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## THE RETURNS TO INVESTMENT IN RESEARCH ON AUSTRALIAN WOOL PRODUCTION\*

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**A production function approach is used to estimate growth in farm productivity in the Australian wool industry from an estimated level of expenditure on wool production R & D. A market equilibrium model of the wool industry is then used to measure the share of total benefits from this productivity growth accruing to Australia and its woolgrowers. A net return is estimated after allowing for lags in the development and adoption of technology.**

Several R & D funding organisations have been increasing their investment in the development of new technologies for the processing as distinct from the production of farm products. This change in emphasis seems to be based on two propositions.

The first is that the farmers' share of the total benefits of new technology is the same whether the technology is introduced at the farm or processing levels. As a consequence research resources should be devoted to that part of the marketing chain where total industry benefits are likely to be greatest. Because the value added to the farm product in processing is often larger than the value of the farm product, smaller gains in processing efficiency are required to give the same returns as production research.

This proposition was stated clearly by Freebairn, Davis and Edwards (1982) and is based on the assumption that farm and non-farm inputs are used in fixed proportions to produce the final product. There is now a greater appreciation of the role of input substitution in the distribution of the returns from new technology (Alston and Scobie 1983; Freebairn, Davis and Edwards 1983; Mullen, Wohlgenant and Farris 1988 and Holloway 1989). In the context of the wool industry, Mullen, Alston and Wohlgenant (1989) found that the share of total

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industry benefits to Australian woolgrowers was different for production and processing research. The returns to Australian woolgrowers were larger from production research than from processing research when research resulted in equal percentage cost reductions at both stages. One implication is that R & D bodies need to consider not only total industry gains but the extent to which producers share in the benefits from new technology at different points in the marketing and processing chain.

The second proposition questions the current and potential profitability of production R & D. In questioning current profitability, Richardson (1988, p.8) for example, is critical of what he terms the production research training industry saying that '... we seem to have a shortage of career scientists in textiles and a surplus in production and run the risk that the allocation of funds is driven more by what the scientists think will lead to successful refereed publications than by what generates net benefits to woolgrowers'. There are also those who doubt potential profitability, arguing that the big gains in production efficiency have already been made and questioning whether biotechnology will have any significant impact at the farm level. As discussed more fully below, estimates of returns to R & D in agriculture have been highly variable, reflecting in part a lack of consensus about how best to analyse limited data on R & D expenditures and productivity growth.

The objective in this paper is to assess the net returns that Australian woolgrowers might expect from wool production R & D activities. First, some conjectures are made about the shape of a production function linking expenditure on wool production R & D activities to the growth in productivity in wool production. This forms a basis for estimating the rate of growth in productivity that might be expected from current levels of investment in wool production R & D activities. The second stage involves translating this estimate of growth in productivity into an estimate of the net benefits from production R & D accruing to Australian woolgrowers and taxpayers. This is done by using a model of the wool industry (Mullen, Alston and Wohlgenant 1989) to estimate the total annual return to woolgrowers from a shift in the supply of Australian wool. In the third stage, the annual return is used to calculate a rate of return to investment in R & D by allowing for lags in the development, adoption and decay of new technology, and by using discounting techniques to account for a continuing flow of benefits and expenditures on R & D.

While the analysis is intended to be illustrative, rather than enabling definitive conclusions to be drawn about the optimal size of investment in production research, some new information is contributed. First, a quantitative estimate is provided of the returns to Australian woolgrowers that might be expected from investment in production R & D. Second, parameters that have an important influence on the returns to Australian woolgrowers from R & D activities are iden-

tified, and an analytical framework of the nature of the relationship between these parameters and returns from R & D is presented.

*Expenditure on Wool Production R & D Activities in Australia*

Wool production R & D is undertaken by many private and public organisations in Australia, including CSIRO, State Departments of Agriculture and universities. While expenditure by the Wool Research and Development Council (WRDC) is known in detail, data on relevant, total expenditure by these other groups have not been collated. R & D expenditure by the WRDC has amounted to roughly one percent of the gross value of the Australian wool clip and is funded by a levy on growers plus a matching contribution of Federal funds of up to ½ percent of the gross value of industry output. Farm production R & D activities have accounted for between forty and fifty percent of total WRDC expenditure. It has been assumed that WRDC funded production research amounts to ½ percent of the value of industry output and is made up of equal contributions from growers and Government.

