# Estimating Distributional Impacts of an Innovation Across Sectors in an Industry: A case study of the Australian wool industry

**by**

**Dave Collins[1] & Brian Davidson[2]**

[1] BDA Group
1/14 Grove Rd, Hawthorn, Vic

[2] Institute of Land and Food Resources
University of Melbourne, Parkville, Vic

A paper submitted to the 48th Annual Conference of the Australian Agricultural and Resource Economics Society, Melbourne,

10th – 14th February 2004.

# ESTIMATING DISTRIBUTIONAL IMPACTS OF AN INNOVATION ACROSS SECTORS IN AN INDUSTRY: A CASE STUDY OF THE AUSTRALIAN WOOL INDUSTRY


## ABSTRACT

In this paper an approach that can be used to determine the distribution of a productivity gain on an industry is detailed. In particular, the model developed in this paper extends earlier evaluations by emphasising the crucial role of substitution between inputs across different participants in the supply chain. Crucial to any analysis of an industry are the estimates of the elasticity's of derived demand at each stage and how it changes, as the product is further refined. The wool industry is used to illustrate the effects of an innovation across sectors.


## 1. BACKGROUND

Increasingly policy makers have become interested in the distributional consequences of successful research and development and promotional expenditures. In addition to those employed in various research funding agencies, the subject has intrigued analysts from academe (like Alston and Pardey 1996 and 1998) and international aid organizations (like the World Bank see Byerlee and Alex 1998 and George 2000). In Australia, a majority of the research on the agricultural sector is funded through commodity specific Research and Development Corporations. These Corporations are funded from levy payments from primary producers and are matched by a contribution from the Australian government, a figure that is capped at 0.5 per cent of the industry's gross domestic value (calculated at the farm-gate). Because successful research and development leads to an expansion of production, benefits flowing from productivity gains are distributed over-time between producers, processors and consumers. To determine the "pay back" to primary producers from the benefits of increased research, the distributional impacts need to be estimated.

It should be noted that interest in this subject is not confined solely to the evaluation of research and development expenditures. Changes in government policies relating to the management of natural resources will have widespread social impacts. Hence, an understanding of the economic impacts on target and downstream industries and methods of evaluating them is an essential tool most need at some stage. For instance, currently governments rarely subsidise industry activities, such as technology extension, marketing and promotion. They have placed the responsibility for these activates on representative industry bodies. Distributional impacts associated with such activities are equally important in determining the 'pay back' to stakeholder funds, as they are in the research and development arena. In addition, government policies targeting social or equity objectives, such as drought relief, will have downstream impacts. An understanding of the degree of capture of benefits by different community groups should be a central consideration in the formulation of such policies.

In this field the early work of Freebairn, Davis and Edwards (1982) on research gains in a multistage production system has stood the test of time. This work was followed by others who have looked at variants to the basic model, like Alston, Edwards and Freebairn (1988) and Freebairn (1992) who looked at the effects of market distortions on the distributions. Yet the early study by Freebairn *et al* (1982) remains the basic approach used by economists to estimate the distributional consequences of productivity impacts at the farm or sector level. Mullen Alston and Wohlgenaut (1989) developed a model that was used to estimate the distributional consequences of productivity impacts across a processing sector where farm production was treated as an input supply. In their study gains from exogenous shifters of farm supply, as well as other top making inputs, were estimated.

The work of Mullen *et al* (1989) provides practical approach to estimating distributional consequences from productivity impacts in any industry, irrespective of the number of sectors that may exist between farm production and final consumption. The appeal of the approach is that data requirements are kept to a minimum, solutions can be generated on simple spreadsheet software and the approach can easily be explained to the non-technically minded.

# 2. AIMS

In this paper the mathematical framework advanced by Mullen *et. al.* (1989) is expanded to account for any number of processing stages between primary production and final demand. How the early work of Freebairn *et. al.* (1982) can be explained in a multi-stage model is demonstrated through an explanation of derived demand. Also, the impacts input substitution has on derived demand, and hence the distribution of R&D benefits between producers, processors and consumers, needs to be incorporated in the analysis.

