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No. 2004-5 – August 2004

Working Paper Series in

Agricultural and Resource Economics

ISSN 1442 1909

http://www.une.edu.au/febl/EconStud/wps.htm

 ISBN 1 86389 883 2

Measuring the Impact of Staple Strength-Enhancing Technologies on Australian Wool Producer Profits: A Duality-Based Approach

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Abstract

Wool tenderness is a significant problem in Australia, especially in areas where sheep graze under highly seasonal conditions. In this study, a duality-based modelling framework is implemented to assess the economic impact of staple strength-enhancing research on the profits of Australian woolgrowers. Within this framework, a normalised quadratic profit function is specified and estimated. The model is based on a number of fundamental characteristics of the Australian wool industry and the staple-strength enhancing technology being assessed. The model consists of a system of equations that are specified in terms of effective, rather than actual, prices. The interrelationships between the netputs are allowed for in the model in a manner that is consistent with the theoretical restrictions that arise as a result of assuming profit maximisation, ensuring that the welfare calculations are unambiguous.

Key Words: profit function approach; research evaluation; wool; staple strength; economic analysis.

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1 Introduction

Wool is a differentiated product that has various quality characteristics that are important to either the wool processor, the final consumer, or to both. These characteristics determine how a lot of wool is classified and the suitability of that wool for a particular final product. The characteristics of clean wool that influence both processing performance and the quality of the endproduct include fibre diameter, staple strength, vegetable matter, staple length, colour and style.

A wool staple is a naturally formed bundle of wool fibres, so staple strength is a measure of how strong the staple is. Staple strength has been estimated to be the second most important characteristic after mean fibre diameter in determining the price paid for clean Merino fleece wool. It is particularly important in the early stages of wool processing. Wool with a staple strength measurement of less than 30 N/ktex is subject to a price discount[1]. For example, the price discount for fine wool which has a staple strength of 28 N/ktex is 5 per cent (Templeton 2002, Appendix A).

Wool tenderness is a significant problem in Australia, especially in areas where sheep graze under highly seasonal conditions. To address this problem, the Cooperative Research Centre (CRC) for Premium Quality Wool undertook research aimed at increasing the staple strength of wool by developing optimal feeding and management techniques that can be readily adopted by woolgrowers. In this paper, a modelling framework is developed to estimate the impact of this research on the profits of Australian wool producers.

Despite the fact that most agricultural production systems are characterised by multiple-outputs, research evaluation has generally been undertaken either by taking economic surplus

[1] Because the number of fibres in a single staple can vary significantly between staples, the measurement of staple strength comprises both a measurement of the force required to break the staple (Newtons) and a measure of the linear density of the material being broken (kilotex). One Newton (N) is approximately 100g and kilotex (ktex) is defined as 1g of clean wool per meter length. Wool is said to be tender if the staple measurement is below 30 N/ktex.

measures off the supply and demand curves for a single (or aggregate) output or by using a single (or aggregate) output production function. In other words, the interrelationship between outputs has generally been ignored. Estimating the welfare effects of a technical change using the economic surplus approach when there are multiple sources of interrelationships between commodities *and* multiple displacements occurring simultaneously is impossible (Alston, Norton and Pardey 1995, p.234). Given the multiple-output nature of the Australian wool industry and the need to be able to disentangle the change in producer welfare from the total welfare measure, a duality-based approach to research evaluation is used here. Unlike the economic surplus approach, this allows for cross-commodity relationships and multiple sources and more complex types of technical change (Martin and Alston 1997). The framework developed in this paper draws on earlier work undertaken by Martin and Alston (1992, 1994).

The format of this paper is as follows. In section 2, an overview of the Australian wool industry and the staple strength management strategies developed through the Wool CRC is given. In section 3, the model is specified and the system of equations is estimated, with a description of the estimation method given and the coefficients and elasticities presented. In section 4, the impact of staple strength-enhancing technologies on the wool production profile is calculated. The demand characteristics of each of the wool types are presented in section 5. In section 6, the research-induced change in wool producer profits is calculated, and some sensitivity analysis is undertaken in section 7. The summary and conclusions are presented in section 8.

2 Industry and Technology Overview and Implications for Modelling

The profit function model specified in this paper is based on a number of fundamental characteristics of the Australian wool industry and the technical change being considered. First, Australia is the world's largest producer and exporter of wool, with around 99 per cent of Australian wool exported each year (Douglas 1997). Therefore, a research-induced change in Australian wool supply will affect the world price of wool. So the price of wool is treated as an endogenous variable on the right hand side of the profit function.

Second, a large proportion of Australian wool is exported in its raw state (Griffith 1993). Thus, the focus is on the effects of the technology on Australian wool producer profits. The research-induced change in consumer welfare is not considered because the vast majority of consumers live overseas.

Third, separate markets exist for different types of wool, by end-use and by country. Accordingly, wool is treated as a heterogeneous commodity in this paper, with discrete variations in quality defined in terms of subjective staple strength measurements (i.e., sound, part-tender, tender and very-tender wool). The different types of wool are accounted for in the modelling framework by including a price variable for each wool type. Consequently, applying Hotelling's Lemma gives a supply equation for each of the four wool categories. In this way, the expected research-induced quality changes in the various wool types are modelled as compensating shifts in the supply of wool in each of the staple strength categories. In addition, as mean fibre diameter is the most important price-determining attribute of wool, a mean fibre diameter variable for each of the wool types has been included to account for price differences that are due to the fibre diameter of the wool rather than to staple strength.

Fourth, there are regional differences in the types of wool produced in Australia, largely due to regional variations in environmental factors. For example, the incidence of tender wool grown in the Mediterranean regions of Australia is higher than it is for wool grown in the non-Mediterranean region (Templeton 2002, Chapter 2). The regional differences in the environment mean that the effectiveness of some of the staple strength-enhancing technologies will also vary from region to region. The regional aspects of wool production are allowed for in the model by including a dummy variable, which is equal to one for the Mediterranean regions and zero for the non-Mediterranean regions of Australia.

Fifth, the sheep feeding and management technologies, developed to increase the strength of wool staples, affect the production of each of the four staple-strength wool categories. Therefore, this research evaluation problem requires that multiple sources of technological change be assessed. In the model, they are allowed for by making the appropriate adjustments to the technology indexes for wool by staple strength class.

Sixth, the Australian wool industry is characterised by multiple-output, multiple-input firms. A model that consists of netput supply equations for each of the related commodities is implemented in this paper. These equations are related through cross-partial derivatives.

Seventh, dynamic supply responses are common in agricultural industries because of biological lags in livestock production. While it is recognised that the dynamic aspects of the Australian wool industry could be important, the complications of applying duality-based methods to dynamic production problems (Howard and Shumway 1988) means that developing a dynamic profit function to account for lagged adjustments in supply to changes in netput prices and technology is beyond the scope of this paper. Nevertheless, dynamics are not completely ignored, as both a short-run and a long-run model are estimated.

Eighth, while conventional duality models do not admit the uncertain nature of livestock production, price uncertainty is accounted for in the profit functions implemented in this paper by lagging output prices by one year. The underlying assumption here is that farmers expect the price in year t to equal the price in year $t\text{-}1$. In other words, the 'naive expectations hypothesis' is used in the stochastic profit functions. There are other expectations models that could have been used, such as the adaptive expectations and rational expectations models. Wall and Fisher (1987, p.p. 59-62) discuss alternative price expectations models in some detail. However, as the alternative models are relatively more complex, the naïve expectations model was chosen for the purposes of this paper.

Ninth, because of the dynamic aspects of livestock production, it is necessary to measure the change in producer welfare from the relevant length-of-run profit function. In other words, a measure of the immediate impact of the technological change should be taken from the short-run profit function, while a measure of the long-run impact should be taken from the long-run profit function. In some earlier studies using the dual approach, all inputs were specified as variable in the cost or profit function and a distinction between short- and long-run behaviour was not made (e.g., Weaver 1983; Shumway 1983; Antle 1984). The underlying implication was that the long-run response was obtained in the short-run (Just 1993). With restricted cost or profit functions, some inputs are specified as quasi-fixed, reflecting short-run supply response (e.g., McKay, Lawrence and Vlastuin 1983; Lawrence and Zeitsch 1989; Low and Hinchy 1990; Wall and Fisher 1987). Both a short-run and a long-run profit function are estimated in this paper.

Tenth, while profit-maximising or cost-minimising behaviour on the part of the economic agents is implicit in duality theory, in reality, wool producers may not behave as profit maximisers under conditions of uncertainty (Wall and Fisher 1987). It is assumed here that producers are risk neutral, even though agricultural production is uncertain, and the effects of risk aversion on producer behaviour are not considered.

Finally, changes in government policy may have affected the decisions of Australian woolgrowers during the period under study. The main policies to consider are the deregulation of the Australian wheat industry in 1989 and the collapse of the wool Reserve Price Scheme in 1991. It could be argued that these policy changes do not need to be accounted for in the estimation of the profit function because it is assumed that the wool producers are risk-neutral. Therefore, it is the actual price of wool and wheat that determines their production decisions and not whether these prices are more or less risky because of the institutional framework within which the producers operate. However, the behaviour of wool producers may change in response to major policy changes for reasons other than risk aversion. For example, farmers could reallocate resources in response to the collapse of the RPS because they expect that there will be a change in the average level of prices, rather than as a response to a change in the variability of these prices. Changes in government policy could be accounted for in the model as dummy variables. However, given the already complex nature of the profit functions, it was decided not to explicitly account for either the deregulation of the Australian wheat industry or the collapse of the reserve price scheme.

3 Specification and Estimation of the Profit Function

3.1 Model Overview

In this section, a simple overview of the profit function approach to research evaluation is presented. The purpose is simply to provide an outline of the steps undertaken to estimate the research-induced change in wool producer profits in this study. Hence, to avoid notational clutter, a basic single-output, single-input model is used for illustrative purposes. As evidenced later, extending the single-output, single-input model to one in which there are multiple outputs and inputs and multiple sources of technical change can be done without too much difficulty.

