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THE RETURNS FROM RESEARCH IN AUSTRALIAN BROADACRE AGRICULTURE*

J. D. MULLEN & T. L. COX
NSW Agriculture, Orange, NSW and University of Wisconsin, Madison U.S.A.

Many people share the view that too little is invested in R & D in agriculture. The relationship between several measures of productivity and research expenditure was estimated using data from ABARE's surveys of broadacre industries and a new data series on R & D expenditure for the period 1953 to 1988. The internal rate of return to research was estimated to be in the range of 15 to 40 percent which does not provide strong evidence that Australia is either under- or over-investing in public research.

Introduction

It is widely held, at least in the agricultural research community, that research makes an important contribution to growth in agricultural productivity; that the returns from investment in research are high; and that investment in research is too low. Echeverria (1990) catalogued over 200 past analyses of agricultural research at both project and aggregate levels in a variety of countries, most of which estimated rates of return greater than twenty percent. In recent U.S. studies, Huffman and Evenson (1993, p.245) estimated that the returns to public research were 41 percent and Chavas and Cox (1992) estimated that the returns were 28 percent. Alston, Pardey and Carter (1994) estimated that the annual average internal rate of return to public investment in California agricultural research and extension has been about 20 percent. Thirtle and Bottomley (1989) estimated that in the U.K., the rate of return was about 100 percent. In a study of New Zealand agriculture, Scobie and Eveleens (1986) estimated that the returns to research had been 'around 30 percent' (p. 92).

In Australia, analyses of individual projects or programs have also generally supported the view that the returns to public research (partly funded by industry levies) are high. Prominent examples of such studies include Duncan (1972); Marsden *et al.* (1980) and the recent GRDC studies funded by the Grains Research and Development Corporation (1993).

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More specific analyses of the underinvestment hypothesis have been conducted in the U.S. by Fox (1985) and in Australia by the Industries (Assistance) Commission (IAC, 1976, IC 1995) and Harris and Lloyd (1990). Fox(1985) concluded that the level of public research expenditure in the U.S. appeared to be neither too high nor too low at that time after adjustments were made for the social benefits of private research and the excess burden of taxation associated with public research. Harris and Lloyd reviewed arguments for and against the underinvestment hypothesis, noted 'rates of return which seem unrealistically large' (Harris and Lloyd, 1991, p24) but found the consistency of findings reassuring and noted arguments which might explain the persistence of high returns and of underinvestment in research. The Industry Commission enquired in rural research in 1976 and research in general in 1995. On both occasions the Commission accepted the view that returns from rural research had been high but did not accept the view that an increase in public funding of rural research was warranted. In its 1995 Report the Commission was particularly concerned about encouraging a more competitive research industry and greater participation by the private sector in both financing and undertaking research.

Generally speaking the focus of these studies has been on public rather than private research. Huffman and Evenson (1993, p.245) found that the return to private research was 46 percent. Chavas and Cox (1992) estimated it to be 17 percent. These estimates are higher and lower than their respective estimates of the returns to public research. The question of what type of research activities are appropriate for public authorities has been seriously addressed only recently and this issue will not be pursued here.

In Australia empirical analysis at an aggregate level that might shed some light on this underinvestment hypothesis has not been possible because research expenditure data have been unavailable. Such data have only been collected by Department of Science and more recently the Australian Bureau of Statistics since 1968 at intervals of several years.[1] In the absence of such data, Hastings (1981) found a significant positive relationship between productivity and research as measured by a lagged research personnel variable but was unable to go as far as estimating a rate of return to investment.

In an alternative approach, Scobie, Mullen and Alston (1991) synthesised a production function linking expenditure on research with productivity growth in the Australian wool industry. Gauging public investment in wool production R & D to have been about $40m in 1985, they estimated that the average internal rate of return to Australia might be in the order of 9.5 percent and the internal rate of return to woolgrowers might be in the order of 25 percent. These rates of return are low relative to past

[1] R&D expenditure data were first collected as part of Project Score by the Department of Science. There are less than ten observations in this series.

studies but they account for the leakage of research benefits to non-residents of Australia and the excess burden of raising taxes to fund research.

The broad objective of research reported here has been to estimate the rate of return to public investments in research in broadacre agriculture in Australia.[2] Important components of the project have been first, the assembling of a unique database on research and extension expenditure by Departments of Agriculture, CSIRO and the major universities from 1953 to 1988, second, the measurement of productivity growth in broadacre agriculture from ABARE survey data, third, the specification and estimation of a relationship between productivity and research and extension expenditure, and finally, the estimation of an internal rate of return.

In estimating the returns from investment in research, choices have to be made about the specification of the lag profiles associated with research and extension variables. These issues have been discussed in detail in previous papers by Mullen and Cox (1994a and 1994b). A choice can also be made about the way in which productivity is measured. Most past studies of returns to research have used the traditional Christensen and Jorgenson index of total factor productivity as their dependent variable. Mullen and Cox (1994a) have used several alternative measures of productivity which impose fewer restrictions on the nature of technology in broadacre agriculture. The focus of this paper is on the sensitivity of estimates of the returns to research to the measure of productivity growth.

Factors Explaining Productivity Growth

Detailed presentations of the structural model linking investment in research with productivity growth can be found in Scobie and Jardine (1988) and Alston, Norton and Pardey (1995). In brief, their line of reasoning is that the product of investment in research is a lagged increase in the stock of technology or knowledge in use which yields a flow of benefits to producers and consumers over many years. Changes in this stock of knowledge in use cannot be measured directly. Most often, a weighted flow of past expenditures on research has been used as a proxy for this stock variable.[3] Extension adds to the stock of knowledge in use but lag effects are much shorter than for research.

Conceptually there are several approaches to measuring the contribution of research and extension to productivity growth. These are reviewed in detail in Alston, Norton and Pardey (1995). We have followed the approach of most empirical studies in regressing an index of total factor productivity, TFP, against several explanatory variables including

[2] Broadacre agriculture refers to the sheep, beef and cropping industries.

[3] Other measures of the change in the stock of knowledge have included the number of personnel engaged in agricultural research (Hastings 1981); the annual output of published scientific papers arising from research activities (Hastings 1978; Evenson and Kislev, 1973); and the flow of patent registrations (Evenson, 1989).