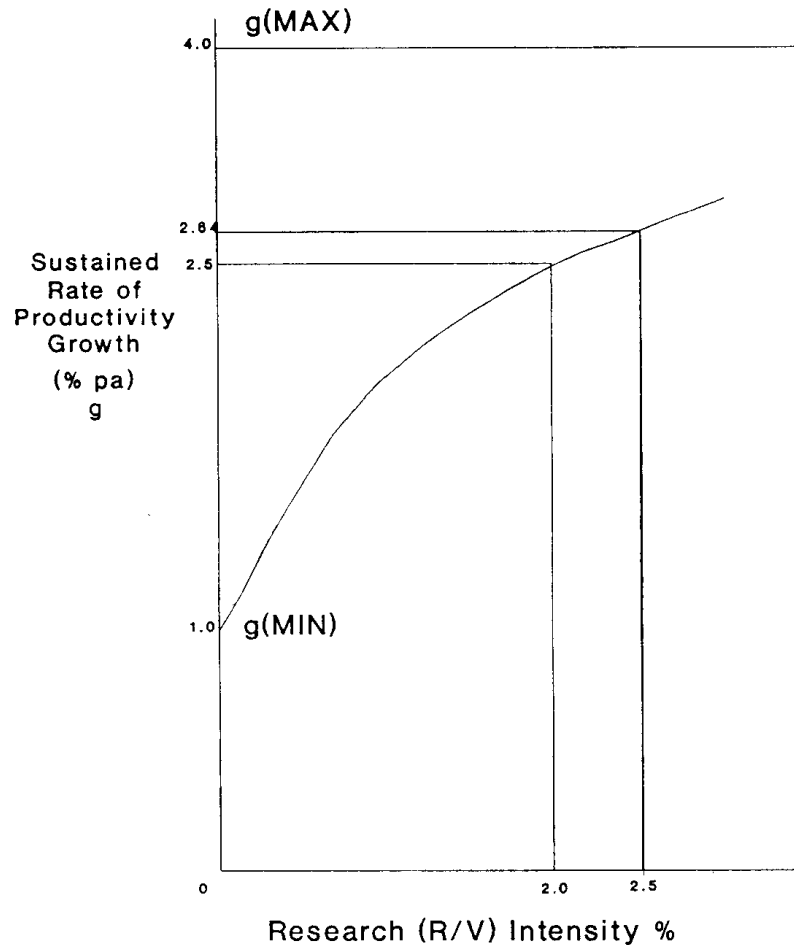
Data on R & D expenditure in Australia have been collected at irregular intervals since 1968/69 by a several Federal departments, most recently by the Australian Bureau of Statistics. Total expenditure is clasified in two main ways — by field of science and by socio-economic objective. Total spending on R & D across all fields of science for the purpose of enhancing productivity in agriculture is estimated under the socio-economic classification. In 1984/85 expenditure by government organisations and universities on R & D in agriculture was estimated to be \$382m (ABS 1990). The gross value of farm production in that year was \$15,537m (ABARE 1989). Hence research intensity in agriculture (the ratio of R & D expenditure to gross value of production) was 2.5 percent. Research intensity in 1986/87 and 1988/89 was 2.7 and 2.4 percent. There is little information on research intensity in different industries within agriculture, although the manner in which the Commonwealth Government contributes to R & D is similar for the major industries. From unpublished data from some State Departments of Agriculture, smaller industries appear to attract a disproportionate share of R & D expenditure. The extension activities of State Departments also contribute to productivity growth in the wool industry. In this study it has been assumed that research intensity in the wool industry, defined to include extension activities, has been about 2.0 percent or four times the level of spending by the WRDC. This is likely to be a lower bound estimate of expenditure on R & D and extension activities in the wool industry.

In 1985 the WRDC spent about \$10m on wool production R & D. Hence total spending on production R & D by all organisations may have been in the order of \$40m in 1985, of which woolgrowers contributed \$5m and government \$35m.

*Productivity Gains from Wool Production R & D*

A production function approach (Norton and Davis 1981) is often used to examine the relationship between R & D activities and productivity growth for agriculture in total or for particular sectors. Total factor productivity, measured as a ratio of output to conventional inputs, is regressed on research expenditures to estimate the contribution from R & D activities and identify the lag structure. An empirical application of that approach has not been attempted, partly because the data required are presently unavailable but also because the approach adopted provides insights which are complementary to econometric approaches. Rather, the approach has been to impose some restrictions on the shape of the production function from a review of past studies of productivity growth in Australian agriculture and the wool industry, and from studies of the nature of the research process.

