 5: Disaggregation of the Components of Change in the Variance of Total Cereal Production in Australia 1951/2-1970/1 to 1971/2-1984/5 (per cent)[a]

	Source of Change							
	Change in mean yields	Change in mean areas	Change in yield variances & covariances	Change in area variances & covariances	Change in area - yield covariances	Change in interaction	Change in residual	Row Sums
Crop variances								
Wheat	1.4	10.3	5.0	-3.0	0.6	6.3	0.3	20.9
Barley	0.0	0.7	0.1	0.3	-0.1	0.4	-0.2	1.2
Oats	0.0	-0.0	0.1	0.1	0.0	0.1	0.1	0.4
Sorghum	0.0	0.2	0.0	0.1	-0.0	0.0	-0.0	0.3
Rice	0.0	0.0	0.0	0.1	-0.0	0.3	0.1	0.4
Maize	0.0	-0.0	0.0	0.0	-0.0	0.0	-0.0	0.0
Sum crop variances within States	1.4	11.2	5.1	-2.4	0.5	7.1	0.3	23.2
Intercrop covariances within States	0.0	5.4	1.9	0.2	2.0	5.2	-0.7	14.0
Interstate covariances within crops	2.4	6.7	11.2	-6.9	1.9	15.3	-0.4	30.2
Covariances between different crops in different States	-0.6	6.8	6.0	1.8	4.1	16.0	-1.3	32.8
Column sums	3.4	30.2	24.2	-7.3	8.5	43.2	-2.2	100.0

[a]Components of change estimated by the procedure of Hazell (1982, Appendix 1).

covariances within crops. This observation is also worth further investigation. From the crop-specific data of the third column of results, most of the effects must be due to wheat. Some possible hypotheses that warrant testing are that the genetic composition of modern cultivars is increasingly uniform. This uniformity is evident in the eastern States of Australia where a greater proportion of genes coming through the CIMMYT (Mexico) breeding program are now to be found in widely-grown varieties (Brennan 1986).

The interaction terms are also important in aggregate and, although for the sake of brevity not reported in Table 5, the most significant contributor to this is the interaction between mean area and yield variance (37.8 per cent of the total). Interaction effects are those that, in the procedure adopted, cannot be partitioned further among the individual components of the interaction.

3.1 Symptoms of an "increasing togetherness" problem

The evidence of increasing correlation revealed in Table 5 can be examined further by looking at the tendency for yields in different States to move together. The analyses reported in Table 6 are simple correlation coefficients computed from residuals after the detrending process.

Correlation coefficients based on small samples-- here, respectively, 20 and 14 years of observation--

Table 6: Correlations among State Detrended Yields of Wheat for Two Periods - 1951/2 - 1970/1 and 1971/2 - 1984/5[a,b]

	Victoria	Queensland	South Australia	Western Australia	Tasmania
New South Wales	0.55	0.45	0.56	0.08	-0.04
	0.77	0.79*	0.75	0.17	0.64*
Victoria		0.08	0.78	-0.31	-0.21
		0.54	0.87	-0.17	0.73*
Queensland			0.28	0.09	-0.07
			0.61	0.40	0.67*
South Australia				-0.11	-0.31
				0.23	0.64
Western Australia					0.28
					0.23

[a]The couplets of correlations follow the conventions defined in footnote a of Table 4.

[b]An asterisk denotes a significant increase (5 per cent level) in correlations using the Fisher (1921) transformation of a correlation coefficient r to a normal variate $z = 0.5 \log_e ((1 + r) / (1 - r))$ with approximate standard error given by $(3/(3n - 8))^{0.5}$ where n is sample size.

are notoriously labile. The remarkable feature of the data in Table 6 is the consistent pattern of increasing correlation--either increasingly positively correlated yields or less negatively correlated yields, with the one exception of Tasmania-Western Australia. However, in a simple pairwise significance test of the increases in correlations, only three individually show statistically significant increases at the 5 per cent level.