TABLE 1
Variables Explaining Productivity Growth

Year	Research $,000	Extension $,000	Educ %	Weather Index	Terms of Trade	Research Deflator	CPI
1953	6412	2832	73	110	248	100	100
1954	7147	3204	73	87	248	104	102
1955	9058	3890	73	89	230	107	103
1956	8627	4018	74	135	224	115	107
1957	9199	4342	74	177	236	119	113
1958	10129	5134	75	66	209	121	114
1959	11112	5064	76	88	193	122	116
1960	12381	5126	76	98	195	130	119
1961	13813	5911	77	94	184	135	124
1962	15337	5821	78	84	168	138	124
1963	17042	6502	78	94	172	140	125
1964	20828	7378	78	127	186	145	126
1965	22742	7812	77	89	175	152	131
1966	24437	9054	77	50	173	156	135
1967	29969	11429	77	72	167	164	139
1968	32412	12663	77	68	157	171	144
1969	35194	13665	77	121	153	179	147
1970	39184	14856	77	97	149	189	152
1971	44444	16335	78	94	137	206	159
1972	48384	18205	78	105	139	225	170
1973	53046	21111	79	73	175	245	180
1974	65220	24594	79	115	186	281	204
1975	81081	31590	79	139	126	353	238
1976	91206	35566	79	88	115	406	269
1977	98767	38351	79	96	112	451	306
1978	114266	44035	78	100	106	487	335
1979	123917	46301	78	108	121	518	362
1980	145789	54888	78	73	129	575	399
1981	162883	61721	77	80	121	645	437
1982	193592	70824	77	97	108	729	482
1983	216073	81099	77	77	102	808	538
1984	224396	85521	78	140	99	857	575
1985	240820	92705	78	140	96	909	599
1986	263359	99362	78	100	89	973	649
1987	266592	103309	78	100	89	1032	710
1988	287856	111798	78	100	100	1074	762

weather, the education level of farmers, the terms of trade, and a stock of knowledge about technology arising from public investments in research and extension. Data series for these explanatory variables are presented in Table 1.

The level of education of farmers is likely to influence the ability and rate at which farmers adopt new technology. We have followed Hastings (1978) in attempting to capture the effects of education in a school enrolment variable measured as the ratio of school enrolments to the potential number of students (the number of people aged 5 to 19).[4] We followed Beck *et al.* (1985) in using a crude rainfall index based on annual district rainfall weighted by district sheep numbers in 1966-67 as our weather variable and ABARE's (ABARE, 1992) terms of trade series (ratio of prices received to prices paid by farmers). Both variables are expected to contribute to short run variations in productivity growth. Beck *et al.* hypothesised a short run negative relationship between terms of trade and productivity growth arguing that 'in a high income period (increasing terms of trade), expenditure on inputs will increase but the relatively inelastic supply will be little affected, thus resulting in an apparent short-term decline in productivity. The converse can be expected when output prices fall' (1985, p.7).

Productivity is also likely to be affected by private research and by research in other countries. Data on agricultural research conducted by the private sector in Australia are only available for the limited period covered by the ABS. In other countries such as America and the U.K., private sector research is as large as public sector research but it appears to be much smaller in Australia. The Industry Commission estimated that rural research by business enterprises only amounted to ten percent of total rural research in Australia in 1992/93 (IC, 1995, p691) although this share of total research financed by the private sector rises to over 20 percent when R & D levy payments are included. The contribution from the private sector was likely to have been much smaller over the period of this study. We have made no attempt to incorporate private research in our analysis[5] nor did we attempt to account for 'spillover effects' from research conducted in other countries. Other factors influencing productivity growth that are often ignored or subsumed in a time trend are changes in communications, transport etc.

[4] Hastings (1978) used average attendance as the numerator but this variable is no longer reported and we were forced to used total school enrolments. The variable fluctuates more than we would perhaps expect suggesting that it has not been measured well. We smoothed the data by using a five year moving average of the raw series.

[5] Intuitively we would expect that if private sector research is omitted, the impact of public sector research is likely to be overstated but Huffman and Evenson (1993) found that when private sector research was included in their US study, the impact of public sector research increased.

Research and Extension Expenditure Data

The dataset used here and the methods by which it was assembled are described in Mullen, Lee and Wrigley (1995). Total expenditure by Departments of Agriculture on all activities was collected from publicly available financial statements. Where possible, expenditures associated with government enterprises, such as abattoirs; agricultural colleges; rural adjustment schemes and crisis grants; and expenditure on community services such as (domestic) animal welfare, were deducted to arrive at expenditure by State Departments on research, advisory and regulatory activities in production agriculture.

Jointness both in production agriculture at the farm level and in the supply of research, extension, regulatory and education services by public authorities meant that it was not possible to identify expenditure by function, such as research, in broadacre agriculture. To estimate expenditure on research and extension in broadacre agriculture, some allocation rules had to be applied to total expenditure by State Departments. The proportion of total expenditure in broadacre industries was assumed to be the same as the share of broadacre industries in the gross value of agricultural production, GVP, in the State.[6] This allocation rule is often referred to as the congruence model. Fox (1987, p. 452) listed a number of studies that have applied this model. During the 80's many Departments introduced management information systems from which we were able to derive estimates of the shares of total expenditure that were devoted to research, advisory and regulatory functions. For want of better information we applied the average of these shares to total expenditure by Departments back to 1952. This type of allocation has been referred to as the precedence model (Fox, 1987). This is an important decision as it means that there is little information on extension that is independent of research. In the absence of obvious alternatives these allocation rules are thought to be a reasonable approximation of how State Departments allocate their budgets. As a group, the Departments account for the largest share of expenditure on agricultural research, and the expenditure by Departments has grown steadily relative to the GVP of agriculture since 1953.

CSIRO is the largest single agricultural research body in Australia. Total expenditure by CSIRO on agricultural research was estimated from published financial statements and the share in total GVP of broadacre agriculture in Australia was applied to this to arrive at an estimate of expenditure by CSIRO on broadacre research. Note that research into processing industries was not included where identifiable.

