THE IMPACT OF SCIENTIFIC RESEARCH ON AUSTRALIAN RURAL PRODUCTIVITY

TREVOR HASTINGS*

Adelaide College of the Arts and Education, Adelaide, S.A. 5000

In this paper the relationship between scientific agricultural research and aggregate rural productivity is investigated. The Solow 'residual' model is used to estimate productivity changes. An attempt is made to investigate the extent to which scientific research, measured by scientific personnel, 'explains' technical change. An education and climatic variable are added to the model. The results suggest a positive relationship between scientific research, climate and aggregate productivity.

The Industries Assistance Commission in its report, *Financing Rural Research* (1976, p.30) made the observation that:

> There has been no analysis of the returns to rural research in aggregate for Australia, nor of the impact of research on rural productivity.

In this paper an aggregate productivity index, utilising the 'residual' method developed by Solow (1957), is derived for Australian agriculture for the period 1926-68. An attempt is then made to incorporate the sources of productivity change into a model designed to reduce the residual to zero.[1] To meet this end, an index of Australian scientific research activity is developed utilising scientific personnel data. In addition, variables accounting for climatic conditions and education levels are also included in the model.

Total Productivity in Australian Agriculture, 1926-1968

Several attempts have been made to estimate total productivity for Australian agriculture.[2] Most recent was an extensive study by Powell (1974) who systematically extended and refined aggregated data on rural inputs and outputs for the period 1920/21 to 1969/70. These data are used in the present paper.

As indicated, the Solow method of estimating productivity change is used in this study.[3] This method is not without significant limitations, perhaps the most significant being the residual nature of the estimate. That is, productivity changes are attributed to changes in output which are unexplained by changes in conventionally measured inputs. In this paper labour and capital inputs are the conventional inputs included; thus productivity change is attributed to all other inputs which might affect output.

---

* The research for this paper was undertaken at the Economics Department, University of Adelaide and was supported by the Australian Wool Corporation. With the usual caveats, the assistance of anonymous referees is acknowledged.

[1] An early example of such a procedure appears in Denison (1962).

[2] For example, Herr (1964), A. Powell (1969) and Young (1971).

[3] For a review of these techniques see Nadiri (1970) and Kennedy and Thirlwall (1972).

Of particular interest when investigating the impact of scientific research on rural productivity, is the contribution of non-factor inputs, such as fertilisers and chemicals, to changes in output. In a model which contains only two-factor inputs, it is implicitly assumed that the relative use and marginal productivity of non-factor inputs remain constant.[4] In circumstances, such as exist in Australia, where there has been much scientific research on non-factor inputs, these assumptions are likely to be violated with the residual being consequently biased. While this is a matter of concern, the problem is diminished to the extent that we are investigating the impact of scientific research on productivity. This impact includes the indirect impact made through the use of inputs which have been developed through the research process. Thus there is some defence, albeit not a perfect one, for adopting the two-factor model.

It was previously mentioned that the data series produced by Powell (1974) would be used in this study. Powell made estimates of aggregate productivity movements for Australian agriculture. However, these were presented in both graphic and aggregated average forms which were unsuitable for the present task. In view of this, a cumulative productivity index was estimated for the period 1926-68, this index being contained in Table 1 along with the data used.[5]

Derivation of an Aggregate Scientific Research Index

The research index in this paper is based on Australian scientific personnel data. The collection of these data is briefly described, followed by a discussion of the limitations of the index as a measure of research activity.

The number of people engaged in scientific agricultural research in Australia has been estimated for the period 1925-75. Because of the difficulties associated with the collection of these data, the collection was divided into two sub-periods; 1925-46 and 1947-75. For the period 1947-75, the Commonwealth Agricultural Bureaux (CAB) publication, *List of Research Workers in the Agricultural Sciences*, was used. In 1936, the British Commonwealth Scientific Conference laid down the principles underlying the list which included that:

> . . . the scheme should be *strictly* limited to those who were engaged in research or actually concerned with its organization; that only the more senior workers need be mentioned to the exclusion of junior technical assistants (own italics).

---

[4] See Domar (1962). For summaries of the difficulties arising from the use of different methods see Young (1971) and te Kloot and Anderson (1977).