Apart from building on the work of Mullen *et. al.* (1989), some conclusions are established that can be readily applied to other primary industries to determine the likely distributions of research and development benefits within an industry, without the onerous need for complicated econometric models. It could be argued that the lack of an easily understood and robust multi-stage model limits the use of distributional impact models by those in Australian (and indeed overseas) who fund research and development. As a consequence, there may be an over investment in research and development activities by Australian funders that target productivity gains in downstream processing activities.

Finally, the multi-stage model is applied in the context of the global worsted wool industry, for three segments; mainly wool products, blended wool products and knitwear. This application is useful in;

- demonstrating the distributional impacts from research and development expenditure under different supply, processing and demand conditions;
- updating estimates from Mullen *et.al.* (1989) in light of the demise of the Reserve Price Scheme and
- assessing the shift in consumer attitudes away from formal apparel to smart casual attire.

The aim in this paper is to first, outline the approach used to determine the distribution of a productivity gain on an industry. Second, to explain the crucial role of substitution across inputs on the distribution of benefits across different participants in an industry, by adding additional processing sectors to the theoretical framework developed by Mullen *et. al.* (1989). Finally, to update distributional results in light of fundamental changes in the market and consumption patterns of Australian wool.

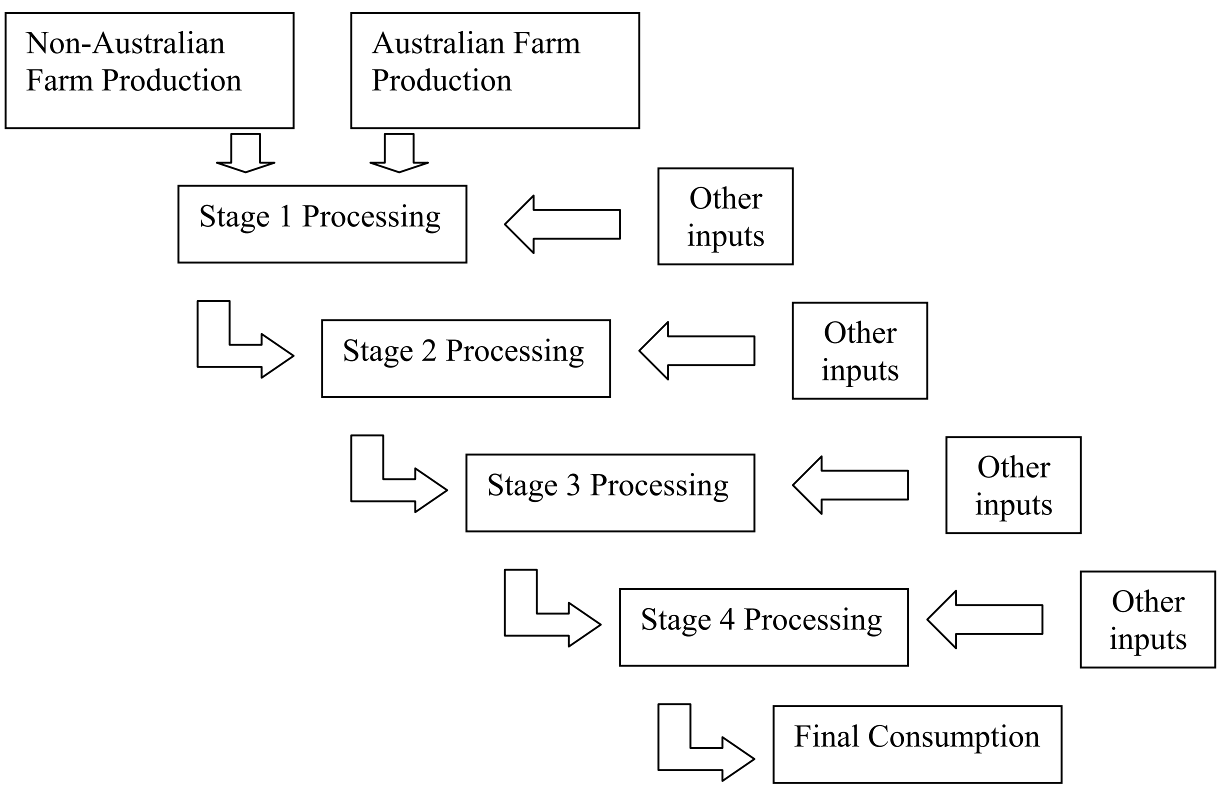
# 3. The Modelling Approach

To assess the distributional impacts of an innovation, like an increase in investment in research and development in one sector on an industry, it is necessary to understand the process by which a product changes as it passes through the supply chain and gains value. Further, it is necessary to understand how the various processing stages can be linked and described in a mathematical framework, rather than if the sectors stand-alone.

A typical view (see Figure 1) of an industry is one in which the inputs from a primary production unit are combined with other inputs from other sectors and countries. As all primary commodities need to be refined before they are consumed (by definition a primary commodity is one that is not refined) the goods must pass through a number of processing stages, in which other inputs are added.

The worsted wool industry is like this. The main processing stages are top making (which includes scouring), yarn production (spinning), fabric production (weaving or knitting) and garment manufacture. The main difference between primary industries is the number of processing stages that exist between farm production and final consumption. For example, in the beef industry primary production occurs on farm and in feedlots and processing includes mainly abattoir and boning operations.

Figure 1: Commodity Processing Stages – Production to Final Consumption



