The Australian Journal of
Agricultural and Resource Economics
Journal of the Australian Agricultural and Resource Economics Society

Australian Journal of Agricultural and Resource Economics, 58, pp. 314–335

Valuing quality attributes of Australian merino wool*

Elizabeth Nolan, Terence Farrell, Madeleine Ryan, Candice Gibbon and Fredoun Z. Ahmadi-Esfahani†

We measure the relationship between clean prices of individual lots of wool sold at auction and a range of characteristics of the raw wool. Based on the data for 111,440 fleece lots sold in the 2008–2009 auction season, five hedonic models are estimated to determine the premiums and discounts associated with each wool characteristic in five micron categories. Several wool characteristics exhibited significant nonlinear relationships, and therefore, joint density functions were assessed where appropriate. The results indicate that fibre diameter has the greatest influence on price in all markets. Brand contamination, higher levels of unscourable colour and vegetable matter contamination were found to negatively influence price.

Key words: hedonic pricing, wool, wool attributes.

1. Introduction

The Australian wool industry contributes $A2.3 billion to export earnings (8 per cent of total value of farm exports) (ABARES 2011). Despite the continuing importance of the industry, the last major study that valued attributes of wool was published in 1993 (Gleeson *et al*. 1993). Since that time, the profile of the Australian wool clip has become finer, more attributes are objectively measured, much of the early-stage processing has relocated from Europe to China, and price differences between types have changed considerably.

Viability and profitability of the Australian wool industry will depend on woolgrowers meeting the requirements of users along the supply chain. Awareness of the premiums and discounts applied by buyers to wool characteristics may assist growers to evaluate the benefits of changes to production methods to take advantage of premiums and to avoid discounts for undesirable characteristics. It is therefore important that the values of the characteristics inherent within wool lots in the market are known.

* The authors would like to thank the staff of the Australian Wool Exchange Ltd for providing the data and for support in their interpretation. They would also like to thank the editor, associate editor and anonymous referees for their helpful comments.

† Elizabeth Nolan (email: elizabeth.nolan@sydney.edu.au), Madeleine Ryan, Candice Gibbon and Fredoun Ahmadi-Esfahani are present and past members of staff and honours students at Department of Agricultural and Resource Economics, University of Sydney, Sydney, New South Wales, Australia. Terence Farrell is at the Charolais Society of Australia, Armidale, New South Wales, Australia.

doi: 10.1111/1467-8489.12027

Previous studies of the Australian wool market were undertaken before or during the life of the Reserve Price Scheme (RPS) or while the resulting stockpile affected the market. The Reserve Price Scheme no longer has an influence on prices, and the data used in this study relate to sales in 2008–2009 when prices were determined by free market forces. Detailed information about the attributes of each wool lot was more limited at the time of earlier studies as objective measurement had not yet been widely adopted. In this study, we take advantage of the widespread use of objective measurement to expand on the parameters included in previous studies and thus provide a more detailed analysis of additional aspects of wool quality, including a new set of values for wool faults (an important concern of the wool industry) which have not been reported elsewhere. Another important influence on the market has been the changed demand structure resulting from the major shift in early-stage processing from Europe to China. This structural change in the industry has led to a decrease in the relative value of some characteristics as new machinery can process large volumes of uniform lines of wool. The increased proportion of finer wool in the Australian clip is likely to have changed the relative value of many wool traits during the past decade. In this study, we identify the premiums and discounts in the new ultrafine end of the market and explain some of the features of this evolving market.

The hedonic pricing model is a well-established method for analysis of the implicit demand for wool quality characteristics (see, for example, Beare and Meshios 1990). We employ the same model, using data relating to sale lots of fleece wool sold through the Australian Wool Exchange (AWEX) in the 2008–2009 selling season. Since wool is a heterogeneous commodity, and separate markets exist for different types of wool, it can be expected that attributes will vary according to the likely end use of the wool (Stanley-Boden *et al*. 1986; Templeton *et al*. 2004). Accordingly, the data have been divided into sales of ultrafine, superfine, fine, medium and broad merino wool, and five models have been estimated.

2. Background

Following the collapse of the Reserve Price Scheme, Australian shorn wool production fell from a peak of 1100.3 million kg (greasy) in 1990 to 350 million kg in 2010 (Australian Wool Innovation 2011). Production of finer wool increased to take advantage of premiums paid. Average fibre diameter of the Australian wool clip fell from 22.43 to 21.2 μm between 1993–1994 and 2009–2010, reaching a minimum of 21.06 μm in 2006–2007. The percentage of the wool clip with a diameter of 19.5 μm or less has increased from 8.84 to 38.24 per cent over the same period (Australian Wool Testing Authority 2011).