The first step is to specify a model. On the supply side it is assumed that producers maximise profit:

$$\pi_t = P_t X_t - W_t Q_t \tag{1}$$

where π_t is profit in time *t*, P_t is the price of the commodity in time *t*, X_t is the quantity of output demanded in time *t*, W_t is the price of the input in time *t*, and Q_t is the quantity of the input in time t. Profit is subject to the technology constraint:

$$X_t = f(Q_t) \tag{2}$$

That is:

$$\pi(P_t, W_t) = \max\{P_t X_t - W_t Q_t : X_t = f(Q_t)\} \tag{3}$$

Given the profit function (1), by Hotelling's lemma the output supply equation is:

$$X_t = X^s(P_t, W_t). \tag{4}$$

On the demand side, the quantity consumed is a function of the price of the commodity and income. That is:

$$X_t = X^d(P_t, Y_t) \tag{5}$$

where Y_t is the consumer's income in time *t* and all other variables are as previously defined. For given Y_t and W_t, equilibrium P_t and X_t are determined by solving equations (1) to (5) simultaneously.

The second step is to look at the effects of a new technology on equilibrium prices and quantities. Suppose a new supply-side output-augmenting technology, τ^e, is developed. This can be accounted for in the model by re-writing equation (2) as:

$$\tau^e X_t = f(Q_t) \tag{6}$$

where $\tau^e > 1$ is known. The profit maximisation problem (3) becomes:

$$\pi(P_t, W_t) = \max\{P_t \tau^e X_t - W_t Q_t : \tau^e X_t = f(Q_t)\} \tag{7}$$

or

$$\pi(P_t^e, W_t) = \max\{P_t^e X_t - W_t Q_t : X_t = f^e(Q_t)\} \tag{8}$$

where $P_t^e = P_t \tau^e$ is an effective price (see subsection 3.3.4) and $f^e(.) \equiv f(.)/\tau^e$. By Hotelling's Lemma:

$$X_t^e = X^s(P_t^e, W_t) \tag{9}$$

or

$$X_t / \tau^e = X^s(P_t \tau^e, W_t). \tag{10}$$

Note that, if $\tau^e = 1$, (10) collapses into (5).

For given Y_t and W_t, equilibrium P_t and X_t are determined by solving equations (1) to (10) simultaneously.

A third step is to take account of uncertain output prices. If output price is unknown, producers maximise expected profit:

$$\pi(E\{P_t^e\}, W_t) = \max\{E\{P_t^e\} X_t - W_t Q_t : X_t = f^e(Q_t)\}. \tag{11}$$

By Hotelling's Lemma

$$X_t^e = X^s(E\{P_t^e\}, W_t) \qquad (12)$$

or

$$X_t / \tau^e = X^s(E\{P_t\}\tau^e, W_t). \qquad (13)$$

If expectations are naïve, then:

$$X_t / \tau^e = X^s(P_{t-1}\tau^e, W_t). \qquad (14)$$

For given Y_t and W_t, equilibrium P_{t-1} and X_t is determined from solving equations (1) to (14) simultaneously.

3.2 Variables and Data

The variables specified in the short-run profit function (equation (15a) below) include six output prices (sound wool, part-tender wool, tender wool, very-tender wool, livestock outputs and crops), two variable input prices (labour, and materials and services) and eight non-price exogenous variables (livestock capital, land, building and plant capital, a time trend, fibre diameter for each of the four wool categories and a dummy variable for the climatic region where the wool was produced). There are no additional variables specified in the long-run profit function (equation (16a)) compared with the short-run profit function. A distinction between short- and long-run behaviour is made by specifying *all* the netputs (variable or quasi-fixed in the short run) as variable in the long run. A list of all the variables for both profit functions is presented in Table 1.

(Insert Table 1 here)

Data for the variables in the profit function, with the exception of the wool and fibre diameter variables, were taken from the Australian Agricultural and Grazing Industry Survey (AAGIS) conducted by the Australian Bureau of Agricultural and Resource Economics (ABARE). The survey data includes all farms with more than 200 sheep on a State-by-zone basis for the 16 years ending 1997/98. The States comprise New South Wales, Queensland, Victoria, Western Australia and South Australia and the zones are the pastoral zone, the wheat-sheep zone and the high-rainfall zone. Data for all three zones are available for New South Wales and South Australia, but not for the Western Australia pastoral zone or the Queensland high-rainfall zone, as the respective sample sizes are too small to be included. In addition, Victoria does not have a pastoral zone. In sum, there are a total of 192 observations (i.e., 16 years times 12 State-by-zone regions) for the pooled cross-sectional and time-series data. Price, quantity and fibre diameter data for each of the four wool types were obtained for Merino fleece wool grown in the 131 Wool Statistical Areas (WSA) in mainland Australia for the 16 years ending 1997/1998 (data available from Auswool Direct Pty Ltd).

In the stochastic profit functions specified in equations (15a) and (16a), the price of each of the outputs are lagged one year to take account of the uncertain nature of agricultural prices. Therefore, wool prices are not endogenous variables on the right-hand side of the profit function. Consequently, it is not necessary to obtain the predicted values for the price of each wool type so there are no 'demand-side' variables required for the estimation of the profit function. However, because the demand for Australian wool by the rest-of-the-world is less than perfectly elastic, some minimal information on the demand for each of the wool staple strength categories is needed so the netput supply equations and the four wool output demand equations can be solved as a system to ensure all the interactions between the equations are accounted for.

3.3 Estimating Equations

Short-run profit function

The normalised quadratic specification of the expected, effective short-run profit function, is:

$$
\begin{aligned}
E[\overline{\pi}] = {} & \alpha_0 + \sum_{i=1}^{7} \alpha_i E[P_i^e] + \sum_{i=9}^{16} \beta_i z_i + 0.5 \sum_{i=1}^{7} \sum_{j=1}^{7} \alpha_{ij} E[P_i^e] E[P_j^e] \\
& + 0.5 \sum_{i=9}^{16} \sum_{j=9}^{16} \beta_{ij} z_i z_j + \sum_{i=1}^{7} \sum_{j=9}^{16} \chi_{ij} E[P_i^e] z_j
\end{aligned}
\qquad (15a)
$$

where $E[\overline{\pi}]$ is the expected, effective normalised short-run profit (normalized on the expected, effective price of the numeraire good, materials and services ($E[P_8^e]$), which is not a lagged variable); $E[P_i^e]$ is the normalised expected, effective price of the i-th netput (which is positive and lagged one year for the outputs and negative and not lagged for the variable input); and z_i is the i-th non-price exogenous variable (see Table 1 for a description of the variables).

Following the proof by Varian (1992), applying Hotelling's Lemma to equation (15a) gives the corresponding system of non-numeraire effective netput supply equations:

$$X_i^e = \alpha_i + \sum_{j=1}^{7} \alpha_{ij} E[P_j^e] + \sum_{j=9}^{16} \chi_{ij} z_j \qquad i = 1, \ldots, 7 \qquad (15b)$$

where X_i^e is the effective quantity of the netput and all other variables are as previously defined.

Similarly, the effective netput supply equation for the numeraire good is:

$$X_8^e = \alpha_0 + \sum_{i=9}^{16} \beta_i z_i - 0.5 \sum_{i=1}^{7} \sum_{j=1}^{7} \alpha_{ij} E[P_i^e] E[P_j^e] + 0.5 \sum_{i=9}^{16} \sum_{j=9}^{16} \beta_{ij} z_i z_j \qquad (15c)$$

where X_8^e is the effective quantity of the numeraire netput and all the variables are as previously defined.

Long-run profit function

The normalised quadratic specification of the expected, effective long-run profit function is:

$$E[\overline{\pi}]_{\mathrm{LR}} = \alpha_0 + \sum_{i=1}^{9} \alpha_i E[P_i^e] + \sum_{i=11}^{16} \beta_i z_i + 0.5 \sum_{i=1}^{9} \sum_{j=1}^{9} \alpha_{ij} E[P_i^e] E[P_j^e]$$
$$+ 0.5 \sum_{i=11}^{16} \sum_{j=11}^{16} \beta_{ij} z_i z_j + \sum_{i=1}^{9} \sum_{j=11}^{16} \chi_{ij} E[P_i^e] z_j \qquad (16a)$$

where $E[\overline{\pi}]_{\mathrm{LR}}$ is the expected, effective long-run normalised profit (normalized on the expected effective price of the numeraire good, materials and services ($E[P_{10}^{\mathrm{e}}]$), which is not a lagged variable); $E[P_{\mathrm{i}}^{\mathrm{e}}]$ is the normalised expected, effective price of the *i*-th netput (which is positive and lagged one year for outputs and negative and not lagged for the variable inputs) and $\mathrm{z_i}$ is the *i*-th non-price exogenous variable. In this case, the profit function probably corresponds to a period of about five years, which is considered sufficient for long-term adjustments in outputs, variable inputs and quasi-fixed inputs, such as livestock capital and land, building and plant capital, to occur.

Applying Hotelling's Lemma to equation (16a) gives the corresponding system of non-numeraire effective long-run netput supply equations:

$$X_{i\,LR}^{e} = \alpha_i + \sum_{\mathrm{j}=1}^{9} \alpha_{ij} E[P_j^e] + \sum_{\mathrm{j}=11}^{16} \chi_{\mathrm{ij}} z_{\mathrm{j}} \qquad i = 1, \ldots, 9 \qquad (16b)$$

where $X_{i\,LR}^{e}$ is the effective long-run quantity of the netput and all other variables are as previously defined.

Similarly, the effective long-run netput supply equation for the numeraire good is:

$$X_{10\,LR}^{e} = \alpha_0 + \sum_{i=11}^{16} \beta_i z_i - 0.5 \sum_{i=1}^{9} \sum_{j=1}^{9} \alpha_{ij} E[P_i^e] E[P_j^e]$$
$$+ 0.5 \sum_{i=11}^{16} \sum_{j=11}^{16} \beta_{ij} z_i z_j \qquad (16c)$$

where $X_{10\,LR}^{e}$ is the effective long-run quantity of the numeraire netput and all the variables are as previously defined.

3.4 Estimation Method for the Short-run and Long-run Models

First, random error disturbance terms are added to the system of equations (15a) and (15b) ((16a) and (16b)) to estimate the coefficients of the short-run (long-run) profit function. It is assumed that the disturbance terms are normally distributed with zero means and are uncorrelated through time, although possibly contemporaneously correlated across equations.

Second, the coefficients of the equations are estimated by normalising on the index price for materials and services and setting the technology index, $\tau_{\mathrm{i}}^{\mathrm{e}}$, to unity (so expected, effective prices equal expected, actual prices). The model is estimated using the non-linear seemingly unrelated regression (SUR) estimator in the SHAZAM (version 8.0) econometric package. The SUR estimator was chosen as it allows for the possibility of contemporaneous correlation between the error terms across the netput equations.