[5] The productivity index was calculated using the familiar equation:

$$\triangle Y/Y = \triangle A/A + W_k \triangle K/K,$$

where $\triangle A/A$ = rate of productivity change; $\triangle Y/Y$ rate of growth of output per unit of labour; $\triangle K/K$ = rate of growth in capital per labour unit; and W_k = share of output payable to capital. The cumulative index is then derived from the following:

$$A_{t+1} = A_t(1 + \triangle A/A_{t+1}),$$

where $\triangle A/A_{t+1}$ refers to the change in A between time periods t and $t+1$, letting 1925/26 = 1.

TABLE 1

Estimates of 'Technical Change' for Australian Agriculture; 1925/26 to 1969/70

Year	(1) Gross agric. output[a]	(2) Rural work-force[b]	(3) Total rural capital[c]	(4) Capital share[d]	(5) $\triangle A/A$	(6) A_t
1925/26	1158	472.2	4738	0.273		1.00
1926/27	1179	471.1	4981	0.165	0.006	1.01
1927/28	1103	469.3	5130	0.167	−0.067	.94
1928/29	1258	473.4	5404	0.179	0.124	1.06
1929/30	1182	463.8	5469	0.026	−0.047	1.01
1930/31	1362	458.2	5597	−0.035	0.165	1.18
1931/32	1384	447.1	5440	0.082	0.041	1.23
1932/33	1563	464.4	5404	0.165	0.188	1.46
1933/34	1458	475.9	5357	0.344	−0.085	1.34
1934/35	1453	474.4	5356	0.295	−0.002	1.34
1935/36	1406	480.5	5340	0.375	−0.040	1.29
1936/37	1404	485.4	5408	0.462	−0.013	1.27
1937/38	1609	491.7	5407	0.412	0.137	1.44
1938/39	1512	482.2	5724	0.272	−0.075	1.33
1939/40	1546	477.8	5753	0.347	0.028	1.38
1940/41	1352	475.5	5504	0.283	−0.107	1.23
1941/42	1466	442.1	5628	0.353	0.138	1.40
1942/43	1468	406.2	5527	0.427	0.066	1.49
1943/44	1432	403.9	5399	0.428	−0.011	1.47
1944/45	1237	419.8	5178	0.234	−0.166	1.23
1945/46	1261	441.4	5086	0.325	−0.016	1.21
1946/47	1236	449.2	5081	0.349	−0.031	1.17
1947/48	1544	440.9	5090	0.675	0.266	1.48
1948/49	1518	441.8	5211	0.584	−0.034	1.43
1949/50	1607	444.6	5335	0.668	0.042	1.49
1950/51	1515	445.5	5532	0.775	−0.082	1.37
1951/52	1469	448.9	5428	0.492	−0.018	1.35
1952/53	1712	458.0	5609	0.566	0.136	1.53
1953/54	1725	461.8	5712	0.483	−0.006	1.52
1954/55	1766	459.7	5952	0.410	0.006	1.53
1955/56	1899	456.5	5961	0.436	0.079	1.65
1956/57	1947	450.9	6272	0.469	0.010	1.67
1957/58	1815	445.7	6354	0.136	−0.069	1.55
1958/59	2147	435.4	6426	0.340	0.206	1.87
1959/60	2098	425.1	6657	0.364	−0.020	1.83
1960/61	2147	415.3	6790	0.336	0.032	1.89
1961/62	2256	422.4	7150	0.271	0.021	1.93
1962/63	2375	413.4	7435	0.336	0.059	2.04
1963/64	2495	408.5	7680	0.468	0.048	2.14
1964/65	2614	406.1	8055	0.394	0.028	2.20
1965/66	2342	397.5	8434	0.178	−0.113	1.95
1966/67	2839	397.7	8798	0.393	0.205	2.35
1967/68	2620	392.1	9486	0.097	−0.101	2.11
1968/69	3125	378.4	9928	0.322	0.228	2.59
1969/70	3070	363.7	10125	0.211		

[a] Source: Powell (1974), Appendix 8A, p.335, $m, 1949/50 prices.

[b] Source: Powell (1974), Appendix 3F, p.299, adult male equivalents.

[c] Source: Powell (1974), Appendix 9A, p.339, $m, 1949/50 prices.

[d] Source: Determined as [Total Factor Output (Powell, 1974, Appendix 8c, p.337) − Total Wage Payments (Powell, 1974, Appendix 4c, p.303)]/Total Factor Output, all in 1949/50 prices.