Universities make a relatively small contribution to agricultural research and rely heavily on external grants for funding. Total expenditure on agricultural research was estimated to be the sum of external and

[6] The share of broadacre industries in GVP was estimated as a five year moving average to smooth out short term price and seasonal fluctuations.

internal grants and a matching contribution from the University. Grants for research into intensive industries or for non-agricultural purposes were deducted to arrive at research into broadacre agriculture.

In nominal dollars, total expenditure by State Departments, CSIRO and Universities in agriculture rose from $16.3m in 1953 to $733.6m in 1988. Expenditure grew very slowly until about 1970 and then at a very rapid rate until 1988. Relative to the value of GDP in agriculture, this is an increase from 1.1 percent in 1953 to 6.5 percent in 1988. Over the same period expenditure on agricultural research rose from $9.0m (0.6 percent of farm GDP) to $421.8m (3.7 percent).[7] Research as a percentage of farm GDP was as high as 5.9 percent in 1983. Alston, Chalfant and Pardey (1993, p. 14) note that of OECD countries, Australia is second only to Canada in the level of its research intensity (defined as the ratio of research expenditure to agricultural GDP).[8] Expenditure on broadacre research in Australia rose from $6.4m in 1953 to $287.9m in 1988.[9]

Research and extension expenditure were deflated by the price index for total expenditure on goods and services by public authorities (base = 100 in 1953). In real dollars expenditure on broadacre research grew linearly until about 1970. There was little change in real expenditure during the 1980s (Figure 1).[10]

Research and Extension Lag Profiles

As alluded to above, productivity is influenced by the stock of knowledge in use which arises from investments in research and extension over many years. Relative to research, extension activities are expected to have a much quicker but still lagged impact on productivity.

In practice productivity is regressed against weighted aggregates of past expenditures on research, R_{t-j}, and extension, E_{t-j}, which act as proxies for the unobserved stock of knowledge in use, K_t. To reduce

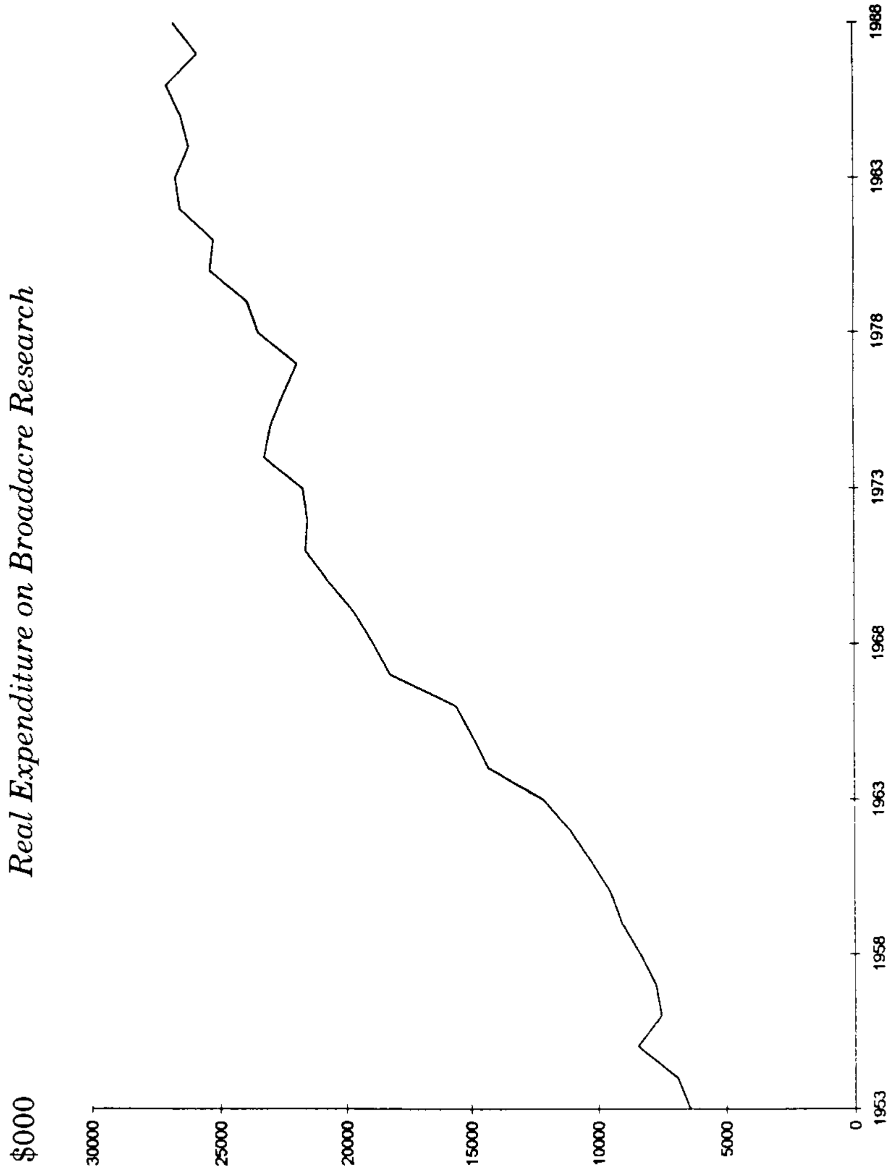
[7] In calculating these percentages, expenditure has been related to nominal GDP rather than to a 5 year moving average of GDP.

[8] Mullen, Lee and Wrigley (1995) noted that the increase in research intensity in real terms was much smaller.

[9] The estimates of expenditure on agricultural research used in this study were within ten percent of the ABS estimates in six years and within 25 percent for the remaining three years.

[10] The research data set used here is slightly different from that used in Mullen and Cox (1994b and 1994c). There were some small errors in the 1994c paper and the method of measuring productivity has since been revised. The only difference between the present paper and the 1994b paper is the treatment of the large capital expenditure ($200m) associated with the construction of the Animal Health Laboratories for CSIRO from 1977/78. Because we could not reliably identify capital expenditure, we normally treated it as operating expenditure. The commencement of these laboratories caused a temporary peak in expenditure in 1977/78. In this paper, following a suggestion from Ray Trewin (pers. comm.) we amortised this expenditure over 20 years in case the peak in 1977/78 was influential. As can be seen below, the change in estimated coefficients was very small.