The approach used by Mullen *et. al.* (1989) to estimate the wool processing sector is described by Piggott (1992) as a 'comparative static analysis of general functional models', or more commonly as an 'equilibrium displacement model'. Piggott suggests that such models were first developed by Muth (1964) and have been widely employed in the United States to investigate a number of issues. Piggott distinguishes between comparative static models (which usually involve the use of calculus to indicate the direction of change in an endogenous variable following a change in an exogenous variable) and equilibrium displacement models. In the latter changes in both exogenous and endogenous variables are measured in proportionate terms, or as ratios of proportionate changes (i.e. elasticities). In both approaches the markets in question are specified using a matrix of own-price and (possibly) income elasticities estimates and each is bound to the other by a set of cross-price elasticities. Of importance in a multistage commodity model, where the good is refined through a number of stages of a processing sector, are the derived demand relationships, which are also expressed in elasticity format.

The theory underlying the demand for inputs is well documented. The usual method of presenting this theory is to start with a firm's input demand schedule and build up to a market level analysis. Layard and Walters (1978) and Gravelle and Rees (1981) suggest that in analysing a firm's demand for inputs, it is necessary to assume that:

- the firm is a profit maximiser;
- that it faces no adjustment costs involved in varying input levels;
- that perfect knowledge exists;
- no production externalities occur;

- all resources are perfectly mobile and can be combined continuously; and
- that the firm's actions will not affect either input or output prices.

Theoretically, a firm will adjust its input levels until the cost of an extra unit of input is equal to the extra revenue generated by that extra unit of input. An increase in the input increases output by the marginal product of that input and a unit increase in output increases revenue by its marginal revenue. Therefore, the extra revenue derived from using an extra unit of input is equal to the marginal revenue multiplied by the inputs marginal product, (or more formally, its marginal revenue product). A necessary, but not sufficient, condition for profit maximisation is that the marginal cost of an input should be equal to marginal revenue.

It can be deduced that a firm's demand for inputs will depend on the prices of inputs and the parameters of the production and output functions. From this base, a number of properties of input demand equations can be derived. The most important of these (although not proved here but listed in Gravelle and Rees 1981) are that;

- input demand schedules are always negatively sloped, regardless of the structure of the input and product markets;
- if the cross-price effects between inputs are positive then they are substitutes, alternatively if the cross-price effects are negative the inputs can be regarded as complements; and
- the slope of a firm's input demand equation will depend on the magnitudes of the substitution and output effects so that the impact of the substitution effect is governed by the specification of the production function and hence the elasticity of substitution

between inputs, or alternatively, the output effect is dependent on variations in the marginal cost and marginal revenue schedules.

