Technological Change Embodied in Southern NSW and British Wheat Varieties

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A comparison was made of increases in British and southern NSW wheat yields associated with genetic improvements. Estimates of these improvements were initially compared in each location using two different techniques. These techniques were a "variety improvement index" and a "vintage yield function". Yield increases "due to" genetic improvements were then compared between countries using both techniques. The variety improvement index technique suggested that there was little overall difference between genetic improvement in wheat in Britain and southern NSW. The vintage yield function technique suggested that the rate of yield increase for all varieties "due to" genetic improvement was markedly inferior in southern NSW. Estimated genetic improvement in southern NSW "food" wheats was similar to estimated genetic improvements in British bread wheats.

1. Introduction

The development of new plant varieties is a form of technological change embodied in the seed input. Such technological change is denoted "varietal embodied technological change" in this paper. Important economic aspects of new plant varieties include optimal structures for plant breeding (Brennan 1988), the impact of Plant Variety Rights (Godden 1987a), measurement of rates of varietal yield improvement (Godden 1987b), estimates of non-yield improvements in varieties (Antony and Brennan 1988), and *ex post* cost-benefit analysis of plant breeding (Akino and Hayami 1976). Estimates of the benefits of plant breeding depend upon some measure of the rate of varietal improvement. In general, estimated varietal improvement rates are based on indexes of yield increase "due to" new varieties (Godden 1987b). Godden (1988a, Appendices 1-4) showed that, in general, index procedures used for estimating varietal improvement "due to" new varieties were likely to be biased because the effects of changes in non-varietal factors were difficult to exclude. Because of this probable bias, analysis relying on such estimates - e.g. *ex post* estimates of the benefits of new plant varieties - will have a similar likelihood of bias. It is therefore desirable to develop methods which provide unbiased - or, at least, less biased - estimates of varietal embodied technological change. Perrin et al. (1983,1984) used a non-index method - "vintage yield function" (see Godden 1987b for the terminology) - to estimate technological change embodied in US soybean varieties, and Godden (1988b) refined this method in analysing British wheat and barley. Godden (1988b) compared "index" and "vintage yield function" estimates of technological change embodied in British cereals.

In this paper, the estimates of wheat varietal technological change in southern NSW are compared to the corresponding estimates for Britain to test Campbell's (1977, p. 49) argument that "the performance of Australian plant breeders in the matter of yield improvement, in comparison with their overseas counterparts, is most disappointing." Campbell had reported estimates that the overall trend in Australian wheat yields for the period 1960-74 was negative. Although acknowledging the effect of non-varietal factors on farm yields, Campbell claimed that "the reasons given by apologists for the failure of agronomists and breeders to

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improve yields of wheat and other crops in this country [are] rather unconvincing" (p. 49) and that "the apparent neglect of yield considerations in breeding programs and/or the failure to achieve yield gains through genetic improvements over the longer period is hard to understand" (p.49). In this paper it is shown that, while Australian yield increases resulting from new cereal varieties were low in the period of Campbell's analysis, they did not compare unfavourably with the British experience. Additionally, before 1960 and after 1974, there were periods of substantial increases in Australian cereal yields resulting from new varieties.

The "index" and "vintage yield function" methods of estimating varietal technological change are described and compared in section 2. Data for the estimates of varietal technological change obtained for both methods in Australia and Britain are described in section 3. Estimated "vintage yield functions" for four sites in southern NSW are reported in section 4 (corresponding estimates for British data were presented in Godden 1988b). Varietal technological change estimated by the two methods in the two countries are compared in section 5.

The results reported in this paper have three important caveats. First, increases in yields resulting from new varieties are a sufficient but not necessary indicator of technological change being embodied through new varieties. New varieties may have improved characteristics - e.g. "quality" (improved end-use characteristics such as milling, breadmaking or biscuit making attributes) or storability - which are not expressed as, and may even be negatively correlated with, yield (Antony and Brennan 1988). Additionally, successful maintenance research - e.g. research into maintaining the current level of technology in disease resistance - of which rust resistance is probably the most important example in Australia, will not be expressed as observed yield increases. Second, the optimal combination of characteristics in new varieties, including yield, is a function of the economic values of these characters. No opinion is expressed here as to whether or not the yield-increasing endeavours of Australian or British plant breeders have been optimally directed. Third, if varietal improvement and conventional inputs (e.g. fertiliser) are not independent variables in the production function, the correct apportionment of yield increases to "new varieties" and changes in conventional inputs requires appropriate methods of estimating the corresponding interaction effect. In general, the data are too limited to permit this interaction to be estimated.