To explore the intuitive impression of significance revealed by the consistent pattern of correlation changes in Table 6, the comparisons were pooled using the Central Limit Theorem (which deals with the tendency for sums of random variables to approach normality) and an assumption that each of the individual comparisons of change between serial pairs of correlations is statistically independent. Applying this assumption to the independently computed standard normal variates in the pairwise significance tests yields a single approximately standard normal variate given by $Z = \Sigma_i \ e_i / m^{0.5}$ where m is the number of standard normal variates e_i that are pooled (see, for example, Scandizzo, Hazell and Anderson 1984, p. 47). Using this approach, an overall statistic of Z = 5.84 is computed, which is highly significant and thus supports the intuitive appraisal of the combined set of data in Table 6. Recomputing this test after excluding the correlations involving the very small producing State of Tasmania yields the still very significant Z = 3.17. There does therefore seem to have been a trend towards increasing correlation amongst State yields. Elsewhere, it has been suggested that tendencies towards greater homogeneity of production practices (such as methods and timing of tillage, pest and disease control) may be associated with related tendencies for similar genetic materials to be used over widespread areas of production (Hazell 1984, 1985). This hypothesis is also worth further investigation.

4. The Case of Wheat in New South Wales

The primary concern in this section is yield variability in N.S.W. Yearly data were collated from information from the Australian Bureau of Statistics using tabulations by Wijnen and Ole (1984), supplemented by data from the Statistical Registers, for the period from 1946 to 1984 on area sown, yield, production, and proportion of wheat area sown with modern cultivars. The last series is for N.S.W. as a whole, and all others are for each of 45 Local Government Areas (LGAs). These LGAs account for more than 90 per cent of total N.S.W. wheat production over the period studied.

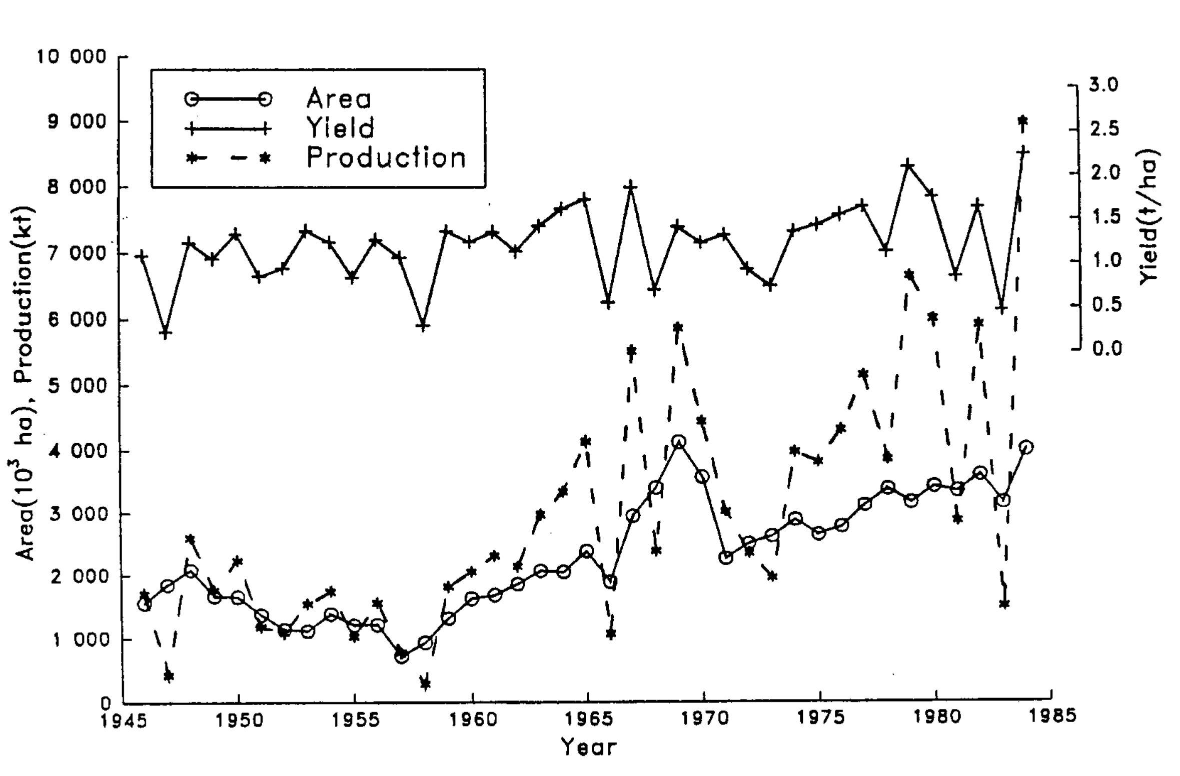
The whole period is divided into two sub-periods for most of the analysis. This division is based on the introduction and development of the modern cultivars. The first period encompasses the 1945-46 to 1973-74 seasons (n=29) and the second the 1976-77 to 1983-84 seasons (n=8). The seasons 1974-75 and 1975-76 are a transition in the use of modern cultivars in N.S.W. and are omitted from the analysis in order to sharpen the inter-period comparison. The short second period naturally makes inferences about it less reliable than for the first period.