While these properties hold for all input demand equations, a distinction needs to be made between a firm's input demand function and the market's input demand schedule. Essentially, a market's input demand schedule cannot be deduced by horizontally summing the individual firms' input demand functions. Hence the,

> ... market input demand curve is ... determined by the demand conditions in the market for the output produced by the input, the change in the firms' cost curves caused by the change in the input price and by the elasticity of substitution amongst the inputs (Gravelle and Rees 1981, p. 374).

# 4. Specification of a Multi-Stage Processing Model

In Mullen *et al* (1989) the distributional consequences of the first wool processing stage were modelled. Instead of final consumption, Mullen *et al* used the derived demand for wool top. The implication of there approach is that discrete parts of an industry (as opposed to the whole industry) can be assessed, depending on the purpose to which the results are required. Increasing the number of processing stages does not increase the model's complexity at an exponential rate. The added complexity is simply linear and additive, depending on the number of stages to be included. Apart from gaining a better understanding of distributional impacts across all processing stages, adding sectors will result in greater consistency amongst the model's parameters. For example, in a single stage model, the derived demand is an exogenous variable and hence caution must be exercised to ensure that the value chosen accounts for other processing stages between the stage being modelled and final consumption.

The algebraic specification of a multi-stage model can be described in the following manner. It is assumed that only linear demand and supply functions, that display parallel shifts, exist (see Rose 1980). For ease of exposition, the equations specified in Mullen *et al* (1989) are written in a slightly different format. Taking a one stage three input system then the equations, expressed in elasticity form, needed to explain it are:

- For demand;

$\delta P_f = (1/e_f)\delta Q_f + \delta N$ (Equation (9) in Mullen *et. al.* 1989) (1)

where $\delta$ indicates a relative change,

$P_f$ is the price of the product produced in the sector,

$e_f$ is the own price elasticity of demand for that product,

$Q_f$ is the quantity consumed; and

N is an exogenous demand shifter.

- The market clearing condition that in the long run, the change in product prices equal the change in average total costs;

$\delta P_f = \sum_i (x_i \delta P_i)$ (Equation (10) in Mullen *et. al.* 1989) (2)

where $P_i$ is the price of input (i) used in the production of $Q_f$;

$x_i$ is the input cost share of input (i) in the production of $Q_{f;}$ and

all other variables are as defined as above.

- The output constrained demand for inputs can be expressed as:

$\delta Q_i = \sum_j (x_j \sigma_{ij} \delta P_j) - [\sum_j (x_j \sigma_{ij})]\delta P_i + \delta Q_f$ ((11) to (13) in Mullen *et. al.*1989) (3)

where $Q_i$ is the volume of input (i) used in the production of $Q_h$;

$P_j$ is the price of other inputs, and

$\sigma_{ij}$ is the Allen partial elasticity of input substitution between inputs (i) and (j) and it is assumed that $i \neq j$; and

all other variables are as defined as above.

- The price dependent input supply function are

$\delta P_i = s_i \delta Q_i + T_i$ (Equations (14) to (16) in Mullen *et. al.*1989) (4)

where $s_i$ is the inverse of the own price elasticity of supply of input (i) and an exogenous supply shift $T_{i\,;}$ and

all other variables are as defined as above.

Equations (1) to (4) can be applied to a single sector or for any number of sectors (n). Equation (1) is simply the final demand at the last sector and equation (2) applies only to the external inputs (i) used. Between the two stages there will be internally produced inputs (c). That is, the output of one stage will be one of the inputs in the following stage. Thus, equation (3) can be rewritten as:

$$\delta Q_{ni} = \sum_z (x_{nz}\sigma_{iniz}\delta P_{nz}) - [\sum_z (x_{nz}\sigma_{niz})]\delta P_i + \delta Q_f \quad (5)$$

where $Q_{ni}$ is the volume of external input (i) used in stage (n) and $n \neq 1$ in the production of $Q_f$,

$P_z$ is the price of internally produced or other inputs (z),

$\sigma_{niz}$ is the Allen partial elasticity of input substitution between inputs (i) and (z) where $i \neq z$;

$x_{nz}$ where z = c is simply the sum of all input cost shares for inputs (i + c) used in the preceding stage (n-1) ; and

all other variables are as defined as above.

