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THE IMPACT OF FARM AND PROCESSING RESEARCH ON THE AUSTRALIAN WOOL INDUSTRY*

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An equilibrium displacement model of the world wool top industry is used to estimate the returns to the Australian wool industry from productivity improvements in farm production, in top making and in textile manufacturing. The returns to the industry from these different types of research and development are sensitive to the extent of substitution possibilities between Australian wool and other inputs used by the wool processing and textile industries but it appears that research resources have to be much more efficient in off-farm activities for the Australian wool industry to receive benefits similar to those from farm research activities.

In 1986/87 the Wool Research and Development Council (WRDC) of the Australian Wool Corporation (AWC) spent $26.3m on a range of research and development (R&D) activities selected to 'maximise net returns to the Australian woolgrower and the national economy' (AWC 1987, p. 103). The research is funded by a tax on woolgrowers and a matching grant from the Australian Government. The two largest areas of research have been farm production research and textile research, accounting for roughly 50 per cent and 40 per cent respectively of total research outlays.

Our objective is to estimate returns to woolgrowers from equal percentage reductions in the cost of growing wool, top making and textile processing.[1] The sensitivity of returns from R&D in these broad areas to changes in the demand and supply parameters that characterise the world wool top industry is examined. The exchange between Freebairn, Davis and Edwards (1982, 1983), and Alston and Scobie (1983) suggested that the extent of input substitution was likely to be a crucial parameter. Our approach allows us to focus on that issue. Allowing substitution in top making between wool from different countries and between wool and processing inputs means that the Australian wool industry receives a larger share of the returns from farm research than from R&D in other sectors. It also means that the share of benefits it receives from R&D in these other sectors will be smaller than its share of the wool tax. Consequently, the WRDC needs to consider the distribution of the benefits from R&D as well as the total benefits to the entire wool chain.

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[1] This study concentrates on the distribution of gross benefits from research-induced supply shifts. The incidence of the wool tax and the matching government grant, and the implications for R&D are discussed in Alston *et al.* (1988).

A Model of the Wool Top Industry

The benefits from farm research compared to processing research and the importance of substitution in processing between wool types and between wool and processing inputs are examined within the context of a 'world' wool top industry which 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. Successful research reduces the cost of producing or processing wool and is modelled as shifting the supply of wool or the supply of processing inputs to the right. 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. Adoption of Australian farm research by competing woolgrowers is modelled as an increase in their supply of wool. Modelling technical change in this way implies that it is biased towards use of the factor whose supply shifts to the right.

An equilibrium displacement model of the world wool top industry is used to estimate changes in the prices and quantities of wool from different sources, processing inputs and wool top that result from exogenous supply and demand shifts caused by successful research. The methodology, following Muth (1964) and Gardner (1975), involves describing the wool top industry in terms of general supply and demand conditions for the inputs and output of the industry. A constant returns to scale production function enforces equilibrium.

The production function for the wool top industry can be written as

$$Y = f(X1,\ X2,\ X3)$$

When the production function shows constant returns (see Diewert 1981 for a discussion of this assumption), the industry total cost function can be written as

$$C = Yc(W1,\ W2,\ W3)$$

where the W's refer to input prices and $c(.)$ is the unit cost function. Implications of this specification are that for given factor prices, marginal and average costs are equal and independent of output and that equilibrium in the industry can be described by

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

Equation (1) 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 (2) expresses the long-run condition that product price equals minimum average total cost. The output-constrained demand functions for inputs, equations (3), (4) and (5), 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 encompassing the impact of AWC-funded research.[2]

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 1 to 8 and converting them to elasticity form to give equations 9 to 16:

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

(10) $EP = x_1EW1 + x_2EW2 + x_3EW3$

(11) $EX1 = -(x_2\sigma_{12} + x_3\sigma_{13})EW1 + x_2\sigma_{12}EW2 + x_3\sigma_{13}EW3 + EY$

(12) $EX2 = x_1\sigma_{12}EW1 - (x_1\sigma_{12} + x_3\sigma_{23})EW2 + x_3\sigma_{23}EW3 + EY$

(13) $EX3 = x_1\sigma_{13}EW1 + x_2\sigma_{23}EW2 - (x_1\sigma_{13} + x_2\sigma_{23})EW3 + EY$

(14) $EW1 = s_1EX1 + ET1$

(15) $EW2 = s_2EX2 + ET2$

(16) $EW3 = s_3EX3 + ET3$

where E indicates relative change (for example $EP = \Delta P/P$), η is the own price elasticity of demand for wool top, x_i is the share of total wool top processing costs for input i, σ_{ij} is the Allen 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. For small changes from an initial equilibrium, market parameters are assumed to be constant and no presumption is made about the functional form taken by these equations. The derivation of this system of equations can be found in Appendix 1.