FIGURE 1
Real Expenditure on Broadacre Research



problems of multicollinearity and to conserve degrees of freedom, the usual practice in econometric modelling has been to construct research and extension variables as weighted sums of past annual expenditures where the r_j and e_j terms are series of normalised weights L_R and L_E years in length, imposed in aggregating the research and extension variables. Ideally the research and extension coefficients, β and ϕ, are estimated during the regression procedure but often, as discussed more fully below, some fixed relationship between them is imposed because they cannot both be estimated with precision. In log form this relationship can be represented as:

$$(1) \qquad \ln K_t = \beta \sum_{j=0}^{L_R} r_j \, lnR_{t-j} + \phi \sum_{j=0}^{L_E} e_j \, lnE_{t-j}$$

There is little agreement in the literature about either the length or the shape of the lag profiles. With respect to lag length, Chavas and Cox (1992) and Pardey and Craig (1989) have estimated that expenditure on research may have an impact on productivity for up to 30 years in the case of U.S. agriculture. The lag structure for public research preferred by Huffman and Evenson (1993) was 35 years. Scobie and Eveleens(1986) estimated that research had an impact on NZ agriculture for 23 years. Several alternative lag profiles have been used including an inverted-V (or Deleeuw) profile (Evenson, 1968); a trapezoidal lag structure (Huffman and Evenson, 1993) and an Almon or polynomial lag structure (Thirtle and Bottomley, 1988; Hastings, 1978). These approaches serve the additional purpose of giving a smooth pattern of lag weights. They are discussed more fully in Alston, Norton and Pardey (1995).[11] Collinearity in the data and too few observations have generally meant that the lag profile is chosen as much on the basis of prior expectations as on what is revealed by the data.

Major constraints to analysing the length and shape of the research profile are the small number of observations on research expenditure available and the lack of variation in this variable. Whereas Pardey and Craig (1989) had 93 observations, we were limited to the 36 observations between 1953 and 1988. One strategy was to limit the research lag profile to 16 years, leaving 21 years of data for identifying sources of productivity growth.[12] Our concern was that if the research lag profile was as long

[11] Alston *et al.* (1994) note that there are other approaches which impose less structure on the lag profile, such as the use of probability generating functions and a form -free approach but these approaches are yet to be applied to the particular problem of agricultural research and have not been pursued here. Nor has the distributed lag literature (Dhrymes, 1981) involving the use of lagged dependent variables with associated complicated error structures been thoroughly investigated.

[12] Restricting the impact of research to be zero at the endpoints explains the apparent anomaly here. Some degree of support for a short lag length is provided by Hastings (1989) who examined Almon quadratic lags ranging from 12 to 30 years and chose the

as thirty five years as suggested by Huffman and Evenson (1993), then our estimate of the returns to research over shorter investment periods may be biased. Huffman (pers. comm.) suggested that in the absence of expenditure data prior to 1953, we extrapolate expenditure backwards.[13] While this procedure does not create new information about expenditure, it does allow use of the full series on productivity[14] and we were able to estimate models with research lags of up to 35 years.

Three procedures were used by Mullen and Cox (1994b) to choose between models which were estimated over the same observation period and which differed only by the length and shape of the lag profile. One procedure, used by Huffman and Evenson (1993), was to choose the lag profile which minimised the sum of squared residuals. Mullen and Cox (1994b) also used a likelihood ratio test. Some models were tested using non-nested hypothesis testing procedures. However, they were unsuccessful in discriminating between models having reasonable lag lengths (of more than six years) using these procedures. The explanatory power of models increased as the lag length increased but not to a statistically significant extent. Since it has not been possible to resolve the issue of the length and shape of research lags econometrically, the sensitivity of research coefficients and IRRs was assessed in the results below.[15]

The preferred approach to measuring the impact of extension is to include it as a separate variable but one which has a different lag profile to research, as represented in the equation above. However past studies have had varying degrees of success in measuring the impact of extension that is separate from research and have usually, either explicitly or implicitly, imposed assumptions about the values of ϕ and e in equation 1.[16] Huffman and Evenson (1993) met with success in assigning weights of 0.5, 0.25 and 0.25 to the current and previous two years of expenditure on extension. They went on to estimate that the marginal internal rate of return to extension was about 20 percent. Most other studies have been less successful.

Previous work by Mullen and Cox (1994b) confirmed the expectation that the high degree of collinearity between extension and research in this

twelve year profile on the basis of highest R^2. Thirtle and Bottomley (1989) were restricted to a maximum lag length of 14 years but preferred a 12 year lag from a second degree Almon polynomial.

[13] It is our view that because precedent is such an important influence on the allocation of research and extension funds, even a longer data series may not allow issues of lag length and the separate contributions of research and extension to be resolved.

[14] The basis of the extrapolation was a regression of the log of real research expenditure against time from 1953 to 1972. There was a marked reduction in the rate of growth in real expenditure after 1972. A log relationship was preferred to a linear relationship in non-nested testing.

[15] Pardey and Craig (1989) used causality testing to examine lag lengths (among other issues) but lack of data precludes this approach here.

[16] Davis (1979) estimated a significant negative impact of extension on productivity and noted several other studies that encountered a similar problem. Thirtle and Bottomley (1989) simply omitted extension because of collinearity problems.

Australian data series would make it impossible to precisely estimate the separate contributions of research and extension to productivity growth.[17] The problem with either omitting extension or measuring its contribution with error is that the estimates of the other coefficients are to some extent biased and inconsistent. Mullen and Cox (1994b) followed Huffman and Evenson in assigning weights of 0.5, 0.25 and 0.25 to the current and previous two years of expenditure on extension but were unable to estimate both β and ϕ. They imposed and tested several alternative ways of summing the aggregated research and extension variables, effectively enforcing different relationships between β and ϕ. Mullen and Cox (1994b) started by imposing the condition that β and ϕ be equal, that is, that a one unit change in the stock of knowledge in use through extension had the same impact on productivity as a one unit change in the research variable. In this scenario the returns to extension were about 600 percent. The explanatory power of the model was improved, though not to a statistically significant extent, and more reasonable estimates of the rates of return to research and extension were obtained by dividing the extension variable by a factor of 10, effectively setting the impact of a unit increase in extension to be one tenth that of a unit increase in research. This procedure has been followed here.