Equation (4) can be rewritten the same for all external inputs (i) across all stages (n). Equations (1) to (4) are solved simultaneously, using a basic spreadsheet program (such as Microsoft Excel).

In essence, the approach outlined above can be applied across any number of stages, by mathematically specifying the output of one stage as an input into the next. The attractiveness of this approach lies in the fact that the number of input substitution elasticities ($\sigma_{niz}$) is kept to a minimum, because substitution of an input in stage (n) for an input in either the preceding stage (n-1) or the next (n+1) is not possible.

The implied derived demand for input (i) used in the production of $Q_f$ can be readily calculated. It also provides a useful check of the robustness of the estimated coefficients from an initial specification of final demand, as follows;

$$e_i = x_i e_h - \sum_z x_z \sigma_{iz} \qquad (6)$$

where $e_i$ is the elasticity of demand for input (i) and $i \neq j$: and all other variables are as described above.

Changes in economic surplus can then be calculated as:

$$\delta CS = P_f Q_f \delta P_f (1+0.5\delta Q_f) \quad \text{(Equation (17) in Mullen } et.\ al.\text{)} \qquad (7)$$

where $\delta CS$ is the change in consumer surplus; and all other variables are as described above.

$$\delta PS_i = P_i Q_i (\delta P_i - \delta T_i)(1+0.5\delta Q_i) \quad \text{(Equations (18) to (20) in Mullen } et.\ al.\text{ (1989))} \quad (8)$$

where $\delta PS_i$ is the change in producer surplus for supply of input (i) : and all other estimates are as described above.

# 5. An Application

The multi-stage model of productivity gains in an industry described in the pervious section can be applied to any industry. However, the wool industry is ideal as it has multiple processing stages. The application presented below is for the four stage worsted processing industry. In most applications a comprehensive set of demand, supply and substitution elasticities are not available. It should be remembered that the skill involved in this type of modelling is in defining industry structures, not (as has typified attempts in the past) in estimating the model's elasticities.

## 5.1 Data

Details of global worsted wool production is presented in Table 1. This information was sourced from net domestic availability data produced by Australian Wool Innovation. Cost share data was derived from Collins (1997) and updated where appropriate. Financial flows are provided in Table 2.

Table 1 and 2 here

Data on elasticities were obtained from Tulpule *et al* (1992) and are reported in Table 3. Estimated derived demand elasticities at each stage are also reported in Table 3. It is interesting to note the difference between the derived demand for mainly wool products and blends and knitwear. For the former, as there is little opportunity for substitution of Australian wool for wool for elsewhere the derived demand is highly inelastic. In contrast, the availability of medium micron wool from other countries provides greater substitution possibilities at top making and hence the derived demand for Australian wool is more elastic at the top making sector.

Table 3 here

## 5.2 Results

The distribution of gains to Australian wool growers from exogenous supply and demand shifts are shown in Table 4. Distribution of gains are reported for supply shift shocks in terms of the initial gain generated to the supplying sector and expressed in percentage terms. Demand shocks are reported in terms of dollar gains generated from a 1 mg increase in demand.

The distributions of gains from an increase in the supply of wool are presented in the top section of Table 4. Estimated gains to Australian wool growers were estimated at 6% of initial gains generated within the farm sector. In contrast, wool growers capture 48% of the gains from productivity increases in the farm sector. When productivity gains occur in the processing sector the level of capture of gains by Australian wool growers is typically less, estimated at 5% for blended products for example.