Demand for raw wool can be derived from demand for woollen apparel at retail. Consumption decisions are made by the spinner, who selects yarn suitable to convert into fabric desired by the consumer (Drummond 1993).

The spinner's purchase decision will depend on the inherent characteristics of the yarn which affect its processing requirements and the quality of the final product (Skinner 1965). Producers need a good understanding of fleece and fibre characteristics to be able to make informed production decisions about maximising returns in the short run and in the longer run producing the types of fibre demanded in response to price signals.

While increasing demand for softer, lighter fabrics has caused producers to alter the fibre diameter of their wool, buyers have other quality concerns. One such concern is the presence of faults in wool, and these faults include branding fluid, unscourable colour and vegetable matter. Branding fluid causes discolouration of otherwise clean lines, discolouration of wool grease and a reduction in processing choices. The expense and inconvenience involved in its removal often result in the price of affected wool being discounted (Lipson 1951). Other concerns relate to the presence of unscourable colour and vegetable matter. A strong market advantage for merino wool, relative to other fibres, is that it can readily take up dye, and can produce and hold a uniform colour. However, very small quantities of discoloured wool can contaminate large batches of wool top, yarn and fabric. Buyers are very wary of any odd colours found in sale samples and will discount wool at all stages of the supply chain (Lipson 1951). The level and type of vegetable matter generally limit the number of available processing options and increases the costs of its removal during processing.

Most wool sold by auction through AWEX (86 per cent of Australian wool sales) is represented by a sample, accompanied by a standardised lot report (Teasdale 2005). The AWEX-ID is used to grade qualitative, appraised characteristics of the wool, including the presence of faults, and is combined with objective, quantitative measurements of other attributes by the Australian Wool Testing Authority (AWTA). The buyer has a complete product description, and the price paid for a lot reflects the supply of, and demand for, the attributes displayed. The same information can be used to evaluate the effects of wool characteristics on price.

3. Literature review

The analysis in this paper follows the hedonic pricing model developed by Rosen (1974), which builds on the new approach to consumer theory proposed by Lancaster (1966). Lancaster suggested that traditional theory did not sufficiently deal with variations in product quality and proposed a new approach by which goods are no longer considered the object of utility; rather, it is the properties of those goods from which utility can be derived. Rosen (1974, p. 34) defined hedonic prices as '…the implicit prices of attributes that are revealed…from observed prices of differentiated products and the specific amounts of characteristics associated with them'.

The work of Lancaster (1966) and Rosen (1974) was the basis for development of subsequent hedonic pricing models, including the neoclassical model of Ladd and Martin (1976), which focusses on the role of inputs in the production process. Hedonic analysis has been applied in studies of product heterogeneity in many agricultural commodities, including wheat (Hill 1988; Espinosa and Goodwin 1991; Ahmadi-Esfahani and Stanmore 1994), soybeans and milk (Perrin 1980), milk (Lenz *et al*. 1994; Gillmeister *et al*. 1996) and cotton (Ethridge and Davis 1982; Ethridge and Neeper 1987; Bowman and Ethridge 1992).

The hedonic pricing method has been applied in a number of studies which focus on statistical relationships between wool characteristics and price in the Australian wool market, and because the Ladd and Martin approach values attributes of a good as purchased not for final consumption, but as inputs into further production, it is particularly appropriate for an analysis of the value of wool attributes (Beare and Meshios 1990). Simmons (1980) and Bramma *et al*. (1985) found statistically significant price premiums and discounts associated with wool of differing fibre diameter and level of vegetable matter content, and Beare and Meshios (1990) allowed for substitution between fibre diameters. Angel *et al*. (1990) and Stott (1990) found statistically significant price premiums and discounts associated with the staple measurement characteristics of length and strength, and Angel *et al*. (1990) also considered arbitrage in the Australian and New Zealand markets and the relevance of end use. Others have estimated the costs and benefits of more extensive objective measurement and of market innovations (for example, Jackson and Spinks 1982; Spinks and Lehmer 1986; Gleeson *et al*. 1993). Other methods have been employed to investigate elasticities of substitution between wools of different diameters (Beare and Meshios 1990) and to analyse longer term behaviour of wool prices (for example, Bardsley and Olekalns 1996; Chang 2000).