Estimating the Returns to Research

After establishing a relationship between productivity and research expenditure, the next steps are first, to value the contribution of research and second, to estimate the return to the investment in research, the marginal internal rate of return (IRR).[18] Again this process is made complex by the long period over which research activities have an effect on productivity.

For the double log specification used here, the research coefficient, β, is an estimate of the elasticity of total factor productivity, TFP, with respect to the research stock variable in equation 1. Of more practical interest is the elasticity of TFP with respect to research expenditure in year t-j, β-j. The profile of β-j's is derived by multiplying the research coefficient by the normalised series of weights $(r_j/\sum r)$.[19] The marginal product in year t of a unit increase in research expenditure in year t-j is:

[17] The high degree of collinearity is partly inherent to the way in which public research and extension resources are allocated in Australia but also arises from the allocation rules applied here in assembling the research and extension series.

[18] An important criticism of the IRR as an investment criterion is that it assumes that revenue generated by the investment can be reinvested at the same rate (Hirshleifer, 1958). We have persevered with the IRR mainly because it has been used in all similar studies and partly because the assumption may be reasonable when the reported rates of return from many individual research projects are much larger than the aggregate estimates reported here.

[19] For a symmetric inverted v profile the r_i terms start at zero and increment by one until reaching a maximum at the midpoint of the profile and then decline to zero.

$$MP_{t,t-j} = \beta_{-j} \,.\, TFP_t/R_{t-j} \,.$$

The marginal product is a quantity measure since TFP is the level of output that is unexplained by input growth. The value of the marginal product is:

$$VMP_{t,t-j} = \beta_{-j} \,.\, TFP_t \,.\, P_t/R_{t-j} \,,$$

where P_t is a Divisia index of the prices of the four outputs from the ABARE survey data deflated by the Australian consumer price index for all groups (Reserve Bank, 1991) and R is actual research expenditure on broadacre agriculture in year t-r deflated by the price index for total expenditure on goods and services by public authorities. This procedure was recommended by Davis (1981) who pointed out the variety of past approaches.[20]

A change in R in year t-j will add to productivity for L_R years. The total value of marginal product, TVMP, in year t of a unit change in R in year t- L_R over L_R years is given by:

$$(2) \qquad TVMP = \sum_{j=0}^{L_R} \frac{\beta_{-j} TFP_{t-j} P_{t-j}}{R_{t-L_R} (l+i)^j}$$

where i, the IRR, is the interest rate at which the flow of discounted benefits exactly offsets a one unit change in R. This is a measure of the benefits from a one time increase in R and is the scenario we concentrate on in this paper.[21] The $TFP_{t-j}.P_{t-j}$ / R_{t-lr} term is time dependent. Hence TVMP is likely to vary with the year in which the change in R is set to occur. The possibilities range from the first year of the observation period up to the most recent year which would involve projecting productivity and price forward for L_R years.[22] To overcome this problem, the general practice in past studies, which has been followed here, has been to set TFP, P and R at their geometric means. But as Alston, Norton and Pardey (1995) point out, this 'averaging' procedure does not have an exact economic interpretation.

[20] TFP is a measure of output unexplained by the growth in inputs. The original index of output used in its construction was derived implicitly as the value of output in nominal terms from ABARE survey data divided by the price index, P.

[21] If R were to increase permanently then a measure of the benefits could be obtained by treating TVMP as a perpetuity. Note that after the initial L_R adjustment period, the change in productivity in any year is β, the research coefficient.

[22] Assuming a ten year research lag we could have calculated an MIRR for each year from 1962 to 1978 using actual data for TFP, P and R. This could have been done for a fixed research coefficient or for a time varying coefficient. This approach would have a clearer economic interpretation, being the MIRR from increments in research in the period from 1962 to 1978, but would perhaps be more subject to the 'peculiarities' of those years.

The productivity data used here relate to average farm data from ABARE broadacre surveys. One approach to scaling this farm level value to an aggregate value was to multiply the VMP of research for the average farm by the ratio of the gross value of production from broadacre industries to the average farm value of production from the survey data. This ratio was relatively stable and averaged 96,000 from 1953 to 1988.

Measures of Productivity Growth

The data used in this study to estimate productivity growth were obtained from the Australian Bureau of Agricultural and Resource Economics (ABARE)[23] and are described more fully in Mullen and Cox (1994a). ABARE has been collecting farm survey data since 1952-53. In that time the target population for the surveys has been broadened from the Australian sheep industry, defined to include all farms carrying at least 200 sheep, to those engaged in broadacre agriculture in Australia, as covered by the Australian Agricultural and Grazing Industries Survey. The outputs were wool, crop, livestock and a residual category. The inputs were contracts, materials, services, labour, livestock use, and the flow of services from livestock capital, land, and plant and structures. The alternative measures of productivity that we have used are presented in Figure 2 and Table 2.

The most widely used measure of productivity is the Christensen and Jorgenson (1970) total factor productivity (C&J TFP) index formed as the ratio of Tornqvist-Theil approximations of Divisia indices of aggregate output to aggregate input (Table 2).[24] This C&J TFP index rose from 100 in 1953 to 227 in 1987 before declining to 208 in 1988. In 13 years (out of 36) the index fell. Some of the variability in this index can be attributed to changes in weather and a weather variable was used in the models below. The average rate of growth was 2.3 percent per year.[25] This is very similar to the rate of growth of 2.2 percent reported by Males *et al.* (1990) for broadacre agriculture in Australia between 1977 and 1988 but is a little lower than estimates from a range of sheep industry studies reviewed in Scobie, Mullen and Alston (1991). Although cross country comparisons should be made cautiously, a rate of productivity growth of 2.3 percent is larger than those reported by Thirtle and Bottomley (1989, p.1077) from several studies of U.K. agriculture and those reported by Alston, Chalfant and Pardey (1993, p.9) from several studies of U.S. agriculture.

While the Christensen and Jorgenson TFP Index is widely used and easy to estimate, there are concerns that the estimate of productivity

23 We are particularly grateful for the assistance of Phil Knopke both in assembling the data and painstakingly explaining his approach to us.

