THE RETURNS TO FARM R&D IN THE AUSTRALIAN WOOL INDUSTRY

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Several R&D funding organisations have been increasing the proportion of their funds spent on developing new technology for the processing as opposed to the production of farm products. This switch in resources seems to be based on two propositions.

The first proposition 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 and therefore 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. 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 Australian woolgrowers receive a larger share of the benefits from production research than they do from processing research. This result follows because a reduction in the price of Australian wool from new production technology provides an incentive for wool processors to substitute Australian wool for wool from other sources and, of lesser significance, for processing inputs. This substitution effect does not arise from processing research. One implication is that the allocation of R&D resources between on- and off-farm activities should not be driven solely by value added or input cost share considerations. 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 productive efficiency have already been made and question the farm level impact of biotechnology. 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 analyze limited data on R&D expenditures and productivity growth.

Our objective has been to assess the returns that Australian woolgrowers might expect from wool production R&D activities. In the the first stage of this work we made some conjectures from the literature about the shape of a production function linking expenditure on wool production R&D activities to wool productivity growth with a view to estimating the rate of productivity growth that might be expected from the current level of wool production R&D activities. The second stage of our work involved translating this estimate of productivity growth into an estimate of the net benefits from production R&D to Australian woolgrowers and taxpayers. This was done by using the Mullen, Alston and Wohlgenant (1989) model of the wool industry to estimate the total annual return

to woolgrowers from a shift in the supply of Australian wool. In a third and final stage, the annual return was 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 using discounting techniques to account for a continuing flow of benefits and expenditure on R&D.

This is an exploratory analysis of factors determining the current rate of return from farm production research. Little is known about many of the parameters used, hence the emphasis on the exploratory nature of the work. The analysis is intended to be illustrative rather than enabling definitive conclusions to be drawn about the optimal level of investment in production research. Despite these qualifications we suggest that this research is valuable for two reasons. First, to our knowledge, it provides the only quantitative estimate of the returns to Australian woolgrowers that might be expected from production R&D activities. Second it identifies parameters that have an important influence on the returns to Australian woolgrowers from R&D activities, shows the nature of the relationship between these parameters and returns from R&D, and demonstrates how they might be incorporated in a consistent analytical framework. We suggest that our approach is a fruitful avenue for further research in this area of strategic R&D planning. At the very least similar analyses should be undertaken of R&D activities at other stages in the wool chain to assist in allocating research resources between farm and processing activities.

Expenditure on Wool Production R&D Activities in Australia

Wool production R&D is undertaken by many private and public organsations 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 R&D expenditure in the wool industry by these other groups have never been assembled as far as we are aware. 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 1/2 percent of the value of the industry. Farm production R&D activities have accounted for between forty and fifty percent of total WRDC expenditure. For the purposes of this analysis let us assume that WRDC funded production research contributes 1/2 percent towards total production research intensity. We have assumed that the other research organisations contribute a further one percent towards total research intensity so that total R&D spending is assumed to be 1.5 percent of the value of wool produced at the farm level.

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 $30m in 1985.

The Productivity of Production R&D Activities

In this first part of the paper the literature concerning productivity growth in the wool industry is briefly reviewed, the shape of a research production function is postulated and then an attempt is made to estimate the contribution of production R&D activities to the growth in productivity in the Australian wool industry.

The approach used most often to examine the relationship between R&D activities and productivity growth for agriculture in total or for industries within agriculture (as opposed to individual projects) is what Norton and Davis (1981) refer to as the production function approach. In this approach some form of agricultural productivity index is regressed on a set of variables including

several years of lagged R&D expenditures to identify the lag structure involved and the size of the R&D effect, the research production coefficient, which is usually estimated as the sum of the coefficients on the individual lagged R&D expenditures. The production coefficient is then translated into a marginal value product and thence a marginal internal rate of return to R&D expenditure[1].

We have not attempted an empirical application of the production function approach here. Rather, our 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.

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. In other words, successive increments to research spending result in smaller gains to productivity; nature is increasingly niggardly.

(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. Furthermore, formally funded R&D is not the only source of innovation. Much of the improvement in productivity comes from improvements discovered by growers and applied in their individual circumstances.

A convenient form for the relationship is given by:

(1) $\overset{.}{g}$ = g(MAX) - {DIFF/(1 + (R/V))$^{\alpha}$}

where:
$\overset{.}{g}$ = 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
α = a parameter influencing the curvature of the production function.

This function is best interpreted as showing the expected long term relationship between productivity growth and R&D. That is, it shows the 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 levels of research intensity and associated rates of 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 1.5 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 be experienced as successively smaller increments to the rate of productivity growth.