FIGURE 1  
*The Research Production Function*



Following Scobie (1979), a research production function of the form depicted in Figure 1 is adopted. There are two key assumptions incorporated in this relationship:

- (i) As research intensity (total research spending ( $R$ ), expressed as a percentage of the value of production of the sector ( $V$ )) increases, productivity growth increases but at a diminishing rate, eventually approaching a maximum rate.
- (ii) In the absence of research, productivity would grow at some minimal rate, due to innovations in such areas as transport, communication and services (which the wool sector uses as inputs) and from farmers' own R & D activities.

One possible form for the relationship which incorporates these features, is given by:

$$(1) \quad g_t = g(MAX) - [DIFF / (1 + (R/V))^\alpha]$$

where:

- $g_t$  = the rate of growth of productivity;
- $g(MAX)$  = the maximum feasible rate of sustained growth of productivity;
- $g(MIN)$  = the rate of productivity growth observed in the absence of R & D investment;
- $DIFF$  =  $g(MAX) - g(MIN)$ ;
- $R/V$  = research intensity; and
- $\alpha$  = a parameter influencing the curvature of the production function.

This function is best interpreted as showing the expected long term relationship between the sustained annual growth rate of productivity and the sustained annual research intensity. It abstracts from important dynamic issues, in particular the lags between research investments and resulting improvements in productivity. It also implies that inputs to productivity growth other than R & D are being supplied at such a rate as to maintain a fixed relationship between research intensity and productivity growth through time so that, for example, a rate of productivity growth of 2.5 percent is always associated with a research intensity of 2.0 percent. If research intensity is increased while holding constant the rate at which other productivity enhancing inputs are supplied, diminishing returns to R & D will lead to successively smaller increments in the rate of productivity growth.

The position of the research production function at any time is determined in part by the existing stock of research capital. This includes the extant stock of knowledge related to the research area and the productivity of resources used in the research process such as the physical and human capital, research methodologies and systems of research management that can be applied to the research area. The rate

at which the stock of research capital grows determines whether the rate of productivity growth increases, remains constant or decreases for a given level of research intensity through time. Empirical evidence of how the research production function for the wool industry is behaving through time is unavailable and hence the static representation described above has been used.

Rates of growth in productivity were set at  $g(\text{MAX}) = 4.0$  percent and  $g(\text{MIN}) = 1.0$  percent. The choice of these values was based on a survey of studies of productivity growth in the rural sector and the sheep industry in particular. These are summarised in Tables 1 and 2. While there is considerable variation depending on the time period and the approach adopted by the researchers, annual rates of productivity growth typically vary between one and three percent.

Setting  $g(\text{MIN})$  at 1.0 percent may be understating the contribution of R & D to productivity growth because these historical rates of productivity growth reflect the contribution from past R & D. On the other hand an implication of the approach used is that all productivity growth above this minimum level can be attributed to R & D. The maximum rate of productivity growth,  $g(\text{MAX})$ , of 4.0 percent, has rarely been sustained in agricultural industries anywhere in the world.

TABLE 1  
*Annual Rate of Productivity Growth in Australian Agriculture:  
Selected Estimates*

Time Period	Source				
	Saxon 1939-63	Herr 1922-57	Young 1949-68	McLean <sup>a</sup>	Powell <sup>b</sup>
Percent per annum					
Overall average	0.6	1.2	1.7	1.3	0.8
Sub-periods:					
1871-1900				0.9	
1900-1920				2.2	
1921-1930		2.0			-2.7
1931-1940		0.7			4.0
1941-1950	-0.4	0.7 <sup>c</sup>			0.5
1951-1960	0.6	3.0 <sup>c</sup>	1.9		0.5 <sup>c</sup>
1961-1970	4.0		0.5 <sup>c</sup>		1.1

<sup>a</sup> Victoria only    <sup>b</sup> Selected values only    <sup>c</sup> Apply to early part of the sub-period

Source: Adapted from Jarrett and Lindner (1982)

TABLE 2  
*Annual Rate of Productivity Growth in the Australian Sheep  
 Industry: Selected Estimates*

Region	<u>Source</u>				
	Hoogvliet 1958-59 to 1970-71	Lawrence and McKay 1953-54 to 1976-77	Lawrence 1960-61 to 1976-77	Paul et al 1967-68 to 1980	Paul 1967-68 to 1981-82
Percent per annum					
Overall average		2.9	3.1		1.14
Specified regions:					
Pastoral zone	0.9(a)		3.1	2.4	
Wheat/Sheep zone	2.7		3.2		
High rainfall zone	2.9		3.0		

Source: Adapted from Paul (1984).