24 Other recent studies to use this approach include Males *et al.* (1990) and Ball (1985). In constructing indices of aggregate quantities of inputs and outputs we used direct price and implicit quantity indices rather than the reverse. This choice is discussed in Mullen and Cox (1994a).

25 Obtained by regressing the log of TFP against a time trend.

FIGURE 2
Measures of Productivity Growth

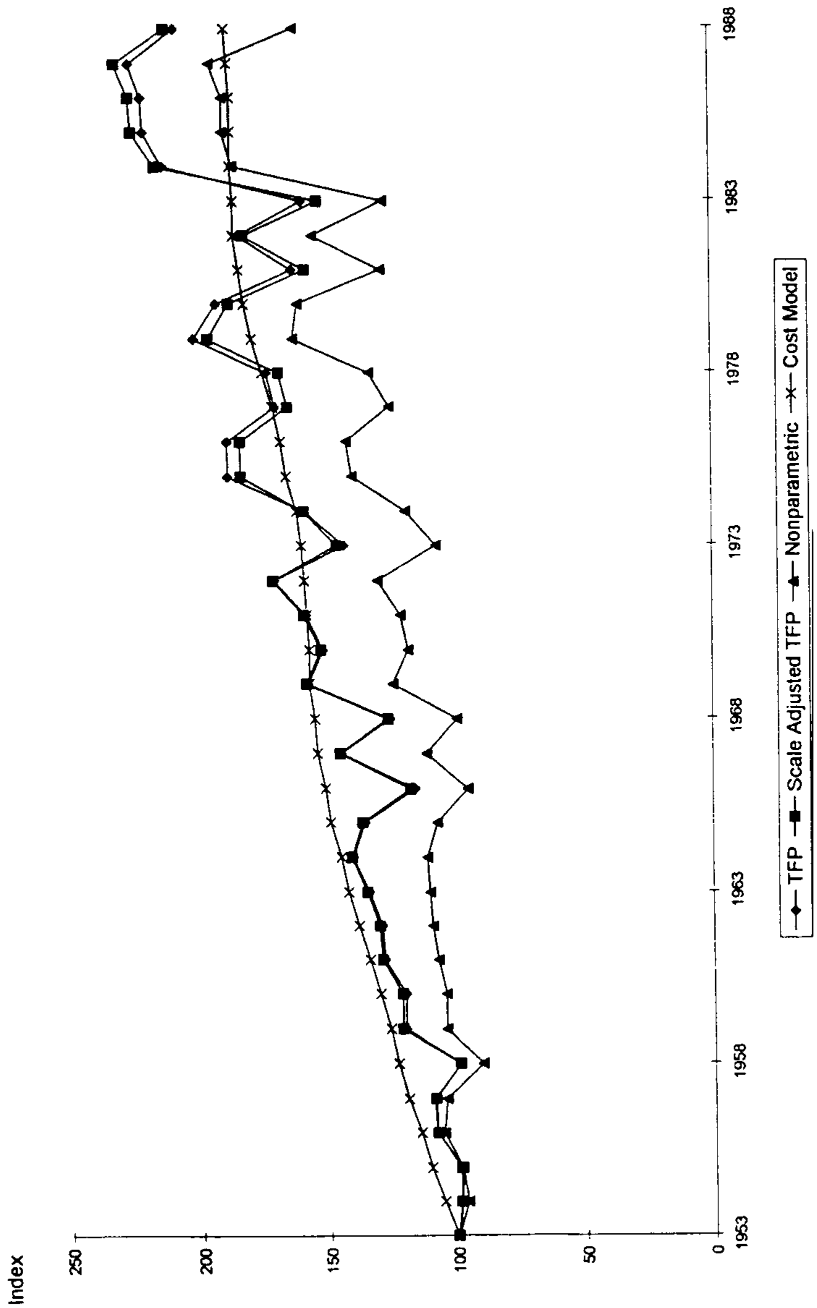


TABLE 2
Alternative Measures of Productivity Growth

	C&J	CCD	C&C	COST
1953	100	100	100	100
1954	98	99	96	105
1955	98	99	98	110
1956	108	108	105	114
1957	109	108	104	119
1958	98	99	90	123
1959	120	121	104	126
1960	120	121	104	130
1961	128	129	107	134
1962	129	130	109	138
1963	134	135	110	142
1964	140	141	111	145
1965	135	136	107	149
1966	116	117	95	151
1967	144	145	111	154
1968	125	126	99	155
1969	157	158	124	157
1970	152	153	118	157
1971	158	159	121	158
1972	171	171	130	159
1973	143	146	107	160
1974	159	159	119	162
1975	189	184	140	166
1976	189	184	142	168
1977	170	165	125	171
1978	173	169	133	175
1979	202	196	163	179
1980	193	188	161	182
1981	163	158	128	184
1982	184	182	155	186
1983	159	153	127	186
1984	213	216	186	187
1985	221	225	190	187
1986	221	226	190	187
1987	226	232	195	188
1988	209	212	162	189
Av. Rate	2.3%	2.2%	1.8%	1.6%

C&J: Christensen and Jorgenson index
CCD: Caves, Christensen and Diewert index allowing scale adjustment
C&C: Chavas and Cox nonparametric measure
COST: Measure from translog cost model

growth from it may be biased because it assumes constant returns to scale and a translog functional form. Mullen and Cox (1994a) report a number of alternative measures of productivity which relax these restrictions. Caves, Christensen and Diewert (1982) developed an approach based on Malmquist indices, the CCD measure, that allowed the assumption of constant returns to scale to be relaxed. While there was some evidence of decreasing returns to scale, there was little difference in the behaviour of the C&J and CCD indices as can be seen in Figure 2. This suggests that deviations from constant returns to scale may be quite modest. The CCD annual rate of growth was estimated to be 2.2 percent.

Chavas and Cox (1994) have developed TFP measures (C&C in Table 2) using nonparametric methods which do not impose a particular functional form. The average rate of growth in productivity from this measure using a disaggregated outputs and inputs specification was 1.8 percent. This suggests that imposing a translog functional form may be an undesirable restriction on the nature of technology in this industry and may result in the rate of productivity growth being overestimated.