Figure 1   The Research Production Function
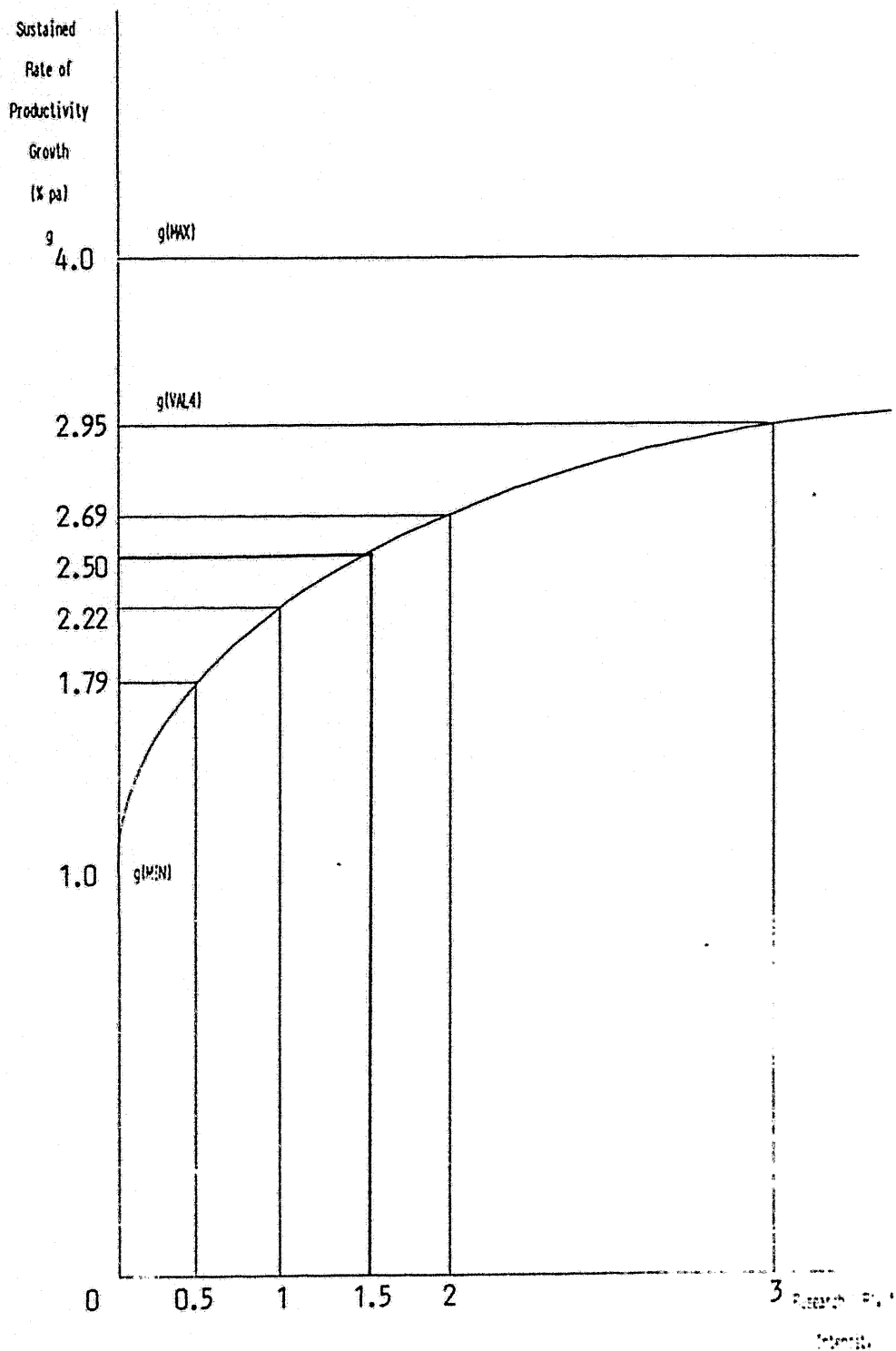
The actual position of the research production function at any point in time is determined in part by the existing stock of research capital. This includes the extant stock of knowledge related to the research area and the productivity of resources used in the research process such as the physical and 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. For example, a by-product of initial research in a particular area could be the development of an improved research technique which, when applied in the future, could augment the productivity of the research process, in effect displacing upward the research production function in Figure 1. On the other hand, as more and more knowledge accumulates about a given area, the stock of research capital may not be growing at a sufficient rate to maintain the rate of productivity growth from the existing rate of R&D in that area.

There is no way to generalise about these dynamic effects; the actual shifts in the function through time would depend on the nature and circumstances of the particular topic or research area. We have no empirical evidence of how the research production function for the wool industry is behaving through time and hence have fallen back on the static representation described above.

We set g(MAX) = 4.0 percent and g(MIN) = 1.0 percent. The choice of these values was based on a survey of studies of productivity growth for both the rural sector and the sheep industry in particular. These are summarized 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.

In setting g(MIN) at 1.0 percent we are perhaps understating the contribution of R&D to productivity growth because these historical rates of productivity growth reflect the contribution of R&D. On the other hand our approach implies that all productivity growth above this minimum level can be attributed to R&D.

The maximum rate of productivity growth, g(MAX), of 4.0 percent requires some further response by productivity growth to higher rates of research intensity than have applied historically. Such a high rate of productivity growth has rarely been observed over long periods for agricultural industries anywhere in the world. Clearly it is important to check the sensitivity of our findings to these parameters and to different functional forms.

