R&D and Productivity Growth in Australian Broadacre Agriculture

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Abstract

Many people share the view that too little is invested in R&D in agriculture. In the context of Australian agriculture, benefit/cost analyses of individual projects and some large programs lend support to this view. However the lack of a long data series on R&D expenditure has precluded the analysis of the relationship between R&D and productivity growth for the large broadacre component of the Australian agricultural sector. The objective of this paper is to examine this relationship using data from ABARE's survey of broadacre industries and a new data series on R&D expenditure for the period 1953 to 1988.

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1. Introduction

Views widely held, at least in the agricultural research community, are 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. Echevarria (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 and hence provided support for these views. In recent US studies, Huffman and Evenson (1993) estimated that the returns to public research were 45 and 11 percent for the crop and livestock industries and Chavas and Cox (1992) estimated that the returns in aggregate were 28 percent. Thirtle and Bottomley (1989) estimated in the UK, the rate of return was about 100 percent. In a study of New Zealand agriculture, Scobie and Everleens (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).

More specific analyses of the underinvestment hypothesis have been conducted in the US by Fox (1985) and in Australia by the Industries Assistance Commission (IAC, 1976) and Harris and Lloyd (1990). Fox (1985) concluded that the level of public research expenditure in the US 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. The IAC (1976) seemed to be looking for an each way bet arguing at one point that there was 'inadequate evidence at the present time to justify a continuation of such a rapid expansion (in public research expenditure) as has been occurring'. This was followed almost immediately by the conclusion that 'rural research has a high social return, particularly when account is taken of the external benefits to the community' (IAC, 1976 p.1)[1]. Harris and Lloyd (1990) reviewed arguments for and against the underinvestment hypothesis, noted 'rates of return which seem unrealistically large' (Harris and Lloyd, 1990, p19) but found the consistency of findings reassuring and noted arguments which might explain the persistence of high returns and of underinvestment in research.

Generally speaking the focus of these studies has been on public rather than private research. Evenson and Huffman (1993) found that the return to private research was 83 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. Only recently has the question of what type of research activities are appropriate for public authorities been seriously addressed 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[2]. 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 from a review of past studies of productivity growth in the Australian sheep industry and an estimate of the level of expenditure on on-farm research by public research institutions in Australia. They hypothesised that from an annual rate of expenditure of $40m (in 1985 dollars), of which only $5m are funded by the wool levy, an annual rate of productivity growth of 1.5 percent might be attained. Using a model of the wool industry developed by Mullen, Alston and Wohlgenant (1989), they estimated that from this investment, 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 of the order of 25 percent. They went on to estimate that the internal rates of return to Australia and Australian woolgrowers of a $10m increase in on-farm research might be about 5 and 18 percent. These rates of return are low but they account for the leakage of research benefits to non-residents of Australia and the excess burden of raising taxes to fund research, issues which will be discussed at greater length below.

In this paper we report progress on a project funded by the Wool Research and Development Corporation which has the objective of empirically analysing the relationship between productivity growth and investment in research in Australia's broadacre agriculture. An important part of the project has been to assemble a database on research expenditure by Departments of Agriculture, CSIRO and the major universities and the results of this are briefly described below. Another important component of the project has been to measure productivity growth in broadacre agriculture using index number, econometric and nonparametric techniques and the results of this are also briefly described below. We have also attempted to use these three techniques to measure the contribution of research to productivity growth. This work is not yet complete and the focus of this paper is on the relationship between the traditional Christensen and Jorgenson (1970) total factor productivity index and research expenditure.

2. The Relationship Between Research and Productivity Growth

Our objective is to estimate the contribution of research to productivity growth in Australia's broadacre agricultural industries. The product of investment in research is a lagged increase in the stock of technology or knowledge which yields a flow of benefits to producers and consumers over many years. Changes in this stock of knowledge cannot be measured directly. Most often, a flow of past expenditures on research has been used as a proxy for the annual flow of services deriving from this stock variable. 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).

More 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 (1994). Most of this literature examines this relationship from a primal or production function viewpoint. However the relationship can also be viewed from a dual perspective. Following the latter authors, a reduced form cost model can be written as:

1. $$C_t = c(Q_t, W_t, F_t, R_t, \ldots, R_{t-r}, E_t, \ldots, E_{t-e}, H_t, Z_t)$$

where Q_t is a vector of outputs from broadacre agriculture, W_t is a vector of input prices, F_t is a vector of fixed inputs, R_t is a series of past expenditure on broadacre research, E_t is a series of past investments in extension, H_t is the stock of human capital of farmers from education, and Z_t is a vector of other variables influencing productivity such as weather and a time trend which might pick up the impact of changes in communication, transport etc. This relationship could be similarly represented by profit or production functions.

It should be noted that Australian agriculture borrows technology from other countries and the model above could be complemented with variables reflecting research investments in countries with similar agriculture to that of Australia. Note also that investment in agricultural research has private and public components.

Alston, Norton and Pardey (1994) identified three categories of approaches to estimating the relationship between productivity and research. The parametric approach involves econometric estimation of a production relationship specified in terms of production, cost or profit functions or in terms of an ad hoc single equation supply response model. In addition to conventional inputs (or their prices), measures of 'non-conventional' inputs such as the stock of technology or knowledge, the flow of extension services and the level of education of farmers have been directly incorporated in these models. This can be termed a one-step procedure and is the preferred approach. We attempted this approach by incorporating a research variable into the cost function used by Mullen, Cox and Foster (1992). We were not successful despite adequate degrees of freedom because of a singularity problem which seems to imply that our data set did not contain enough information to allow estimation of all coefficients in this model. In future research we need to reduce the number of interaction terms particularly those involving the research and trend variables. Another approach may be to use a more restrictive functional form such as the Cobb-Douglas as has commonly been done.