Third, convexity is imposed on the system of equations to ensure that the matrix of coefficients, $A = [\alpha_{ij}]$, is positive semi-definite for both the short- and long-run profit functions, and that the matrix of the B coefficients, $B = [\beta_{ij}]$, is negative semi-definite for the short-run profit function only. It is not necessary to ensure that the long-run profit function is concave in quasi-fixed inputs because there are no quasi-fixed inputs in the long run.

3.5 **Estimated Coefficients and Elasticities**

The coefficients, standard errors and asymptotic t-ratios estimated from the short-run and long-run models are given in Table 2 and Table 3, respectively. For both models, almost 60 per cent of the estimated coefficients are significant at the 10 per cent level.

(Insert Table 2 and Table 3 here)

For the system of equations (15a) to (15b), the short-run own- and cross-price elasticities for the non-numeraire netputs ($\varepsilon_{\mathrm{ij}}$), the own-price elasticity for the numeraire netput (ε_{88}), the cross-price elasticities for the numeraire netput with respect to the non-numeraire netputs (ε_{8j}) and the cross-price elasticities for the non-numeraire netputs with respect to the numeraire netput (ε_{i8}) are:

$$\varepsilon_{ij} = \alpha_{ij} \frac{E[P_i^e]}{X_j^e} \qquad \text{i, j} = 1,\ldots, 7, \qquad (17a)$$

$$\varepsilon_{88} = \frac{1}{X_8^e} \sum_{i=1}^{7} \sum_{j=1}^{7} \alpha_{\text{ij}} E[P_i^e] E[P_j^e] \qquad \text{i, j} = 1,\ldots, 7, \qquad (17b)$$

$$\varepsilon_{\text{8j}} = -(P_j^e / X_8^e) \sum_{i=1}^{7} \alpha_{\text{ij}} E[P_i^e] \qquad \text{j} = 1,\ldots, 7, \qquad (17c)$$

$$\varepsilon_{\text{i8}} = -\frac{1}{X_i^e} \sum_{j=1}^{7} \alpha_{\text{ij}} E[P_j^e]. \qquad \text{i} = 1,\ldots, 7. \qquad (17d)$$

Similarly, following equations (16a) to (16b), the long-run own- and cross-price elasticities for the non-numeraire netputs ($\varepsilon_{\text{ijLR}}$), the long-run own-price elasticity for the numeraire netput ($\varepsilon_{\text{1010LR}}$), the long-run cross-price elasticities for the numeraire netput with respect to the non-numeraire netputs (ε_{10jLR}) and the long-run cross-price elasticities for the non-numeraire netputs with respect to the numeraire netput (ε_{i8LR}) are:

$$\varepsilon_{ijLR} = \alpha_{ij} \frac{E[P_i^e]}{X_{jLR}^e} \qquad i, j = 1,\ldots, 9, \qquad (18a)$$

$$\varepsilon_{\text{1010LR}} = \frac{1}{X_{10LR}^e} \sum_{i=1}^{9} \sum_{j=1}^{9} \alpha_{\text{ij}} E[P_i^e] E[P_j^e] \qquad (18b)$$

$$\varepsilon_{\text{10jLR}} = -(P_j^e / X_{10LR}^e) \sum_{i=1}^{9} \alpha_{\text{ij}} E[P_i^e] \qquad j = 1,\ldots, 9, \qquad (18c)$$

$$\varepsilon_{\text{i10LR}} = -\frac{1}{X_{iLR}^e} \sum_{j=1}^{9} \alpha_{\text{ij}} E[P_j^e]. \qquad i = 1,\ldots, 9. \qquad (18d)$$

For both the short-run and the long-run, own- and cross-price elasticities can be interpreted as the percentage change in the quantity supplied (demanded) given a one per cent change in the expected price of the output (input). The estimated short-run elasticities and the respective standard errors are presented in Table 4.

(Insert Table 4 here)

The short-run own-price supply elasticities for each of the six outputs have the expected signs and are inelastic. In addition, with the exception of the own-price supply elasticity of tender wool, they are all significant.

The signs of the short-run cross-price elasticities for each of the four wool types indicate that in some cases the different types of wool are substitutes while in other cases they are complements. The short-run cross-price elasticities for livestock with respect to sound wool, and for sound wool with respect to livestock, are positive and significant, indicating that sound wool and livestock are complements. In contrast, the relationship between livestock and part-tender wool is negative indicating that, as one might expect, these are substitutes. A possible reason why sound wool and livestock are complements, while livestock and part-tender wool are substitutes, could be because wool grown on crossbred sheep, primarily raised to produce meat, is broader and less prone to tenderness than wool from fine-wool Merinos. The cross-price elasticities for crops with respect to sound wool, and for sound wool with respect to crops, are negative, indicating that these two commodities are substitutes. However, the positive and generally significant relationships between crops and each of the tender wool categories are counter-intuitive.

The signs of the cross-price elasticities for sound wool with respect to the input labour, and for labour with respect to sound wool, are in line with *a priori* reasoning. In contrast, the relationship between very-tender wool and labour is counter-intuitive and significant. A possible explanation is that management strategies that reduce wool tenderness could be relatively labour intensive. Therefore, while an increase in the cost of labour may result in a fall in total wool production, the amount of very-tender wool produced could increase, as staple strength-enhancing, but labour-intensive, management practices are reduced. Similarly, if the price paid for very-tender wool increases, wool producers may reduce the quantity of labour used to enhance staple strength.

The relationship between each of the four wool categories and the input, materials and services, meet *a priori* expectations, although the only significant relationship is between materials and services and very-tender wool. The signs of the cross-price elasticities for crops with respect to labour, and for labour with respect to crops, are in line with *a priori* reasoning and are significant.

The own-price short-run demand elasticities for the two inputs, labour, and materials and services, have the expected signs and are significant. The relationships between materials and services and livestock, and between materials and services and crops, also have the expected signs and are significant. Similarly, the cross-price elasticities between these two inputs also have the expected signs and are significant, indicating that these inputs are substitutes.

The long-run own- and cross-price elasticities are presented in Table 5. More than half of the estimated long-run elasticities are significant at the 10 per cent level. The long-run own-price supply elasticities for each of the 10 netputs have the expected signs, are inelastic and, with the exception of tender wool, are significant. In line with *a priori* expectations, the absolute value of the long-run own-price supply elasticities for sound wool, tender wool and very-tender wool are higher than their short-run counterparts. However, this is not the case for part-tender wool, livestock outputs or crops. With respect to the two common inputs, the long-run own-price demand elasticity for labour is larger than its short-run counterpart, which is consistent with expectations, but the long-run own-price demand elasticity for materials and services is smaller than its short-run counterpart.

(Insert Table 5 here)

It could be expected that the long-run own-price supply elasticity for crops and the absolute value of the long-run own price demand elasticity for materials and services would be no larger than the short-run elasticities because a one-year period is long enough for producers to fully adjust their composition of crops and materials and services in response to changes in the price of these netputs. In contrast, given that the production cycles for both tender wool and livestock outputs are longer than one year, one would not expect the long-run elasticities for these netputs to be smaller (in absolute terms) than their short-run counterparts. While it is difficult to explain why the short-run own-price elasticity for part-tender wool is higher than the long-run own-price elasticity, the counter-intuitive results for livestock could be due to the fact that livestock is both an output and an input.

The signs of almost 90 per cent of the long-run cross-price elasticities for each of the four wool types, livestock outputs, crops labour and materials and services are the same as they are for the short-run counterparts. Further, where exceptions occur, they are insignificant.

The relationship between livestock capital and sound wool is in line with *a priori* reasoning but not statistically significant. In contrast, the signs of cross-price elasticities for livestock capital with respect to each of the tender wool categories, and for each tender wool category with respect to livestock capital, indicate that an increase in the price of livestock capital will result in an increase in the production of each of the wool types, or conversely, an increase in the price of each of the tender wool categories will result in a fall in the quantity of livestock capital used. However, only the relationship between livestock capital and very-tender wool is statistically significant at the 10 per cent level.

The relationships between livestock capital and labour, and between livestock capital and materials and services are insignificant, while the relationship between livestock capital and land, building and plant capital is significant and in line with *a priori* expectations.

The relationship between the input, land, building and plant capital, and the six outputs, are in line with *a priori* reasoning and, with the exception of the relationship between land building and plant capital and livestock, they are all significant at the 10 per cent level. The significant relationship between land, building and plant capital and livestock capital indicates that these inputs are substitutes, as does the significant relationship between land, building and plant capital and the input, materials and services. The significant relationship between land, building and plant capital and labour, indicates that these inputs are complements.

4 The Impact of Staple Strength-enhancing Technologies on the Wool Production Profile

Research funded by the CRC for Premium Quality Wool shows that a major contributing factor to staple strength is the seasonal variation in fibre diameter along fibres, due to marked seasonal variation in the availability of nutrients (Peterson 1997; Peterson, Gerardo and Doyle 1998). A range of feeding and management strategies were examined to determine their effect on fibre diameter variation and hence staple strength. A significant finding was that the timing and magnitude of the feed restriction is an important factor determining the effectiveness of this strategy in increasing staple strength (Peterson, Gherardi and Ellis 2000)[2]. The results clearly showed that variation in diameter and, hence, staple strength,

[2] This research also indicated that restricting feed intake after the break of season results in finer wool being produced (18.7 *v.* 19.7 µm, $p<0.05$). However, the economic impact of this result is not being examined here

could be controlled by simply increasing stocking rates at the onset of green feed[3]. The purpose of this paper is to estimate the potential returns to this research.

To determine the impact of this research on the industry supply curves, the participating scientists were also asked whether the results were transferable to adult sheep and what the expected adoption level of the results by Australian woolgrowers would be. Peterson (2000, pers. comm.) said that 30 per cent of woolgrowers in Mediterranean environments would adopt the new feed management strategy. However, as the variability in climatic conditions is not as marked in the non-Mediterranean regions, it is likely that low staple strength is due to factors other than the sudden onset of a flush of green feed in these regions. Therefore, it would be optimistic to expect that 30 per cent of woolgrowers in the non-Mediterranean environments would adopt this feed management strategy. Consequently, a lower adoption rate (10 per cent) is assumed for these regions.