The parameter α reflects the curvature of the research production function. When α is zero, R&D activities don't contribute to productivity growth. As α increases the contribution of R&D activities increases and productivity growth approaches its maximum rate. When α is small the curvature of the production function in Figure 1 is relatively flat. The contribution of R&D to productivity growth from successive increments of R&D is smaller at first but does not diminish as rapidly as for large values of α.

Having specified maximum and minimum levels of productivity growth the value of α can be established from one other point on the production function. Our approach has been to observe from the literature cited above that productivity growth in the wool industry has been about 2.5 percent. We further assume that research intensity in the wool industry has been about 1.5 per cent. This relationship between a productivity growth rate of 2.5 percent and research intensity of 1.5 percent gives the required point on the production function. These assumptions imply a value of α of 0.76. The contribution of R&D activities

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[a] 1871-1910	Powell[b] 1921-70
			percent p.a.		
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[c]			0.5
1951-1960	0.6	3.0[c]	1.9		0.5[c]
1961-1970	4.0		0.5[c]		1.1

(a) Victoria only.
(b) Selected values only.
(c) 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 | Source | | | | |
	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 1980-81	Paul 1967-68 to 1981-82
			percent p.a.		
Overall average		2.9	3.1		1.14
Specific 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).

to productivity growth is 1.5 percent. If productivity growth of 2.5 percent were achieved from a research intensity of 1.0 percent then the implied value of α is 1.0. The contribution of R&D to growth is 1.8 percent when research intensity is 1.5 percent and α is 1.0.

The rates of productivity growth associated with different levels of research intensity and the increments to growth from successive increments in research intensity for both values of α are shown in Table 3[2]. As the value of α falls from 1.0 to 0.76, that is as research production function becomes flatter, the marginal rate of productivity growth is lower and higher at low and high levels of research intensity but is not very different for levels of research intensity occurring in the wool industry at present. This means that 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 insensitive to the curvature of the research production function. However the actual growth in productivity decreases from 2.8 percent to 2.5 percent when α falls from 1.0 to 0.76 when research intensity is 1.5 percent.

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 we could consider.

A simpler alternative is a linear relationship between productivity growth and research intensity over the range of research intensity we observe. It may take the form:

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

When $g(MIN)$ is 1.0 percent and $\dot{q}$ and R/V are 2.5 and 1.5 percent, β is 1.0 and hence the increment to productivity growth from an increase in research intensity of 0.5 precent is always 0.5 percent up to a research intensity of 4.0 percent. While this representation has the attraction that we do not have 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 sophisticated representation would say that at very low levels of research (and little accumulated stock of knowledge), it is difficult to make advances with only a marginal increment 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 is no conceptual barrier to incorporating research production functions which display such characteristics. The only limitation is our 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. At this stage we are simply lacking adequate understanding to formulate a general model of the research process. Simple representations, such as that adopted here capture the essential features, we hope, and by using known "bounds" we are able to provide reasonable magnitudes for key parameters.

It is also clear from Table 3 that for the particular research production function we have chosen, the productivity gains from successive increments in research intensity fall sharply. This raises the question of whether or not it

Table 3: <u>Implied Relation between Research Investment and Productivity Growth</u>

Research Intensity z	Rate of Productivity Growth		Increment to Growth	
	$\alpha=0.76$	$\alpha=1.0$	$\alpha=0.76$	$\alpha=1.0$
0.0	1.00	1.00		
0.5	1.79	2.00	0.79	1.00
1.0	2.22	2.50	0.43	0.50
1.5	2.50	2.80	0.28	0.30
2.0	2.69	3.00	0.19	0.20
2.5	2.84	3.14	0.14	0.14
3.0	2.95	3.25	0.11	0.11

is possible to identify areas of research or research organisations who operate where research intensity increases from 1.0 to 1.5 percent. For example is the 0.5 percent increment to research intensity provided by the WRDC directed to this marginal area where the gain in productivity from this increment is only 0.28 percent as compared to a gain of 0.79 percent from the first increment. Perhaps it could be argued that WRDC funds activities at the margin because other research groups would be expected to continue or even expand their R&D activities if the WRDC ceased funding R&D or that WRDC funding attracts other funding to projects that perhaps would not otherwise have been undertaken.

Against this is the view that research organisations determine a programme of research that addresses their priorities which are likely to be closely but not perfectly aligned with the priorities of woolgrowers. They then seek financial support from organisations such as the WRDC. If support is granted then research resources are freed to conduct projects that are more marginal from the viewpoint of the organisation. It seems difficult to make a strong case that particular research programmes are marginal or inframarginal. However it still remains important to recognise that productivity gains from successive increments in research intensity may decrease quite markedly.

Norton and Davis (1981) pointed out that the usual procedure in estimating the returns to R&D is to use the estimated rate of the productivity growth attributable to R&D to estimate a marginal value product for R&D. Instead we have used it to estimate a vertical supply shift (that is, a reduction in farm production costs) which can then be used in the Mullen, Alston and Wohlgenant (1989) wool industry model to estimate benefits to the different sectors of the industry. An attraction of this approach is that it allows the distribution between producers, processors and consumers of the benefits from and costs of research to be examined. The approach is described in the following sections.