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.

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.[3] The formulae to calculate surplus changes are

(17) $CS = P\,Y(EN - EP)(1 + 0.5EY)$

[2] The exogenous demand and supply shifters can also represent taxes on different sectors in the wool chain by reversing the direction of the shift.

[3] 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. If, in the case of farm research, the induced supply shift is divergent then some Australian woolgrowers may receive higher returns from research in other sectors which, as this paper points out, is unlikely to be the case for a parallel shift. 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.

(18) $PS1 = W1\,X1(EW1 - ET1)(1 + 0.5EX1)$
(19) $PS2 = W2\,X2(EW2 - ET2)(1 + 0.5EX2)$
(20) $PS3 = W3\,X3(EW3 - ET3)(1 + 0.5EX3)$

The total change in surplus to the industry can be found by summing these four measures.[4] 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 small for the small shifts considered here.

The returns to the Australian wool industry from different types of research are compared in two ways. First, the changes in economic surplus from 1 per cent reductions in the costs of growing and processing wool are estimated. A second perspective is provided by an assessment of the reduction in processing costs that would return the same benefits to Australian woolgrowers as a 1 per cent reduction in wool production costs.

Parameter Values

Price, quantity and surplus changes can be estimated if the market parameters in the equations above are known. Parameter values are selected on the basis of the theory of derived demand and after reviewing past studies of supply and demand conditions in the world wool industry.

Input cost shares

Input cost shares for a competitive industry are calculated as

$$\kappa_i = X_i W_i / Y P$$

Wool top production in non-centrally planned economies in 1985 was 480 kt (Commonwealth Secretariat 1986). Using an average price for 21 micron top of \$A8.86 per kg (*Wool Record* data), the value of production, YP, is estimated to be \$A4251m. This value is also used to estimate changes in surplus to the different sectors of the industry.

At the input level, data on raw wool consumption from Australia and the rest of the world by the wool top industry are unavailable. We were able to derive estimates of the production of wool suitable for apparel use in non-centrally planned economies. The proportion of this wool that is used in the woollen (as opposed to worsted) industry is unknown and will vary with relative prices. The share of total costs attributable to all wool can be estimated as the ratio of the price of wool to the price of

[4] The estimates of surplus changes could be interpreted as the annual change in gross surplus from 1 per cent cost reductions in the three stages of the wool chain modelled here, if the entire industry adopted the new technology immediately and if 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. If adjustment does not occur within the year, care needs to be taken to ensure that the market parameters and value of production data used apply to the same length of run. To aggregate surplus changes through time correctly an approach such as that adapted by Mullen, Wohlgenant and Farris (1988) from Just, Hueth and Schmitz (1982) needs to be used and account taken of the time preference for money. The approach to aggregating surplus changes can be adapted to allow a more gradual rate of adoption of technology. Net surplus gains can be estimated from information on the cost of developing and implementing the new technology and on the incidence of these costs which can also be derived from the present model. If the stages in the wool chain differ in the time taken for adjustment of demand and supply and in the rate of adoption of new technology then the rankings of research areas may change and an aggregation procedure will be a necessary component of the analysis.

wool top where the price of wool is expressed as the price of the number of units of clean wool required to produce a unit of wool top. Using the price of Australian 21 micron wool, the cost share for all wool is about 0.8. Australia's share of all wool used by the wool top industry is estimated to be about 65 per cent (AWC, personal communication). Consequently, the cost shares for Australian wool, x_1, wool from the rest of the world, x_2, and processing inputs, x_3, have been set at 0.5, 0.3 and 0.2 respectively.