Given information on the effectiveness of the new feed management strategy on staple strength, the profile of the Australian wool clip in terms of staple strength categories and on an assumed level of adoption, the next step is to translate this information into a measure of the technology index. Information on the profile of the Australian wool clip in terms of staple strength categories by climatic region is given in Table 6. This information is combined with

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because it would require wool to be defined in terms of fibre diameter within each staple strength class. Such a fine degree of disaggregation is beyond the scope of this study.

[3] In some cases, production cost could increase as farmers spend more time managing sheep or putting in additional fencing so that the stocking rate per hectare can be increased, while in other cases, production costs would fall as supplementary feeding to reduce wool tenderness is not necessary. Overall, it is assumed that the cost of adoption for the average Australian wool producer is zero.

[4] Instead of using the average values for the 16-year period, values from alternative periods could have been chosen. For example, average values for the price and non-price exogenous variables for the most recent three years could have been used in the analysis. While the most recent data may provide a more accurate representation of future price relativities, technology and so on, these values were not used because the confidence intervals for predicting the research-induced changes in profit were large at the means of the data for the most recent three years (as evidenced by the perverse results when these three-year mean values were used).

the expected adoption rate of the staple strength-enhancing technology to approximate the technology index. The first column in Table 6 contains data on the average quantity of Merino fleece wool by staple strength category for both the non-Mediterranean and Mediterranean regions. The figures in this column represent the average quantity of Merino fleece wool produced in three agricultural zones in New South Wales and South Australia and in two agricultural zones in Western Australia, Queensland and Victoria for the 16 years ending 1997/98. In the second column, the adoption rate for each climatic region is given. The product of these two columns is the quantity of each wool type affected by the new technology. Given that the feeding management strategy is expected to result in a 6.5 N/ktex increase in the staple strength of wool (Peterson, Gherardi and Ellis 2000), and given the range of staple strength measurements of each wool type (Table 6), it is possible to calculate the new (with-technology) quantities (presented in column 4, Table 6). The new (with-research) technology indexes for the four wool categories are then calculated as the proportional change in the quantities of each wool type produced. These are: 1.08 for sound wool; 0.85 for part-tender wool; 0.80 for tender wool; and 0.75 for very-tender wool.

(Insert Table 6 here)

5. Own- and Cross-price Short-run Demand Elasticities for Raw Wool by Staple Strength Class

As noted above, Australia is a large country-trader in wool. Consequently, the demand curves for each of the four staple strength classes of Australian wool by the rest-of-the-world are less than perfectly elastic. Hence, the adoption of staple strength-enhancing technologies by the Australian wool industry will affect the supply of, and the price paid for, each wool category. To estimate these price changes, information on the demand elasticities for each of the wool categories needs to be combined with information on the technology indexes and equilibrium price and quantity data for each wool category. The six netput supply equations and the four wool output demand equations can then be solved as a system to ensure that all the cross-commodity interactions between the equations are accounted for.

There do not appear to be any estimates of the own- and cross-price elasticities for wool by staple strength class in the professional literature. However, estimates of short- and long-run demand elasticities for Australian raw wool, wool top and wool-in-apparel by the rest-of-the-world (in total and by destination) are available (e.g., Dewbre, Vlastuin and Ridley 1986;

Mullen, Alston and Wohlgenant 1989; Connolly 1992). Short- and long-run demand elasticities estimated by Connolly (1992) are presented in Table 7.

(Insert Table 7 here)

In addition to the estimates of own-price demand elasticities for Australian wool (as a heterogenous product) presented in numerous studies, Beare and Meshios (1990) estimated the own- and cross-price elasticities for combing wools of different fibre diameters. As shown in Table 8, all the own-price elasticities are elastic, and the estimated cross-price elasticities decline as the difference in fibre diameter increases. Moreover, positive elasticities, which indicate direct pair-wise substitution, are limited to fibre diameter differences of four microns or less. None of the negative cross-price elasticities are statistically significant at the five per cent level.

(Insert Table 8 here)

The published demand elasticities for wool are low. This is particularly true in the case of the long-run elasticities. This could be because the earlier models do not fully account for the short-run dynamics of the processing sector and the long-run responses of domestic supply in other countries. In other words, these models have not captured the full response to changes in prices. Consider the dramatic response of the Australian wool industry to changes in prices over the past 10 or so years. Extrapolating that to other countries, it is clear that elasticities of demand for Australian wool exports are likely to be significantly higher than those reported in earlier studies. This is particularly so now that protectionism and inefficiencies in the textile and apparel sector are decreasing as a result of the Multi-fibre Arrangements (William Martin, World Bank 2002, pers. comm.). In addition, given that wool processors can substitute one type of wool for another in response to changes in the relative prices of the different types of wool, one would expect that the cross-price demand elasticities for the four wool types would be relatively large.

Information on the Australian wool industry, knowledge of the technical substitutability of the different wool types and the previously estimated own- and cross-price elasticities of wool is combined with economic theory and the author's judgement to obtain 'best-bet' own- and cross-price elasticities of demand for each of the four staple strength wool classes. The homogeneity restriction from demand theory is also drawn on.

The short-run and long-run demand elasticities are presented in Table 9. As can be seen, the absolute values of the own-price elasticities are higher for the tender wool categories, indicating a greater degree of substitution between the more tender wool types, as wool tenderness does not pose a technical problem in the woollen industry because short and/or 'broken' wool is usually used to produce knitwear. Also, in line with *a priori* reasoning, the long-run own- and cross-price demand elasticities are all larger than their short-run counterparts. Other short-run linkages, such as an increased degree of substitution with increasing wool tenderness and direct pair-wise substitution, are also expected to hold.

(Insert Table 9 here)

6. Impact on Australian Wool Producer Profits

6.1 Method

To calculate the technology-induced change in wool producer short-run profits, the base and new expected profit solutions need to be obtained. The base expected short-run profit, $E[\overline{\pi}^0]$, is:

$$E[\overline{\pi}^0] = \alpha_0 + \sum_{i=1}^{7}\alpha_i E[P_i^{e^0}] + \sum_{i=9}^{16}\beta_i z_i^0 + 0.5\sum_{i=1}^{7}\sum_{j=1}^{7}\alpha_{ij}E[P_i^{e^0}]E[P_j^{e^0}] + 0.5\sum_{i=9}^{16}\sum_{j=9}^{16}\beta_{ij}z_i^0 z_j^0 + \sum_{i=1}^{7}\sum_{j=9}^{16}\chi_{ij}E[P_i^{e^1}]z_j^0 \quad (19a)$$

where $E[P_i^{e^0}]$ is the base effective normalised price of the i-th netput and z_i^0 is the base value for the i-th non-exogenous variable. The relationship between the base effective price ($E[P_i^{e^0}]$) and base actual price ($E[P_i^0]$) for the i-th netput is $E[P_i^{e^0}] = E[P_i^0] * \tau_i^{e0}$, where τ_i^{e0} is the base technology index. Given that the base technology index is set to unity, the base expected, actual and expected, effective prices are equal.

The new expected short-run profit, $E[\overline{\pi}^1]$, is given by:

$$E[\overline{\pi}^1] = \alpha_0 + \sum_{i=1}^{7}\alpha_i E[P_i^{e^1}] + \sum_{i=9}^{16}\beta_i z_i^0 + 0.5\sum_{i=1}^{7}\sum_{j=1}^{7}\alpha_{ij}E[P_i^{e^1}]\mathrm{E}[P_j^{e^1}]$$
$$+ 0.5\sum_{i=9}^{16}\sum_{j=9}^{16}\beta_{ij}z_i^0 z_j^0 + \sum_{i=1}^{7}\sum_{j=9}^{16}\chi_{ij}E[P_i^{e^1}]z_j^0 \qquad (19b)$$

where $E[P_i^{e1}]$ is the new expected, effective normalised price of the i-th netput and the relationship between the new expected, effective price ($E[P_i^{e1}]$) and new expected, actual price ($E[P_i^1]$) for the i-th netput is $E[P_i^{e^0}] = E[P_i^0] * \tau_i^{e1}$, where τ_i^{e1} is the new technology index. In the short-run model specified here, the technology indexes for each of the four wool netputs are adjusted to reflect the development of the new staple-strength technology (Table 6). The technology indexes for the other netputs (crops, livestock and labour) are not altered. Therefore, the new actual and effective prices for each of the wool types are no longer equal and they vary from their original base values. In contrast, the new actual and effective prices for the other netputs are not affected by the wool staple strength-enhancing technology and so the new effective and actual prices for livestock, crops and labour are equal to their respective base values (see Table 10).

(Insert Table 10 here)

Given that the base values for the netput prices and the technology variables are known, the values of the coefficients have been estimated, and the value of the new technology indexes for each staple strength class has been determined, equations (19a) and (19b) can be solved. The effect of the wool technology on producer profits, $\Delta E[\overline{\pi}]$, is the difference between equations (19b) and (19a):

$$\Delta E[\overline{\pi}] = E[\overline{\pi}^1] - E[\overline{\pi}^0]. \qquad (20)$$

Following from equation (19a), the base effective short-run quantity for the i-th netput, $X_i^{e^0}$, is:

$$X_i^{e^0} = \alpha_i + \sum_{j=1}^{7}\alpha_{ij}E[P_j^{e^0}] + \sum_{j=9}^{16}\chi_{ij}z_j^0. \qquad i = 1,\ldots, 7 \qquad (21a)$$

Given that the relationship between the base actual short-run quantity (X_i^0) and base effective short-run quantity (X_i^{e0}) for the i-th netput is $X_i^0 = X_i^{e0} * \tau_i^{e0}$, and substituting the definitions of X_i^{e0} and $E[P_i^{e0}]$ into equation (21a), the base actual short-run quantity for the i-th netput is:

$$X_i^0 = \tau_i^{e0}(\alpha_i + \sum_{j=1}^{7}\alpha_{ij}(E[P_j^0]\tau_j^{e0}) + \sum_{j=9}^{16}\chi_{ij}z_j^0). \qquad i = 1,\ldots, 7 \qquad (21b)$$

Similarly, the new short-run effective quantity for the i-th netput, X_i^{e1}, is:

$$X_i^{e1} = \alpha_i + \sum_{j=1}^{7}\alpha_{ij}E[P_j^{e1}] + \sum_{j=9}^{16}\chi_{ij}z_j^0. \qquad i = 1,\ldots, 7 \qquad (21c)$$

and, given that the relationship between the new short-run actual quantity (X_i^1) and new short-run effective quantity (X_i^{e1}) for the i-th netput is $X_i^1 = X_i^{e1} * \tau_i^{e1}$, substituting the definitions of X_i^{e1} and P_i^{e1} into equation (7c) gives the new short-run actual quantity for the i-th netput:

$$X_i^1 = \tau_i^{e1}(\alpha_i + \sum_{j=1}^{7}\alpha_{ij}(E[P_j^1]\tau_j^{e1}) + \sum_{j=9}^{16}\chi_{ij}z_j^0). \qquad i = 1,\ldots, 7 \qquad (21d)$$

Calculations of the long-run profits and quantities follow the same procedure.