An alternative two step-procedure is to approximate productivity growth as an unexplained residual from parametric models using conventional inputs and outputs (or their prices). Ball and Chambers (1982) defined the rate of cost reduction as the derivative of the translog cost funciton with respect to a trend variable. To derive a rate of technical change equivalent to such a measure from a primal model, the rate of cost diminution has to be adjusted for scale effects. Antle and Capalbo (1988, p.45) suggest that this can be done by dividing the series on the rate of cost diminution by the sum of the fitted values of the output revenue shares (in the case of a translog model). This measure of technical progress can then be regressed against non-conventional inputs. We have not yet pursued this approach.

The second category includes non-parametric approaches which involve checking whether the data, that is observed choices concerning inputs and outputs, are consistent with axioms of rational behaviour such as cost minimisation. Nonparametric analysis does not impose a functional form but neither does it provide the usual goodness of fit measures of parametric approaches. Again nonparametric analyses can conducted using one- and two-step procedures.

The third category includes index number procedures and involves a two step estimation procedure. In the first step an index of productivity growth is formed, most commonly as the difference between Divisia indices of growth in outputs and inputs. In the second stage, the measure of productivity growth is regressed against the research, extension and education variables.

We hope to use an approach from each of these categories but in this paper attention is confined largely to the traditional index number approach. The immediate task however is to define the research, extension and education variables that are common to all three approaches.

3. Data Sources for the Research, Extension and Education Variables

Agricultural research and extension in Australia have traditionally been undertaken by State Departments of Agriculture, the large universities and by the CSIRO. An important component of the project reported here was the development of a database on research expenditure in Australian agriculture since 1952. The extent of this database and the way in which it was assembled will be described in detail in later publications[3]. In brief, the data were collected from publicly available financial reports. 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 without resort to arbitrary allocation rules.

Total expenditure by Departments of Agriculture on all activities was collected from publicly available financial statements. Where possible we deducted expenditures associated with government enterprises, such as abattoirs; agricultural colleges; rural adjustment schemes and crisis grants; and expenditure on community services such as animal welfare (domestic) to arrive, as nearly as possible, at expenditure by State Departments on research, advisory and regulatory activities in production agriculture. 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[4]. This allocation rule is often referred to as the congruence model. Fox (p. 452, 1987) 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 a precedence model (Fox, 1987). This is an important decision as it means that there is little information on extension that is independent of research. 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 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.

The 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 these 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 $15.1m in 1953 to $671.3m in 1988. Expenditure grew very slowly until about 1970 and then grew at a very rapid rate until 1988. Relative to the value of GDP in agriculture, this is an increase from 1.0% in 1953 to 5.9% in 1988. Over the same period expenditure on agricultural research rose from $8.4m (0.5% of farm GDP) to $394.6m (3.5%)[5]. Research as a percentage of farm GDP was as high as 6.0% in 1983 (Figure 1). Alston, Chalfont and Pardey (1993, p14) 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). Expenditure on broadacre research in Australia rose from $6.0m in 1953 to $273.9m in 1988. There is a growing divergence between the estimate of expenditure on agricultural research used in this study and the ABS data. In 1989 the estimate used here was about 75 percent of the ABS estimate. As yet no attempt has been made to reconcile these estimates.

Research and extension expenditure were deflated by the price index for total expenditure on goods and services by public authorities. Price indices for research expenditure have only been available from the ABS since 1977-78. We constructed an index of salaries from 1953 for a research officer in CSIRO of 'average' experience and qualifications (what is now referred to as an ES 3M) but this series did not explain changes in the more recent ABS state and commonwealth research indices as well as total expenditure on goods and services by public authorities, hence our choice of the latter as the appropriate deflator. In real dollars expenditure on broadacre research grew linearly until about 1970. Since then the rate of growth of expenditure has been slow and has declined from its maximum in 1983 (Figure 2). The construction of lagged research and extension variables is discussed in following sections.

Data on agricultural research conducted by the private sector in Australia is only available for the limited period covered by the ABS. In other countries such as America and the UK, private sector research is a large as public sector research but it appears to be much smaller in Australia. The Industries Assistance Commission estimated that private research only amounted to seven percent of total rural research in Australia in 1973/74 (IAC, 1976, p31). We have made no attempt to incorporate private research in our analysis. 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.

Productivity growth in Australian agriculture is also likely to be affected by research in other countries. The issues involved in accounting for 'spillover effects' are discussed in Alston et. al. (1994), Huffman and Evenson (1993) and Davis, Oram and Ryan (1987). American R&D in particular is expected to have an impact in Australia. In a crude attempt to account for this impact we used data series on US public and private agricultural R&D from Chavas and Cox's (1992) study but originally assembled by Huffman and Evenson (1993) . We made no attempt to identify those components of these series that were most likely to 'spillover' to Australia because of industry and climatic similarities. Another difficulty is that, at least in part, US R&D is likely to affect Australian productivity through its influence on Australian R&D. The US data series starts in 1900 but only extends to 1984, 4 years shorter than the Australian series. We have had little success in using US R&D expenditure to explain productivity growth but have not pursued the question exhaustively[6].

The level of education of farmers, reported in Table 1, is also 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 enrolment to the potential number of students (the number of people aged 5 to 19)[7]. This variable has several deficiencies which need to be addressed in future research. First it is an indirect measure of the educational attainment of the population of Australia rather than of its farmers[8] although as Roy Powell (pers. comm.) pointed out, the qualifications of the advisers to farmers are also important. Second, this variable fluctuates more than we would perhaps expect suggesting that it has not been measured well. Certainly it is unclear what effect short term fluctuations in the enrolment of children 5 to 19 have on the educational attainment of the population of farmers. We smoothed the data by using a five year moving average of the raw series. It also seems likely that this variable, a measure of current school enrolment, will have a lagged relationship with productivity growth. We found that a five year lag seemed to perform best.