The parameter  $\alpha$  reflects the curvature of the research production function. When  $\alpha$  is zero, R & D activities do not contribute to productivity growth. As  $\alpha$  increases, the contribution of R & D activities increases and productivity growth approaches its maximum rate. Having specified maximum and minimum levels of productivity growth, the value of  $\alpha$  can be established (from equation 1) given one other point on the production function.

From the literature cited, annual productivity growth in the sheep industry has been typically about 2.5 percent. It should be noted that these estimates of productivity growth are made from ABARE survey data from farms that typically have cropping and cattle enterprises in addition to a sheep enterprise. Hence it is assumed that the growth in productivity in this enterprise equals productivity growth for the whole farm. The joint product nature of agriculture and of the sheep industry itself, makes it difficult to attribute productivity growth between enterprises. It also means that there are spillover effects between R & D in different industries that are equally difficult to handle and are ignored in this paper.

If it is further assumed that research intensity in the wool industry has been about 2.0 per cent, the implied value of  $\alpha$  is 0.63. If productivity growth of 2.5 percent were achieved from a lower research intensity of 1.5 percent, the implied value of  $\alpha$  would be 0.76.

The rates of productivity growth associated with different levels of research intensity and the increments to growth from successive increments in research intensity for these two values of  $\alpha$  are shown in



Table 3<sup>1</sup>. For the assumed maximum and minimum levels of productivity growth and for the level of research intensity commonly observed in the wool industry, the marginal productivity of R & D is relatively insensitive to the curvature of the research production function.

TABLE 3  
*Implied Relation between Research Investment  
and Productivity Growth*

Research Intensity %	Rate of Productivity Growth		Increment to Growth Rate	
	$\alpha = 0.76$	$\alpha = 0.63$	$\alpha = 0.76$	$\alpha = 0.63$
0.0	1.00	1.00		
0.5	1.80	1.68	0.80	0.68
1.0	2.23	2.06	0.43	0.38
1.5	2.50	2.32	0.27	0.26
2.0	2.70	2.50	0.20	0.18
2.5	2.84	2.64	0.14	0.14
3.0	2.95	2.75	0.11	0.11

Strong assumptions have been made about the functional relationship between  $g_t$  and  $R/V$  and about minimum and maximum values for  $g_t$  but of most interest is the small segment of the complete production function that encompasses the expected range of research intensity. An estimate is made of the relationship between the current level of research intensity and productivity growth and the rate at which this relationship changes for small changes in research intensity in the region of this expected range. Despite the strong assumptions made, the values derived for these parameters appear plausible and can readily be subjected to sensitivity analysis.

The particular representation of the research production function used in this analysis assumes diminishing returns throughout its range with the degree of curvature determining the size of gains from increments in research intensity. Obviously there are other representations of the production function that could be considered.

A simpler alternative might be a linear relationship between productivity growth and research intensity over the range of research intensity observed. It could take the form:

<sup>1</sup> A marginal rate of productivity growth can be calculated as the slope of equation 1. This would give a linear approximation to the increase in productivity from a one percent increase in research intensity and has to be halved for a one half percent increment in research intensity, the unit used here. Equation 1 was used to calculate actual changes in productivity growth for successive increments in research intensity because the linear approximation considerably overestimated the increase in productivity.

$$g_t = g(MIN) + \beta (R/V) \text{ iff } (R/V) < 4.0\%$$

When  $g(MIN)$  is 1.0 percent and  $g_t$  and  $R/V$  are 2.5 and 2.0 percent,  $\beta$  is 0.75 and hence the increment to productivity growth from an increase in research intensity of 0.5 percent is always 0.375 percent up to a research intensity of 4.0 percent. While this representation has the attraction that it is not necessary to make assumptions about the curvature of the research production function, it implies constant returns to R & D over a wide range of research intensity.

A more complex representation might include recognition that at very low levels of research (and little accumulated stock of knowledge), it is difficult to make advances with only marginal increments to funding. This view is reflected in the approach taken by Davis, Oram and Ryan (1987), who argued that the probability is low that additional research will be successful, both when current research efforts are very low as well as when they are already at a high level. There are no conceptual barriers to incorporating research production functions which display such characteristics. However lack of insights into the process of generating new knowledge and how the size of the existing stock of knowledge governs the response to current research funding, makes it difficult to establish a strong case for any one particular representation of the production function.