The base (without-technology) and new (with-technology) values for the expected actual and effective prices, the predicted actual quantities and expected profit are presented in Table 10 for the short-run and in Table 11 for the long-run. These estimates are partly based on the best-bet elasticities presented in Table 9, and so for ease of comparison with results from other scenarios presented in the section on sensitivity analysis, these results are referred to as best-bet results (and the whole scenario is referred to as the best-bet scenario). The base values for the expected actual normalised price indexes for each of the non-numeraire netputs are the average normalised price indexes for the 16 years ending 1997/98, which are lagged one year for outputs but not for inputs. Similarly, the base values for the non-price exogenous variables used in the welfare calculations are also the averages for 16 years ending 1997/98.

These averages were chosen as the base values because the confidence interval for predicting the research-induced changes in netput prices and quantities and, hence, profit is the smallest at the mean of the data set (Kennedy 1990). They are used for each of the scenarios presented.[4]

As all the prices are normalised prices, it is the percentage change in expected profit, in particular, that is of interest (Tables 10 and 11). The new feed management strategy results in a change in the technology index for each of the wool types, with the index for sound wool increasing by 8.2 per cent, and the indexes for part-tender, tender and very-tender wool decreasing by 15.2 per cent, 19.8 per cent and 24.7 per cent, respectively.

6.2 Short-run Results

Given the best-bet own- and cross-price demand elasticities for the four wool types, the new expected actual normalised prices for sound wool, part-tender wool, tender wool and very-tender wool are 3.1, 3.2, 3.2 and 3.1, respectively, and the corresponding new expected effective normalised prices are 3.3, 2.7, 2.5 and 2.3 (Table 10). In this case, the staple strength-enhancing technical change yields a 11.6 per cent increase in the actual quantity of sound wool produced, a 21.1 per cent decrease in the quantity of part-tender wool produced, a 19.7 per cent fall in the quantity of tender wool and a 40.2 per cent fall in the quantity of very-tender wool. The partial interrelationships between the each of the outputs, the four wool types, livestock and crops, and between the outputs and the input, labour, are also allowed for in the model. The technology-induced changes in the effective prices of each wool type results in a 1.9 per cent increase in the actual quantity of livestock produced, a 4.4 per cent fall in actual crop production and a 1.4 per cent increase in actual labour usage.

Overall, for the given set of parameters, the development and adoption of the new feed management strategy results in a 4.4 per cent increase in the expected profits of the Australian wool producers in short-run.

6.3 Long-run Results

The long-run results are presented in Table 11. Note that the base expected long-run profit is negative, but this is in line with farm business profit for the Australian sheep industry published by ABARE. For example, the farm business profit for the Australian sheep industry for 1995/96 was -$24 462 (ABARE 1998, p.4).[5]

(Insert Table 11 here)

Combining the technology indexes with the best-bet estimates of the long-run demand elasticities and solving the netput equations and the four wool demand equations as a system, the new expected actual normalised prices for the sound, part-tender, tender and very-tender wool are 3.1, 3.2, 3.1 and 2.9, respectively. The corresponding new effective normalised prices for sound, part-tender, tender and very tender wool are 3.3, 2.7, 2.5 and 2.2, respectively. In this case, the staple strength-enhancing technical change yields a 13.0 per cent increase in the actual quantity of sound wool produced, a 21.4 per cent decrease in the quantity of part-tender wool produced, a 18.9 per cent fall in the quantity of tender wool and a 38.5 per cent fall in the quantity of very-tender wool. The technology-induced changes in the effective prices of each wool type results in a 2.0 per cent increase in the actual quantity of livestock produced, a 2.3 per cent decrease in actual crop production, a 2.8 per cent increase in actual labour usage, a 0.9 per cent increase in livestock capital usage and a 1.7 per cent increase in the quantity of land, building and plant capital used. Overall, the development and adoption of the new feed management strategy results in a 2.2 per cent increase in expected wool producers profits in the long run (Table 11). This is just half of the expected profits in the short run, and is due to the greater flexibility of consumers in the long run to adjust consumption and so dampen price changes.

7. Sensitivity Analysis: Testing the Robustness of the Results

The best-bet results are based on the estimated coefficients given in Table 2 and Table 3, the technology indexes presented in Table 6, the best-bet demand elasticities for wool in each of the four staple strength classes presented in Table 9, and the base price and quantity values

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5 The ABARE calculation for farm business profits is equal to total cash receipts less total cash costs plus buildup in trading stocks less depreciation less operator and family labour.

presented in Table 10 and Table 11. Some of the parameters used in the model are econometrically estimated (the coefficients) and others are based on actual market data (equilibrium prices and quantities), and so there is some confidence surrounding these values. In contrast, relevant previous research, knowledge of the Australian wool industry and economic theory are the basis of the values of the demand elasticities for the four types of wool, so specification of the final values is still heavily dependent on subjective judgement[6]. Similarly, while the values for technology indexes are based on previous scientific research and information elicited from the scientists, some subjective judgement was still required to determine the final values, particularly with regard to the expected adoption level.

When there is uncertainty surrounding model parameters, sensitivity analysis is commonly employed to determine the robustness of the results to changes in the 'unknown' parameters (Mullen, Alston and Wohlgenant 1989; Piggott, Piggott and Wright 1995; Hill, Piggott and Griffith 1997; Zhao 1999). Given the uncertainty surrounding the parameters, conventional discrete sensitivity analysis is undertaken here to highlight the impact of changing values of the own- and cross-price demand elasticities for the four wool types and the technology index.

As a starting point, the robustness of the results to the assumption that the demand elasticities for wool are significantly higher than those reported in the literature is examined. To do this, the short-run and long-run profit functions are implemented using own- and cross-price elasticities of demand for each of the wool types that are half the value of those used in the best-bet scenarios. Clearly, the results of the short-run model are robust to a halving of the demand elasticities for each wool type while the increase in the percentage change in long-run profit is in line with *a priori* reasoning (Table 12).

(Insert Table 12 here)

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[6] In fact, under the first-guess scenario, if all the cross-price elasticities of demand for each of the four wool types were set to zero, the development and adoption of the staple strength-enhancing technology would result in a 9.6 per cent fall in the actual price of sound wool and a 3.9 per cent fall in wool producer profits.

As discussed earlier, the technology indexes were, in part at least, based on a 30 per cent adoption rate in the Mediterranean regions in Australia and a 10 per cent adoption rate in non-Mediterranean regions. Given that the adoption costs of the new feed management technology to the average Australian wool producer is expected to be zero, these relatively high adoption rates are feasible. Nevertheless, given the uncertainty surrounding these estimates, the sensitivity of wool producer profits to adoption rates is investigated.

Under the reduced-technology scenario, it is assumed that the adoption rate is 10 per cent for the Mediterranean regions and 3.3 per cent for the non-Mediterranean regions. As a result, the reduced technology indexes are 1.03, 0.95, 0.93 and 0.92 for sound wool, part-tender wool, tender wool and very-tender wool, respectively. Under the reduced-technology scenario, the changes in short-run and long-run profits accruing to the average Australian wool producer are 1.5 per cent, and 0.7 per cent, respectively. These changes are almost one-third of the change in profit under the original technology adoption assumptions (Table 12).

8. Summary and Conclusions

The main aim of this paper is to estimate the research-induced change in the expected short-run and long-run profits of Australian wool producers due to the adoption of staple-strength enhancing technology. Short-run and long-run profit function models are developed to account for the heterogeneous nature of wool, the regional differences in the types of wool produced, the multiple sources of the staple strength-enhancing technology and the stochastic nature of wool production. The system of equations is estimated, with almost 60 per cent of the coefficients and elasticities statistically significant at the 10 per cent level.

The new feed management strategy developed by the CRC for Premium Quality Wool is expected to result in a 6.5 N/ktex increase in the staple strength of wool. Knowledge of the expected research-induced change in staple strength, the likely adoption rates and information on the Australian wool production profile enable the new indexes for each staple strength class of wool to be calculated. Assuming an adoption level of 30 per cent in the Mediterranean regions in Australia and 10 per cent in the non-Mediterranean regions, the new (with-research) technology indexes for the four wool categories, calculated as the proportional change in the quantities of each wool type produced, are as follows: 1.08 for sound wool; 0.85 for part-tender wool; 0.80 for tender wool; and 0.75 for very-tender wool.

Given that Australia is a large country-trader in wool, information on the demand elasticities for each of the wool categories is needed so the six netput supply equations and the four wool output demand equations can be solved as a system to ensure that the cross-commodity interactions between the equations are accounted for. Best-bet elasticities were derived from previously estimated demand elasticities for wool, knowledge of the Australian wool industry, economic theory and the author's judgment. However, given the uncertainty surrounding the demand elasticities for the four wool categories and the assumptions regarding the adoption levels of the new technology, sensitivity analysis is undertaken to test for the robustness of the results to changes the wool demand elasticities and the assumed level of uptake of the research results.

The results of the base analysis suggest that the development and adoption of the new feed management strategy results in a 4.4 per cent increase in wool producers' expected profits in the short-run, and a 2.2 per cent increase in long-run profits. Sensitivity analysis shows that the estimated short- and long-run profits are fairly robust to changes in the demand elasticities. However, if a much lower adoption rate is assumed (i.e., 10 per cent in the Mediterranean regions and 3.3 per cent in the non-Mediterranean regions), then the research-induced change in expected profit is only 1.5 per cent in the short run and 0.7 per cent in the long-run.

Thus, adopting simple adjustments to feeding and management strategies, such as increasing stocking rates at the onset of green feed, to reduce fibre diameter variation and hence increase staple strength, would be profitable activities for wool producers.