The CAB *List* has also attempted to '. . . exclude people in extension and advisory services as distinct from research'. Quite apart from any general deficiencies inherent in manpower data, the exclusion of these services imposes severe constraints on the data. By providing a link in the effective transmission to, and adoption by farmers, of the results of scientific research, liaison and extension services are important complementary inputs to the research effort. The significance of these inputs was emphasised by Griliches (1957) in his study of the diffusion of hybrid corn where extension and liaison inputs were crucial to the development of appropriate innovationary processes and communication systems and to facilitate perception of profitability. A further problem concerning the use of the CAB *List* as a data source is that it has been published at three-year intervals only; thus the data are not available on a continuous basis. Nevertheless the CAB *List* gives a comprehensive list of Australian research institutions which should be included in the proposed index and, furthermore, it provides personnel data for some institutions for which no other sources exist.[6]

Because of collection difficulties, the data were collected on a more limited basis for the period 1925-46. The choice of 1925 as a starting point is somewhat arbitrary but it corresponds to the origin of the Council for Scientific and Industrial Research (CSIR) and the Waite Agricultural Research Institute which both signify major developments in the institutionalisation of Australian agricultural research. Throughout the period 1947-75, the personnel of the State Departments responsible for agriculture, CSIRO and the Universities accounted for over 90 per cent of the total. In view of this, and because of the paucity of data for other institutions, these groups are the only ones considered for the period 1925-46.

The research index used in this study is derived using a procedure similar to that used to construct the cumulative productivity index. That is:

$$(1) \qquad R_{t+1} = R_t(1 + \triangle R/R_{t+1}),$$

where $\triangle R/R_{t+1}$ is the proportionate change in scientific personnel between the successive periods indicated in Table 2.

This index is based on a limited data source. Of particular significance is the omission of borrowed research findings from overseas and the embodiment of overseas research in imported inputs.[7] Apart from this shortcoming, the index facilitates long-term comparisons of research activity which necessitates making a number of critical assumptions before the index may be used as a proxy for a true index of such activity. Among the more important assumptions which must be made are:

(a) that the proportion of borrowed research from overseas remains constant over time (increased use of overseas ideas facilitates increased research output per unit of domestic input);

---

[6] The institutions included in the data set are indicated in the Appendix. For a more comprehensive description of the data see Hastings (1978).

[7] Evenson and Kislev (1973), in their study of productivity increases in wheat and maize, found that international borrowing of research findings was a significant explanator.

TABLE 2

Estimates of Technical Change 'Explanators'

Year	(1) Changes in research activity $\triangle R/R$	(2) Cumulative research index R_t	(3) Technical change index A_t	(4) School enrolment ratio index S_t	(5) Proxy environmental variable E_t
1926		100	100	100	−1
1929	0.38	138	100	101	0
1932	0.25	173	129	104	1
1935	0.17	202	132	102	0
1938	0.15	232	135	103	0
1941	0.09	253	134	102	0
1944	0.09	276	140	104	0
1947	0.38	381	129	109	−1
1950	0.21	461	143	114	−1
1953	0.23	567	147	121	−1
1956	−0.02	557	162	126	0
1959	−0.02	546	175	133	0
1962	0.30	710	195	141	0
1965	0.18	838	210	145	0
1968	0.18	989	235	146	1

(b) that the relative importance of basic and applied research and extension activities remains constant over time;[8]
(c) that the relationship between the number of scientific personnel and scientific effort remains constant over time; and
(d) that individual labour units are homogeneous with respect to research skills over time.[9]

These are quite clearly restrictive and rather 'heroic' assumptions but it is nevertheless felt that the index has sufficient merit to warrant its use in an area characterised by a lack of prior work.

Productivity and Scientific Research

The link between scientific research and productivity is a complex one. Evenson (1968) reiterates the point already made that scientific research not only results in the use of new inputs but also increases the marginal productivity of existing inputs:

> . . . the contribution of agricultural research cannot be simply expressed in terms of a small number of important 'breakthroughs'. Instead it is hypothesized that the contribution takes the form of numerous small changes in the 'quality' of inputs (Evenson 1968, p.1416.)

---

[8] An extensive literature exists on the different stages of the research and development process in the area of industrial economics which indicates that the mix between basic, applied and development research may change over time. See, for example, Nelson (1959) and Mansfield (1968).

[9] Evenson (1977) provides a typology of researcher skills and indicates that different skills enter the 'technology production function' in different ways. Any change in the composition of skills over time may affect the research output of a given number of scientific personnel. The debate over movements in researcher qualities also transcended the patents literature. See, for example, Sanders (1962) and Schmookler (1962).