Elasticities of input substitution

Looking first at substitution between wool types, it could be argued that apparel wools from different countries are perfect substitutes in the production of wool top. Armington (1969) suggested an alternative view that importers do distinguish between different sources of traded products because suppliers are different in terms of reliability and services provided (such as credit) even if the product is otherwise homogeneous. Hence, identical products from different suppliers may not be perfect substitutes.

Recent empirical studies by Dewbre, Corra and Passmore (1983), and Simmons and Ridley (1987) found surprisingly low levels of substitutability between wool from different countries. Dewbre *et al.* (1983), using an Armington approach, estimated an elasticity of substitution between wool types in the Japanese wool market of 1.68. In the US market the elasticities of substitution between domestic and imported wool and between imported wools were 1.43 and 0.64 respectively. The largest elasticity of substitution estimated by Simmons and Ridley (1987) was 0.6 between wools from South Africa and Argentina.

TABLE 1

Raw Wool Demand Elasticities

Study	Observation period	Country Exporter/Importer	Long-run elasticity
Campbell, Gardiner and Haszler (1980)	Quarterly	World/Aust.	−0.11 to −0.13
Veldhuizen and Richardson (1984)	Quarterly	World/Japan	−0.21 to −0.32
		World/Germany	−0.26 to −0.32
		World/Italy	−0.28 to −0.32
Dewbre *et al.* (1983)	Annual	Aust./Japan	−1.07
		NZ/Japan	−1.47
		S. Africa/Japan	−1.66
		Argentina/Japan	−1.66
		Rest of world/Japan	−1.59
		Aust./USA	−0.77
		NZ/USA	−0.73
		S. Africa/USA	−0.68
		Argentina/USA	−0.68
		Uruguay/USA	−0.67
Simmons and Ridley (1987)	Annual	Aust./world	−0.157
		NZ/world	−0.408
		Argentina/world	−0.327
		S. Africa/world	−0.544

An elasticity of substitution between Australian wool and wool from competitors of 5 is used rather than a much higher value because it is more consistent with published estimates of wool demand elasticities (Table 1) and also with estimates of this parameter for grains from different countries made by Grennes, Johnson and Thursby (1978). There may well be a conflict between the view that Australian and other wools are highly substitutable and the view that the derived demand for Australian wool is not highly elastic. It is clear from the following equation for the elasticity of derived demand that there is a close relationship between the extent of input substitution possibilities and how responsive the demand for products and inputs are to price changes:

$$\epsilon_{ii} = x_i \eta - \Sigma x_j \sigma_{ij}$$

where i does not equal j, ϵ_{ii} is the elasticity of demand for the input, say Australian wool, x_i is the cost share of input i, η is the elasticity of demand for the product, say wool top, and σ_{ij} is the elasticity of substitution between inputs. As discussed below, the elasticity of demand for wool top is unlikely to exceed -1.0. Substituting the input shares previously derived and elasticities of substitution between wool from different sources and between Australian wool and processing inputs of 5.0 and 0.1 implies that the elasticity of demand for Australian wool is about -2.0. This is much more elastic than published estimates. The substitution term, about -1.5, is always likely to dominate the output effect so that reducing the elasticity of demand for wool top is unlikely to greatly reduce the elasticity of demand for Australian wool but any increase in the elasticity of substitution between Australian and other wool quickly increases the elasticity of demand for Australian wool. A qualification to this reasoning is that the formula above assumes that input prices remain constant.[5]

The conventional assumption has been that substitution in processing between farm and non-farm inputs is not possible or is so small as to be of little consequence. Ferguson (1969) and Diewert (1981) made strong cases for a limited degree of input substitution of this nature at an industry level as the proportion of output produced by firms alters in response to changes in relative input prices. Substitution possibilities increase with the number of technologies and firms in the industry. Estimates of substitution between wool and processing inputs are unavailable. In this analysis both types of wool are assumed to be equally substitutable with processing inputs. A value of 0.1 is used for the elasticity of substitution between wool types and processing inputs. This is based on an estimate for a similar parameter in US beef processing by Mullen, Wohlgenant and Farris (1988).