A Model of the Wool Top Industry

Mullen, Alston and Wohlgenant (1989) used an equilibrium displacement model of the world wool top industry to estimate the changes in economic surplus to Australian and other woolgrowers, wool processors and wool consumers that result from exogenous supply and demand shifts caused by successful research. Their methodology closely follows Muth (1964), Gardner (1975), Alston and Scobie (1983) and Mullen, Wohlgenant and Farris (1988).

The "world" wool top industry uses 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.

R&D induced technical change reduces the cost of producing or processing wool and is modelled as shifting the supply of wool or the supply of processing inputs down. Successful research into textile manufacturing is experienced by the wool top industry as an increase in the demand for wool top and is modelled as such.

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 industry is assumed to earn zero profit and is represented by a production function characterized by constant returns to scale. Under these assumptions the industry total cost

function can be written as:

$$C = Y.c(W1, W2, W3)$$

where the W's refer to input prices and c(.) is the unit cost function. Equilibrium in the industry can be described as:

(2) $P = f(Y, N)$ (Wool top demand)
(3) $P = c(W1, W2, W3)$ (Market clearing condition/Supply of wool top)
(4) $X1 = h_1(W1, W2, W3).Y$ (Demand for Australian wool)
(5) $X2 = h_2(W1, W2, W3).Y$ (Demand for competitors' wool)
(6) $X3 = h_3(W1, W2, W3).Y$ (Demand for processing inputs)
(7) $W1 = g_1(X1, T1)$ (Supply of Australian wool)
(8) $W2 = g_2(X2, T2)$ (Supply of competitors' wool)
(9) $W3 = g_3(X3, T3)$ (Supply of processing inputs)

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. Equation (3) expresses the long run condition that product price equals minimum average total cost. 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 remaining equations are price dependent input supply equations in which T1, T2 and T3 are exogenous shifters of supply representing the impact of new technology generated by R&D.

When the adoption of new technology causes a small shift from an initial equilibrium, changes in prices and quantities can be approximated linearly by totally differentiating equations (2) – (9) and converting them to elasticity form to give equations (10) – (17):

(10) $EP = (1/\eta)EY + EN$
(11) $EP = \kappa_1 EW1 + \kappa_2 EW2 + \kappa_3 EW3$
(12) $EX1 = -(\kappa_2\sigma_{12} + \kappa_3\sigma_{13})EW1 + \kappa_2\sigma_{12} EW2 + \kappa_3\sigma_{13} EW3 + EY$
(13) $EX2 = \kappa_1\sigma_{12} EW1 - (\kappa_1\sigma_{12} + \kappa_3\sigma_{23})EW2 + \kappa_3\sigma_{23} EW3 + EY$
(14) $EX3 = \kappa_1\sigma_{13} EW1 + \kappa_2\sigma_{23} EW2 - (\kappa_1\sigma_{13} + \kappa_2\sigma_{23})EW3 + EY$
(15) $EW1 = s_1 EX1 + ET1$
(16) $EW2 = s_2 EX2 + ET2$
(17) $EW3 = s_3 EX3 + ET3$

where E indicates relative change (e.g. $EP = \Delta P/P$), η is the own price elasticity of demand for wool top, κ_i is the share of total wool top processing costs for input i, σ_{ij} is the Allen (1938) partial elasticity of input substitution between inputs i and j, and s_i is the inverse of the own price elasticity of supply of input i[3].

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 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. Australian woolgrowers are expected to capture most of these rents because the inputs they supply are least elastic in supply, comprise a large share of final cost of growing wool and are the subject of the largest component of R&D expenditure in the farm production area. 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 we are

assuming that Australia only benefits from new technology in the wool top
industry to the extent that Australian woolgrowers benefit.

Following Rose (1980), the estimation of surplus changes is based on the
assumption that research-induced shifts of supply and demand are parallel in the
price direction. This assumption of a parallel shift is critical. Lindner and
Jarrett (1978) have shown how the nature of the supply shift affects the total
benefits from R&D and their distribution. However the nature of the supply
shift from past R&D is unknown. We accept Rose's (1980) arguments that even for
a particular innovation, predicting the nature of the supply shift it causes is
virtually impossible because supply prices are usually inclusive of rents.

The formulae to calculate surplus changes are[4]:

(18) $CS = P.Y(EN - EP)(1 + 0.5EY)$
(19) $PS1 = W1.X1(EW1 - ET1)(1 + 0.5EX1)$
(20) $PS2 = W2.X2(EW2 - ET2)(1 + 0.5EX2)$
(21) $PS3 = W3.X3(EW3 - ET3)(1 + 0.5EX3)$

The system of equations, (10) - (17), could be solved for changes in prices and
quantities if the values of all the market parameters were known. Parameter
values were chosen after a review of past studies and of derived demand theory,
after consulting people knowledgeable about the wool industry and from
econometric analysis conducted as part of the project (Mullen and Alston
(1989)).