Other variables used to explain productivity growth have included the terms fo trade faced by farmers and a weather variable, reported in Table 1. 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 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' (p.7). The weather variable was always an important variable explaining productivity growth but collinearity with other variables made it difficult to identify the contribution of the terms of trade variable.

4. Research Lag Profiles

As alluded to above, the impact of research expenditure in a particular year may not increase productivity at all for several years and then persist for perhaps thirty years. In the case of US agriculture, 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. 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.

To reduce problems of multicollinearity and to conserve degrees of freedom, the usual practice in econometric modelling has been to construct a research variable as a function of past annual research expenditures. For example, in logarithmic form, the research variable may be measured as:

$$2. \quad \ln R_t^* = \sum_{r=0}^{L_R} \lambda_r \ln R_{t-r}$$

where L_R is the length of the lag and the λ_r variables reflect the shape of the lag profile linking research expenditure with productivity growth. 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 (1994). 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. Any econometric analysis is often subject to a strong maintained hypothesis.

Evenson (1988), for example, maintained the trapezoidal profile and tested various lengths of rising, constant and falling weights[9]. 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 (Ravenscroft and Scherer, 1982) and a form -free approach suggested by Hatanaka and Wallace (1980) 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.

A major limitation of studies of this nature is the number of observations available. Whereas Pardey and Craig (1989) had 93 observations, most studies have far fewer than this. The present study is limited to the 36 observations between 1953 and 1988. We have decided to limit the research lag profile to 16 years, leaving 21 years of data for identifying sources of productivity growth[10]. Some degree of support for this is provided by Hastings (1989) who examined Almon quadratic lags ranging from 12 to 30 years and chose the twelve year profile on the basis of highest R^2 [11]. 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.

We concentrated on inverted V lag profiles ranging in length from 6 to 16 years. The lag coefficients, λ_r, for an inverted V lag profile are given by:

$$\lambda_r = r\lambda \quad \text{for } 0 \le r \le L_R/2$$
$$= (L_R - r)\lambda \quad \text{for } L_R/2 \le r \le L_R$$

where L_R is the lag length, r takes successive values from 0 to L_R, λ_0 and λ_{LR} are constrained to be zero and

$$3. \quad \ln R_t^* = \sum_{r=0}^{L_R/2} r \ln R_{t-r} + \sum_{r=L_R/2+1}^{L_R} (L_R - r) \ln R_{t-r}$$

where the series of research expenditure, R_t, was deflated using the index described above. In implementing this model we divided the r's by their sum to ensure they added to one. The research coefficient associated with $\ln R^*_t$, λ, is an estimate of the change in the measure of productivity growth, the dependent variable, arising from a one unit change in stock of knowledge in the current year. The impact of a change in research expenditure in year t-r is given by λ_r. Similar expression can be derived for constructing trapezoidal lag profiles. The aggregated research variables for lag lengths of 6 to 16 years are presented in Table 2. The trend in all these derived knowledge stock variables is very similar. They show that since 1968, the first year in which data for a 16 year lag profile is available, expenditure on broadacre research increased at a decreasing rate.

The standard procedure as described by Huffman and Evenson (1993), to choose between models which are estimated over the same observation period and which only differ by the length of lag profile, is to use the criterion of minimising the sum of squared residuals. Surprisingly there seems to be little attention paid in past studies to assessing whether the differences in the sum of squared residuals between models is statistically significant, although Davis (p 75, 1980) had found little difference in the research coefficient between several alternative lag structures and went on to conclude that 'Unless specific estimates of the partial research production coefficients are required it is appropriate to use current research expenditures or a simple average...'. In the empirical work below we have tested whether the different lag structures have significantly different explanatory powers using a likelihood ratio test.

Our expectation was that models based on the 16 year lag profile would be preferred to models based on shorter lag profiles. Our concern was if the research lag profile was as long 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 overstated. While we can conceive of research projects of a highly applied nature that may have an immediate impact on productivity, the results of many projects do not become available for several years and have an impact far longer than 16 years.

5. The Impact of Extension

Extension activities are expected to have an impact on productivity but past studies have had varying degrees of success in measuring the impact of extension that is separate from research. Some studies have simply aggregated research and extension implying that their impacts on productivity are the same in magnitude and timing. Davis (1979) pointed out that another rationale for adding research and extension is that they are complementary inputs used in fixed proportions. Again this is a strong restriction but given the difficulties encountered in this study of estimating extension expenditure, it is an approach to be examined in futrue research. Other studies have regarded extension as adult education and incorporated it into the education variable. However an important rationale for extension services in Australia has been to promote the more rapid adoption of new technology generated by research. Hence the preferred approach is to include extension as a separate variable but one which has a different lag profile to research.

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 80 percent, a higher return than to research. Most other studies have been less successful. 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. Problems of this nature raise uncertainties about the interpretation of the coefficient associated with the research variable. The issue is the extent to which this research coefficient picks up the influence of the omitted or misspecified variables.

The approach adopted by Davis (1979) seems to have been to estimate models with and without extension and after noting little change in the research coefficient proceed to use the research coefficient from the model including extension, apparently satisfied that bias was not a problem. Thirtle and Bottomley (1989) added research and extension expenditure in the denominator when calculating a rate of return but they still referred to their estimate as a return to research rather than a return to research and extension. The problem with either omitting extension or measuring it with error is that the estimates of the other coefficients are to some extent biased and inconsistent. The extent of the bias depends on the correlation between research and extension[12] which we might expect to be positive but to decline as the relative lag lengths between research and extension increases. Perhaps the research coefficients estimated in past studies that have either omitted extension or measured its effects imprecisely, can best be interpreted as the effects of both research and extension. Another interpretation could be that extension has no impact on productivity.