Elasticity of demand for wool top

Few direct estimates of the elasticity of demand for wool top are available because most wool demand studies have been conducted at either the raw wool or retail levels. Recent estimates of the elasticity of demand for apparel wool are contained in a Bureau of Agricultural Economics (BAE, 1987) study of the returns from wool promotion in the US. The parameter was estimated for both the US market and for the world apparel market. The short- and long-run elasticities of final consumer demand for wool

[5] In a preliminary econometric study Mullen, Alston and Wohlgenant (1989) reported an estimate of this parameter of 6.5.

in apparel in the US market were −1.1 and −1.3 respectively. From the model of world apparel wool consumption, short- and long-run elasticities were estimated to be −0.2 and −0.6 respectively. In this model the wool price variable was based on prices of raw wool rather than retail wool prices. Consumption of apparel wool at retail appears to have been estimated by applying fixed yield factors to raw wool production data. The data deficiencies make interpretation of elasticities difficult but the BAE's estimates can probably best be interpreted as elasticities of demand for raw wool.

Estimates of the elasticity of demand for raw wool for individual countries and for raw wool in aggregate are reported in Table 1. Demand for wool from individual countries is expected to be more elastic than the demand for wool in aggregate although this is likely to be less true for Australia because of its often-claimed dominance in the market. Many of the estimates for individual countries are in the inelastic range. The exceptions are the estimates of Dewbre *et al.* (1983).

If we think of the demand for wool top as being derived from the demand for clothing then the formula above for the elasticity of derived demand can provide some useful insights about the elasticity of demand for wool top. When input substitution is not possible, that is when all σ_{ij} values are zero, the formula takes a similar form to that suggested by George and King (1971) and derived demand is less elastic than the demand for the product. However, once input substitution is possible, the demand for an intermediate good such as wool top is not necessarily less elastic than the demand for the final product or more elastic than the demand for the input, raw Australian wool.

Another confounding issue is that it may take wool processors longer than a year to adjust to price changes. In the analysis below an elasticity of demand for wool top of −1.0 is used. This level of response may not be achieved within a year of the initial price change.[6]

Input supply elasticities

Supply elasticities are required for the three inputs in the wool top industry. A range of wool supply elasticities is presented in Table 2. The most notable feature of these estimates is how inelastic is the supply of wool, even in the long run. The only recent estimates larger than 1.0 are from Simmons and Ridley (1987) and from the programming approach of Hall and Menz (1985). Such a low level of supply response certainly seems to be at odds with the popular view in Australia of quite large shifts between enterprises in response to relative price changes.

The supply response by Australian woolgrowers relative to their competitors, and relative to the elasticity of demand, influences the share of efficiency gains to Australian woolgrowers *vis-à-vis* consumers and competing woolgrowers. In the short run, supply is likely to be less elastic than demand and producers will receive a larger share of efficiency gains than consumers.

It is unlikely that supply elasticities across exporters will be equal. However, it is difficult to make strong *a priori* arguments, based on the resource constraints and alternative investment opportunities that confront

[6] Mullen, Alston and Wohlgenant (1989) reported an estimate of the short-run elasticity of demand for wool top of −0.45 but evidence for a longer period of adjustment by the industry was inconclusive.

TABLE 2

Own-Price Supply Elasticities for Wool

Study[a]		Length of run: Short	Intermediate	Long
Australia				
Powell and Gruen	(1967)	0.07	0.33	
Witherell	(1969)	0.07	0.13	
Malecky	(1975)	0.07	0.35	3.9 to 4.7
Wicks and Dillon	(1978)	0.25	0.36	
Vincent, Dixon and Powell	(1980)	0.18	0.26	
Hall and Menz	(1985)		2.02	
BAE	(1987)	0.04	0.35	0.86
Simmons and Ridley	(1987)			1.35
New Zealand				
Witherell	(1969)	0.03	0.72	
Tweedie and Spencer	(1980)		0.33	
Laing and Zwart	(1983)	0.05	1.38	
Shaw	(1986)	0.08	0.43	
Simmons and Ridley	(1987)			0.718
BAE	(1987)	0.02	0.08	0.30
South Africa				
Witherell	(1969)	0.08	0.76	
Simmons and Ridley	(1987)			1.276
Argentina				
Witherell	(1969)	0.04	0.20	
Simmons and Ridley	(1987)			2.116
Uruguay				
Witherell	(1969)	0.21	0.48	
Simmons and Ridley	(1987)			