Distribution of gains to Australian wool growers from demand shocks are presented in the bottom half of Table 4. Greatest gains were estimated for demand shocks for mainly wool products compared to blended and knitted products. For example, a 1mkg increase in final demand of mainly wool products was estimated to generate gains of $16.4m to Australia wool growers. If the demand increase were generated at the top making stage, such as through the use of wool top in non-apparel products, gains to Australian wool growers were estimated to be slightly higher. Changes in the demand for wool in the Mainly Wool sector are greater than in the other sectors.

# CONCLUSIONS

In this paper a methodology was proposed that would extend approaches used to assess how economic gains from supply and demand shocks in different sectors of an industry are captured by primary poducers. This model was applied to the wool industry. It can be concluded that the derived demand for an input will be more inelastic the smaller is its input cost share. Further, the distribution of gains will be greater for an input that is more inelastic compared to other inputs and final demand. In addition, the greater the substitution possibilities between inputs the lower will be the distribution to Australian wool growers, but the effect is significantly more marginal to relative own price elasticities. Finally, the scope to substitute Australian wool for wool produced elsewhere increases the derived demand elasticity for Australian wool and therefore the level of capture from any farm level productivity gain.

## References


Alston, J., Edwards, G.W. and Freebairn, J. (1988), "Market distortions and benefits from research", *American Journal of Agricultural Economics*, 70, 281-288.

Alston, J. and Pardy, P. (1996) *Making Science Pay: The economics of agricultural R&D Policy*, AEI Press, Washington.

Byerlee, D and Alex, G. (1998) "Towards more effective use of external assistance in building agricultural research systems", in Tabor, Janseen and Bruneau, *Financing Agricultural Research: A source book*, ISNAR, The Netherlands.

Collins, DJ & BA (1997, "Adoption benchmarks for wool processing technologies" Report to Australian Wool Research and Promotion Organisation, Melbourne, January.

Freebairn, J.W., Davis, J.S. and Edwards, G. (1982),'Distribution of research gains in multistage production systems', *American Journal of Agricultural Economics*, 64 (1), 39-46.

Freebairn, J.W. (1992), "Evaluating the level and distribution of benefits from dairy industry research", *Australian Journal of Agricultural Economics*, 36 (2), 141-65.

George, P. (2000), "The role of competitive funding in the reform of national agricultural research systems in developing countries". An M.Ag.Sc. Thesis, University of Melbourne.

Gravelle, H. and Rees, R. (1981), *Microeconomics*, Longman, London.

Layard, P. and Walters, A. (1978), *Microeconomic Theory*, McGraw-Hill, Maidenhead.

Mullen, J. Alston, J. & Wohlgenant, M. (1989), " The impact of farm and processing research on the Australian wool industry", *Australian Journal of Agricultural Economics*, Vol. 33, No. 1, April pp 32-47.

Muth, R.F. (1964), "The derived demand curve for a productive factor and the industry supply curve", *Oxford Economic Papers*, 16, 221-34.

Piggott, R.R. (1992), " Old truths revisited", *Australian Journal of Agricultural Economics*, 36 (2), 117-41.

Rose, R.N. (1980), "Supply shifts and research benefits: Comment" *American Journal of Agricultural Economics*, 62 (5), 834-7.

Tulpule, V., Johnston, B. and Foster, M. (1992), *TEXTABARE: A Model for assessing the benefits of wool textile researc*h, ABARE Research Report 92.6, AGPS, Canberra, April

**Table 1: Worsted Products** (Mkgs)

| *Product* | *Australian Wool* | *Other Wool* | *Non-wool* | *Total* |
|---|---|---|---|---|
| Woven Mainly wool | 125 | 0 | 20 | 145 |
| Woven blend | 145 | 140 | 300 | 585 |
| Knitted | 50 | 20 | 40 | 130 |
| | | | | 860 |

Note: 75% of Australian apparel wool used in worsted sector. Mainly wool is finer end (20 microns and less which is 34% of Australian production) because processing is more difficult and advantages for blending limited as detracts value. Blended products also include some pure wool product, but in mid micron range.