4.1 Yield variability and production variability

From the first to the second period, mean wheat production in N.S.W. more than doubled from 2.3 to 5.1 million tonnes. The corresponding variability of production, measured by cvs for the two periods, decreased from 0.60 to 0.46 (although variance increased). At the same time, area sown increased from 2.0 to 3.4 million ha. The cv of area sown decreased from 0.42 to 0.09. Yield variability, as measured by cv, increased by 21 per cent (from 0.34 to 0.41) although the mean yield increased by 30 per cent, from 1.14 to 1.48 tonnes per ha.

In Figure 1 are plotted the area sown, yield and production of N.S.W. wheat over the 39 years 1946 (season 1945-46) to 1984 (1983-84). To make the figure more informative, trends have not been

Figure 1. Area, yield and production of NSW wheat



removed. These graphs show the increase in yield variability and the slight decrease in the variability of area sown in the second period. This impression reinforces the already-noted importance of yield variability.

Using the decomposition technique of Hazell (1982) as discussed in connection with Table 5, it was found that 96 per cent of the increase in the variance of total N.S.W. wheat production arose from an increase in inter-LGA production covariances while the remaining 4 per cent came from an increase in variance within LGAs. Furthermore, 19.5 per cent of the increase in total variance of wheat production came from the changes associated with yield, being made up of 6 per cent due to mean yield changes and 13.5 per cent due to changes in yield variance of which nearly all (13 per cent) is due to changes in inter-regional yield covariance. Of the increase in total variance of wheat production, 30.8 per cent was related to changes in area sown, comprising 11.5 per cent corresponding to changes in mean area sown and 19.3 per cent corresponding to changes in variance of area sown.

4.2 Yield correlation and variability in the context of modern cultivars

The introduction and development of modern cultivars probably have a more direct effect on wheat yield than on area sown. The effect probably is to increase the variability of yield mainly through simultaneous shifts in yield across different regions (Hazell 1982). A set of rough comparative statistics for the two periods is therefore used to evaluate the effect of modern cultivars on the correlation and variability of yields across LGAs in N.S.W.

To explore the changes in the correlation of LGA yields, the correlation coefficient of yield for each pair among the 45 wheat-growing LGAs was calculated for each period. Of the 990 coefficients, 926 were significantly larger than zero (at the 5 per cent level) for period one and 924 were similarly significant for period two.

For the present purpose, it is the change in the correlation coefficients that is of particular interest. Of the 990 correlation coefficients, 872 increased from the first to the second period and 136 (264) of these 872 increases were significant at the 5 (10) per cent level. The changes in N.S.W. wheat production between periods have probably induced higher correlation of wheat yields between LGAs. The higher correlation appears to be associated with the progressive introduction of semi-dwarf cultivars.

Increased correlation coefficients, though likely to occur, are not necessary to raise the variability of wheat yield. This result depends on changes in standard deviation in LGAs. All 45 N.S.W. wheatgrowing LGAs, as well as N.S.W. as a whole and the "residual LGA" (defined as the difference between the sum of the 45 LGAs and the total of N.S.W.), had a higher standard deviation of yield in the second period. Overall, 88 per cent of the correlation coefficients increased while all the standard deviations rose (half of them significantly at the 5 per cent level in F tests) over the two periods. The hypothesis that wheat yield variability has increased since the advent of modern cultivars is provisionally accepted. However, the role played by the correlation coefficients in the context of aggregate production variability is worth further investigation-- especially when rather more than eight observations are available for the second period.