The usual procedure in estimating the returns to R & D is to use the rate of the productivity growth attributable to R & D to estimate a marginal value product for R & D (Norton and Davis 1981). Instead here it has been used to derive a vertical supply shift (that is, a reduction in farm production costs) which can then be used in the Mullen *et al.* (1989) wool industry model to estimate changes in prices and quantities throughout the industry. An attraction of this approach is that it provides estimates of the distribution among producers, processors and consumers of the benefits and costs of research. The approach is described in the following sections.

### *A Model of the Wool Top Industry*

Mullen *et al.* (1989) modelled the 'world' wool top industry as using Australian raw wool, X1; wool suitable for top making from competing wool producing nations, X2; and processing inputs such as labour and capital, X3, in the production of wool top, Y. The wool top industry is a part of the worsted process which uses fine wool to produce woven textiles. About eighty five percent of Australian wool is suitable for this process.

The methodology involved describing the markets for the inputs and the product of the wool top industry in terms of supply and demand equations where prices and quantities are expressed as percentage changes. To ensure that the industry is in equilibrium and that all markets clear, the wool top industry is assumed to earn zero profit and is represented by a production function characterised by constant returns to scale.

When the adoption of new technology causes a small shift from an initial equilibrium, percentage changes in prices and quantities can be approximated linearly from the system of equations below.

$$(2) \quad EP = (1/\eta)EY + EN$$

$$(3) \quad EP = \kappa_1EW1 + \kappa_2EW2 + \kappa_3EW3$$

$$(4) \quad EX1 = -(\kappa_2\sigma_{12} + \kappa_3\sigma_{13})EW1 + \kappa_2\sigma_{12}EW2 + \kappa_3\sigma_{13}EW3 + EY$$

$$(5) \quad EX2 = \kappa_1\sigma_{12}EW1 - (\kappa_1\sigma_{12} + \kappa_3\sigma_{23})EW2 + \kappa_3\sigma_{23}EW3 + EY$$

$$(6) \quad EX3 = \kappa_1\sigma_{13}EW1 + \kappa_2\sigma_{23}EW2 - (\kappa_1\sigma_{13} + \kappa_2\sigma_{23})EW3 + EY$$

$$(7) \quad EW1 = s_1EX1 + ET1$$

$$(8) \quad EW2 = s_2EX2 + ET2$$

$$(9) \quad EW3 = s_3EX3 + ET3$$

where  $E$  indicates relative change (e.g.  $EP = \delta P/P$  or  $d \ln P$ ). Equation (2) is the demand for wool top, where  $P$  is the price of wool top and  $N$  is an exogenous demand shifter encompassing the effects of research in textile manufacturing. The own price elasticity of demand for wool top,  $\eta$ , was assumed to be  $-1.0$ . Equation (3) expresses the long run condition that the change in product price equals the change in minimum average total cost or the sum of changes in input prices weighted by input cost shares where  $W_i$  refers to input prices and  $\kappa_i$  refers to input cost shares. The input cost shares were  $\kappa_1 = 0.5$ ,  $\kappa_2 = 0.3$  and  $\kappa_3 = 0.2$ . The output constrained demand functions for inputs, equations (4), (5), and (6), are obtained by applying Shephard's Lemma to the total cost function. The Allen elasticities of substitution between Australian and other wool,  $\sigma_{12}$ , between Australian wool and processing inputs,  $\sigma_{13}$ , and between other wool and processing inputs,  $\sigma_{23}$ , were set to 5.0, 0.1 and 0.1. The remaining equations are price dependent input supply equations in which T1, T2 and T3 are exogenous vertical shifters of supply representing cost reductions from new technology generated by R & D. The medium term elasticities of supply of Australian and other wool and of processing inputs were assumed to be 1.0, 1.0 and 20.0. The  $s_i$  terms are the inverse supply elasticities for these inputs. The distribution of the benefits from new technology between producers and consumers is sensitive to the values of these parameters. For example, the share of the benefits to Australian woolgrowers increases as the supply of wool becomes inelastic relative to demand. More detailed sensitivity analysis of the impact of new technology in the wool industry can be found in Mullen et. al. (1989).

The estimated changes in prices and quantities are used to calculate changes in economic surplus to consumers of wool top, CS, the Australian wool industry, PS1, the wool industry in competing countries, PS2, and the suppliers of other inputs used in the production of wool top, PS3. The consumers of wool top extend from spinners and

textile manufacturers through to final consumers, who are likely to use and consume other fibres and are generally non-residents of Australia. The Australian wool industry consists of woolgrowers, suppliers of inputs to woolgrowers and the suppliers of marketing and transport services. The rents to wool top processors, PS3, generally accrue to firms off-shore but there is an Australian component to this industry which has not been identified here. In effect the assumption here is that Australia only benefits from new technology in the wool top industry to the extent that Australian woolgrowers benefit. The formulae to calculate surplus changes are:

$$(10) \quad CS = P.Y(EN - EP)(1 + 0.5EY)$$

$$(11) \quad PS_i = W_i X_i (EW_i - ET_i)(1 + 0.5EX_i)$$

In estimating surplus changes it has been assumed, following Rose's (1980) suggestion, that research induced supply and demand shifts are parallel.