[a] An econometric analytical technique was used in all studies except for those by Wicks and Dillon (1978) and Hall and Menz (1985) which used a programming technique.

woolgrowers in different countries, about the extent and direction of the differences. Hence, the issue is best resolved empirically. Only the studies by Witherell (1969) and Simmons and Ridley (1987) provide supply elasticity estimates from countries other than Australia and New Zealand but it is not clear whether Australian wool is more or less elastic in supply than that from its competitors. A raw wool supply elasticity of 1.0, corresponding to a medium- to long-run adjustment period, is used for Australia and the rest of the world in view of the difficulty of assigning different wool supply elasticities on either *a priori* or empirical grounds.

In past studies, processing inputs have been assumed to be perfectly elastic in supply. This implies that, at least in the long run, the processing sector can not appropriate any of the gains from new technology. An elasticity of supply of 20 is used below but the question arises as to why processing inputs are expected to be so much more responsive to price changes than the supply of wool.

Base Run

Results for the base run are presented in Table 3 where the columns represent the impact of cost reductions in textile production. Australian

TABLE 3

Impact of Research on the Australian Wool Industry

	Textile research $EN = 0.005$	Australian farm research $ET1 = -0.01$	Top processing research $ET3 = -0.01$	Adoption of Aust. farm research by competitors $ET1 = -0.01$; $ET2 = ET1/2$
A. Returns to industry sectors (in \$Am at 1985 prices) from 1 per cent cost reductions at each stage in the wool chain when parameters are set at base levels.				
Aust. wool industry	5.82	12.38	2.08	10.97
Other woolgrowers	3.49	−2.80	1.25	1.46
Top processors	0.13	0.10	0.09	0.14
Top consumers	11.85	11.63	5.09	15.13
Total industry	21.28	21.31	8.51	27.69
B. Returns (\$Am) to Australian woolgrowers from 1 per cent cost reductions at each stage in wool chain as market parameters vary.				
Base Run[a]	5.82	12.38	2.08	10.97
σ values = 0	5.88	5.88	2.35	7.65
$\sigma_{13} = \sigma_{23} = 0$, $\sigma_{12} = 100$	5.88	13.79	2.35	11.60
$\eta = -0.5$, $s_1 = s_2 = 2.0$, $s_3 = 0.1$	5.75	13.15	1.82	11.41
C. Productivity gains required from textile and top making research to provide the same returns to the Australian wool industry as a 1 per cent reduction in the cost of growing wool.				
Base run	1.02[b]	1.0	5.95	
σ values = 0	0.50	1.0	2.50	
$\sigma_{13} = \sigma_{23} = 0$, $\sigma_{12} = 100$	1.17	1.0	5.87	
$\eta = -0.5$, $s_1 = s_2 = 2.0$, $s_3 = 0.1$	1.14	1.0	7.23	

[a] Base run parameter values: $\eta = -1.0$; $\kappa_1 = 0.5$; $\kappa_2 = 0.3$; $\kappa_3 = 0.2$; $s_1 = 1.0$; $s_2 = 1.0$; $s_3 = 0.05$; $\sigma_{12} = 5.0$; $\sigma_{13} = 0.1$; $\sigma_{23} = 0.1$. In each scenario all parameters are at base values except those under examination.

[b] Recall that it is assumed that a 1 per cent reduction in textile processing costs causes an increase in demand for wool top of 0.5 per cent. The figures in this column are also required shifts in the demand for wool top. Required reductions in textile processing costs will be larger.

wool production, and wool top production. The scenario in which Australia's competitors are able to adopt Australian technology to the extent that their costs fall by 0.5 per cent is shown in the last column.

An objective of this study is to develop a framework within which different types of research can be assessed consistently. This is most difficult in the case of textiles research. When textile processing uses wool top in fixed proportions with other factors, a 1 per cent reduction in the cost of textile manufacturing leads to a 1 per cent increase in the price of wool top at the initial equilibrium level of output but the increase in price is smaller when processors can substitute the relatively cheaper processing inputs for wool top. When the elasticity of substitution between wool top and processing inputs is more elastic than the elasticity of demand for textiles, textile processing research may result in a fall in the demand for wool top. Plausible values for market parameters in the textile manufacturing sector suggest that the price of wool top is likely to rise by 0.2 per cent when textile processing costs fall by 1 per cent (see Appendix 2). Because it may be possible to develop textile technology that only enhances the demand for wool top rather than lowering processing costs in general, we have examined the situation where the price of wool top increases by 0.5 per cent as a result of textile research (column 1 in Table 3).