In this study, because total expenditure by Departments has been allocated between research, extension and regulatory activities using a fixed proportions rule, the only chance of identifying a separate contribution to productivity growth from these functions was through differences between states in these allocation rules and through the different lag profiles for research and extension. However, as detailed below, we had little success in estimating the contribution of extension to productivity growth. No doubt the high degree of collinearity between extension and research arising from the allocation rules we used is largely responsible for this problem[13]. As a consequence it seems most likely that our research coefficient is measuring the impact of both research and extension.

To ameliorate this problem we need new information such as the ratio of research to extension personnel in Departments through time to allow greater variation between research and extension expenditure. However it seems to us that because research and extension funds come from the same source and because precedence is likely to be an important principle guiding the allocation of funds, there will always be a high degree of collinearity between research and extension. More sophisticated econometric techniques than we have used to date will be required to separate the influences of the two.

6. Measures of Productivity Growth

The data used to estimate productivity growth were assembled from ABARE's sheep industry and grazing industries surveys and its price series[14]. It extended from 1953 to 1988 and included producers with more than 200 sheep. The outputs were wool, crop, livestock and a residual category. The inputs were contracts, materials, services, labour, livestock use, livestock capital, land and plant and structures.

There are alternative measures of productivity growth which can be used as dependent variables in second stage models seeking to estimate the contribution of research to productivity growth. The reference scenario is the traditional

Christensen and Jorgenson (1970) total factor productivity (TFP) index formed as the ratio of Divisia indices of aggregate output to aggregate input (Table 3). In 16 years (out of 36) the index fell. There is little apparent trend in the rate of growth of productivity although perhaps the growth rate has become more variable. 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 TFP index rose from 100 in 1953 to 218 in 1987 before declining to 206 in 1988. The average rate of growth was 2.3 percent per year[15]. 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 UK agriculture and those reported by Alston, Chalfont and Pardey (1993, p.9) from several studies of US agriculture.

Mullen, Cox and Foster (1992) pointed out that the Christensen and Jorgenson TFP index may be biased because it is based on assumptions of constant returns to scale and an underlying translog production function. Using the same data set, they found that nonparametric analysis did not support an assumption of constant returns to scale and derived several alternative estimates of productivity growth. In general these alternative measures of productivity growth suggested that the traditional TFP measure overestimated the rate of productivity growth.

We noted above that other measures of productivity growth in broadacre agriculture can be derived using nonparametric analysis and from a cost function approach but we have not yet pursued these approaches.

7. The Impact of Research from Total Factor Productivity Models

The general form of the TFP models was:

4. $TFP = f(RES(L), EXT, EDUC(-5), TOT, RAIN, T, T^2)$

where TFP is the total factor productivity index; RES(L) is deflated research expenditure with an inverted v lag profile of L years; EXT is deflated extension expenditure lagged over three years as described above; EDUC(-5) is the education variable lagged five years[16]; TOT is ABARE's terms of trade index; RAIN is the weather index based on rainfall; and T and T^2 are the trend variables. All variables except the trend variables were expressed as logarithms of their levels as has been the practise in most past studies[17].

As noted above there was a trade-off to be made between the length of the research lag that could be examined and the length of the observation period over which the relationship between productivity growth and research expenditure could be estimated. Our initial strategy was to examine research lags of up to 16 years which implied that the relationship was estimated over the 21 years from 1968 to

1988.

As expected the main difficulty we encountered was that of multicollinearity. The research, extension, terms of trade and trend variables were all highly correlated (0.80 or higher). Estimated models has R^2's of 0.85 or better and Durbin–Watson statistics of around 2.0 but generally only the coefficient on weather was significantly different from zero. The extension variable was always negative which we cannot explain[18]. The best strategy to increase the number of significant coefficients was to drop both the extension and terms of trade variables. For models with research lags of up to 10 years this generally resulted in a small but significant fall in the models' explanatory powers (as measured by a log likelihood test) and an increase in the research coefficient. For longer research lags there was not a significant change in explanatory power and the research coefficient declined slightly. Details of the full and reduced models for the 10 year lag profiles over the 1968/1988 and the 1962/1988 period are provided in Table 3. As a test for misspecification, the models were subjected to a RESET test by adding as explanatory variables second, third and fourth power terms of the fitted values of the dependent variable. In all cases the change in the value of the log likelihood function was not significant.

The models without the extension and terms of trade variables had several notable features. The trend term was negative and significant, indicating that TFP would decline at rates of around four percent per year but for the influence of research, education and the weather. It is difficult to discern how the left out variables, extension and the terms of trade, which has its expected negative sign, can explain this trend. These variables were positively and negatively correlated with the trend variable respectively. A second feature of the reduced models was that the constant terms for the better models were generally significant and always negative suggesting that without expenditure on research and education, productivity would decline.

In estimating the returns to research below, we have used the full models in the expectation that these models provide the least biased estimates of the research coefficient but suggest that this coefficient probably represents the impact of both research and extension.

Our intention was to discriminate between research lag profiles of different lengths on the basis of a significant difference in the value of the log likelihood function. A difference is significant when twice the difference exceeds a critical χ^2 statistic which for one degree of freedom is 3.84 at the 95 percent confidence level. A summary of the values of the research coefficients, their t–statistics, and the value of the log likelihood function for a range of models varying in the length of research lag profile and observation period over which the models were estimated is presented in Table 4. The critical value for the t–statistic at a 90 percent confidence level and 27 observations is 1.703.

It is difficult to draw definitive conclusions about lag length from these results. While a lag length of 6 years performs poorly in all observation periods, the differences in the log likelihood function are rarely significant for the other lag lengths. Note that we confined our attention to the inverted v lag profile after finding that the trapezoidal profile preferred by Huffman and Evenson (1993) offered no significant changes in the log likelihood value. For the full models, a ten year lag length always gave the highest log likelihood value but with the exception of the 16 year lag model, the differences were not significant. For the reduced models, lag lengths of 14 and 12 years give larger, though not significantly larger, likelihood values in the 1966/88 and 1964/88 observation periods respectively. For the two longest observation periods there are few significant coefficients apart from weather.