The CCD and C&C approaches measure productivity as the radial rescaling of inputs or outputs necessary to return to the frontier isoquant or production correspondence. When the technology exhibits constant returns to scale as imposed in the C&J approach, the output and input based measures are the same. Drawbacks of these approaches are that they do not provide goodness of fit statistics for their estimates of productivity growth nor do they allow for non-radial rescaling of inputs and outputs or biased technical change.

Mullen and Cox (1994a) also derived a measure of productivity from a restricted translog cost model of Australian broadacre agriculture (COST). This model suggested that technology was not homothetic; was characterised by decreasing returns to scale; and that technical progress has been biased. The short run annual rate of productivity growth was estimated to be 1.6 percent. Comparing the plot of the productivity measure from this cost model (which included a weather term), with the plots of the other measures (which did not include weather adjustments), demonstrates the extent to which weather has contributed to short run variability in productivity growth in broadacre agriculture (Figure 2). These findings must be qualified to the extent that the estimated model did not meet all the requirements of a well behaved cost function and the translog functional form was maintained.

The Impact of Research from Total Factor Productivity Models

The form of the TFP models estimated in this paper was:

$$TFP=f(RES(L), EDUC, TOT, WEATHER)$$

where TFP is one of the four indices of total factor productivity; RES(L) is real research expenditure with a lag profile of L years to which has been added real extension expenditure lagged over three years and deflated by a factor of 10 as described above; EDUC is the education variable; TOT is ABARE's terms of trade index; and WEATHER is an index of pasture growth based on rainfall. The WEATHER index was not an explanatory variable in the model in which the productivity measure was derived from a translog cost function because it had already been included there.

All variables were expressed as logarithms of their levels as has been the practice in most past studies. We found little difference in the econometric properties of log and linear specifications and little evidence to prefer one over the other. We applied the non-nested J and JA tests as described by Doran (1993) to both specifications estimated over 1953 to 1988 and 1968 to 1988. Both linear and log specifications of all models were acceptable under the JA test but both specifications failed the J test. From an economic viewpoint, Mullen and Cox (1994b) found that the choice of a log specification resulted in lower IRR's than did the corresponding linear model.

Collinearity between research expenditure and a trend variable meant that we were unable to estimate the separate effects of both these variables. In general the addition of a trend variable did not significantly increase the explanatory power of the models and resulted in the research variable becoming insignificant as well. The exceptions to this were the CCD and C&C models estimated over the longer observation period.

Models were estimated with a 16 year inverted-v research profile over the 1968 to 1988 period and with a 34 year trapezoidal profile over the 1953 to 1988 period (which required extrapolating the research series backwards). As in Mullen and Cox (1994b), we found that the value of the likelihood function increased as the lag length increased but that the increase was not statistically significant.[26] The exception to this was the model based on the translog cost function estimate of productivity. For this model the maximum value of the likelihood was associated with a lag profile of about 20 years.

Models were estimated with each of the four alternative productivity measures as the dependent variable. A difficulty of this approach is that because the dependent variables are not transformations of each other, non-nested testing approaches cannot be applied to discriminate between the models. One strategy in this situation would be to choose the measure of productivity that was derived with the least imposition of structure on the underlying technology. Perhaps the most attractive measures on this basis are those derived using the Chavas and Cox (1994) nonparametric approach and from Mullen and Cox's (1994a) translog industry cost model. The Chavas and Cox approach imposes neither a translog functional form nor constant returns to scale. Mullen and Cox's industry cost model imposes a translog functional form and the estimated elasticities

[26] Davis (1980) found little sensitivity to lag length and went on to suggest that it may be unnecessary to aggregate research expenditure in the way we have done.

are short run in nature but neither constant returns to scale nor neutral technical change is imposed.

However, as can be seen from Table 3, neither of these models performed as well as either the Christensen and Jorgenson measure or the scale adjusted variant of this measure. In these latter models, all variables had their expected signs and were statistically significant, at least over the 35 year observation period. Their R^2's were high and there did not appear to be a problem with autocorrelation. The problem with the Chavas and Cox model was that it suggests that education has had a significant negative relationship with productivity growth for which there is no obvious explanation. The translog cost model had a similar problem with education, at least for the 1968–1988 period and also had serial correlation problems.

Despite the problems with some of these models, the estimated internal rates of return to research are very similar. Over the 1968–1998 period when a 16 year lag profile was used (and research, and extension deflated by a factor of 10, were aggregated), the IRR appears to have been about 30 percent. Over the longer observation period and with a 34 year lag profile imposed, the IRR has fallen to about 17 percent. This decline arises from two sources. First the benefits of research are being spread over a much longer period. Second the research coefficients for the shorter period (0.20 for the CCD model) are much larger than for the longer period (0.15 for the CCD model). To give a better indication of the relative contribution of these two factors, the CCD model was estimated over the 1953–1988 period and a 16 year lag profile was imposed. The research coefficient for this model was 0.14 and the IRR was only 16 percent.

Clearly if the research coefficient does not increase as the lag profile lengthens, the IRR declines as the impact of research is spread over more years. The qualifications to this conclusion are first, that in adapting Huffman and Evenson's 35 year profile and using an inverted-v profile for lag lengths of 16 years and shorter, we did not consider a wide range of range of shapes for research profiles. Second, the conclusion may be peculiar to this dataset in which apart from a trend, there is little variation in the expenditure series and probably in the productivity series once seasonal effects are removed.

The difference of 0.14 versus 0.20 in research coefficients for the CCD models with 16 year lag profiles, provides some evidence that the productivity of research is higher in the period since 1968. While a number of factors can be identified that may have contributed to this, such as the development of the rural industry research funds and more sophisticated management techniques, the data set and our modelling techniques are not rich enough to test this hypothesis.

Estimates of the internal rate of return to extension were more variable. They were 40 and 45 percent for the 16 and 35 year profiles from the CCD model.