The returns to the total wool chain (expressed in 1985 $A) are roughly the same for a 1 per cent reduction in Australian farm costs and a 0.5 per cent increase in the price of wool top from new textile technology ($21m, Table 3, part A). The returns from wool top processing research are much smaller ($9m). Market shares and the extent of the shift in the demand for wool top are the driving influences here. This conclusion is expected to be insensitive to the values of market parameters but not to the size of the demand shift. If the demand shift were only 0.1 per cent total industry surplus gains would only be $4.3m but if the demand shift were 1 per cent then total surplus gains would be $42.6m. It must be stressed again that this is for equal percentage productivity improvements and ignores the question of the efficiency of research resources in these areas.

Individual sectors of the industry rank research areas differently. In general, sectors receive higher returns from research in their sectors although this conclusion is likely to be more sensitive to values of the market parameters. Because the cost share of Australian wool is so large, wool top consumers only benefit marginally from textiles research over Australian farm research. Wool top processors actually receive slightly larger returns from Australian farm research than from research in their sector.

In this base scenario a 1 per cent reduction in farm production costs results in the largest surplus gains to the Australian wool industry ($12.4m). The supply shifts in other stages required to give the same return to Australia are much larger (Table 3, part C). Top processing costs need to fall by 6 per cent. The demand for wool top needs to rise by 1.2 per cent. This is equivalent to a reduction in textile processing costs of between 2 and 10 per cent (depending on the extent to which the shift in the supply of textile processing inputs results in an increase in the demand for wool top). When competing woolgrowers can adopt Australian farm research to the extent that their costs fall by 0.5 per cent (last column in Table 3), worldwide surplus gains increase by about $6m and competing woolgrowers gain about $3m but Australian woolgrowers' gains decline by about \$1m. Clearly, Australian woolgrowers would prefer to be in a position where they could sell new farm technology or at least extract a share of the cost of developing it. However, even if a 'free rider' problem exists, farm research may still result in the largest surplus gains to the Australian wool industry. The importance of the leakage issue will depend not only on the ease with which competitors can adopt Australian technology but also on relative supply elasticities and the degree of substitution between Australian and other wool in the production of wool top.

The model can be used to generate an elasticity of demand for Australian wool by assuming it is perfectly elastic in supply and estimating the change in quantity demanded for a 1 per cent shift in supply. For the base parameters the implied elasticity is -1.4. Similarly, by assuming demand is perfectly elastic and allowing the price of wool top to rise by 1 per cent, an elasticity of the supply of wool top of 1.3 is derived. In both situations the prices of other inputs are allowed to adjust.

By varying market parameters the sensitivity of rankings by the Australian wool industry of research at the different stages can be examined (Table 3, parts B and C). There are two broad approaches to sensitivity analysis. One approach would involve varying the market parameters one at a time and reporting the changes in surplus. We found that the returns to the industry from farm research were much larger than from research in other sectors of the wool chain for reasonable ranges of the market parameters. The only exception is the situation in which Australian wool and wool from other countries are used in fixed proportions. This situation is discussed in more detail below, largely because of its didactic merit, but it is not a reasonable assumption. A second approach, the one used here, is to vary some parameters jointly to represent particular economic scenarios. The scenarios discussed below are when input substitution possibilities are limited and when the adjustment period is short.

Changing Input Substitution Possibilities

Input substitution possibilities have an impact on these base run results. Australian farm level research which is not appropriated by competitors results in decreases in the price, quantity and economic surplus to wool industries in competing countries as relatively less expensive Australian wool is substituted for other wool. Australian woolgrowers gain a larger market share. Substitution effects outweigh scale effects. On the other hand, substitution possibilities between wool types and processing inputs are more limiting relative to the elasticity of demand for wool top and hence processing research results in gains in surplus to all woolgrowers although these gains are smaller than for fixed proportions technology.