2. Methods

2.1 Variety Improvement Index

A general variety improvement index may be defined as:

(1) $I_t = f(z_{it}, w_{it})$ $i = 1,\ldots, N$ varieties

where, for e_{it} being the yield of variety i at time t, z_{it} is the yield of variety i normalised for all non-variety changes (e.g. using relative yields, $z_{it} = e_{it}/e_{ct}$ where variety c is a "control" variety or set of control varieties) and w_{it} are appropriate weights (e.g. the share of variety i in time t in the production of the crop). A comparison between I_t and I_{t+j} is held to be an estimate of yield improvement "due to" new varieties between time periods t and t+j.

A variety improvement index based on relative yields for wheat production in England and Wales was taken from Silvey (1981). Silvey's variety improvement index was of the form:

(1a) $IS_t = f(z_{|i(t-j,\ldots t+j)}, w_{it})$ $i = 1,\ldots,N$ varieties

where $z_{|i(t-j,\ldots t+j)}$ is the mean yield of variety i relative to the mean yield of the control(s) based on a sample of years either side of the current year t, and w_{it} is as previously defined.

Brennan (1984) adopted a related method of estimating a varietal improvement index for four shires in southern NSW. Brennan used Digby's (1979) modified joint regression method to estimate the mean yield of each variety across time including estimates of the missing observations ($z_{|i}$). Digby's procedure uses the implicit linear relationships among experimental yields of varieties over time to estimate missing observations. Inclusion of estimates of the missing observations means that variety means are directly comparable since each is constructed on the same set of sample years. Brennan's variety improvement index was:

(1b) $IB_t = f(z_{|i}, w_{it})$ $i = 1,...,N$ varieties

where $z_{|i}$ is the mean yield of variety i relative to the mean of the control(s), and w_{it} is as previously defined. Brennan's (1984) indexes, augmented with later data, are presented in Appendix 1.

Variety improvement indexes based on relative yield estimates imply stringent conditions in the underlying production structure that are unlikely to be satisfied in practice (Godden 1987b, 1988a). When the levels of other inputs are rising, the choice of the variety (or varieties) comprising the "control" in the relative yield estimates is critical to obtaining unbiased relative yield estimates, and thus unbiased variety improvement indexes (a summary of this argument is shown in Appendix 2).

Silvey's choice of an averaging technique over several years to construct the relative yield estimates eliminates or reduces the index bias in the period when the relative yield estimates are held constant. However, when the controls change, or when a different period is used to construct the mean relative yields $z_{|i(t-j,...t+j)}$, then the problem of bias re-emerges (see equation 5 in Appendix 2).

2.2 Vintage Yield Function

A vintage yield function for an individual experimental site may be defined as:

(2) $e_{it} = a0 + \underline{a1}.Dt + \underline{a2}.Dv + u_t$

where e_{it} is an observation of experimental yield of variety i at time t; Dt is a set of (0,1) dummy variables for the experimental year t; Dv is a set of (0,1) dummies for the vintage of variety i (i.e. year of variety release); and a0, $\underline{a1}$, $\underline{a2}$ are (sets of) coefficients to be estimated. The coefficient a0 represents the mean yield of varieties of vintage V99 in the last year of experimental data; combining a0 with individual values $\underline{a1}_j$ and $\underline{a2}_k$ may be used to estimate the mean yield of the k^{th} vintage in the j^{th} experimental year.

The technique of using individual experiment year dummies to model the non-genetic components of yield is the same as that used by Perrin *et al* (1983, 1984), and is in contrast to that previously reported by Godden (1985, 1986). The use of individual year dummies eliminates the averaging of seasonal effects across years which may bias the estimate of yield increases "attributable" to time *per se*. Further, the incorporation of individual experiment year dummies removes between-season variability from the error variable u_t in equation (2), leaving u_t to model only the variation of individual varieties around the (moving) average genetic "frontier" represented by the set of variety vintage dummies Dv.

The vintage yield functions were estimated by OLS using TSP Version 4.0D. In the case of both Australian and British data, the yield data used in estimation was the mean of replicated variety trials, and also sometimes the mean over nitrogen treatments (for some years of British data) and may also have been averaged over blocks. In the case of British data, the number of replicates and nitrogen treatments has declined over time (Godden 1985, Chapter 5). As the dependent variable in the estimated vintage yield functions was a mean yield, and as the number of observations used to construct the mean is likely to have varied over time, the variance of the error u_t in equation (2) probably varied over time. The OLS estimator employed incorporated a covariance matrix estimator which is consistent with an heteroscedastic error (White 1980).