#### *Present Value of the Benefits from Farm Productivity Gains*

Earlier it was suggested that the present rate of investment in wool production R & D activities (a total expenditure of about \$40m in 1985 dollars) may be associated with annual productivity gains of about 1.5 percent (in addition to a one percent minimum growth in productivity). The gain from a 0.5 percent increment in research intensity (that is, an additional \$10m per year) is perhaps a further 0.14 percent in annual productivity growth (see Table 3). The Mullen *et al.* (1989) model is expressed in terms of vertical supply shifts or percentage reductions in production costs as a result of new technology. They used supply elasticity estimates of 1.0 for Australian and other wool, corresponding to a medium term period of supply response. Productivity gains and cost reductions are equivalent in this scenario. The annual returns to Australian woolgrowers from cost reductions of 1.5 and 0.14 percent are \$18.6m and \$1.73m. These returns were estimated by setting ET1 to -1.5 and then -0.14 and solving the system of equations, (2)-(9), using the parameter values indicated above.

The annual benefits to the entire wool chain from a 1.5 percent reduction in Australian woolgrowing costs are \$32m, of which 58 percent accrues to Australian woolgrowers. Just as the benefits from new technology are shared throughout the wool chain, so is the wool tax paid by Australian woolgrowers to fund R & D. It was noted above that the WRDC spent \$10m on production research in 1985, of which Australian woolgrowers directly funded \$5m. The final incidence on Australian woolgrowers of this levy is 58 percent or \$2.9m. The \$35m of public funds used for production R & D cannot be similarly shared throughout the wool chain and hence the final incidence on Australia of the total expenditure of \$40m in 1985 was \$37.9m.

An increment to research intensity of 0.5 percent costs \$10m in 1985 dollars. If Australian woolgrowers pay the same proportion of this as they do of total expenditure then the final incidence on them is 58 percent of \$1.25m or \$0.73m, and the final incidence on Australia is \$9.5m<sup>2</sup> in 1985 dollars. This increment in research intensity could be funded in other ways and this would alter the net returns to Australia and to woolgrowers.

If research resources were more productive such that  $\alpha$  was 0.76, then the gain in productivity associated with a research intensity of 2.0 percent is 1.7 percent and the gain from a further 0.5 percent research intensity is 0.14 percent (from Table 3). The annual returns to the Australian wool industry from equivalent cost reductions are \$21.09m and \$1.73m in 1985 dollars.

Recall that these estimated returns are gross annual returns after the industry has had time to reach a new equilibrium. To estimate net returns to Australia and Australian woolgrowers the flow of benefits and costs through time must be considered. This is dealt with in the following section.

### *Lags in the Development, Adoption and Decay of Technology*

R & D can be viewed as an investment which adds to the stock of knowledge (Scobie & Eveleens 1987; Pardey 1986). That stock is a capital item, used in conjunction with other inputs, in the production of wool. Typically there is a lag after the R & D activity commences before new technology is generated; the adoption of the technology involves time; and the results 'decay' or depreciate in value with the passage of time (Scobie and Jardine 1988)<sup>3</sup>. A further characteristic is the need for maintenance of the capital stock. It is to be expected that after the initial investment in generating new knowledge, there will be a stream of continuing, albeit reduced, maintenance expenses, as

<sup>2</sup>In assessing the incidence of the cost of R&D on Australian woolgrowers, the share they pay through income and company tax has been ignored. The incidence of the wool tax and matching government grant are discussed more fully in Alston *et al.* (1988). Of the \$40m spent on wool production R&D, \$35m is provided by Australian taxpayers but this understates the net social costs of government spending because it does not include the excess burden of tax measures to finance that spending. Assuming a marginal excess burden of 40 percent, as suggested by Findlay and Jones (1982), the final incidence on the Australian taxpayer is \$49m. An implication of this is that the final incidence on Australia of the total expenditure of \$40m in 1985 on production R&D was \$51.9m. An increment to research intensity of 0.5 percent costs \$10m in 1985 dollars and the final incidence on Australian taxpayers and Australia is \$12.25m and \$12.98m.