Values for market parameters used in the base scenario were:

Elasticity of demand for wool top	η	-1.0
Elasticities input substitution between:		
- Australian and other wool	σ_{12}	5.0
- Australian wool and processing input	σ_{13}	0.1
- Other wool and processing inputs	σ_{23}	0.1
Elasticity of supply of Australian wool	s_1	1.0
Elasticity of supply of other wool	s_2	1.0
Elasticity of supply of processing inputs	s_3	20.0
Cost share of Australian wool	κ_1	0.5
Cost share of other wool	κ_2	0.3
Cost share of processing inputs	κ_3	0.2

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 $30m in 1985 dollars) may result in
annual productivity gains of about 1.5 percent. The gain from a 0.5 percent
increment in research intensity (that is, an additional $10m per year) is
perhaps a further 0.19 percent in annual productivity growth. The Mullen et. al.
(1989) model is driven by vertical supply shifts or percentage reductions in
production costs as a result of new technology. They used supply elasticities 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 0.19 percent are $18.6m and $2.35m. These returns were estimated by
setting ET1 to -1.5 and -0.19 respectively and solving the system of equations
using the parameter values above.

The annual benefits to the entire wool chain from a 1.5 percent reduction in
Australian woolgrowing costs are $32m and the share of this benefit accruing to

Australian woolgrowers is 58 percent. 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 and that Australian woolgrowers directly funded $5m of this. The final incidence on Australian woolgrowers is 58 percent of that or $2.9m. An implication of this is that the final incidence on Australia of the total expenditure of $30m in 1985 on production R&D was $27.9m.

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 $1.67m or $0.97m and the final incidence on Australia is $9.3m[5]. This increment in research intensity could be funded in other ways that would alter the net returns to Australia and to woolgrowers but we have not yet examined them.

The returns to Australian woolgrowers from new technology are sensitive to assumptions made about supply responsiveness. In particular they are eroded as wool producers make larger adjustments to the size of their enterprise in response to lower production costs. Another scenario we examine is when the elasticity of supply of Australian and other wool is 2.0. In this scenario we assumed that percentage cost reductions were half the productivity gains because of the greater supply response. Hence the percentage cost reductions associated with a research intensity of 1.5 percent were -0.75 percent overall and -0.095 percent at the margin and these returned $6.90m and $0.87m to Australian woolgrowers.

When the elasticity of supply of Australian and other wool is 2.0 instead of 1.0, the share of the wool tax paid by Australian woolgrowers falls to 43 percent and hence the final incidence on them of the $5m raised in tax is $2.15m. The final incidence on them of an increment in research intensity is $0.72m. The final incidence on Australia for these two situations is $27.15m and $9.05m.

We have been examining the returns to the wool industry for different supply scenarios but have continued to assume that a research intensity of 1.5 percent is associated with total productivity gains of 2.5 percent, that is that α is 0.76. If research resources were more productive such that similar productivity gains could be achieved at a research intensity of 1.0 percent, that is α is 1.0, then the gain in productivity associated with a research intensity of 1.5 percent is 1.8 percent and the gain from a further 0.5 percent research intensity is 0.20 percent (from Table 3). The returns to the Australian wool industry from equivalent cost reductions, that is when the elasticity of supply of wool is 1.0, are $22.3m and $2.47m. In the long run scenario these returns fall to $8.3m and $0.92m. These scenarios are summarised in Table 4.

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 has to be considered and this is tackled 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 passing of time (Scobie and Jardine (1988))[6]. 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 on-going, albeit reduced, maintenance expenses, as would be the case for any capital item.

These elements in the development, adoption and decay of technology are illustrated graphically in Figure 2. A period of investment in R&D (denoted L_r) is followed by an adoption period (L_a), and finally, a pay-off period. Davis, Oram and Ryan (1987, p.36) offer a useful summary of 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[7].

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

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

where

Z_t = the extent of adoption in year t expressed as a proportion of total adoption;

A = a parameter describing the maximum possible extent of adoption;

a,b = 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 the parameters can be derived either from past studies of technology adoption or by fitting the following linear regression, obtained by dividing both sides of equation (23) by $(A - Z_t)$ and taking natural logarithms:

(24) $\quad \ln\{Z_t/(A - Z_t)\} = a + bt + v_t$,

where v_t is a random disturbance term.

In the absence of data needed to estimate (24), the parameters can be found by specifying the value of A (reasonably set equal to unity reflecting 100 percent adoption) and the values of Z_t at two selected points (Dyer, Scobie and Davis (1984)). In this case the values chosen were:

Z_0 = 0.01 in year 10; and,
Z_1 = 0.95 in year 19.