In general, the research coefficient declines with increases in both the lag length and the length of the observation period. 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. We tested the use of the log of unaggregated research expenditure for the current year and for lags of up to 16 years as an explanatory variable in place of the aggregated research variables but all models using these unaggregated variables performed poorly. This sensitivity to the length of the observation period suggests that a data series on research expenditure from 1953 to 1988 is still too limited.

More importantly a lag length of only ten years as suggested by our results seems to be too short. This may be appropriate for very applied demonstration type research but it is not difficult to think of projects that affect productivity for longer periods than ten years. The fact that the 14 and 16 year lag models were not preferred to the ten year models suggests that the problem is not just one of more data but one of model specification as well.

The variability of the research coefficient as the observation period changed suggested that perhaps it was related to time. To test this an interaction term between the research variable and the time trend was added to each model. In no case did this variable significantly enhance the explanatory power of the model although it was positive.

8. Estimating the Returns to Research

Having established a relationship between productivity and research expenditure, the next steps are first, to value the contribution of research, the value of the marginal product of research, and second, to estimate the return to the investment in research, the marginal internal rate of return, the MIRR. 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 is an estimate of the elasticity of total factor productivity, TFP, with respect to the research stock variable, R_t^*, in equation 2. Of more practical interest is the elasticity of TFP with respect to research expenditure in year t−r, λ_{t-r}. The profile of λ_{t-r}'s is derived by multiplying the research coefficient by the normalised series of weights (r/Σr). The marginal product in year t of a unit increase in research expenditure in year t–r is:

$MP_{t,t-r} = \lambda_{t-r} . TFP_t / R_{t-r}.$

The value of the marginal product is:

$VMP_{t,t-r} = \lambda_{t-r} . TFP_t . P_t / R_{t-r},$

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.

A change in R in year t–r 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:

$$5. \qquad TVMP = \sum_{r=0}^{L_R} \frac{\lambda_{t-r} TFP_{t-r} P_{t-r}}{R_{t-L_R}(1+r)^i}$$

where i is the interest rate. The marginal internal rate of return 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. 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 λ, the research coefficient.

Returning to equation 5, the $TFP_{t-r}.P_{t-r} / R_{t-lr}$ 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[19]. To overcome this problem, the general practice in past studies has been to set TFP, P and R at their geometric means but as Alston, Norton and Pardey (1994) point out, this 'averaging' procedure does not have an exact economic interpretation.

Recall that the productivity data used here relate to average farm data from sheep specialists in the ABARE broadacre survey. One approach to scaling this farm level value to an aggregate value is to multiply by the number of broadacre farms. However the number of farms fell from 101,000 in 1977/78[20] to 80,000 in 1987/88 making the choice of scaling factor difficult. The ratio of the gross value of production from broadacre industries to the average farm value of production from the survey data was more stable at an average of 96,000 from 1953 to 1988 and

93,000 in 1988. We multiplied the VMP of research for the average farm by 96,000 in all scenarios[21].

Fox (1985) raised the issue that consideration be given to the excess burden of raising taxes to fund research when estimating returns to public research. Findlay and Jones (1982) have suggested that the marginal welfare cost of government spending in Australia is in the range of $1.23 to $1.65 per dollar of revenue raised by personal income taxation. We have assumed that the excess burden is $1.40 and hence the 'cost' of unit of research is $1400 rather than $1000[22].

We examined two scenarios here. In the first scenario, TFP, P and R were set at their geometric means for the particular observation period and the excess burden of taxation issue was ignored so that a unit of research cost $1,000. This scenario provides estimates of the returns to research that are most similar to those presented in other studies. In the second scenario they were set at their 1988 undeflated values[23] and a unit of research was costed at $1400. The economic interpretation of this second scenario would appear to be that we are estimating the MIRR to an increment of research in 1988 that is going to increase productivity until 2004 assuming resulting output changes are a proportion of 1988 output rather than of output in subsequent years which will continue to grow because of past research activities and assuming that there is no price effect from either past activities or from the 1988 increment. These price and output assumptions offset each other, hence it is a matter for conjecture whether our approach under or over-estimates the MIRR.

As noted above there is concern about the extent to which the research coefficient picks up the influence of extension (or any other productivity enhancing factor with which it is correlated). As a form of sensitivity analysis within each of the two scenarios above, using the estimated research coefficient (from models where extension is treated as a separate variable) we added expenditure on extension to that on research and interpreted the rate of return as a return to research and extension in aggregate[24]. This procedure was used by Thirtle and Bottomley (1989) but they continued to refer a return to research rather than to research and extension.

Rates of return are highly sensitive to the length of the investment period. From Table 4, it would seem that 2.0 is a conservative estimate of the research coefficient based on these TFP models. Another scenario we examined was that in which the research lag was spread over 35 years as estimated by Huffman and Evenson (1993). We applied this research lag to a research coefficient of 2.0 and an even more conservative estimate of this parameter of 1.5.

The marginal internal rates of return for these different scenarios are presented in Table 5. The rates of return for the 10 year lag scenarios are all very high but fall to more reasonable levels in the 35 year lag scenarios. Clearly an important area for future research is this question of the lag profile for Australian research. In our view the lag profile is likely to be closer to 35 years than to 10. For the scenario in which the research induced increase in output and research expenditure are both valued at their means, the research coefficient is 2.0, and a unit of research costs $1,000, the marginal internal rate of return is almost 100 percent. This is the scenario most comparable with other studies. It suggests that despite a higher research intensity, research in Australia has earned a higher return than that in the US and NZ, reflecting a higher rate of productivity growth. Thirtle and Bottomley (1989) estimated that the rate of return in the UK was 100 percent but this was for a research profile only 12 years in length. As Davis (1981) pointed out, comparing MIRR's from different studies has to be done cautiously because no standard approach has been used in their calculation. In particular we suggest that some previous estimates of the returns to research may be more properly interpreted as returns to research and extension[25]. Hence if the contribution of research and extension is valued at its geometric mean, costed at a $1,000 per unit and spread over a 35 year lag, the MIRR may be around 75 percent.