4.3 Yield variability and geographical distribution of wheat planting

Some factors affecting production (such as rainfall, temperature and soil) tend to vary systematically with geographical location. Accordingly, the relationship between yield variability and geographical distribution of N.S.W. wheat planting should indicate any pattern of yield variability across LGAs. More importantly, further expansion of wheat cropping is expected in the northwest region of N.S.W. and the southeast slopes at the southern fringe of the N.S.W. wheat belt. An examination of N.S.W. LGA mean yields, yield cvs and both their changes for the two periods according to the geographical location of the 45 wheat-growing LGAs along the axis from N.W. to S.E. may provide policy makers with new information concerning variability of wheat production.

In Figures 2 and 3, the LGAs are arranged judgementally from N.W. to S.E. along the X-axis while the Y-axis, respectively, measures cv and mean values (and their respective changes). Figure 2 shows that mean yields tended to be higher in the S.E. than in the N.W. and were invariably higher in the second period than in the first period for all LGAs. Figure 3 shows that the yield cvs tended to decline from N.W. to S.E. and that they also generally increased between the two periods. This implies simultaneous changes in mean yield and standard deviation of yield with changes of standard deviation being proportionally slightly larger. Only 12 of the 45 LGAs had a reduced yield cv in the second period. The inter-period changes in cv were (subjectively) negligible. The largest increase in cv was 0.17 ---*i.e.* from 0.43 to 0.60 while the largest decrease was 0.11-- *i.e.* from 0.72 to 0.61 but none of the changes was significant at the 5 per cent level. The largest decreases in cv occurred in the N.W. and S.E. where much of the expansion of N.S.W. wheat planting has taken place since the 1960s. As also found by Brennan and Spohr (1985), the shift of wheat planting to new areas seemingly did not contribute to the increase in variability of production, and further expansion in the N.W. of N.S.W. may not affect the overall variability of N.S.W. wheat production.