In the case of scientific research the improved 'quality' of inputs is reflected in the discovery of new and improved plant varieties, chemical fertilisers, insecticides and husbandry and management methods.[10] Of particular significance to the present study are the time lags which exist between scientific research effort and any subsequent impact on rural productivity. Evenson (1968) identified three component lags. First, the lag between research expenditures and relevant research output discoveries; second, the lag between these discoveries and the use of new production techniques embodying these discoveries; and third, the lag which incorporates the diminishing impact on production of a new discovery due to the 'depreciation' of that discovery.

Evenson argued that the first of these lags was likely to be of a symmetric or inverted V shape, while the remaining two were likely to be exponentially declining. Clearly, each of these lags is difficult to separate empirically, necessitating the use of a summary lag structure to incorporate the three. To this end, Evenson (1968, p.1421) used two different lag formulations; the exponentially declining lag and an inverted V lag. His investigation suggested that the lag between expenditures on research and relevant research discoveries was dominating the other two lags and that the mean lag between investment in research and the subsequent impact on production was six years.

In this study, the use of a distributed lag function to take explicit account of these postulated lags presents a number of difficulties. Of major importance in this respect is the small number of observations available. In view of this, the choice of an appropriate lag function had to take into account not only the shape of the lag structure, but also the reduction in the number of degrees of freedom. To this end, an Almon lag structure was adopted, the particular form being as follows.[11] First, a polynomial of degree two (quadratic) was adopted, this being a formulation of an inverted V structure and is thus consistent with the hypothesised nature of the lag. Second, it is assumed that the impact of the lagged variable, in this case research activity, on the dependent variable is zero in both the first and last period of the total lagged period. This restriction is not thought to be too unrealistic, especially in the case of the initial period, and it maintains a maximum number of degrees of freedom which, as pointed out above, is considered most important in this case where the number of observations is quite small.[12]

The following equations, each with different lag lengths, were estimated in searching for the model yielding the highest $\bar{R}^2$.[13]

---

[10] Hayami and Ruttan (1971, p.44) refer to these as representing 'biological technology' which facilitates the 'substitution of labor and/or industrial inputs for land'. That is, these improvements are predominantly land-saving.

[11] For a discussion of this lag structure see Almon (1965).

[12] While the selection of this lag structure may be regarded as rather *ad hoc*, a recent study by Davis investigated alternative lag structures, including the one used here, and found that 'research production coefficient estimates were not sensitive to the different specifications. In addition it was found that *all* specifications were appropriate restrictions on the lag effect of research expenditure on output' (Davis 1980, p.75).

[13] $\bar{R}^2$ is used here rather than R^2 in view of the small number of observations. For a discussion on the suitability of $\bar{R}^2$ as a criterion for selecting the best lag estimate, see Theil (1964, Chapter VI). First differences of the dependent variable are used because of the high degree of serial correlation present when A_t was the dependent variable. This procedure assumes that the first autocorrelation coefficient has an absolute value close to zero.

(2) $A_t - A_{t-1} = a + b_o R_t + b_1 R_{t-1} + \ldots + b_4 R_{t-4} + e,$

(3) $A_t - A_{t-1} = a + b_o R_t + b_1 R_{t-1} + \ldots + b_6 R_{t-6} + e,$

(4) $A_t - A_{t-1} = a + b_o R_t + b_1 R_{t-1} + \ldots + b_8 R_{t-8} + e,$

(5) $A_t - A_{t-1} = a + b_o R_t + b_1 R_{t-1} + \ldots + b_{10} R_{t-10} + e,$

where A_t = three-year average of the productivity index centred on the years indicated in Table 2;
R_t = the computed research index (column (2) Table 2);
t = time, corresponding to the three-year intervals listed in Table 2; and
e = an error term.

The averaging of A_t is undertaken because productivity growth may occur independently of technical change. For example, when product prices fall purchased inputs tend to be cut back, but because of the lagged or carryover effects of inputs such as soil fertility, productivity growth is observed to occur. The weights assigned to the lagged research variable were according to an Almon quadratic with end-point restrictions.

Because of the reduction in the number of observations as the length of the lag is increased, it was felt that the structural relationship between the variables might alter as the lag length was changed. In view of this, the maximum number of lagged relationships was estimated for each sample size. The estimated equations are presented in Table 3.