The mean rate of yield improvement due to new varieties between vintages was estimated from the vector of estimated coefficients $\underline{a2}$ in equation (2). Vintage yield functions were estimated for wheat yields at the Cambridge headquarters site of the National Institute of Agricultural Botany in England, and for experimental sites of NSW Agriculture at Wagga Wagga, Temora, Condobolin and Cowra in southern NSW.

The variety improvement index and the vintage yield function are conceptually different. The former is designed to estimate the frontier of varietal improvement as expressed in *commercial* production as the variety shares weight variety yields by commercial importance. The vintage yield function is intended to represent the yield frontier of the best varieties developed by plant breeders. The implicit weight attached to each variety in each vintage is the number of times each variety was included in variety trials relative to the total number of times varieties of that vintage were trialled. Since the better varieties of a vintage - e.g. Olympic for the vintage V94 in NSW - would tend to be trialled more, the vintage frontier would tend to approximate the average vintage frontier of the best commercial varieties. Estimates from the two procedures are also not directly comparable because the variety improvement index is a lagged reflection of experimental yields. The lags arise from the diffusion into commercial practice implied by the variety share weights.

3. Data

The values of a variety improvement index for British wheat 1947-80 were taken from Silvey (1981, Figure 1). Estimates of percentage change between representative years "due to" new varieties, and the corresponding mean annual percentage rates of yield increase "due to" new varieties were also estimated. A variety improvement index derived as described by Brennan (1984) for four southern NSW shires is presented in Appendix 1. The four shires of Mitchell, Narraburra, Lachlan and Waugoola contain the four experimental sites of Wagga Wagga, Temora, Condobolin and Cowra, respectively.

Table 1: Experimental Yield Data Summary

1.1 Cambridge Varieties	All	Feed	Biscuit	Bread
(a) by experiment date (number of observations)				
1942-50	43	28	14	1
1952-59	34	16	8	10
1960-67	25	8	4	13
1968-75	65	20	12	33
1976-83	101	38	24	39
Total	268	110	62	96
(b) by variety vintage (number of observations)				
V91:pre-1945	49	30	16	3
V92:1945-49	0	0	0	0
V93:1950-54	45	21	5	19
V94:1955-59	3	0	0	3
V95:1960-65	12	2	3	7
V96:1965-69	27	5	11	11
97:1970-74	40	16	3	21
V98:1975-79	63	28	10	25
V99:1980-84	29	8	14	7
Total	268	110	62	96
(c) number of varieties with (number of observations):				
1-5 observations	41	15	11	15
6-10 observations	7	2	0	5
11-15 observations	3	2	1	0
16-20 observations	2	0	1	1
21-25 observations	1	1	0	0
Total	54	20	13	21

Table 1 (continued)

1.2 Southern NSW Sites	Wagga Wagga	Temora	Condobolin	Cowra	Total
(a) **by experiment date (number of observations)**					
1945-50	34	51	23	45	153
1951-59	67	73	64	35	239
1960-67	44	53	51	39	187
1968-75	75	75	51	61	262
1976-85	100	101	86	70	357
Total	320	353	275	250	1198
(b) **by variety vintage (number of observations)**					
V91: pre-1945	53	69	50	59	231
V92: 1945-49	59	72	42	40	213
V93: 1950-54	5	4	5	0	14
V94: 1955-59	42	45	44	29	160
V95: 1960-65	27	27	25	20	99
V96: 1965-69	25	26	19	23	93
V97: 1970-74	58	58	46	44	206
V98: 1975-79	20	20	15	15	70
V99: 1980-84	31	32	29	20	112
Total	320	353	275	250	1198
(c) **number of varieties with:**					
1-5 observations	8	8	13	11	40
6-10 observations	13	11	10	16	50
11-15 observations	10	9	6	5	30
16-20 observations	1	4	2	1	8
21-25 observations	1	1	0	0	0
26-30 observations	1	1	1	0	3
Total	34	34	32	33	143

Experimental yield data for winter wheat variety trials 1942-83 at the Cambridge headquarters site of NIAB were taken from Godden (1985, Table 5.13) and are summarised in Table 1.1. Experimental yield data for wheat variety trials at Wagga Wagga, Temora, Condobolin and Cowra were those data described in Brennan (1984), augmented by additional data for 1945-60 and 1973-85 and are summarised in Table 1.2.