<sup>3</sup>This depreciation occurs because of both economic and technical factors. Changing relative prices and technology render knowledge generated in the past, less valuable today. For example, knowledge concerning optimum grazing management schemes

would be the case for any capital item. Davis, Oram and Ryan (1987, p.36) summarized some studies of the lag between the commencement of a research project and the availability of the new technology. They concluded that a medium lag of 8 years was appropriate for their study involving both annual and perennial crops. It is generally found that lags in livestock industries are longer (Scobie and Eveleens 1987) and a lag of 10 years was adopted here<sup>4</sup>.

The pattern of adoption once the technology becomes available is modelled using a logistic function of the form:

$$(12) \quad Z_t = A / \{1 + e^{-(a+bt)}\}$$

where  $Z_t$  is the extent of adoption in year  $t$  expressed as a proportion of total adoption;  $A$  is a parameter describing the maximum possible extent of adoption and is assumed to be 1.0; and  $a$  and  $b$  are parameters whose values are to be specified. The logistic function is asymptotic to both the horizontal axis and the ceiling level,  $A$ . This form, following Griliches (1957), has been widely used for modelling the adoption of agricultural innovations, industrial processes, and consumer durables. The values of  $a$  and  $b$  were established by assuming that in years 10 and 19, the extent of adoption,  $Z$ , was 1 and 95 percent. Hence the form of the adoption function used was:

$$(13) \quad Z_t = 1 / \{1 + e^{(-12.97 + 0.84t)}\}$$

Benefits to the Australian wool industry were estimated by multiplying the level of adoption in each year by the gross returns from the particular research productivity scenario being examined. After reaching peak adoption levels in year 20, benefits were assumed to depreciate at the rate of five percent each year for a further 30 years, until year 50. It was assumed that reducing industry benefits by five percent annually after year 20 reflects the effects of the technology becoming obsolete and negates the need to include an annual charge to maintain the technology.

#### *Net Returns from Production R & D to Australia and Australian Woolgrowers*

Under these assumptions concerning lags in the development and adoption of new technology, the present value of the stream of gross benefits to the Australian wool industry from a 1.5 percent reduction in the cost of growing wool is \$34.72m in 1985 dollars for a real

which was relevant in 1920, will be of little value today when soil fertility levels, breeds or strains of sheep, the cost of labour and other inputs, and wool prices are all different.

<sup>4</sup>This is a controversial area as evidenced by a debate in the British literature between Thirtle and Bottomley (1988), who argued against allowing for such lags and estimated a real rate of return to agricultural research of seventy nine percent, and Wise (1986), who used a lag of five years and estimated real rates of return from R&D of less than

discount rate of ten percent (obtained by applying the appropriate level of adoption to the estimated annual gain of \$18.6m).

As discussed above, in 1985 the final incidence on Australia and Australian woolgrowers of the cost of farm production research was \$37.9m and \$2.9m<sup>5</sup>. Hence, the real net present value of a reduction in wool production costs of 1.5 percent after deducting these costs of R & D is -\$3.2m to Australia and \$31.8m to Australian woolgrowers. The internal rate of return, IRR, to Australia from such an investment (of \$37.9m in 1985) is about 9.5 percent real and the return to Australian woolgrowers (from an investment \$2.9m) is about 25.0 percent real<sup>6</sup>.

The gain in productivity growth when research intensity increases from 2.0 to 2.5 percent is 0.14 percent (see Table 3). The final incidence of the costs of such an increase in research intensity on Australia as a whole is \$9.5m and on Australian woolgrowers is \$0.73m in 1985 dollars. The gross returns from such a gain are \$3.2m at a real discount rate of ten percent. Hence the real net returns are -\$6.3m to Australia and \$2.47m to woolgrowers. The IRR's to Australia and to woolgrowers are 5.0 and 18.0 percent<sup>7</sup>.

If instead of imposing diminishing returns to R & D, the simple linear relationship between the rate of growth in productivity and research intensity was used, then, as noted above, for a one half percent increase in research intensity, the increment to productivity growth is higher and constant at 0.375 percent (up to a research intensity of 4.0 percent). The annual gross returns to Australia are \$4.63m in 1985 dollars, the present value (at 10 percent real) of this increase is \$8.65m and the IRR's to Australia and Australian woolgrowers are about 9.5 and 24.5 percent real.

Another scenario examined was that of a more steeply sloped research production function representing higher productivity from research resources. Increasing the curvature of the research production function by one third had little impact on the IRR's from production

twelve percent in some scenarios he considered. Recent work by Pardey and Craig (1989) suggested lags of up to 30 years.