We assumed a high rate of adoption of technology because the estimates of the historical rate of growth of productivity in the wool industry already reflect the level of adoption of technology[8].
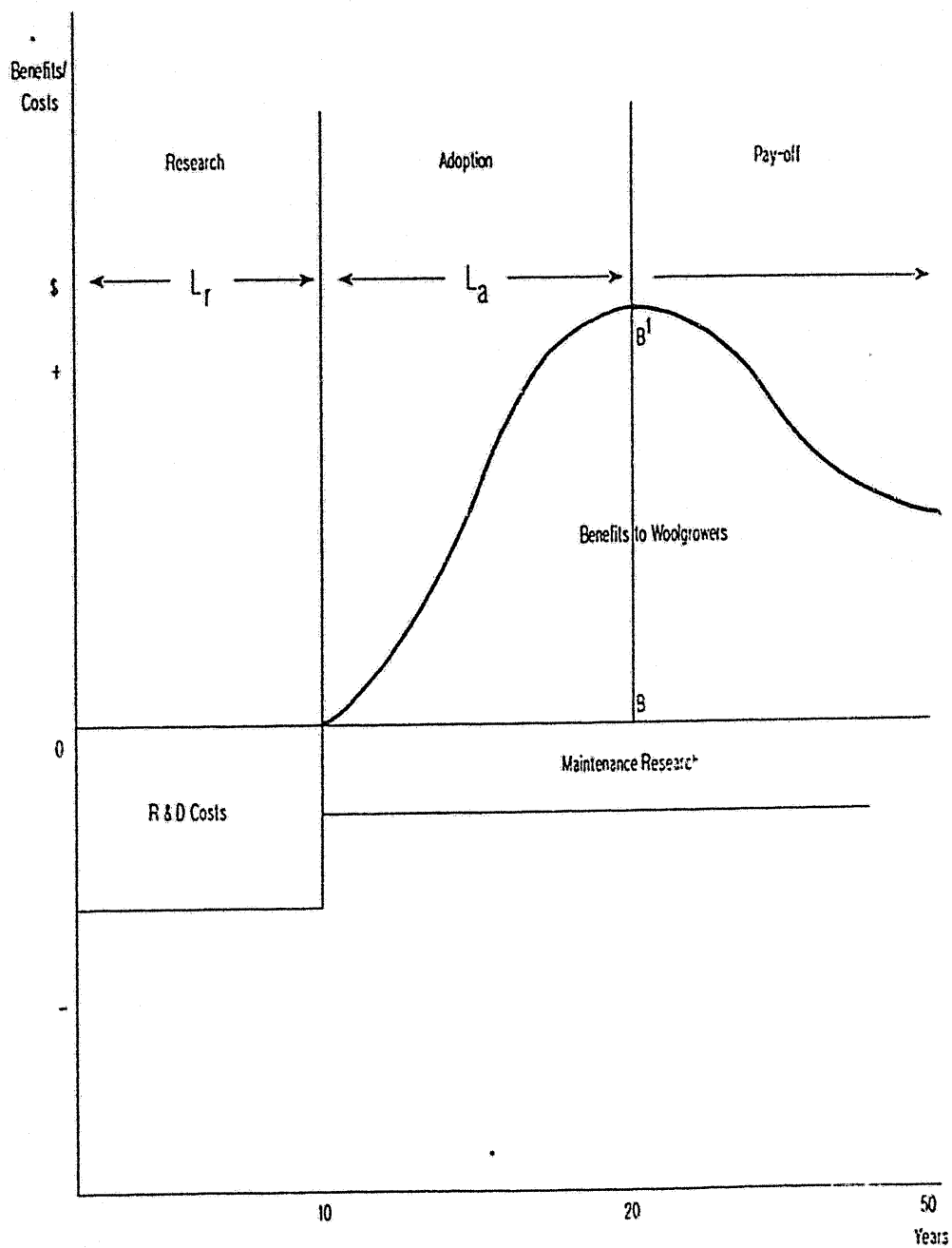
From (24), it follows that:

(25) $\quad b = 1/(t_1 - t_0)\{\ln(Z_1/(A - Z_1)) - \ln(Z_0/(A - Z_0))\}$

(26) $\quad a = \ln\{Z_t/(A-Z_t)\} - bt$

Equations (25) and (26) were used to yield values of a = -12.97 and b = 0.75 so

Figure 2   The Flow of Costs and Benefits from Investment in R & D

that the particular form of the adoption curve was:

$$(27) \quad Z_t = 1/\{1 + e^{-(-12.97 + 0.75t)}\}$$

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 cost 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 for a real discount rate of ten percent. This is obtained by applying the appropriate level of adoption and a discount rate of ten percent to the estimated annual gain of $18.6m to Australia once the industry is in equilibrium.

As discussed above, in 1985 the final incidence on Australia and Australian woolgrowers of the cost of farm production research was $27.9m and $2.9m[9]. Under the assumptions made above concerning adoption lags and using a real discount rate of ten percent, the net present value of a reduction in wool production costs of 1.5 percent after deducting these costs of R&D is $6.8m to Australia or $31.8m to Australian woolgrowers. The internal rate of return, IRR, to Australia from such an investment (of $27.9m in 1985) is about eleven percent and the return to Australian woolgrowers (from their investment of $2.9m) is about 25.0 percent[10].