From the 1979 season, stripe rust affected southern NSW wheat crops with varying degrees of severity. In the wheat trials from which data was drawn for the present analyses, stripe rust only seriously affected varieties in 1983 (Martin, various dates). A stripe rust effect could not be modelled, therefore, separately from the 1983 year effect. The variety Robin succumbed to disease soon after its release (1966), and so no observations on it were included after 1971.

At the NSW sites, the variety vintage V97 included only one variety (Teal) which was not a semi-dwarf. The other thirteen varieties in vintages V97-V99 were all semi-dwarfs. As the mean yield of Teal observations was not statistically significantly different from the mean yield of each of the four varieties in vintage V97, no attempt was made to distinguish a semi-dwarf effect in this vintage.

4. Estimated Vintage Yield Functions

Summary estimated vintage yield functions are presented in Table 2 for the NSW sites; comparable estimates for the Cambridge site were reported in Godden (1988b). The year dummies are not presented as there were 28-36 dummies for the NSW site equations (see further discussion of these variables below). In each equation, each set of year dummies was jointly statistically significantly different from zero.

The estimated variety coefficients of the vintage dummy variables V91-V98 (defined in Table 1) are the estimated yield deviations of the nominated variety vintage from the vintage V99, holding the experiment date effect constant at the 1985 level for NSW equations (1983 level for the comparable Cambridge equations). For the estimated Cambridge equations, the variety vintage effect was statistically significant for the all varieties, feed and bread varieties classes, but not for the biscuit varieties class. For the estimated NSW equations, the variety vintage effect was statistically significant for the Wagga Wagga, Temora and Cowra sites, but non-significant for the Condobolin site.

Table 2: Vintage Yield Functions for Southern NSW[a]

	Wagga	Temora	Condobolin	Cowra	Temora[f]
Constant	3.5504	4.5842	4.6786	4.8408	4.7681
	(27.47)[c]	(41.73)	(38.48)	(29.90)	(41.41)
V91[b]	-0.6159	-0.9150	-0.2240	-0.9218	-0.6875
	(-3.65)	(-5.10)	(-1.39)	(-4.03)	(-2.84)
V92	-0.4377	-0.8051	-0.09583	-0.6553	-0.7000
	(-2.66)	(-4.70)	(-0.60)	(-2.90)	(-2.98)
V93	-0.3656	-0.5833	0.2155		-0.4630
	(-1.87)	(-2.26)	(1.36)		(-1.70)
V94	-0.2318	-0.4248	0.1763	-0.4805	-0.4615
	(-1.50)	(-2.75)	(1.25)	(-2.71)	(-2.36)
V95	-0.3010	-0.6455	0.06870	-0.4995	-0.6718
	(-1.78)	(-3.86)	(0.46)	(-2.26)	(-3.11)
V96	-0.4593	-0.6475	0.02353	-0.4825	-0.6324
	(-2.61)	(-3.82)	(0.16)	(-2.21)	(-2.84)
V97	0.1169	-0.1598	0.1088	-0.09112	-0.1623
	(0.88)	(-1.39)	(0.85)	(-0.60)	(-0.88)
V98	0.1220	-0.5159	-0.05402	-0.2733	-0.4123
	(0.78)	(-2.54)	(-0.29)	(-1.14)	(-3.10)
$\bar{R}^2$	0.78	0.84	0.92	0.79	0.86
n[a]	320	353	275	250	180
Experiment year	[Ft][d]=24.0	41.5	76.8	25.1	26.1
FV[e]	4.51	5.55	1.06	3.04	1.94
SER[a]	0.4122	0.4639	0.3572	0.5184	0.4413

Notes:

a Dependent variable is yield (e_t); n is number of observations; SER standard error of regression.

b Dt: experiment year dummy variables; V91-V98: variety vintage dummies.

c ( ) t-statistics for estimated coefficient.

d Ft: F-statistics for null hypothesis of jointly zero-valued coefficients on all experiment year dummy variables (Dt).

e FV: F-statistics for null hypothesis of jointly zero-valued coefficients on all variety vintage dummies (V91-V98).

f Vintage yield function for Temora for best two varieties in each vintage.