The results provide a consistent finding in terms of the length of lag which maximises $\bar{R}^2$; in all cases the 'Almon variable' incorporating four lagged periods provides the highest $\bar{R}^2$.[14] If the highest $\bar{R}^2$ is a suitable criterion for selecting the optimum lag structure, then the results suggest (a lag of four periods corresponding to a lag of 12 years) a mean unweighted lag of six years. On the basis of past research in this area, notably Evenson (1968), the finding of a six-year mean lag would seem to represent a plausible finding.

Quite clearly, the inclusion of only a lagged research variable in the model may give a biased estimate of the research coefficient. The exclusion of other relevant variables (in particular, climatic conditions and education levels) may bias the estimated research coefficient upwards, with the extent of the bias being a function of the correlation between the included and excluded variables and of the coefficients of the excluded variables. In an attempt to try and ascertain the extent of this bias, the model is extended to include variables reflecting variations in climatic conditions and changes in the level of education.

As already indicated, the estimate of technical change is a residual measure and as such any substantial disturbances, such as a severe drought, will be reflected in the estimate. It is felt that some effects of changes in climate or environmental factors have already been taken into account with the adoption of an average value of A_t. In an aggregate model, it is difficult to measure changes in environmental factors; for

---

[14] These models were also estimated with the inclusion of a time variable, but owing to the high degree of multi-collinearity between this and other variables, the estimated coefficients were unrealistic. These estimations revealed similar results in terms of the ranking of $\bar{R}^2$.

TABLE 3

Estimated Lag Relationship Between Scientific Research and Total Productivity

Number of observations	Constant	Almon variable	$\bar{R}^2$	$D-W$	Number of lagged periods
12	−7.17	−0.004	.61	3.26	4
	(1.72)[a]	(4.25)			
10	−10.94	−0.005	.62	3.59	4
	(1.92)	(3.95)			
	−9.59	−0.002	.60	3.48	6
	(1.71)	(3.79)			
8	−15.41	−0.006	.60	2.89	4
	(1.79)	(3.32)			
	−12.93	−0.002	.55	2.72	6
	(1.52)	(3.07)			
	−11.72	−0.076	.54	2.65	8
	(1.42)	(3.01)			
6	−15.34	−0.006	.76	3.44	4
	(2.00)	(4.08)			
	−9.49	−0.001	.67	3.17	6
	(1.25)	(3.34)			
	−7.21	−0.064	.64	3.05	8
	(0.98)	(3.16)			
	−6.66	−0.001	.64	3.01	10
	(0.93)	(3.15)			

[a] t values in parentheses.

example, all products will respond differently to given changes in rainfall, temperatures or soil types.

In view of these difficulties, the following proxy measures were used to reflect particularly 'favourable' and 'unfavourable' years. Powell's (1974, p.335) estimate of real gross output for Australian agriculture for the years 1925/26 to 1969/70, was regressed linearly against time to observe residual values of real output from the estimated trend values. A three-part variable, E_t, was used as a proxy variable to reflect marked changes in environmental conditions, a value of -1 was assigned to periods where real gross output was 15 per cent or more below the estimated trend values for the same period;[15] 0 was assigned to periods where real gross output was within ∓ 15 per cent of the estimated trend values; and $+1$ was assigned to periods where real gross output was 15 per cent or more above the estimated trend values.

Denoting the environmental proxy variable by E_t, the variable was added to the model giving:

---

[15] The values again are derived from three-year averages centred on the years indicated by Table 2. The particular values are contained in column (5) of Table 2.

$$A_t - A_{t-1} = a + bAV + cE_t + e, \tag{6}$$

where AV = Almon variable.

The following estimates were made given an 'Almon variable' incorporating four lagged periods:

$$\begin{aligned} A_t - A_{t-1} &= -4.131 - 0.004AV + 4.513E_t.\\ &\quad (-0.880)\ (-3.374)\ (1.281)\\ \bar{R}^2 &= 0.631 \qquad D-W = 3.19 \end{aligned}$$

The inclusion of the environmental proxy variable has qualitatively improved the model, the $\bar{R}^2$ value has increased from 0.608 to 0.631.