The gain in productivity growth when research intensity increases from 1.5 to 2.0 percent is 0.19 percent (see Table 3). The final incidence of the costs of such an increase in research intensity on Australia as a whole is $9.3m and on Australian woolgrowers is $0.97m. The gross returns from such a gain are $4.39m at a discount rate of ten percent. Hence the net returns are -$4.91m to Australia and $3.42m to woolgrowers. The IRR's to Australia and to woolgrowers are 6.5 and 18 percent[11].

If, instead of imposing diminishing returns to R&D, we use the simple linear relationship between the rate of growth in productivity and research intensity for which the increment in productivity growth from a one half percent increase in research intensity is constant at 0.5 percent up to a research intensity of 4.0 percent, the returns to an increase in research intensity are higher. The annual gross returns to Australia are $6.18m, the present value using a discount rate of ten percent of this increase in productivity is $11.5m and the IRR's to Australia and Australian woolgrowers are about 9.25 and 25 percent.

The other scenarios we examined were a more steeply sloped research production function representing higher productivity from research resources, and a more elastic supply of wool. The returns to Australia and Australian woolgrowers from these different scenarios are presented in Table 4.

Increasing the curvature of the research production function by one third has had little impact on the IRR's from production R&D. There was little change in either the return from total R&D activity or from a 0.5 percent increment in

Table 4: The Returns from Farm Production Research to Australia and Australian Woolgrowers

	Net Present Value at 10%			Internal Rate of Return
	Gross Benefits $m	Costs $m	Net Benefits $m	%

ELASTICITY OF SUPPLY OF WOOL = 1.0

Curvature of Research Production Function — $\alpha = 0.76$

Returns when research intensity (R/V) is 1.5% to:

Australia	34.72	27.90	6.8	11.00
Australian woolgrowers	34.72	2.90	31.8	25.00

Returns from 0.5% increment in research intensity to:

Australia	4.39	9.30	-4.91	6.50
Australian woolgrowers	4.39	0.97	3.42	18.00

Curvature of Research Production Function — $\alpha = 1.0$

Returns when research intensity (R/V) is 1.5% to:

Australia	41.70	27.90	13.8	12.00
Australian woolgrowers	41.70	2.90	36.8	26.00

Returns from 0.5% increment in research intensity to:

Australia	4.61	9.30	-4.69	6.75
Australian woolgrowers	4.61	0.97	3.64	19.00

ELASTICITY OF SUPPLY OF WOOL = 2.0

Curvature of Research Production Function — $\alpha = 0.76$

Returns when research intensity (R/V) is 1.5% to:

Australia	12.89	27.15	-14.26	6.50
Australian woolgrowers	12.89	2.15	10.24	20.00

Returns from 0.5% increment in research intensity to:

Australia	1.62	9.05	-7.43	2.50
Australian woolgrowers	1.62	0.72	0.90	14.00

Curvature of Research Production Function — $\alpha = 1.0$

Returns when research intensity (R/V) is 1.5% to:

Australia	15.46	27.15	-11.69	7.25
Australian woolgrowers	15.46	2.15	13.31	21.50

Returns from 0.5% increment in research intensity to:

Australia	1.72	9.05	-7.33	2.50
Australian woolgrowers	1.72	0.72	1.00	14.50

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.

As already discussed, in a static world the marginal productivity of research resources is expected to decline in the way illustrated here. In a more dynamic setting the marginal productivity of research resources may not decline at the same rate. If for example, the growth in productivity when research intensity increased from 1.5 to 2.0 percent remained at 0.28 percent, the rate associated with the previous increment to research intensity, then the net present value at a discount rate of ten percent to Australia and Australian woolgrowers is - $2.84m and $5.49m. The IRR's are about 8.25 and 20.5 percent to Australia and to woolgrowers.

The returns to Australia and Australian woolgrowers are particularly sensitive to the elasticity of supply of Australian and other wool. Clearly when supply responsiveness is larger the returns from production R&D are far less attractive from Australia's viewpoint. In looking at a steady state equilibrium position we abstract from the time it takes woolgrowers to adjust production to price changes associated with new technology. A more sophisticated approach would be to allow market parameters to change through time using the approach suggested by Just, Hueth and Schmitz (1982) and adapted by Mullen, Wohlgenant and Farris (1988). We would expect Australia to get a much larger share of the benefits from new production technology in the early years but as the supply of wool became more elastic relative to demand the share of benefits to consumers would increase.

Concluding comments

While the rates of return to production R&D activities estimated above are lower than those suggested in the literature, nevertheless it would appear that from the current level of research intensity of 1.5 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 we have been concerned with the benefits to Australia rather than to the total worldwide industry which are up to twice those discussed here (when the elasticity of supply of wool is 1.0).

The returns to Australia from an increment in R&D of 0.5 percent to 2.0 percent are not nearly as attractive, reflecting our assumptions about the curvature of the research production function. However even if the rate of productivity growth were the same as for the previous increment in research intensity (from 1.0 to 1.5 percent), the IRR to Australia falls from 11 to 8.25 percent. The question naturally 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. Clearly the answer depends on the opportunity cost of investing resources in the wool production R&D. However even if this were known we would be reluctant to draw firm conclusions about research intensity, largely because of the static nature of our model.