When input substitution is not allowed in the model, market participants receive the same share of total benefits regardless of where the research is undertaken. Hence, research areas are ranked by all according to global benefits. Australian woolgrowers are indifferent between textile and farm level research in this scenario (a conclusion sensitive to the assumed shift in the demand for wool top from textile research). The returns to them from top processing research are still less than from other areas because of the small cost share of top processing inputs.

This is also the only scenario in which the incidence of a wool tax to fund research is the same as the incidence of research benefits wherever the research is undertaken (see Alston and Scobie 1983; Alston, Mullen and Ridley 1988). The incidence of the Australian wool tax corresponds to a decrease in the supply of Australian wool. Once input substitution is allowed the share of the returns to Australian woolgrowers from research in other sectors is less than the share they pay of the wool tax.

Another plausible scenario concerning input substitution is where wool from different sources is highly substitutable but wool and processing inputs are used in fixed proportions ($\sigma_{12} = 100$, $\sigma_{13} = \sigma_{23} = 0$, Table 3, part B). In this scenario the returns to Australian woolgrowers from farm research are enhanced because top processors can more easily substitute Australian wool for other wool as the price of the former falls. The elasticity of demand for Australian wool implied by this scenario is -1.8.

Short-Run Adjustments

While there is much uncertainty about the market parameters used in the base run, it does seem likely that the demand and supply parameters represent a level of response that would occur over several years rather than within a year. The short-run impact of new technology has been examined by halving the elasticity of demand for wool top and the elasticity of supply of all inputs. Opportunities for input substitution may also be time-dependent but are not altered in this scenario. The ranking of research areas by the Australian wool industry remains unchanged but both textile and top processing research have to be more effective than in the base run to give equivalent returns to Australian woolgrowers, reflecting more significant substitution effects relative to scale effects.

Concluding Comments

We have found that the Australian wool industry is likely to gain more from farm production research than from research at other stages in the wool chain when costs are reduced by 1 per cent at each stage, even when competing woolgrowers can partially adopt Australian farm research. While this finding is quite robust to reasonable alternative values of the relevant market parameters, it may be more sensitive to the assumption that the research-induced supply shifts are parallel and to the way in which textile research affects the demand for wool top. If textile research is largely directed to lowering textile manufacturing costs in general (or can be appropriated in textile manufacturing using other fibres) then the increase in demand for wool top and the consequent return to Australian woolgrowers are likely to be small. If, however, textile research can be specifically targetted to increase the demand for wool top then the return to the Australian industry from a 1 per cent increase in the price of wool top from this type of research is approximately the same as the return from farm research that lowers the cost of growing wool by 1 per cent.

Because Australia provides such a large share of inputs to the wool top processing industry, research areas are ranked in the same way by the Australian wool industry and by the entire wool chain. However, while the ranking by Australian woolgrowers is clear-cut, the entire wool chain is almost indifferent between textile and Australian farm research and the ranking is quite sensitive to input shares and the extent of the shift in demand for wool top. By contrast, both top consumers and producers receive larger returns from textiles research and top producers are almost indifferent between Australian farm research and research into top making. The divergence in rankings is explained by opportunities for substitution between wool types and between wool and processing inputs in the productin of wool top. Even limited substitution possibilities can result in a radical re-ordering of research priorities. Allowing for the possibility of input substitution also has implications for perceptions about the responsiveness of demand for raw wool and wool top to price changes.

APPENDIX 1

Derivation of Equations 9 to 16

In the following, d refers to a total differential and δ is used in the context of a partial derivative. Because we are examining 1 per cent shifts in the price direction, the elasticity terms associated with the exogenous shifters, N, $T1$, $T2$ and $T3$, are all assumed to take a value of 1 and are expressed as relative changes in price.

Demand for wool top

(1) $P = f(Y, N)$

By total differentiation and division through by P

$$\mathrm{d}P/P = (Y/P)(\delta P/\delta Y)(\mathrm{d}Y/Y) + EN$$

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

where η is the own price elasticity of demand for wool top.