It is important also to remember that these rates of return accrue to the whole industry and not just to Australia. Mullen, Alston and Wohlgenant

TABLE 3
Estimates of Research Models with Alternative Measures of Productivity

	1968–1988		1953–1988	
	Coefficient	t–stat	Coefficient	t–stat
Christensen & Jorgenson TFP Index:				
constant	–6.31	–0.72	–5.84	–1.87
research/ext.	0.22	2.22	0.16	3.44
terms of trade	–0.27	–1.92	–0.27	–2.52
education	2.11	0.98	2.22	3.05
weather	0.26	3.22	0.04	5.19
R^2	0.83		0.95	
D–W	1.73		2.02	
Internal Rate of Return	30%		17%	
Caves Christensen & Diewert TFP Index:				
constant	–4.87	–0.48	–6.02	–1.72
research/ext.	0.20	1.75	0.15	2.90
terms of trade	–0.28	–1.73	–0.27	–2.30
education	1.81	0.72	2.29	2.81
weather	0.29	3.06	0.21	4.66
R^2	0.79		0.94	
D–W	1.83		1.82	
Internal Rate of Return	28%		17%	
Chavas and Cox TFP Index:				
constant	10.75	0.90	12.94	3.11
research/ext.	0.31	2.28	0.14	2.30
terms of trade	–0.31	–1.59	–0.38	–2.73
education	–2.10	–0.71	–2.00	–2.07
weather	0.32	2.87	0.24	4.45
R^2	0.80		0.89	
D–W	1.83		1.77	
Internal Rate of Return:	32%		14%	
Translog cost model index of productivity (corrected for first order serial correlation):				
constant	12.49	15.37	0.94	0.49
research/ext.	0.24	31.27	0.26	9.36
terms of trade	–0.02	–2.60	0	0
education	–2.25	–11.67	0.35	0.78
R^2	0.99		0.99	
D–W	1.48		0.70	
Internal Rate of Return	30%		24%	

(1989) found that about 60 percent of the benefits of new production technology in the wool industry accrue to Australia. For broadacre industries as a whole, demand is likely to be less elastic than for wool; supply in aggregate at least as inelastic and the proportion of output exported smaller, hence Australia seems likely to capture a larger share of the benefits than sixty percent. Perhaps 25 percent of the benefits from research induced productivity growth in broadacre agriculture are captured by non-residents of Australia.

Concluding Comments

In this study, a common research strategy used in past U.K., U.S. and N.Z. studies of returns from investment in research by the public sector has been adapted in an attempt to measure the returns from research in broadacre agriculture in Australia. This research strategy has presumed that there is an underlying long term relationship such that investment in research gives rise to increased productivity. Some recent studies have investigated these presumptions. Schimmelpfennig and Thirtle (1994), using cointegration analysis, concluded that productivity and lagged research expenditure were cointegrated and hence that there was a long run relationship between the two for the U.K., the U.S. and ten EC countries. Both Schimmelpfennig and Thirtle (1994) and Pardey and Craig (1989) using time series techniques have concluded that research 'causes' productivity, although both studies also noted evidence of simultaneity between investment in research and growth in productivity. These issues have not yet been examined in the research program reported here but maintained hypotheses are that the findings of these two studies also apply to public sector rural research in Australia.

The econometric techniques used above were not powerful enough to resolve some important issues such as the length and shape of the research lag profile and the separate contributions of research and extension to productivity growth. The sensitivity of returns from research to alternative ways of modelling lag profiles and research and extension was examined. In future research with a longer series of research expenditure it may prove useful to apply time series techniques such as those used (with limited success so far) by Schimmelpfennig and Thirtle (1994) and by Pardey and Craig (1989) to shed more light on these issues. It seems highly probable however that the present data set is not rich enough to allow these issues to be resolved even with more sophisticated econometric tools. Unravelling the separate effects of research and extension is always likely to be difficult because of the way in which a large proportion of research and extension funds are allocated within State Departments of Agriculture. It may also be unreasonable to expect the identification of a stable lag profile and this problem was noted by Schimmelpfennig and Thirtle (1994). At least some of the recent changes in research administration have been motivated by desire to reduce lags in the adoption of new technology

The estimation procedure employed here can be described as being two stage in which a measure of productivity is derived in the first stage and this measure is regressed against explanatory variables including research, in the second stage. While this procedure is the most widely applied in studies of returns to research, it does impose separability restrictions on the nature of technology, the most obvious one being neutral technical change, that may bias estimates of returns to research. In future research we hope to incorporate research into a nonparametric analysis of productivity as in Chavas and Cox (1992). In similar fashion, research could be incorporated into the translog cost model developed by Mullen and Cox (1994a) as suggested by Clark and Youngblood (1992).

Based on the results reported here and in Mullen and Cox (1994b) it would seem that the returns to research in broadacre agriculture in Australia may be in the order of fifteen to forty percent. The low rate is associated with a log specification of the Chavas and Cox measure for a 34 year research profile and the high rate is for a linear specification of the Chavas and Cox measure with a 16 year research profile. This is larger than the rates of return hypothesised by Scobie, Mullen and Alston (1991) but is smaller than some of the estimates of the return to research in other countries noted at the start of this paper. Given the uncertainty associated with any of these estimates, the differences are small and hence it is difficult to assert that Australia's agricultural research industry performs better or worse than the research industries of other countries.

There has been much speculation about whether there has been underinvestment in agricultural research in Australia. From a narrow perspective we could argue as did Alston, Pardey and Carter (1994) that agricultural research has been a good public investment because government could borrow funds at less than 20 percent. However in a broader context, any assessment of whether Australia is underinvesting in public research must be made in the context of the opportunity cost of agricultural research funds in both other public investments and in private uses.[27] Perhaps less is known of the opportunity cost of agricultural research investments than of the returns from agricultural research itself. Despite this lack of knowledge of opportunity cost, Harris and Lloyd (1991, p24), concluded that there was evidence of high rates of return to agricultural research and because of market and government failure, underinvestment was a credible hypothesis. The fact that the rates of return from research reported here are much lower than expectations based on past analyses of individual projects, means that the underinvestment hypothesis is less likely to be true. We follow Fox (1985) in arguing that there is little evidence of a wide divergence between the return from public investments and the social returns from private investments. Hence there does not

[27] We also recognise that government involvement in enhancing the efficiency of agriculture needs to be justified by the existence of market failure as well as the opportunity to earn high rates of return.

appear to be a strong basis for arguing either that there is under- or over-investment by government in agricultural research and extension in Australia.

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