In the analysis reported above, it was assumed that the cost of adoption for the average Australian wool producer was zero. In some cases, production cost could increase as farmers spend more time managing sheep or putting in additional fencing so that the stocking rate per hectare can be increased, while in other cases, production costs could fall as supplementary feeding to reduce wool tenderness was no longer necessary. For those producers who would find it necessary to invest more time or capital in the adoption process, the estimated increase in profits represents an upper bound on the value of such an investment. Also, for those producers who face a real trade-off between stronger but coarser wool, the estimated increase in profits provides an upper bound on the value of any decline in premiums for finer microns that they could manage.

Another implication of these results is that the more widespread is the adoption of the new technology the greater the aggregate benefits to producers. However, widespread adoption at the levels assumed would suggest some quite large changes in the quantities of each wool type produced: an increase of 8 per cent for sound wool; a decrease of 15 per cent for part-tender wool; a decrease of 20 per cent for tender wool; and a decrease of 25 per cent for very-tender wool. These changes would be important for manufacturers who have employed specific blends of sound and tender wools into their production processes.

A formal benefit-cost analysis was not undertaken, so it was not possible to make any judgements about the return on investment of Wool CRC funds used to fund the underlying R&D. However, the robust nature of the reported results suggests that the profit function approach to research evaluation is a worthy alternative to the economic surplus approach. This is especially so when the research problem has characteristics such as heterogeneous products, regional differences in the types of product, multiple sources of technological change, and stochastic aspects in the production process.

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Table 1 Variables specified in the short-run and long-run profit functions

Short-run Profit Function		Long-run Profit Function	
Abbreviation	**Variables**	**Abbreviation**	**Variables**
Price/quantity	**Outputs**	**Price/quantity**	**Outputs**
P_1 / X_1	Sound wool	P_1 / X_1	Sound wool
P_2 / X_2	Part-tender wool	P_2 / X_2	Part-tender wool
P_3 / X_3	Tender wool	P_3 / X_3	Tender wool
$P_4 / X4$	Very-tender wool	$P_4 / X4$	Very-tender wool
P_5 / X_5	Livestock outputs	P_5 / X_5	Livestock outputs
P_6 / X_6	All crops	P_6 / X_6	All crops
Price/quantity	**Variable inputs**	**Price/quantity**	**Variable and quasi-fixed inputs**
P_7 / X_7	Labour	P_7 / X_7	Labour
P_8 / X_8	Materials and services	P_8 / X_8	Livestock capital
Quantity	**Non-price exogenous variables**	P_9 / X_9	Land, building and plant capital
z_9	Livestock capital	P_{10} / X_{10}	Materials and services
z_{10}	Land, building and plant capital	**Quantity**	**Non-price exogenous variables**
z_{11}	Time trend variable	z_{11}	Time trend variable
z_{12}	Fibre diameter for sound wool	z_{12}	Fibre diameter for sound wool
z_{13}	Fibre diameter for part-tender wool	z_{13}	Fibre diameter for part-tender wool
z_{14}	Fibre diameter for tender wool	z_{14}	Fibre diameter for tender wool
z_{15}	Fibre diameter for very tender wool	z_{15}	Fibre diameter for very tender wool
z_{16}	Climatic region	z_{16}	Climatic region

Table 2 Estimated coefficients for the short-run profit function

Name	Coefficients	Standard errors	Asymptotic t-ratios	Name	Coefficients	Standard errors	Asymptotic t-ratios
α_0	-2034.700*	543.290	-3.745	α_{44}	0.107*	0.075	1.424
α_1	-72.186*	22.701	-3.180	α_{45}	-0.098	0.855	-0.115
α_2	-26.694*	10.288	-2.595	α_{46}	2.936*	0.898	3.269
α_3	-11.189*	5.435	-2.059	α_{47}	2.419*	1.397	1.732
α_4	-6.052*	1.682	-3.599	α_{55}	101.930*	42.417	2.403
α_5	-13.592	67.582	-0.201	α_{56}	32.790	42.045	0.780
α_6	-48.078	187.730	-0.256	α_{57}	11.880	14.900	0.797
α_7	-268.990*	38.505	-6.986	α_{66}	431.540*	113.880	3.789
β_9	37.460*	9.217	4.064	α_{67}	-34.259*	15.253	-2.246
β_{10}	-6.550*	2.185	-2.998	α_{77}	112.360*	34.934	3.216
β_{11}	-67.677*	28.076	-2.410	β_{99}	0.000	0.000	0.000
β_{12}	62.521	288.440	0.217	β_{910}	0.000	0.000	0.000
β_{13}	-2419.500*	701.250	-3.450	β_{911}	0.069	0.094	0.729
β_{14}	1318.000*	609.350	2.163	β_{912}	-0.989	1.004	-0.985
β_{15}	1185.800*	499.800	2.373	β_{913}	2.154	2.114	1.019
β_{16}	1237.400*	335.520	3.688	β_{914}	-1.313	1.786	-0.735
α_{11}	12.914*	3.517	3.672	β_{915}	-1.468	1.340	-1.096
α_{12}	-2.961*	2.176	-1.361	β_{916}	-4.411*	1.256	-3.513
α_{13}	0.193	0.647	0.299	β_{1010}	0.000	0.000	0.000
α_{14}	-0.497*	0.250	-1.993	β_{1011}	0.004	0.023	0.157
α_{15}	15.229*	8.723	1.746	β_{1012}	0.042	0.171	0.249
α_{16}	-40.428*	13.802	-2.929	β_{1013}	-1.033*	0.453	-2.279
α_{17}	-10.452*	5.343	-1.956	β_{1014}	0.383	0.415	0.925
α_{22}	2.833*	1.820	1.556	β_{1015}	0.857*	0.339	2.527
α_{23}	0.062	0.492	0.127	β_{1016}	-0.056	0.547	-0.103
α_{24}	0.390*	0.207	1.881	β_{1111}	1.447*	0.802	1.804
α_{25}	-10.716*	6.676	-1.605	β_{1112}	-1.526	3.683	-0.414
α_{26}	14.474*	7.391	1.958	β_{1113}	2.239	6.274	0.357
α_{27}	2.886	4.663	0.619	β_{1114}	-4.968	4.693	-1.059
α_{33}	0.043	0.078	0.547	β_{1115}	5.990*	4.572	1.310
α_{34}	-0.019	0.074	-0.254	β_{1116}	3.325	3.433	0.969
α_{35}	-0.090	2.606	-0.034	β_{1212}	6.108	19.086	0.320
α_{36}	1.850	3.699	0.500	β_{1213}	-67.036*	38.976	-1.720
α_{37}	-1.901	1.977	-0.961	β_{1214}	62.119*	40.935	1.518

Table 2 Estimated coefficients for the short-run profit function (continued)

Name	Coefficients	Standard errors	Asymptotic t-ratios	Name	Coefficients	Standard errors	Asymptotic t-ratios
β_{1215}	-4.809	27.341	-0.176	χ_{315}	-2.472*	1.624	-1.522
β_{1216}	-10.084	24.801	-0.407	χ_{316}	6.262*	1.385	4.523
β_{1313}	92.567	123.690	0.748	χ_{49}	0.009*	0.006	1.372
β_{1314}	-80.501	66.359	-1.213	χ_{410}	0.004*	0.001	2.569
β_{1315}	171.630*	75.314	2.279	χ_{411}	-0.022	0.033	-0.647
β_{1316}	-91.991*	71.547	-1.286	χ_{412}	0.154	0.154	0.997
β_{1414}	-6.367*	4.758	-1.338	χ_{413}	0.293	0.385	0.761
β_{1415}	-35.848	42.739	-0.839	χ_{414}	-0.012	0.060	-0.204
β_{1416}	27.758	38.444	0.722	χ_{415}	-0.347	0.341	-1.018
β_{1515}	-187.990*	76.056	-2.472	χ_{416}	1.291*	0.275	4.704
β_{1516}	3.944	59.521	0.066	χ_{59}	7.603*	0.416	18.267
β_{1616}	619.190*	167.760	3.691	χ_{510}	-0.569*	0.099	-5.740
χ_{19}	1.357*	0.163	8.311	χ_{511}	8.245*	1.843	4.473
χ_{110}	0.540*	0.039	13.806	χ_{512}	2.317	9.379	0.247
χ_{111}	-0.675	0.723	-0.933	χ_{513}	-4.786	22.098	-0.217
χ_{112}	8.636*	3.714	2.325	χ_{514}	0.564	3.524	0.160
χ_{113}	-37.261*	8.862	-4.205	χ_{515}	1.353	19.363	0.070
χ_{114}	-3.594*	1.542	-2.330	χ_{516}	-23.508*	16.525	-1.423
χ_{115}	35.658*	7.602	4.691	χ_{69}	-12.182*	1.208	-10.088
χ_{116}	23.891*	6.277	3.806	χ_{610}	1.592*	0.324	4.911
χ_{29}	0.350*	0.059	5.953	χ_{611}	27.731*	5.251	5.281
χ_{210}	0.052*	0.014	3.789	χ_{612}	104.420*	32.096	3.253
χ_{211}	0.606*	0.284	2.135	χ_{613}	114.720*	77.353	1.483
χ_{212}	1.168	1.310	0.892	χ_{614}	-5.838	12.324	-0.474
χ_{213}	10.904*	3.297	3.307	χ_{615}	-206.210*	67.486	-3.056
χ_{214}	-0.394	0.563	-0.700	χ_{616}	-6.955	53.857	-0.129
χ_{215}	-10.856*	2.917	-3.722	χ_{79}	-1.113*	0.133	-8.384
χ_{216}	12.321*	2.400	5.134	χ_{710}	-0.547*	0.033	-16.825
χ_{39}	0.144*	0.033	4.389	χ_{711}	1.560*	0.692	2.255
χ_{310}	0.014*	0.008	1.732	χ_{712}	-7.174*	3.051	-2.351
χ_{311}	0.544*	0.154	3.529	χ_{713}	4.870	7.324	0.665
χ_{312}	1.241*	0.821	1.512	χ_{714}	2.972*	1.249	2.380
χ_{313}	1.417	1.817	0.780	χ_{715}	0.203	6.418	0.032
χ_{314}	0.035	0.310	0.112	χ_{716}	-9.199*	5.165	-1.781

*Significant at the 10 per cent level.