5. Discussion

5.1 Estimated Effect of New Varieties

The initial focus is a comparison of the index and estimated function techniques for each site separately. Results discussed here are summarised in Table 3. Comparing the techniques of the variety improvement index for British wheat, and vintage yield function for all varieties of winter wheat at the Cambridge site, it can be seen that the index estimates result in consistently higher estimates of increases in yields "due to" new varieties than does the yield function approach. In the period 1947-62, the index approach results in estimates of the annual yield increase "due to" new varieties of 1.13-1.37 per cent per annum. Estimates from each of the vintage yield function models suggest little or no increase in yields due to new varieties in this period. The most likely reason for the apparent over-estimate of this genetic effect is the failure of the index model to satisfactorily normalise for changes in conventional farm inputs (Godden 1986, 1987b, 1988a); an alternative explanation is that the rate of adoption of superior varieties was much more rapid than the rate of yield increases in new varieties. The vintage yield function for feed varieties exhibits dramatically greater rates of yield increase due to new varieties in the 1967-77 period than do the all or bread varieties functions. The "index" estimates for all British wheat are closer to the "function" estimates for feed wheat in this period, mirroring the dominance of feed wheat in British wheat production (and hence the dominance of the feed wheat weights in the variety improvement index). The rate of increase in other inputs slowed in the second half of the sample period, thus reducing the potential for bias in the index approach.

In the southern NSW data, the variety improvement indexes also appear to over-estimate the rate of purely genetic improvement. These apparent over-estimates are more difficult to rationalise than in the British case, as there was no dramatic increase in farm/experimental input levels in Australia comparable with nitrogen use in Britain. A possible alternative explanation is again that the rate of adoption of superior varieties was much more rapid than the rate of yield increases in new varieties. There is evidence, however, of generally positive time trends in yields of many individual varieties, especially at the Wagga Wagga and Temora sites (Table 4). Especially since the major reference variety (Olympic) had no significant yield trend (except at Condobolin), it is possible that the positive yield trends of many other varieties have been transformed into a "genetic" effect in the index model. The variety improvement indexes also exhibit lags compared to the variety yield functions, reflecting the lags in the diffusion of new varieties implicit in the indexes.

Comparing the British and southern NSW experience using the variety improvement indexes suggests that the rate of yield improvement "due to" new varieties in the latter was only a little less than in Britain. There was a slightly higher rate of yield improvement in Britain for each of the periods "late 1940s to early 1960s", "early 1960s to early 1970s"; rates of yield increase as estimated by "index" methods were similar in Britain and southern NSW for the period "early 1970s to early 1980s", with the latter showing a slightly higher rate of increase.

Results from the vintage yield function method suggest that the experience of yield improvement from new varieties was similar in Britain and southern NSW in the period "late 1940s to early 1960s". On *average*, yield improvements from new varieties were similar in both locations in the period "early 1960s to early 1970s", but the rate of yield improvement in feed varieties in Britain was approximately twice that of southern NSW varieties. Yield improvements from new varieties in southern NSW were substantially worse than in Britain in the period "early 1970s to early 1980s".

Since all the NSW wheats included in the present analysis were "food" wheats, an attempt was made to compare estimated NSW vintage yield functions with corresponding models for British "food" wheats (i.e. biscuit plus bread varieties). The British food wheat model was so different from the estimated parameters of the bread wheat model that it was clear the biscuit and bread varieties formed two different classes, and thus could not be combined for analysis.

Table 3: Estimated Effects of New Varieties

3.1 Cambridge

	Variety Improvement Index[a]				Vintage Yield Function[b] (% p.a. or (% total))[b]		
	Index	Change %	Change (% p.a.)		All	Feed	Bread
				pre-1947	(	(	(
1947	2.42	-	-	1947	(	(	(
1952	2.59	7.02	1.37	1952	((5.27)	((-1.86)	((-12.06)
1957	2.74	5.79	1.13	1957	-0.71	(	(
1962	2.90	5.84	1.14	1962	0.91	(0.11	(-0.16
1967	3.05	5.17	1.01	1967	1.16	2.87	0.88
1972	3.40	11.48	2.20	1972	0.50	1.73	1.15
1977	3.82	12.35	2.36	1977	1.49	2.37	0.81
1980	4.01	4.97	1.63	1982	0.51	0.83	0.84
1947-62		19.83	1.21	1952-62	0.10	0.11	-0.16
1962-72		17.24	1.60	1962-72	0.83	2.30	1.02
1972-80		17.94	2.08	1972-82	1.00	1.60	0.83