The returns to Australian woolgrowers are much higher because of the small share of the cost 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, Mullen and Ridley (1988). Some would argue that because R&D is a risky investment, the return should include a risk premium and hence that the returns

estimated here are not satisfactory. Clearly, decisions about the level of investment are made in a risky world.

> "*That the world is a risky place has not been recognised in the literature of agricultural research planning and priority setting.*"(Anderson (1988),p.(i)).

The research process itself is risky. Embarking on a particular project is no guarantee of ultimate success. The very notion of what constitutes success is not self-evident; partial findings may well be valuable. Future prices and costs are uncertain, and our knowledge of key parameters is imperfect. Methods do exist for analysing R&D in the face of risk, and can provide a distribution of rates of return, instead of the point estimates given here (Dyer, Scobie and Davis, 1984).

Opposing this argument for a risk premium is the view that observed rates of productivity growth already reflect the risk associated with R&D activities, at least to some extent.

Finally, we have used past rates of productivity growth as guides to that which might be expected in future. History can sometimes be a very imperfect guide to the rate of future innovation. 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 "easy" problems have been solved. The productivity of research funding will decline in the future, as increasingly difficult and more peripheral questions are tackled. Only the judgment and insights of scientists with an intimate knowledge of particular areas can offer guidance on these questions.

As already indicated this study represents one step in addressing the problem of determining an optimal portfolio of wool research across major research areas. 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 we begin to address the question: "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?" This analysis takes one step toward meeting that challenge.

FOOTNOTES

1. Davis (1981a) noted that most studies had not adopted a consistent approach in estimating marginal internal rates of return. He (1981b) also pointed out that the functional forms used to estimate production functions in most applications implied that R&D caused a divergent shift in the supply function. We assumed parallel supply shifts in this study because of the difficulty of identifying the nature of the supply shift (Rose, 1980). As Davis points out, the total industry returns from a divergent shift are half those from a parallel shift. There are scenarios in which Australian woolgrowers lose from a divergent supply shift.

2. A marginal rate of productivity growth can be calculated as the slope of equation 1. This would give a linear approximation of 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 we are dealing with. We used equation 1 to calculate actual changes in productivity growth for successive increments in research intensity because the linear approximation considerably overestimated the increase in productivity.

3. For small changes from an initial equilibrium, market parameters are assumed to be approximately constant. However no presumption is made about the functional form taken by these equations. In particular, it is not assumed that the supply and demand equations are of the constant elasticities form.

4. As shown by Alston a i Wohlgenant in Mullen and Alston (1989) these formulae are exactly correct for parallel shifts of linear supply or demand curves but are only approximate for other functional forms. The approximation errors are trivially small for the small shifts considered here. The estimates of surplus changes could be interpreted as the annual change in gross surplus from one per cent cost reductions in the three stages of the wool chain modelled here, assuming that the entire industry adopted the new technology immediately and that all adjustments in demand and supply occurred within the year. Alternatively it might be viewed as the change from an initial equilibrium to a new equilibrium in some future year. In any case, care needs to be taken to ensure that all of the market parameters, and the value of production data used, apply to the same length of run.

5. In assessing the incidence of the cost of R&D on Australian woolgrowers we have ignored the share they pay through income and company tax. In assessing the benefits from R&D we have assumed that because most Australian wool is processed and consumed overseas, the benefits to Australia are the benefits to Australian woolgrowers. The incidence of the wool tax and matching government grant are discussed more fully in Alston, Mullen and Ridley (1988). Of the $30m spent on wool production R&D, $25m 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 Johnes (1982) government funding of $25m to finance production R&D involves a final incidence on the Australian taxpayer of $35m. An implication of this is that the final incidence on Australia of the total expenditure of $30m in 1985 on production R&D was $37.9m. An increment to research intensity of 0.5 percent costs $10m in 1985 dollars and the final incidence on Australian taxpayers and Australia is $11.67m and $13.34m.

6. 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 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. If resistance to pathogens has been bred into a crop or pasture species, it may well break down over time as the disease vector mutates and new strains emerge.

7. 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 rate of return to agricultural research of seventy nine percent, and Wise (1986), who used a lag of five years and estimated rates of return from R&D of less than twelve percent in some scenarios he considered. This difference was explained, to a large degree, by assumptions about the research lag and the persistence of productivity gains.

8. Bob Lindner suggested this to us.

9. We have assumed that the costs of an R&D programme are all incurred in the first year and hence have underestimated the net benefits from R&D. The largest share of costs probably are incurred in the early years of a project but an alternative approach would be to distribute costs over the 20 year development and adoption periods.

10. The internal rates of return are approximate to the extent that they are accurate to the last unit rather than to any decimal place.

11. 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 5, the IRR to Australia when research intensity is 1.5 percent is about 9.5 percent and it is 4.75 percent for an increase in research intensity of 0.5 percent.

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