Figure 2. Mean wheat yields of LGAs and their changes

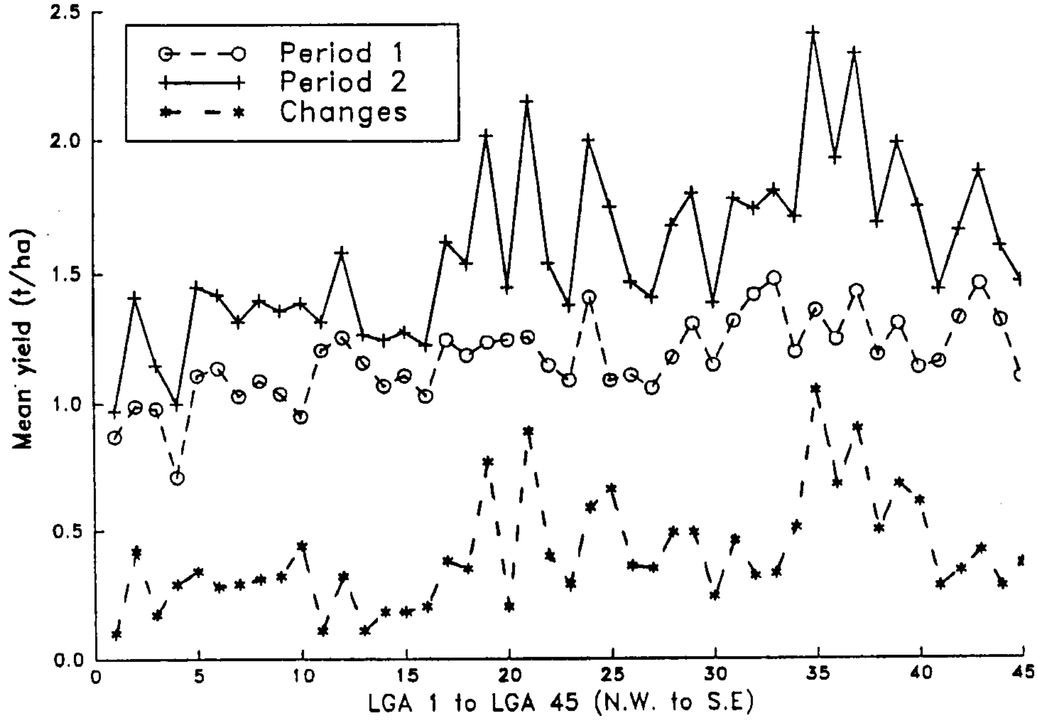
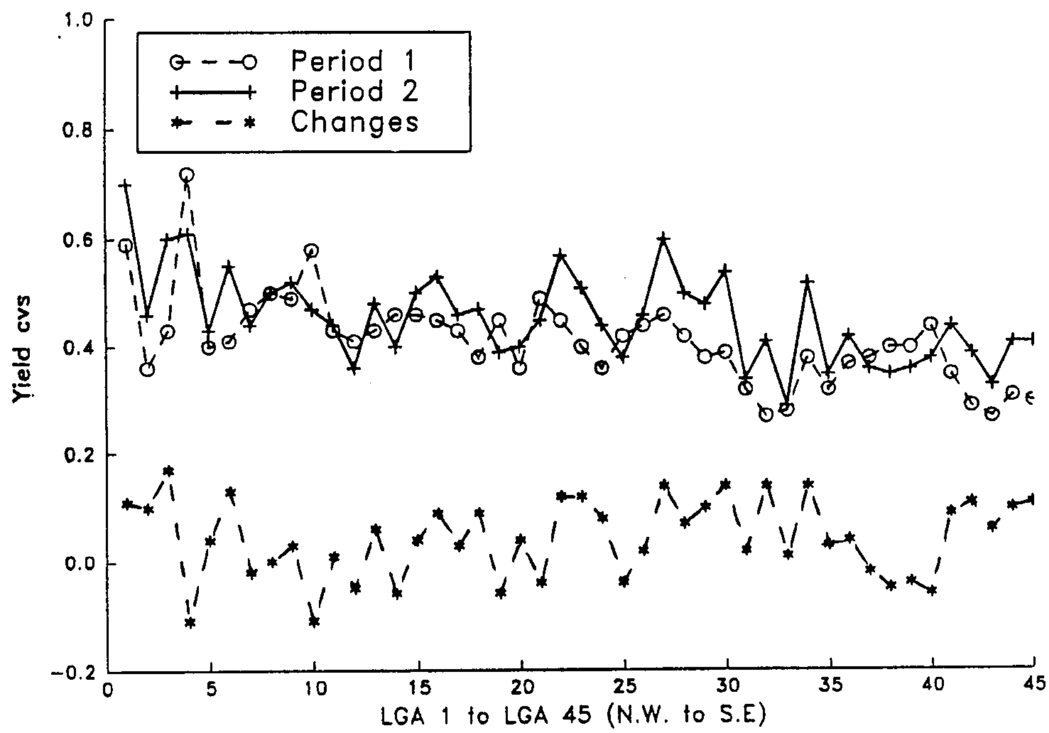


Figure 3. Yield cvs of LGAs and their changes



4.4 Yield variability and modern cultivars

Most modern wheats are derived from semi-dwarf cultivars that originated in Japan in the 1800s. These were introduced to the United States in 1948 and, in the 1960s, to Mexico from where new wheats carrying semi-dwarf genes spread to many regions of the world and contributed significantly to the green revolution (Dalrymple 1978, 1986).

Australia first obtained semi-dwarf cultivars in 1956 and released its first local high-yielding semi-dwarf cultivar, Wren, in 1968. However, due to quality requirements, it was not until 1973 that the first acceptable semi-dwarf cultivars--Condor, Kite, and Egret--were made available to Australian wheat growers (Australian Wheat Board 1984, Brennan 1986). Since then, and in common with many of the spring-wheat regions of the world, eastern Australia and N.S.W. in particular have been moving away from the traditional cultivars to those of the semi-dwarf type. The proportion sown to modern cultivars in N.S.W. increased over the five years beginning 1974 from 4 to 66 per cent and more recently has been around 80 per cent. Needless to say, the percentage of area sown to modern cultivars is not a perfect proxy for the degree of genetic uniformity in the N.S.W. wheat crop.

It has been suggested and variously debated (see, for example, the range of comments by Evans, Holden, Austin, Barker, Duvick, and Peterson in Hazell 1986) that the modern cultivars have a more homogeneous genetic base than the set of cultivars they replaced. Any such increasing homogeneity could bring about an increase in the variability of overall yield and aggregate production because of the resultant higher correlation between yields in different regions (Barker, Gabler and Winkelmann 1981, Mehra 1981). To assess this possibility of simultaneous fluctuation in the N.S.W. LGA context, a simple regression model was used. The focus of attention is confined to modern cultivars only. Of course, many other changes have also taken place in the N.S.W. wheat industry, such as increased mechanisation and modified cultural practices, particularly involving agricultural chemicals. A more comprehensive investigation than is presented here would span the wider range of changes in the technology of production.