Table 3 Estimated coefficients for the long-run profit function

Name	Coefficients	Standard errors	Asymptotic t-ratios	Name	Coefficients	Standard errors	Asymptotic t-ratios
α_0	-2201.800*	555.680	-3.962	α_{34}	-0.072	0.082	-0.874
α_1	102.630*	35.107	2.923	α_{35}	-0.759	2.312	-0.328
α_2	-1.410	11.583	-0.122	α_{36}	1.052	2.933	0.359
α_3	2.315	5.217	0.444	α_{37}	-3.003*	2.126	-1.413
α_4	-5.143*	1.764	-2.915	α_{38}	0.593	1.744	0.340
α_5	446.840*	99.512	4.490	α_{39}	-0.486*	0.228	-2.132
α_6	-122.990	216.540	-0.568	α_{44}	0.133*	0.082	1.617
α_7	-479.840*	47.233	-10.159	α_{45}	-0.677	0.867	-0.781
α_8	-355.370*	60.790	-5.846	α_{46}	1.931*	0.963	2.005
α_9	-144.810*	26.989	-5.366	α_{47}	3.105*	1.551	2.002
β_{11}	-37.900	38.822	-0.976	α_{48}	1.161*	0.462	2.516
β_{12}	-541.700	474.280	-1.142	α_{49}	-0.098*	0.043	-2.259
β_{13}	-2030.900*	853.880	-2.378	α_{55}	75.308*	47.105	1.599
β_{14}	1010.400*	702.130	1.439	α_{56}	3.994	50.855	0.079
β_{15}	1737.600*	717.080	2.423	α_{57}	4.217	16.743	0.252
β_{16}	1708.700*	412.680	4.140	α_{58}	-32.096	28.214	-1.138
α_{11}	17.923*	3.983	4.500	α_{59}	-5.644	4.471	-1.262
α_{12}	-2.401	2.318	-1.036	α_{66}	422.850*	110.550	3.825
α_{13}	0.379	0.662	0.573	α_{67}	-60.991*	19.570	-3.117
α_{14}	-0.346	0.279	-1.240	α_{68}	84.716*	39.576	2.141
α_{15}	12.025	10.753	1.118	α_{69}	-55.306*	9.599	-5.762
α_{16}	-12.548	15.489	-0.810	α_{77}	173.680*	41.346	4.201
α_{17}	-19.924*	6.318	-3.154	α_{78}	0.473	9.082	0.052
α_{18}	-1.359	6.643	-0.205	α_{79}	12.653*	1.547	8.182
α_{19}	-10.766*	1.723	-6.249	α_{88}	70.528*	27.456	2.569
α_{22}	2.822*	2.030	1.390	α_{89}	-15.925*	2.701	-5.896
α_{23}	-0.001	0.490	-0.003	α_{99}	18.886*	1.733	10.895
α_{24}	0.325*	0.241	1.349	β_{1111}	0.232	1.217	0.190
α_{25}	-10.703*	7.155	-1.496	β_{1112}	-16.562*	4.636	-3.573
α_{26}	11.492*	8.067	1.425	β_{1113}	5.399	10.038	0.538
α_{27}	5.446	5.433	1.002	β_{1114}	2.683	7.575	0.354
α_{28}	4.076	3.847	1.059	β_{1115}	10.135*	7.092	1.429
α_{29}	-1.244*	0.445	-2.792	β_{1116}	2.282	5.428	0.420
α_{33}	0.081	0.104	0.783	β_{1212}	21.643	26.928	0.804

Table 3 Estimated coefficients for the long-run profit function (continued)

Name	Coefficients	Standard errors	Asymptotic t-ratios	Name	Coefficients	Standard errors	Asymptotic t-ratios
β_{1213}	-59.549	48.504	-1.228	χ_{413}	0.639*	0.388	1.648
β_{1214}	113.640*	62.446	1.820	χ_{414}	-0.011	0.064	-0.166
β_{1215}	-49.618	44.221	-1.122	χ_{415}	-0.641*	0.347	-1.848
β_{1216}	-196.530*	33.412	-5.882	χ_{416}	1.407*	0.310	4.544
β_{1313}	27.260	172.300	0.158	χ_{511}	13.445*	2.703	4.974
β_{1314}	-121.230*	93.129	-1.302	χ_{512}	28.628*	16.211	1.766
β_{1315}	249.030*	129.300	1.926	χ_{513}	14.805	39.316	0.377
β_{1316}	310.740*	124.110	2.504	χ_{514}	-0.974	6.463	-0.151
β_{1414}	-17.171*	6.071	-2.829	χ_{515}	-50.984*	34.432	-1.481
β_{1415}	-27.494	65.994	-0.417	χ_{516}	-89.669*	30.052	-2.984
β_{1416}	119.890*	62.439	1.920	χ_{611}	15.839*	5.850	2.708
β_{1515}	-248.800*	128.730	-1.933	χ_{612}	68.919*	35.620	1.935
β_{1516}	-334.170*	101.100	-3.305	χ_{613}	13.010	89.089	0.146
β_{1616}	854.860*	206.340	4.143	χ_{614}	2.374	15.132	0.157
χ_{111}	-0.901	1.021	-0.882	χ_{615}	-71.698	79.082	-0.907
χ_{112}	-2.376	6.081	-0.391	χ_{616}	277.090*	67.262	4.120
χ_{113}	-2.711	13.988	-0.194	χ_{711}	0.840	1.005	0.836
χ_{114}	-5.009*	3.062	-1.636	χ_{712}	3.686	5.230	0.705
χ_{115}	12.277	12.009	1.022	χ_{713}	-22.440*	12.190	-1.841
χ_{116}	-7.873	10.708	-0.735	χ_{714}	4.030*	2.610	1.544
χ_{211}	0.799*	0.326	2.453	χ_{715}	17.069*	10.584	1.613
χ_{212}	0.152	1.579	0.096	χ_{716}	9.866	9.394	1.050
χ_{213}	17.366*	3.878	4.478	χ_{811}	-0.210	1.557	-0.135
χ_{214}	-0.611	0.746	-0.819	χ_{812}	-28.557*	8.894	-3.211
χ_{215}	-16.421*	3.389	-4.846	χ_{813}	-94.494*	22.521	-4.196
χ_{216}	6.961*	3.144	2.214	χ_{814}	-0.230	3.483	-0.066
χ_{311}	0.605*	0.146	4.150	χ_{815}	126.760*	19.749	6.419
χ_{312}	1.040	0.859	1.211	χ_{816}	197.840*	18.467	10.713
χ_{313}	3.443*	1.957	1.759	χ_{911}	0.753	0.875	0.860
χ_{314}	-0.027	0.345	-0.078	χ_{912}	22.310*	5.621	3.969
χ_{315}	-4.375*	1.707	-2.563	χ_{913}	-31.227*	12.607	-2.477
χ_{316}	4.268*	1.560	2.735	χ_{914}	1.155	3.170	0.364
χ_{411}	-0.025	0.034	-0.728	χ_{915}	8.287	10.788	0.768
χ_{412}	0.080	0.152	0.526	χ_{916}	12.041	10.342	1.164

*Significant at the 10 per cent level.

Table 4 Estimated elasticities for the short-run profit function

	Sound wool (P_1)	Part-tender wool (P_2)	Tender wool (P_3)	Very-tender wool (P_4)	Livestock (P_5)	Crop (P_6)	Labour (P_7)	Materials & services (P_8)	Σ^a
Sound wool (X_1)	**0.293***	-0.067*	0.004	-0.010*	0.094*	-0.208*	-0.078*	-0.027	0
	(0.080)	(0.049)	(0.014)	(0.005)	(0.054)	(0.071)	(0.040)	(0.078)	
Part-tender wool (X_2)	-0.314*	**0.300***	0.006	0.038*	-0.309*	0.349*	0.101	-0.171	0
	(0.231)	(0.193)	(0.050)	(0.020)	(0.192)	(0.178)	(0.164)	(0.229)	
Tender wool (X_3)	0.061	0.020	**0.013**	-0.005	-0.008	0.133	-0.200	-0.015	0
	(0.205)	(0.156)	(0.024)	(0.021)	(0.225)	(0.266)	(0.208)	(0.342)	
Very-tender wool (X_4)	-1.006*	0.787*	-0.037	**0.198***	-0.054	1.348*	1.620*	-2.858*	0
	(0.505)	(0.419)	(0.144)	(0.139)	(0.470)	(0.412)	(0.936)	(0.990)	
Livestock (X_5)	0.118*	-0.083*	-0.001	-0.001	**0.215***	0.058	0.031	-0.338	0
	(0.068)	(0.052)	(0.020)	(0.006)	(0.090)	(0.074)	(0.038)	(0.091)	
Crops (X_6)	-0.320*	0.115*	0.014	0.021*	0.071	**0.777***	-0.090*	-0.587*	0
	(0.109)	(0.059)	(0.028)	(0.007)	(0.906)	(0.205)	(0.040)	(0.168)	
Labour (X_7)	0.116*	-0.032	0.020	-0.025*	-0.036	0.086*	**-0.414***	0.283*	0
	(0.059)	(0.052)	(0.021)	(0.014)	(0.045)	(0.038)	(0.129)	(0.134)	
Materials & services (X_8)	0.027	0.037	0.001	0.030*	0.273*	0.389*	0.195*	**-0.953***	0
	(0.079)	(0.050)	(0.024)	(0.010)	(0.073)	(0.111)	(0.092)	(0.156)	

Standard errors are in parenthesis; *Significant at the 10 per cent level. [a]The homogeneity condition states that the sum of the own- and cross-price elasticities is zero.