In an early study of the role of education in the growth of agricultural output, Griliches (1964) found that education was a significant factor affecting output. This relationship reflects the probability that increased education increases both farm managers' and farm labourers' ability to *use* resources more efficiently and also to *allocate* resources more efficiently. To try to estimate the contribution of education to increases in total factor productivity for Australian agriculture, a school enrolment ratio, which measures the ratio of average attendance of school students to the potential number of students, was used. The construction of these data is described in Hastings (1978, p.197). The data were averaged to try to establish a variable which reflected a stock of education, for example, the ratio for say 1965, was the average of the ratio for the years 1961-66. The index of the school enrolment ratio is contained in column (4) of Table 2.[16]

The data on the enrolment ratio were then included in the model to estimate the following:

$$A_t - A_{t-1} = a + bAV + cE_t + dS_t + e, \tag{7}$$

where S_t = stock of education as defined in the text.

The estimate of this equation is:

$$\begin{aligned} A_t - A_{t-1} &= -31.424 - 0.001AV + 5.001E_t + 0.320S_t.\\ &\quad (-0.530)\ (-0.104)\ \ (1.304)\ \ \ (0.462)\\ \bar{R}^2 &= 0.595 \qquad D-W = 3.26 \end{aligned}$$

The estimates of this equation are qualitatively inferior to those of equation (6), all coefficients lack statistical significance and the $\bar{R}^2$ is less. The poor performance of the model is probably largely the result of the high degree of collinearity between AV and S_t, the value of the correlation coefficient being −0.986.[17] In addition, the included variables defy precise measurement which again could contribute to the poor performance of equation (7).

---

[16] This variable is deficient to the extent that it applies to the entire population rather than just to the agricultural sector. Ideally, the variable should reflect the schooling of adult farmer decision makers, but data to construct such a variable are not readily available.

[17] The models were also tested substituting first differences of the enrolment ratio for the enrolment ratio but with no qualitative improvement in the results.

The most efficient models then, would appear to be those represented by equations (2) and (6); in each case the coefficient on the 'Almon variable' is -0.004. This value was used to compute the respective coefficients on the lagged research variables with the following estimate (remembering that in the formulation of the model it was assumed that the coefficients for R_t and R_{t-4} were zero):

$$A_t - A_{t-1} = -4.131 + 0.011R_{t-1} + 0.015\mathrm{R}_{t-2} + 0.011R_{t-3} + 4.513E_t.$$

The sum of the lagged research coefficients in this case is 0.04.[18] The positive value suggests that, over the period 1926-68, increases in research activity have been associated with greater than proportional increases in total factor productivity, which allows the tentative conclusion that there have been increasing returns to scientific research activity in Australia over the period.

Conclusion

In many respects the models tested here, and the results which are reported, reflect the attitude of Evenson and Kislev (1973, p.1324):

> We purposely did not follow the practice . . . of limiting the report to 'reasonable' results. The crudeness of the data, the lack of information, and the absence of prior work in the field justified in our mind more than the usual dose of experimentation.

The major aim of the analysis was to investigate the contribution of Australian scientific research activity to agricultural productivity for Australian agriculture. The utilisation of a distributed lag function to describe the research/productivity relationship suggested a mean lag of approximately six years between changes in research activity and total factor productivity. As the model was expanded to account for possible 'bias' in the estimates, the research variable remained a significant 'explanator' (with the exception of equation (7)).

The preliminary nature of the analysis must again be stressed; it represents the first of its kind for Australia and suffers because of constraints on both the availability and quality of data. However, in spite of the 'crudeness' of the data, the results seem to consistently support the proposition that agricultural scientific research has made a positive contribution to the growth of agricultural productivity. Whilst this conclusion must necessarily be tentative, the defence made by Griliches (1964, p.972) in his conclusion to his pioneering work on the contribution of education to agricultural productivity applies:

> None of these conclusions is very firmly established, and some may be subject to substantial bias, but the only known way of either confirming them or disproving them is the slow and expensive but cumulative process of conducting additional studies of this type on different bodies of data.

---

[18] The finding of a positive research coefficient despite negative Almon variable coefficient stems from the procedures used to derive the b-system; see Koutsoyiannis (1973, pp. 289-94) and Davis (1980, pp. 73-4).

APPENDIX

Research Institutions Included in the Collection of Research Data.