There are several alternative ways of representing variability in time series data, such as moving variance or a moving standard deviation. A very simple measure, the moving range, is used here to indicate variability since no clear superiority of the more complex measures over the simpler ones was found in one careful contrast which showed high correlation between the moving range over three or four periods and a number of alternative measures (Brennan 1982). The moving range of N.S.W. yield over three years (MR)--*i.e.* for each year, the difference between the highest and lowest yields observed over the previous three years--is used as the dependent variable representing variability over time, and the percentage of N.S.W. wheat sown with modern cultivars (MC) is used as the explanatory variable. Using data for the ten years 1974 to 1983, this regression model gives a partial explanation as follows:

$$\underset{}{MR} = \underset{(0.59)}{0.15} + \underset{(3.13)}{0.012MC},$$

$$n = 10,\ \text{adj.}R^2 = 0.55,\ d = 1.21,$$

where numbers in parentheses denote t statistics (for the null hypothesis of no effect). The slope coefficient is significantly positive. The Durbin-Watson statistic falls within the inconclusive ranges (5 per cent significance level). This equation suggests that, to the extent that the model may embrace causal associations, the increasing use of modern cultivars (and other changed practices associated with them) may have led to increased variability (as measured by the moving range). Whether such changes have also increased the risk faced by farmers is a different question, addressed by Anderson, Findlay and Wan (1989) and, at least for one specific southern N.S.W. farm, answered negatively. There is clearly considerable scope for refining such possibly causal associations using richer sets of data and more sophisticated econometric models and methods.

5. Conclusion

The data examined here do not permit definitive statements about or explanations of the changing pattern of variability in Australian cereal production. They do, however, reveal some facets of this phenomenon and raise questions that appear worth further investigation.

It does seem that many changes in aggregate variability have been relatively small and are no justification for new policy initiatives such as further stabilisation measures, crop insurance schemes, *etc.* (Anderson, Hazell and Evans 1987). On the issue of yield stability amongst modern Australian cultivars, there does seem to be some cause for concern, and the results support the need for continued vigilance by plant breeders to ensure selection of the most robust and well adapted varieties possible for the challenging environments in which the Australian grain industries operate.

For the more specific case of wheat in N.S.W., the analysis indicates that the introduction of modern cultivars has been associated with higher spatial correlation of yields across wheat producing regions, and with increasing variability over time as measured by the coefficient of variation and moving range of regional yields. The degree of causality involved in these associations is unknown but deserving of detailed research attention. Such effects have probably added to the difficulty of local storage managers, railway planners, bulk grain handling authorities, and the Australian Wheat Board. Whether farmers as individuals are disadvantaged by such developments is a pertinent question on which evidence is needed. Since producers are enthusiastically adopting the modern cultivars it must be presumed that, even if such cultivars are somewhat more variable in yield performance, their increased average performance is such that they are still attractive to growers.

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APPENDIX

On Testing for Differences in Coefficients of Variation

Consider a random variable x with mean M and variance V. Defining the standard deviation as $S = +V^{0.5}$, the coefficient of variation is $cv = S/M$. The sampling distribution for this standardised statistic is complex but tests are made here by appeal to normality in the population and estimation of its variance (Kendall and Stewart 1969, ps. 233, 243) as:

$$\mathrm{var}(cv) = c^2(1 + 2c^2)/(2n),$$

where c is the coefficient of variation in the parent population and the sample size is n.

Tests reported herein for changes in variances involve standard two-tailed F or variance ratio tests. Test for cvs involve a comparison of a cv for one period, cv_1 based on n_1 observations, with that for a second, cv_2 and n_2. The ad hoc procedure adopted consists of assuming (a) that the "parent" population cv is approximated by cv_1, and (b) that the estimates of the cvs are statistically independent, so that a standard error of the difference between the cvs is given by:

$$D = c\{[(1 + 2c^2)/2](1/n_1 + 1/n_2)\}^{0.5},$$

and the approximately standard normal test statistic by:

$$Z = (cv_2 - cv_1)/D.$$