<sup>5</sup> It has been assumed that the costs of an R&D programme are all incurred in the first year and hence the net benefits from R&D have been underestimated.

<sup>6</sup> A stable relationship between productivity growth and research intensity has been assumed. Hence we can think of a stream of investments of \$37.9m each associated with a stream of gross benefits of \$34.72m with an annual IRR to Australia of 9.5 percent. The internal rates of return are approximate to the last unit. If the research intensity required for a 1.5 percent gain in productivity were 2.5 percent, the IRR to Australia falls to 8.5 percent real. At this point on the production function the gain in productivity from an increment in research intensity is only 0.1 percent and the IRR to Australia from this is only 3.5 percent real.

<sup>7</sup> If the cost of the R&D programme to Australia was augmented by a factor of 1.4 reflecting the excess burden of taxation as discussed in footnote 2, the IRR to Australia when research intensity is 2.0 percent is about 8.0 percent real, with a marginal return of 3.5 percent real corresponding to an increase in research intensity of 0.5 percent.

R & D (Table 4). There was little change in either the return from total R & D activity or from a 0.5 percent increment in research intensity. However the degree of curvature assumed in either case is such that the returns from an increment in research intensity are much lower than from the previous level of research intensity. These returns are quite low from the viewpoint of Australia as a whole but remain attractive from the viewpoint of Australian woolgrowers.

TABLE 4  
*The Returns from Farm Production Research to Australia  
and Australian Woolgrowers*

	Gross Benefits \$m	Costs \$m	Net Benefits \$m	Internal Rate of Return %
Net Present Value at 10%				
<i>Curvature of Research Production Function – <math>\alpha = 0.63</math></i>				
Returns when research intensity (R/V) is 2.0% to:				
Australia	34.72	37.90	-3.2	9.5
Aust. Woolgrower	34.72	2.90	31.8	25.00
Returns from 0.5% increment in research intensity to:				
Australia	3.2	-9.50	-6.3	5.0
Aust. Woolgrower	3.2	0.73	2.47	18.0
<i>Curvature of Research Production Function – <math>\alpha = 0.76</math></i>				
Returns when research intensity (R.V) is 2.0% to:				
Australia	39.39	37.90	1.49	10.25
Aust. woolgrower	39.39	2.90	36.49	25.00
Returns from 0.5% increment in research intensity to:				
Australia	3.2	-9.50	-6.3	5.0
Aust. woolgrower	3.2	0.73	2.47	18.0

### *Concluding Comments*

While the real rates of return to production R & D activities estimated above are lower than those suggested elsewhere in the literature, nevertheless it would appear that from the current level of research intensity of 2.0 percent, Australia has been earning a real rate of return which is comparable to or higher than the opportunity cost of funds. In comparing these returns with other studies of the returns to R & D it should also be borne in mind that the focus has been on the



benefits to Australia rather than to the total worldwide industry which may be up to twice those discussed here (see Mullen *et al.* 1989).

The returns to Australia from an increment in R & D of 0.5 percent to 2.5 percent are not nearly as attractive, reflecting the assumptions made about the curvature of the research production function. The question arises as to whether increasing research intensity by 0.5 percent is profitable from Australia's viewpoint or perhaps whether Australia should reduce research intensity by 0.5 percent. The answer depends on the opportunity cost of the resources invested in wool production R & D. However even if this were known, the static nature of the model used here limits the extent to which firm conclusions can be drawn about the appropriate intensity of research.

The returns to Australian woolgrowers are higher than to Australia simply because of the small share of the costs of R & D that they bear. This question of the divergence in the interests of Australia and its woolgrowers is discussed in more detail in Alston *et al.* (1988).

Finally, the past rate of productivity growth has been used as a guide to what might be expected in future. Major breakthroughs in, say, genetic engineering for both plants and animals could alter dramatically the future pay-offs. In contrast, there is the view that the productivity of research funding will decline in the future, as increasingly difficult and more peripheral questions are tackled. Even a thorough assessment of future prospects for new technology is unlikely to remove the uncertainty surrounding this issue.

In this study, some of the questions that arise in determining an optimal portfolio of wool research across major research areas have been examined. While it appears that the return to wool production research is likely to be 'adequate', this tells us nothing about whether the return is falling over time, or whether it might be even higher in other areas. Only by developing a similar framework for, say textile research, can questions such as: 'If \$40m were available for R & D, how should it be divided among the key research areas (production, processing, distribution, etc.) in order to maximise the returns to Australian wool growers?' be answered.

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