If research and output are valued at their 1988 levels and the excess burden of taxation is accounted for, the marginal internal rate of return to research and extension for a 35 year lag and a research coefficient of 2.0, is 49 percent. It falls to 42 percent[26] if the research coefficient is only 1.5, reflecting the view of Mullen, Cox and Foster that the Christensen/Jorgenson TFP index probably overstates productivity growth. If we assumed that a research coefficient of 2.0 only reflected the impact of research then the estimated MIRR to research is 58 percent.

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 (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. If we assume, for lack of empirical evidence, that Australia can capture 75 percent of the returns from research, then the MIRR to Australia , for the 35 year lag, and research/extension coefficient of 2.0, is of the order of 36 percent in 1988 dollars.

9. Concluding Comments

This study reports the first empirical analysis of the relationship between productivity growth in Australian broadacre agriculture and expenditure on research. Data on research expenditure were collected from State Departments of Agriculture, CSIRO and the major universities for the period 1953 to 1988. Data from ABARE's sheep industry and grazing industry surveys were the basis of measures of productivity growth. Australia ranks high against OECD countries with respect to expenditure on research and productivity growth.

The relatively short data series restricted our examination of research lags to profiles of up to 16 years in length which is about half the length of profiles recently estimated for US agriculture. Additionally high collinearity between research, extension , the terms of trade variable and the trend variables meant that the coefficients on these variables could not be estimated precisely although models had high explanatory powers and little evidence of serial correlation.

Omitting the extension and terms of trade variables generally had little impact on the size of the research coefficient and did not significantly reduce the explanatory powers of the models but did result in more significant coefficients in most models. In estimating returns to research we used the research coefficients from the full models in the expectation that they would be least biased. We have adopted a conservative approach of interpreting the so-called research coefficient as measuring the impact of both research and extension. Further research is required into the relationship between research, extension and productivity growth and how this is best modelled, to enable the separate contributions of these variables to be measured.

Models with ten year research profiles had the highest values of the log likelihood function although in general the differences from the 8, 12 and 14 year profiles were not significant. Such short lags do not seem credible and perhaps arise because of problems in measuring and specifying the extension variable. We note that because of the way in which research and extension resources are allocated in Departments of Agriculture, who are almost solely responsible for extension in Australia, collinearity between these variables is always likely to be a problem. Hence collecting more data may not be a panacea.

We estimated marginal internal rates of return from a one-off one unit increase in research expenditure that gave rise to a stream of productivity gains over the length of the research lag profile. We estimated rates of return for the ten year lag profile but also estimated rates of return under the assumptions that the lag length was 35 years and the research coefficient was 2.0 and 1.5 The assumption about the length of the research lag profile had the greatest impact on the MIRR reducing it from values in excess of 180 percent to values of less than 100 percent.

In our view the estimate of the MIRR for research that is most comparable with other studies is that for the scenario in which productivity gains were valued at their geometric means, the excess burden of taxation was ignored and a 35 year research profile was assumed. The MIRR's for this scenario were 98 or 85 percent depending on whether a research coefficient of 2.0 or 1.5 was used. These are larger than recent US and NZ estimates and almost as large as Thirtle and Bottomley's estimate of 100 percent for UK agriculture based on 14 year resaerch profile. They suggest that the Australian agricultural research industry has performed at least as well as that in some other countries. Higher rates of productivity growth in Australia underlie these higher MIRR's and more than compensate for higher rates of research intensity. We pointed that that the uncertainty surrounding the interpretation of the research coefficient with respect to the impact of extension, is another factor making comparisons between studies difficult.

Any assessment of whether Australia is underinvesting in pubic 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]. We have little information on these alternatives, particularly with respect to other public investments. In our view the appropriate MIRR estimates are those for the scenario in which output gains are valued at 1988 prices, the excess burden of taxation is accounted for and a 35 year research lag is assumed. In addition these MIRR's can be further discounted if it is assumed that 25 percent of benefits flow to non-residents of Australia and if we interpret the research coefficient as reflecting the impact of both research and extension. In this case the MIRR's are 36 and 32 percent for research coefficients of 2.0 and 1.5. We follow Fox (1985) in arguing that there is little evidence of a wide divergence between the return from public investments adjusted for the excess burden of taxation and the social returns from private investments. Hence there does not 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.

Endnotes

1. The Industries Commission has recently begun a new inquiry into R&D in the Australian economy (not just agriculture) to be completed in 1995.

2. R&D expenditure data were first collected as part of Project Score by the Department of Science.

3. Ms Kim Lee was largely responsible for assembling the database.

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

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

6. In deriving US research variables, expenditure was deflated by a US research deflator and Huffman and Evenson's (1993) preferred lag profile over 35 years was applied.

7. Hastings (1978) used average attendance as the numerator but this variable is no longer reported and we were forced to used total school enrolments.

8. Huffman and Evenson (1989) used average number of years of schooling completed by farmers.

9. He discriminated between models on the basis on maximising partial correlation coefficients but could have used the more conventional approach of minimising the residual sum of squared errors.

10. Restricting the impact of research to be zero at the endpoints explains the apparent anomaly here.

11. Note that in selecting a research profile Hastings included only the research variable in his model. Having selected the lag length he then examined the influence of other variables such as education and a weather variable to pick up the impact of droughts.