3.2 Southern NSW[f]

	Change in Variety Improvement Index[c] (% p.a.)				Vintage Yield Function (% p.a. or (% total))[d]			
	Mitchell	Narraburra	Waugoola		Wagga	Temora[e]		Cowra
				pre-1945	-	-		-
1950/51	-	-	-	1947	(6.07)	(3.00)	(-0.31)	(6.81)
1952/53	-0.10	0.25	-0.60	1952	0.46	1.15	1.14	(
1957/58	0.06	0.36	0.38	1957	0.83	0.78	0.01	(-0.41
1962/63	1.11	2.23	1.07	1962	-0.42	-1.08	-1.00	-0.09
1967/68	0.65	0.96	3.21	1967	-0.99	-0.02	0.19	0.08
1972/73	0.47	0.46	0.18	1972	3.48	2.36	2.18	1.74
1977/78	4.18	2.69	2.89	1977	0.02	-1.66	-1.11	-0.78
1980/81	2.05	2.10	1.61	1982	-0.67	2.42	1.83	1.17
1950/51-1962/63	0.47	1.11	0.50	1947-62	0.29	0.28	0.04	0.24
1962/63-1972/73	0.56	0.71	1.68	1962-72	1.22	1.17	1.18	0.90
1972/73-1980/81	3.37	2.47	2.41	1972-82	-0.32	0.36	0.35	0.19

Notes:

a Data from Silvey (1985, pers. comm) and estimates from Silvey (1981, Figure 1); 1962 value averaged; years are endpoints of time periods.

b Estimated from Godden (1987c, Table 1); years are mid-points of variety vintage classes.

c Estimated from Appendix 1.

d Estimated from Table 2.2.

e First column: all varieties; second column: best varieties in each vintage.

f Wagga Wagga is an experimental site in Mitchell Shire, Temora in Narraburra Shire and Cowra in Waugoola Shire

Table 4: Summary of Yield Trends for Individual Varieties in Southern NSW

Variety	Wagga	Temora	Condobolin	Cowra
Avocet	-ve	conv	..	..
Banks	..	+ve	..	..
Bencubbin	+ve	..	..	..
Bordan	+ve	..	..	..
Celebration	..	..	..	+ve
Condor	..	+ve	..	+ve
Corella	..	..	..	..
Eagle	..	..	+ve	+ve
Egret	..	..	..	..
Falcon	..	-ve	..	..
Ford	..	..	..	..
Gabo +ve	..	..	..	
Gamenya	-ve	conv	..	-ve
Glenwari	..	+ve	..	..
Halberd	..	conc	..	conc
Harrier	+ve	+ve	..	..
Heron	..	conv	..	-ve
Insignia	..	..	..	..
Javelin	..	..	..	..
Kendee	..	..	..	..
Kite	..	conc	..	+ve
Koala	+ve	+ve	..	..
Millewa	+ve	+ve	+ve	conv
Osprey	..	+ve	+ve	..
Olympic	..	..	+ve	..
Oxley	..	..	..	..
Pinnacle	conv	..	..	..
Quarrion	+ve	+ve	+ve	..
Robin	..	..	..	-ve
Sherpa	..	..	..	..
Skua	+ve	+ve	..	..
Summit	-ve	-ve	..	..
Sundor	..	..	..	..
Teal	..	+ve	..	..

Key:

[a] +ve: positive linear trend (minimum critical level: 10% level of significance for one-way test).

[b] -ve: negative linear trend (significance as preceding)

[c] conv: significant quadratic time effect, convex upwards (5% significance level)

[d] conc: significant quadratic time effect, concave upwards (5% significance level)

[e] .. no statistically significant relationship

[f] Estimation: equations initially estimated as $e_{it} = c + b.t + c.t^2$; if no significant quadratic effect, re-estimated as $e_{it} = a + b.t$; minimum number of observations = 5 for reported trends.

Results for the best of the southern NSW sites (Temora) may be compared with the Cambridge bread model for a more appropriate comparison (ignoring the question as to whether Australian breeders - or, for that matter, British breeders - should have concentrated on food wheat breeding). Over the whole period, the yield improvement due to new varieties at Temora was approximately equal to (i.e. 98 per cent of) that achieved at Cambridge for bread wheats. In the latter part of the period, however, yield improvements due to new varieties at Temora were only 42 per cent of those for bread varieties at Cambridge in 1972-82.

The vintage yield functions defined and estimated in this paper represent the average "genetic frontier" of all varieties released for commercial use, with an uncontrolled weighting for the commercial importance of a variety (cf. the variety improvement index). The genetic frontier of varieties in commercial use may be better represented by the best varieties in each vintage. Table 2 (column 5) reports an estimate of the "best varieties" frontier for the Temora site using the highest yielding varieties for each vintage (V91: Javelin, Koala; V92: Glenwari, Kendee; V93: Sherpa: V94: Heron, Olympic; V95: Falcon, Gamenya; V96: Halberd, Robin; V97: Condor, Oxley; V98: Banks, Millewa; V99: Corella, Osprey). This model clearly reveals that genetic advance in southern NSW wheats was sharply divided into two distinct periods - viz. 1955-59 (varieties Sherpa, Olympic and Heron) and post-1970 (the semi-dwarfs). Surprisingly, however, this estimate of the genetic frontier is only on the margin of statistical significance.