Table 5 Estimated elasticities for the long-run profit function

	Sound wool (P_1)	Part-tender Wool (P_2)	Tender wool (P_3)	Very-tender wool (P_4)	Livestock outputs (P_5)	Crop (P_6)	Labour (P_7)	Livestock capital (P_8)	Land, building & plant capital (P_9)	Materials & services (P_{10})	Σ [a]
Sound wool (X_1)	**0.406***	-0.054	0.008	-0.007	0.074	-0.065	-0.150*	-0.009	-0.450*	0.245*	0
	(0.090)	(0.052)	(0.015)	(0.006)	(0.066)	(0.080)	(0.047)	(0.042)	(0.072)	(0.098)	
Part-tender wool (X_2)	-0.255	**0.299***	0.000	0.031*	-0.309*	0.277*	0.191	0.120	-0.243*	-0.112	0
	(0.246)	(0.215)	(0.050)	(0.023)	(0.206)	(0.194)	(0.191)	(0.113)	(0.087)	(0.251)	
Tender wool (X_3)	0.120	0.000	**0.025**	-0.021	-0.065	0.076	-0.315*	0.052	-0.284*	0.413*	0
	(0.210)	(0.155)	(0.032)	(0.024)	(0.199)	(0.211)	(0.223)	(0.154)	(0.133)	(0.264)	
Very-tender wool (X_4)	-0.700	0.656*	-0.140	**0.247***	-0.372	0.887*	2.080*	0.652*	-0.365*	-2.944*	0
	(0.564)	(0.486)	(0.160)	(0.153)	(0.477)	(0.442)	(1.039)	(0.259)	(0.162)	(1.092)	
Livestock outputs (X_5)	0.094	-0.083*	-0.006	-0.005	**0.159***	0.007	0.011	-0.069	-0.081	-0.027	0
	(0.084)	(0.056)	(0.017)	(0.006)	(0.100)	(0.090)	(0.043)	(0.061)	(0.064)	(0.094)	
Crops (X_6)	-0.099	0.091*	0.008	0.014*	0.009	**0.761***	-0.160*	0.186*	-0.808*	-0.002	0
	(0.123)	(0.064)	(0.022)	(0.007)	(0.110)	(0.199)	(0.051)	(0.087)	(0.140)	(0.166)	
Labour (X_7)	0.221*	-0.060	0.032*	-0.032*	-0.013	0.154*	**-0.639***	-0.001	-0.259*	0.597*	0
	(0.070)	(0.060)	(0.023)	(0.016)	(0.051)	(0.049)	(0.152)	(0.028)	(0.032)	(0.155)	
Livestock capital (X_8)	0.021	-0.063	-0.009	-0.016*	0.134	-0.296*	-0.002	**-0.301***	0.452*	0.081	0
	(0.102)	(0.059)	(0.026)	(0.006)	(0.118)	(0.138)	(0.046)	(0.117)	(0.077)	(0.151)	
Land, building & plant capital (X_9)	0.266*	0.031*	0.012*	0.002*	0.038	0.310*	-0.103*	0.109*	**-0.860***	0.196*	0
	(0.043)	(0.011)	(0.005)	(0.001)	(0.030)	(0.054)	(0.013)	(0.019)	(0.079)	(0.071)	
Materials & services (X_{10})	-0.251*	0.024	-0.029*	0.031*	0.022	0.001	0.412*	0.034	0.338*	**-0.582***	0
	(0.100)	(0.055)	(0.019)	(0.011)	(0.076)	(0.110)	(0.107)	(0.063)	(0.122)	(0.175)	

Standard errors are in parenthesis; [*]Significant at the 10 per cent level [a]The homogeneity condition states that the sum of the own- and cross-price elasticities is zero.

Table 6 Technology indexes for sound, part-tender, tender and very-tender wool

	Base quantity[a] kt	Adoption rate proportion	Technology impact on quantity[b] kt	New quantity kt	New technology index proportion[c]
Sound (>30 N/ktex)					
Non-Mediterranean	136.442	0.000	3.001	139.443	
Mediterranean	87.842	0.000	15.378	103.219	
Total	224.283	0.000	18.378	242.662	1.082
Part-tender (25 N/ktex to 30 N/ktex)					
Non-Mediterranean	30.009	0.100	-1.969	28.040	
Mediterranean	51.259	0.300	-10.378	40.880	
Total	81.268		-12.348	68.920	0.848
Tender (18 N/ktex and 24 N/ktex)					
Non-Mediterranean	10.317	0.100	-0.958	9.360	
Mediterranean	16.664	0.300	-4.374	12.290	
Total	26.981		-5.332	21.649	0.802
Very Tender (less than 18 N/ktex)					
Non-Mediterranean	0.742	0.100	-0.074	0.668	
Mediterranean	2.084	0.300	-0.625	1.458	
Total	2.825		-0.699	2.126	0.753
Australian total	**335.357**			**335.357**	

Source: Auswool Direct Pty Ltd; Peterson 2000, pers. comm.; [a]Average quantity of Merino fleece wool sold at auction for the 16 years ending 1997/98. [b]Net value comprising a 'flow in' from the more tender category and a 'flow out' to the less tender category. [c]New technology index equals new quantity divided by base quantity.

Table 7 Own-price elasticity of demand for Australian wool exports to all destinations

Time lag from price change (years)	Elasticity
0	-0.33
1	-0.67
2	-0.79
3	-0.85
4	-0.87
5	-0.91
Long term	-1.01

Source: Connolly 1992

Table 8 Estimated own- and cross-price demand elasticities for combing wools of different fibre diameters

Percentage change in demand	**With respect to a percentage in the price of:**							
	19m	**20m**	**21m**	**22m**	**23m**	**24m**	**25m**	**26m**
Micron								
19m	**-1.02**	0.52	0.42	0.31	0.13	-0.01[a]	-0.13[a]	-0.20[a]
20m	0.28	**-1.23**	0.43	0.34	0.20	0.08	-0.01[a]	-0.06[a]
21m	0.14	0.26	**-1.15**	0.36	0.22	0.12	0.04	-0.00[a]
22m	0.10	0.20	0.34	**-1.16**	0.28	0.16	0.07	0.03
23m	0.06	0.17	0.31	0.42	**-1.44**	0.27	0.15	0.07
24m	-0.01[a]	0.11	0.27	0.39	0.45	**-1.76**	0.35	0.19
25m	-1.19[a]	-0.02[a]	0.18	0.34	0.45	0.65	**-2.00**	0.59
26m	-0.43[a]	-0.24[a]	-0.01[a]	0.18	0.31	0.52	0.86	**-1.17**[a]

Source: Beare and Meshios 1990; [a]estimates were not significant at the five per cent level; all remaining estimates were significant at the five per cent level.

Table 9 Short-run and long-run own-price demand elasticities for raw wool by staple strength class

Staple strength class		**Sound wool (P1)**	**Part-tender wool (P2)**	**Tender wool (P3)**	**Very-tender wool (P4)**
Short-run					
Sound wool	**(P1)**	**-5**	2	0	0
Part-tender wool	**(P2)**	3	**-7**	1	0
Tender wool	**(P3)**	0	1	**-7**	2
Very-tender wool	**(P4)**	0	1	3	**-8**
Long-run					
Sound wool	**(P1)**	**-10**	4	0	0.0
Part-tender wool	**(P2)**	6	**-14**	2	0
Tender wool	**(P3)**	0.0	2	**-14**	4
Very-tender wool	**(P4)**	0.0	2	6	**-16**

Table 10 Impact of staple strength-enhancing technologies on Australian wool producer profits in the short-run: best-bet scenario

	Base values	New values	Actual change	Percentage change
Technology variable				
Sound wool	1.00	1.08	0.08	8.20
Part-tender wool	1.00	0.85	-0.15	-15.20
Tender wool	1.00	0.80	-0.20	-19.80
Very tender wool	1.00	0.75	-0.25	-24.70
Expected actual normalised prices				
Sound wool	3.10	3.07	-0.03	-0.97
Part-tender wool	3.10	3.20	0.10	3.38
Tender wool	3.00	3.16	0.16	5.44
Very tender wool	2.84	3.05	0.21	7.49
Livestock	0.84	0.84	0.00	0.00
Crops	0.70	0.70	0.00	0.00
Labour	1.03	1.03	0.00	0.00
Expected effective normalised prices				
Sound wool	3.10	3.32	0.22	7.15
Part-tender wool	3.10	2.72	-0.38	-12.34
Tender wool	3.00	2.54	-0.46	-15.44
Very tender wool	2.84	2.30	-0.54	-19.06
Livestock	0.84	0.84	0.00	0.00
Crops	0.70	0.70	0.00	0.00
Labour	1.03	1.03	0.00	0.00
Predicted actual quantities				
Sound wool	132.74	148.14	15.40	11.60
Part-tender wool	28.45	22.45	-6.00	-21.10
Tender wool	9.40	7.54	-1.85	-19.72
Very tender wool	1.50	0.90	-0.60	-40.21
Livestock	396.51	404.08	7.57	1.91
Crops	385.62	368.67	-16.94	-4.39
Labour	-276.87	-280.72	-3.85	1.39
Profit	**329.35**	**343.68**	**14.33**	**4.35**

Table 11 Impact of staple strength-enhancing technologies on Australian wool producer profits in the long-run: best-bet scenario

	Base values	New values	Actual change	Percentage change
Technology variable				
Sound wool	1.00	1.08	0.08	8.20
Part-tender wool	1.00	0.85	-0.15	-15.20
Tender wool	1.00	0.80	-0.20	-19.80
Very tender wool	1.00	0.75	-0.25	-24.70
Actual normalised prices				
Sound wool	3.10	3.08	-0.02	-0.65
Part-tender wool	3.10	3.15	0.05	1.62
Tender wool	3.00	3.08	0.08	2.61
Very tender wool	2.84	2.94	0.10	3.59
Livestock outputs	0.84	0.84	0.00	0.00
Crops	0.70	0.70	0.00	0.00
Labour	1.03	1.03	0.00	0.00
Livestock capital	0.86	0.86	0.00	0.00
Land, building & plant capital	5.72	5.72	0.00	0.00
Effective normalised prices				
Sound wool	3.10	3.33	0.23	7.50
Part-tender wool	3.10	2.67	-0.43	-13.82
Tender wool	3.00	2.47	-0.53	-17.71
Very tender wool	2.84	2.21	-0.62	-22.00
Livestock outputs	0.84	0.84	0.00	0.00
Crops	0.70	0.70	0.00	0.00
Labour	1.03	1.03	0.00	0.00
Livestock capital	0.86	0.86	0.00	0.00
Land, building & plant capital	5.72	5.72	0.00	0.00
Actual quantities				
Sound wool	103.94	129.73	14.91	12.98
Part-tender wool	24.14	20.20	-5.50	-21.41
Tender wool	8.19	7.01	-1.64	-18.94
Very tender wool	1.30	0.84	-0.53	-38.49
Livestock outputs	374.76	388.78	7.44	1.95
Crops	451.79	415.40	-9.83	-2.31
Labour	-250.79	-267.94	-7.18	2.75
Livestock capital	-208.28	-209.92	-1.84	0.88
Land, building & plant capital	-86.33	-103.29	-1.71	1.68
Profit	**-504.70**	**-493.40**	**11.30**	**2.24**

Table 12 Comparison of research-induced short-run and long-run changes in expected profit for each scenario

Scenario	Change in expected profit Short-run %	Long-run %
Best-bet	4.4	2.2
Own-price and cross-price elasticities halved	4.2	3.4
Reduced-technology	1.5	0.7