Market clearing condition

(2) $P = c(W1, W2, W3)$
$\mathrm{d}P/P = (W1/P)(\delta c/\delta W1)(\mathrm{d}W1/W1) +$
$(W2/P)(\delta c/\delta W2)(\mathrm{d}W2/W2) + (W3/P)(\delta c/\delta W3)(\mathrm{d}W3/W3)$

Recall that $c(W1, W2, W3) = C/Y$ where C is the industry total cost function. Hence, $\delta c/\delta W_i = (\delta C/\delta W_i)/Y = X_i/Y$. Note that the input cost share, κ_i, is W_iX_i/PY. Hence,

(10) $EP = \kappa_i EW1 + \kappa_2 EW2 + \kappa_3 EW3$

Input demand equations

(3) $X1 = h_1(W1, W2, W3)Y$
$\mathrm{d}X1/X1 = W1(Y/X1)(\delta h_1/\delta W1)(\mathrm{d}W1/W1)$
$+ W2(Y/X1)(\delta h_1/\delta W2)(\mathrm{d}W2/W2)$
$+ W3(Y/X1)(\delta h_1/\delta W3)(\mathrm{d}W3/W3) + Y(h_1/X1)(\mathrm{d}Y/Y)$

Since $h_1(W1, W2, W3) = X1/Y$, $\delta h_1/\delta W_i = (\delta X_1/\delta W_i)/Y$. When the output-constrained elasticity of demand for input $X1$ with respect to the price of input j is denoted as v_{1j} for $j = 1, 2, 3$,

$$EX1 = v_{11}EW1 + v_{12}EW2 + v_{13}EW3 + EY$$

By symmetry of the cost function $v_{ij} = v_{ji}$. Imposing homogeneity of degree zero in prices on this demand function means that $v_{11} = -v_{12} - v_{13}$. Finally, by Allen's definition of the elasticity of input substitution $v_{ij} = \kappa_j\sigma_{ij}$. Hence,

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

Similarly,

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

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

Input supply equations

(6) $W1 = g_1(X1,\ T1)$
$dW1/W1 = (X1/W1)(\delta g_1/\delta X1)(dX1/X1) + ET1$

(14) $EW1 = s_1 EX1 + ET1$

where s_1 is the inverse of the own price elasticity of supply. Similarly,

(15) $EW2 = s_2 EX2 + ET2$

(16) $EW3 = s_3 EX3 + ET3$

APPENDIX 2

Estimating the Increase in Demand for Wool Top from New Textile Technology

A 1 per cent reduction in textile processing costs results in a 1 per cent increase in the price of wool top at the initial level of output, represented by *EN*, only if textile production has a fixed proportions nature. Clearly, some substitution between wool top and other fibres is possible if not between wool top and processing inputs. The model above has been redesignated as the production of textiles (*Y*) from wool top (*X*1), other fibres (*X*2) and processing inputs (*X*3) with market parameters interpreted accordingly, and used to estimate the change in the price of wool top from a 1 per cent reduction in textile production costs, *ET*3. This approach assumes that new technology in textile production applies to all fibres and not just wool top. Further, the question of research that changes the characteristics of wool textiles is not considered. Market parameters are assumed to take on the following values:

Elasticity of demand for textiles	−1.00
Share of wool top	0.13
Share of other fibres	0.37
Share of processing inputs	0.50
Elasticity of substitution between wool top and other fibres	3.0
Elasticity of substitution between wool top and processing inputs	0.5
Elasticity of substitution between other fibres and processing inputs	0.5
Elasticity of supply of wool top	2.0
Elasticity of supply of other fibres	2.0
Elasticity of supply of processing inputs	20.0

An elasticity of supply of wool top of just under 2.0 (1.85) is derived from the wool top model by making the demand for wool top (almost) perfectly elastic and increasing the demand for wool top by 1 per cent. The elasticity of supply of other fibres is set equal to this although the supply of these fibres may be more elastic when the length of run is less than that required for full adjustment. For these parameters a 1 per cent fall in textile production costs results in a 0.19 per cent increase in the price of wool top. As a starting point an increase in price of 0.5 per cent is used.

The elasticity of demand for wool top estimated from the textile model by making the supply of wool top perfectly elastic and reducing wool top price by 1 per cent is -1.2, close to the value of -1.0 used above.

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