12. As measured by the coefficient on research in a regression of extension against the other explanatory variables.

13. An alternative approach was to argue that the research activities of Departments could be classified as being largely of a very applied nature having an immediate but short lived impact on productivity and hence to treat all the activities of Departments as having the time profile described above for extension. Conversely the activities of CSIRO and universities would continue to be classified as research with a 16 year research profile. Preliminary results suggest that there is still such a high degree of collinearity between these two variables that their precise estimation is not possible and we reverted to the former approach.

14. The data set was assembled by Phil Knopke of ABARE with financial support from the WRDC.

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

16. A lag of five years was chosen on the basis of log likelihood tests over several observations periods starting in 1962 for a research lag profile of 10 years.

17. Linear models were also estimated but were discarded because their coefficients were less stable as the observation period was altered than the log models.

18. It was significantly negative for some short lag models. We tested extension defined as expenditure in the current year. There was little basis to prefer one definition against the other.

19. Assuming a ten year research lag we could have calculated an MIRR for each year from 1962 to 1972 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 1972, but would perhaps be more subject to the 'peculiarities' of those years.

20. Data on the number of broadacre farms prior to this were unavailable but was undoubtedly larger. The geometric means of the TFP, P and R series occurred prior to 1977/78.

21. Another scaling alternative was to replace the TFP.P term by the gross value of broadacre agriculture deflated by the CPI but this series reflects changes in input use.

22. Research spending was measured in thousands of dollars.

23. In this scenario the choice was between using 1988 nominal values for P and R or 1988 values in 1953 dollars. The approaches differ because the deflators used for P and R differed by about thirty percent by 1988. We chose the more conservative approach of using nominal 1988 values.

24. we estimated models in which research and extension were simply added together prior to the imposition of a lag profile. This model says that research and extension are the same and hence is clearly misspecified. The explanotory power of these models was less than though not significantly less than that of our preferred models but the research/extension coefficient was sometimes twenty percent lower.

25. They overestimate the returns to research and extension if extension expenditure is not included in the denominator of their formula to estimate the MIRR.

26. Apparently a number of some significance to galactic hitch hikers.

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.

Table 1: Variables Explaining Productivity Growth

Year	TFP	Research as % of GDP	Educ %	Weather Index	Terms of Trade	Research deflator	CPI
1953	100	0.54	73	110	248	100	100
1954	99	0.62	73	87	248	104	102
1955	97	0.85	74	89	230	107	103
1956	106	0.83	75	135	224	115	107
1957	106	0.77	75	177	236	119	113
1958	94	1.08	77	66	209	121	114
1959	114	1.02	78	88	193	122	116
1960	114	1.09	77	98	195	130	119
1961	122	1.16	76	94	184	135	124
1962	124	1.38	80	84	168	138	124
1963	129	1.36	78	94	172	140	125
1964	135	1.33	77	127	186	145	126
1965	128	1.47	76	89	175	152	131
1966	109	1.82	76	50	173	156	135
1967	137	1.77	77	72	167	164	139
1968	118	2.57	78	68	157	171	144
1969	149	2.07	78	121	153	179	147
1970	143	2.60	78	97	149	189	152
1971	148	3.38	79	94	137	206	159
1972	158	3.24	79	105	139	225	170
1973	134	2.58	79	73	175	245	180
1974	150	2.29	79	115	186	281	204
1975	187	3.32	79	139	126	353	238
1976	185	3.65	78	88	115	406	269
1977	166	3.55	78	96	112	451	306
1978	168	5.03	78	100	106	487	335
1979	197	2.71	77	108	121	518	362
1980	188	2.75	77	73	129	575	399
1981	159	3.35	77	80	121	645	437
1982	180	3.79	77	97	108	729	482
1983	152	6.00	78	77	102	808	538
1984	208	3.55	79	140	99	857	575
1985	216	3.78	78	140	96	909	599
1986	213	4.25	78	100	89	973	649
1987	218	4.00	78	100	89	1032	710
1988	206	3.48	78	100	100	1074	762

Table 2: Lagged Research Variables with Inverted V Profiles

Year	RES6	RES8	RES10	RES12	RES14	RES16
1962	9.05	9.00	8.95			
1963	9.13	9.06	9.01			
1964	9.21	9.13	9.07	9.01		
1965	9.30	9.22	9.14	9.08		
1966	9.40	9.31	9.22	9.15	9.09	
1967	9.50	9.40	9.31	9.23	9.16	
1968	9.59	9.50	9.40	9.31	9.23	9.17
1969	9.66	9.58	9.49	9.40	9.31	9.24
1970	9.74	9.66	9.58	9.49	9.40	9.32
1971	9.80	9.74	9.66	9.57	9.49	9.40
1972	9.86	9.80	9.73	9.65	9.57	9.48
1973	9.90	9.85	9.79	9.72	9.64	9.56
1974	9.93	9.89	9.84	9.78	9.71	9.63
1975	9.96	9.93	9.89	9.84	9.77	9.70
1976	9.99	9.96	9.93	9.88	9.83	9.76
1977	10.01	9.98	9.95	9.92	9.87	9.82
1978	10.01	10.00	9.97	9.95	9.91	9.86
1979	10.02	10.01	10.00	9.97	9.94	9.90
1980	10.03	10.02	10.01	9.99	9.97	9.93
1981	10.08	10.04	10.03	10.01	9.99	9.96
1982	10.09	10.07	10.04	10.03	10.01	9.99
1983	10.11	10.09	10.07	10.05	10.03	10.01
1984	10.12	10.11	10.09	10.07	10.05	10.03
1985	10.14	10.13	10.11	10.09	10.07	10.05
1986	10.15	10.13	10.12	10.10	10.08	10.07
1987	10.15	10.14	10.13	10.12	10.10	10.08
1988	10.13	10.14	10.14	10.13	10.11	10.10

Table 3: Full and Reduced Total Factor Productivity Models for a 10 Year Research Lag Profile and the 1962/88 and 1968/88 Observation Periods