5.2 Effect of "Other" Factors

The vintage yield function results presented in Table 3 represent the estimated effects of the "purely genetic" contribution to wheat yields measured at the experimental level. The individual dummy

Table 5: Trends in Deviation from Control Mean Yield Adjusted for Variety Vintage Effects (dependent variable: mean yield)

	constant	trend	n	$\bar{R}^2$	SER
1. Cambridge (1942: t=1)					
1.1 All varieties	-2.7384	0.05733	36	0.36	0.9465
(-11.24)	(5.17)				
1.2 Feed varieties	-1.7197	0.04270	36	0.19	1.0603
(-6.43)	(3.53)				
1.3 Bread varieties	-3.4149	0.06955	27	0.29	1.0268
(-6.97)	(4.19)				
2. Southern NSW (1945: t=1)					
2.1 Wagga Wagga	-1.1394	0.01557	36	0.06	0.7045
(-4.26)	(1.44)				
2.2 Temora	-1.0610	- 0.01276	38	-0.01	1.0991
(-2.72)	(-0.82)				
2.3 Condobolin	-3.6023	0.02625	35	0.08	1.0086
(-12.00)	(1.61)				
2.4 Cowra	-1.9165	0.00985	28	0.02	0.8819
(-8.40)	(0.80)				

Notes: see Table 2

variables for years represent the effects of all other factors including the interaction of genetic improvement with other inputs. The estimated coefficients for each year's dummy variable are themselves random variables. It is therefore possible to examine the trend in the effects of non-purely-genetic variables on yield. Table 5 presents regressions on time of the estimated coefficients of the experiment date dummies.

As shown in Table 5, the trends in deviations from the 1983 mean yields of British varieties are very obvious, being both statistically significant and of a large magnitude. The estimated annual increments ranged from 42.7 kg/ha/year for feed varieties to 69.6 kg/ha/year for bread varieties. By contrast, the corresponding trends in deviations from 1985 mean yields adjusted for variety vintage in southern NSW were not statistically significant. In the cases of Wagga and Condobolin, where the results suggest a possibly positive trend, the magnitudes are low at approximately 16 kg/ha/year and 26 kg/ha/year respectively.

The British/Australian comparison suggests that Australian experimenters have seen little reason to dramatically change input levels in wheat variety trials, whereas British experimenters have increased the levels of inputs in variety trials in parallel with the increasing intensity of non-land input use in British cereal production. Where, as in the case of the British data, there are rapid increases in yield effects not attributed to "vintage" effects but arising from non-specific "year" effects, substantial caution is required in using index models as indicators of purely genetic yield increases because the genetic effects are likely to be highly confounded with trends in input levels (Godden 1985, 1987b, 1988a).

6. Conclusions

The objective of this paper was to examine "varietal embodied technological change" - i.e. technological change embodied in new plant varieties - in the wheat industries of southern NSW and Britain. Comparisons of estimates of wheat yield increases obtained from variety improvement indexes suggest that such increases were of similar orders of magnitude in Britain and southern NSW in the post-war period. When such comparisons are undertaken solely on experimental yield data to abstract from all other influences on farm-level yields, the rate of "purely genetic" improvement in southern NSW wheat yields was estimated to have been dramatically less than in Britain and particularly in the latter part of the sample period. The "purely genetic" improvement in southern NSW (i.e. food) wheats at these sites was, however, roughly comparable to the "purely genetic" improvement in bread wheats at Cambridge.

The reasons for these considerably different results are difficult to define precisely. The use of relative yields as a normalising procedure in the variety improvement index model can be shown not to be adequate to correct for non-varietal effects on yield. Because the index model also has each individual variety's crop share as a variable, changes in varietal diffusion rates may also be confounded with changes in the genetic technology embodied in new varieties. The "pseudo" vintage yield functions reported in this paper are, as misspecified models, clearly not the best conceptual models, although the deficiencies of input data precluded estimation of more satisfactory models.