1. Departments responsible for agriculture in
   New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia.
2. CSIRO
   Divisions of
   Animal Health and Production, Animal Genetics, Animal Physiology, Nutritional Biochemistry, Entomology, Irrigation Research, Horticultural Research, Plant Industry, Land Research, Tropical Pastures, Soils and Wildlife Research.
3. Universities
   Melbourne, Sydney, Adelaide, Queensland, Western Australia, New England, Tasmania and La Trobe.
4. Agricultural Colleges
   Hawkesbury, Queensland, Roseworthy and Wagga.
5. Commonwealth Departments
   Commonwealth Serum Laboratories and Department of the Interior.
6. State Research Institutions
   Queensland Bureau of Sugar Experiment Stations, Victorian Department of Crown Lands and Survey and South Australian Institute of Medical and Veterinary Science.

References

Almon, S. (1965), 'The distributed lag between capital appropriations and expenditure', *Econometrica* 33(1), 178-96.

Commonwealth Agricultural Bureaux, *List of Research Workers in the Agricultural Sciences in the Commonwealth and in the Republic of Ireland*, Slough, various years.

Davis, J. S. (1980), 'A note on the use of alternative lag structures for research expenditure in aggregate production function models', *Canadian Journal of Agricultural Economics* 28(2), 72-6.

Denison, E. F. (1962), *The Sources of Economic Growth in the United States and the Alternatives Before Us*, Supplementary Paper No. 13, Committee for Economic Development, New York.

Domar, E. (1962), 'On productivity and all that', *Journal of Political Economy* 70(6), 597-608.

Evenson, R. E. (1968), 'The contribution of agricultural research to production', *Journal of Farm Economics* 49(5), 1415-25.

——— (1977), 'Comparative evidence on returns to investment in national and international research institutions', in Arndt, T. M., Dalrymple, D. G., and Ruttan, V. W. (eds) *Resource Allocation and Productivity in National and International Agricultural Research*, University of Minnesota Press, Minneapolis.

——— and Kislev, Y. (1973), 'Research and productivity in wheat and maize', *Journal of Political Economy* 81(6), 1309-29.

Griliches, Z. (1957), 'Hybrid corn: an exploration in the economics of technological change', *Econometrica* 25(4), 501-22.

——— (1964), 'Research expenditure, education and the aggregate production function', *American Economic Review* 54(6), 961-74.

Hastings, Trevor (1978), The economics of public sector scientific research in Australian agriculture, Ph.D. thesis, University of Adelaide.

Hayami, Y. and Ruttan, V. W. (1971), *Agricultural Development: An International Perspective*, John Hopkins, London.

Herr, W. McD. (1964), 'Capital formation: its importance and determinants', *Australian Journal of Agricultural Economics* 8(2), 97-111.

Industries Assistance Commission (1976), *Draft Report on Financing Rural Research*, AGPS, Canberra.

Kennedy, C. and Thirlwall, A. P. (1972), 'Surveys in applied economics: technical progress', *Economic Journal* 82(1), 11-72.

Koutsoyiannis, A. (1973), *Theory of Econometrics*, MacMillan, London.

Mansfield, E. (1968), *Industrial Research and Technological Change: An Econometric Analysis*, Norton, New York.

Nadiri, M. I. (1970), 'Some approaches to the theory and measurement of total factor productivity: a survey', *Journal of Economic Literature* 8(4),1137-77.

Nelson, R. R. (1959), 'The simple economics of basic scientific research', *Journal of Political Economy* 67(3), 297-306.

Powell, A. A. (1969), 'Productivity change in Australian agriculture: an overall view', *Economic Papers* (31), 18-34.

Powell, R. A. (1974), Technological change in Australian agriculture, 1920-21 to 1969-70, Ph.D. thesis, University of New England.

Sanders, B. S. (1962), 'Some difficulties in measuring inventive activity', in N.B.E.R., *The Rate and Direction of Inventive Activity*, Princeton University Press, pp. 53-77.

Schmookler, J. (1962), 'Comments' on Sanders (1962), in N.B.E.R., *The Rate and Direction of Inventive Activity*, Princeton University Press, pp. 78-83.

Solow, R. M. (1957), 'Technical change and the aggregate production function', *Review of Economics and Statistics* 39(3), 312-20.

te Kloot, J. H. and Anderson, J. R. (1977), 'Estimates of technological change in the pastoral zone', *Review of Marketing and Agricultural Economics* 45(4), 159-66.

Theil, H. (1964) *Forecasting Policy*, North-Holland, Amsterdam.

Young, R. (1971), 'Productivity growth in Australian rural industries', *Quarterly Review of Agricultural Economics* 24(4), 185-205.