Variable	Full Model		Reduced Model	
	Coefficient	t-statistic	Coefficient	t-statistic
1968 – 1988:				
Constant	–37.52	–0.97	–61.25	–2.23
RES(10)	2.62	1.81	3.08	2.34
EDUC	5.90	1.00	9.45	2.20
RAIN	0.32	3.57	0.33	4.12
EXT	–0.54	–0.61		
TOT	–0.15	–0.84		
T	–0.33	–1.26	–0.46	–2.16
T^2	0.005	1.26	0.007	2.22
R^2	0.88		0.87	
D–W stat	2.13		2.10	
1962 – 1988:				
Constant	–23.97	–1.08	–32.57	–1.55
RES(10)	1.67	1.71	1.57	1.70
EDUC	4.53	1.24	5.62	1.61
RAIN	0.30	4.67	0.29	4.54
EXT	–0.57	–1.54		
TOT	–0.14	–0.91		
T	–0.19	–1.17	–0.25	–1.60
T^2	0.003	1.21	0.004	1.73
R^2	0.92		0.90	
D–W stat	2.16		1.95	

Table 4: Research coefficients for different lag lengths and observation periods

Observation period/Lag length	Research coefficient	t–stat	Log likelihood
1968/1988:			
RES6	–2.090	–0.82	28.195
RES8	3.046	1.34	29.016
RES10	2.621	1.81	30.031
RES12	2.120	1.64	29.643
RES14	2.112	1.43	29.194
RES16	1.891	0.97	28.399
1966/1988			
RES6	0.004	0.00	30.046
RES8	1.991	1.26	31.204
RES10	2.255	1.83	32.371
RES12	2.111	1.72	32.112
RES14	2.279	1.58	31.806
1964/1988			
RES8	1.983	1.52	34.947
RES10	2.196	1.88	35.714
RES12	1.466	1.32	34.571
1962/1988			
RES6	0.440	0.42	37.186
RES8	1.816	1.53	38.623
RES10	1.672	1.71	38.994

Table 5: MIRR's from TFP Models

	1988 Values Cost of Research Unit $1400		Geometric Mean Values Cost of Research Unit – $1000	
	Research Only	Research + Extension	Research Only	Research + Extension
	%	%	%	%
10 Year Lag from 1962	229	180	424	328
10 Year Lag from 1968	328	255	562	430
35 Year Lag Research Coef. – 2.0	58	49	98	83
35 Year Lag Research Coef. – 1.5	50	42	85	72

Figure 1: Research as a % of GDP

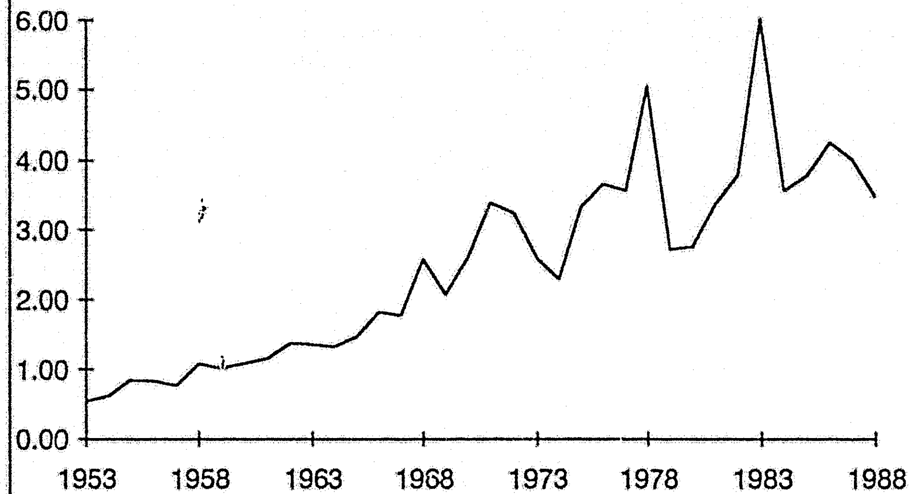
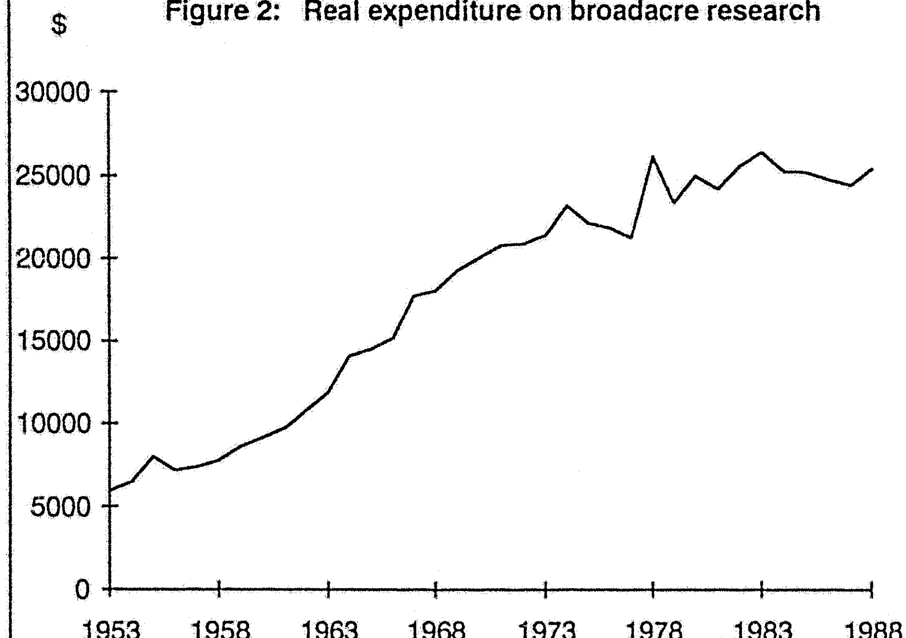


Figure 2: Real expenditure on broadacre research



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