Based on variety improvement index estimates, southern NSW yield improvements were substantially less than in Britain up to the early 1960s, but similar in the subsequent period up to the early 1970s. These estimates suggest that improvements in southern NSW wheat yields were at least as great as, and possibly greater than, those in Britain in the last period to the early 1980s. By contrast, however, vintage yield function estimates suggest that southern NSW yield improvements were comparable to British experience in the first half of the sample period, but dramatically inferior in more recent times. Clearly, the choice of analytical technique has a major impact on the conclusion as to whether or not Australian wheat breeders have been as successful as their overseas counterparts in developing improved wheat varieties. This conclusion is patently unsatisfactory and suggests that further analysis is required concerning the sources of variety-induced technical change in wheat production.

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Appendix 1

Index of Varietal Improvement for Wheat in Four Shires in Southern New South Wales

	Mitchell (Wagga)	Narraburra (Temora)	Lachlan (Condobolin)	Waugoola (Cowra)
1950-51	100.0	100.0	100.0	100.0
1951-52	98.9	100.8	99.5	99.7
1952-53	99.8	100.5	100.9	98.8
1953-54	99.9	100.6	100.2	99.5
1954-55	100.2	100.9	100.9	99.6
1955-56	100.3	101.4	100.2	99.7
1956-57	99.5	101.9	98.1	99.6
1957-58	100.1	102.3	97.5	100.7
1958-59	99.9	102.7	96.6	102.8
1959-60	100.0	103.2	97.3	99.5
1960-61	101.2	104.2	97.1	100.5
1961-62	103.5	109.2	97.4	103.5
1962-63	105.8	114.2	97.6	106.2
1963-64	107.8	117.4	96.4	116.0
1964-65	108.6	118.5	95.5	121.0
1965-66	109.3	119.2	94.7	122.9
1966-67	109.5	119.6	94.6	124.3
1967-68	109.3	119.8	94.1	124.4
1968-69	108.8	120.1	94.0	125.5
1969-70	107.8	119.7	93.5	125.6
1970-71	108.7	119.2	93.0	125.2
1971-72	109.5	121.0	92.9	125.0
1972-73	111.9	122.6	92.9	125.5
1973-74	111.8	123.4	92.8	126.1
1974-75	115.2	126.9	92.9	127.9
1975-76	122.8	130.6	95.2	134.3
1976-77	130.2	134.1	98.3	138.2
1977-78	137.3	140.0	101.1	144.7
1978-79	140.6	143.9	99.9	148.1
1979-80	144.3	147.2	100.1	150.9
1980-81	145.9	149.0	100.3	151.8

Source: based on Brennan (1984).

Appendix 2

Theoretical Structure of Variety Improvement Indexes

Consider a constant returns to scale (CRS) production function (Allen 1938, pp.315-321):

(1) $Y_{Bt} = F(y_{kt}, k = 1,..., K; B)$

where Y_{Bt} is the output of a variety of technological status B at time t, produced with inputs y_{kt} (k=A is the land input). Equation (1) is equivalent to the yield function:

(2) $e_{Bt} = f(y_{kt}/Y_{At}, k \neq A; B)$

Variety improvement indexes based on time-varying yields and normalised using relative yields may be represented as:

(3) $I_t = \sum_{i=1}^{N} (e_{it}/e_{ct}).w_{it}$ for i = 1,...,N varieties

where I_t is the index level in year t; e_{it} is the yield of variety i at time t (i=c is a "control" variety or set of varieties); and w_{it} is a variety weight (e.g. share of variety i in the crop at time t).

For index I_t to be a unique, unbiased and consistent estimator of the contribution of (new) varieties to crop yield, the following conditions are necessary:

(i) Varietal technological change is strictly independent of all other production variables - i.e. variable B in equation (2) can only be represented as:

(4) $e_{Bt} = B_t.f(y_{kt}/Y_{At}, k \neq A)$

Variable B_t has been made time-dependent to allow for varietal decay (e.g. development of susceptibility to pathogens). The condition represented by equation (4) is required so that the relative yield variable (e_{it}/e_{ct}) in equation (3) is only a function of the genetic differences between varieties i and c (i.e. B_{it} and B_{ct} respectively); and

(ii) Variety improvement index is invariant to choice of "control" variety - i.e. the same index I_t may be derived regardless of the choice of "control" variety. This invariance requires that any two varieties (e.g., i=c,k) satisfy:

(5) B_{ct}/B_{kt} = constant

that is, varieties c,k satisfy condition (i); and these varieties respond identically to seasonal differences, and there is no differential varietal decay between the varieties, nor differential varietal drift, over time. The condition represented by equation (5) must also hold to enable construction of a consistent index where different "control" varieties are used in different years.