**Table 2: Worsted Production ($ per kg)**

| *Item* | *Mainly Wool* | *Blends* | *Knitwear* |
|---|---|---|---|
| Australian Wool | 11 | 7 | 7 |
| Other Wool | | 7 | 7 |
| Top making inputs | 5 | 4 | 4 |
| | | | |
| Wool top | 16 | 11 | 11 |
| Non-wool top | 5 | 3 | 3 |
| Yarn Making inputs | 30 | 20 | 20 |
| | | | |
| Wool containing yarn | 45 | 28 | |
| Non-wool yarn | 8 | 8 | |
| Fabric Making inputs | 70 | 30 | |
| | | | |
| Wool containing fabric (a) | 113 | 54 | 28 |
| Non-wool fabric | | 30 | |
| Garment Making inputs | 200 | 100 | 100 |
| | | | |
| Garment (b) | 314 | 154 | 128 |

(a) For knitted products refers to yarn input as no fabric stage. (b) at wholesale. Non-wool inputs include all other operations and margins and associated costs.

TABLE 3: ELASTICITIES

| Sector | Mainly Wool | Blends | Knitted |
|---|---|---|---|
| ***Own Price Elasticities*** | | | |
| Demand | -1.0 | -2.0 | -1.5 |
| Aus wool supply | 0.5 | 0.5 | 0.5 |
| Other wool supply | - | 0.5 | 0.5 |
| Top processing input supply | ∞ | ∞ | ∞ |
| Non-wool top supply | ∞ | ∞ | ∞ |
| Yarn processing input supply | ∞ | ∞ | ∞ |
| Non-wool yarn supply | ∞ | ∞ | ∞ |
| Fabric processing input supply | ∞ | ∞ | ∞ |
| Non-wool fabric supply | ∞ | ∞ | ∞ |
| Garment processing input supply | ∞ | ∞ | ∞ |
| ***Substitution elasticities*** | | | |
| Australian Wool / Other wool | 0 | 200 | 200 |
| Australian Wool / Top processing Inputs | 0.07 | 0.07 | 0.07 |
| Other Wool / Top processing Inputs | - | 0.07 | 0.07 |
| Wool top / Synthetic top | 0 | 0.30 | 0.10 |
| Wool top / Yarn processing inputs | 0.03 | 0.03 | 0.03 |
| Synthetic top / Yarn processing inputs | 0.01 | 0.01 | 0.01 |
| Wool yarn / Synthetic yarn | 0 | 0.01 | - |
| Wool yarn / Fabric processing inputs | 0.09 | 0.09 | - |
| Synthetic yarn / Fabric processing inputs | 0 | 0.01 | - |
| Wool fabric / Synthetic fabric | 0 | 0.01 | - |
| Wool fabric / Garment processing inputs | 0.15 | 0.15 | 0.15 |
| Synthetic fabric / Garment processing inputs | 0 | 0.15 | - |
| ***Derived Demand (endogenous)*** | | | |
| Australian wool | -0.029 | -1.580 | -1.462 |
| Top | -0.044 | -0.063 | -0.073 |
| Yarn | -0.160 | -0.304 | -0.440 |
| Fabric | -0.460 | -0.778 | - |
| | | | |

Note: For knitted sector garment production input substitution elasticities refer to yarn.
TEXTABARE model by ABARE used to derive estimates of substitution elasticities.

**TABLE 4: GAINS TO AUSTRALIAN WOOL GROWERS (% OF INITIAL GAIN)**

| Sector of Gain | Mainly Wool | Blends | Knitted |
|---|---|---|---|
| ***Supply changes (% of initial gain)*** | | | |
| *Farm Level* | 6 | 48 | 34 |
| *Processing* | 6 | 5 | 7 |
| ***Demand changes ($m per 1 mkg)*** | | | |
| Top | 17.1 | 4.2 | 5.3 |
| Elsewhere | 16.4 | 2.3 | 4.2 |