Such studies provide evidence of demand for quality attributes associated with wool, and this information can be used by woolgrowers, and other interested stakeholders, to ensure that wool quality meets market demand. However, price data employed in previous analyses of the wool market during the 1980s and 1990s were, to some extent, influenced by the regulated pricing schedule of the Reserve Price Scheme (Gleeson *et al*. 1993). Stockpile sales carried out after the termination of the Scheme in 1991 may also have affected the relative price for wool types in studies conducted during the 1990s. The possible bias resulting from the operations of the Reserve Price Scheme does not affect this study, since the data relate to sales in 2008–2009 where prices were determined by free market forces.

Previous studies have not, as far as we are aware, considered the effect on price of a number of important attributes. While Templeton *et al*. (2004) have analysed the effect of staple strength enhancing technology on wool production, they did not assess price variation due to the position of break. Lipson (1951) discusses the costs of tar brands in a number of processing segments of the supply chain; however, we are not aware of contemporary economic studies relating to the effects on price of the presence of unscourable colour or branding fluid, or different types of vegetable matter.

4. Data, model, and estimation procedures

The data used to estimate our model are described in the following section, and we then present the model specifications.

4.1. Data

Auction price and lot characteristics data for all lots of wool sold in the season from 1 July 2008 to 30 June 2009 were obtained from AWEX. The total number of lots offered was 189,033. Our analysis is based on the data for the 111,440 fleece lots actually sold at auction. Because wool is used in a number of different end uses and the production process required for each of these end products is distinct, the demand for attributes inherent within a lot will vary according to processing, and ultimately, consumer needs. To allow for differences in demand for different wool types, the data were divided into five categories: ultrafine (<16.5 μm), superfine (16.5–18.5 μm), fine (18.5–20.5 μm), medium (20.5–23.5 μm) and broad (23.5 μm and above). The sample for ultrafine wool was 5618 observations, superfine wool 24,419, fine wool 34,709, medium wool 33,695 and broad wool 12,999.

4.2. Model

Summary statistics for the variables included in the model can be found in Table 1. Detailed definitions of the wool characteristics can be found on the websites of the Australian Wool Exchange (AWEX), Australian Wool Innovation (AWI) and the Australian Wool Testing Authority (AWTA).

4.3. Dependent variable

The dependent variable is the log of the Australian clean on-floor (ACOF) price, which is greasy price expressed as a percentage of yield.

4.4. Independent variables

The independent variables were divided into continuous or discrete groups.

4.4.1. Continuous variables

The continuous group includes the objectively measured attributes: fibre diameter, length, strength and percentage of mid-break (POB). Previous research has shown that a number of the variables are functionally related (Maddever *et al.* 1988). We treat the analysis of products that have a joint attribute distribution as a quasi bundle of attributes, which is fixed at each

Table 1 Summary statistics

Variable	Ultrafine (5618 observations)				Superfine (24,419 observations)				Fine (34,709 observations)				Medium (33,605 observations)				Broad (12,999 observations)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Clean Price	2108.02	3154.39	712	63291	1269.27	280.03	254	4776	883.13	136.61	72	2310	753.20	62.34	394	1042	454.01	118.90	114	862
Micron	15.78	0.58	12.4	16.4	17.55	0.55	16.5	18.4	19.51	0.57	19	20.4	21.53	0.76	21	23.4	28.86	2.80	24	42.2
Length	78.50	6.56	70	113	82.67	7.91	70	137	89.07	9.17	70	141	92.86	9.12	70	140	86.77	34.82	0	151
Strength	36.58	7.90	11	59	36.65	8.49	10	63	33.29	8.29	8	67	33.31	8.06	8	65	28.50	12.09	0	64
Vegetable matter (%)	1.03	0.97	0	12.2	1.26	1.27	0	29.7	1.27	1.22	0	21	1.19	1.11	0.1	20.2	0.84	1.11	0.1	24.9
Percent midpoint break	48.19	22.00	0	100	46.21	22.24	0	100	49.75	22.26	0	100	48.71	21.81	0	98	43.15	23.08	0	98
Weaner	0.48	0.50	0	1	0.16	0.37	0	1	0.06	0.24	0	1	0.01	0.09	0	1	0.00	0.02	0	1
Style																				
Choice	0.01	0.08	0	1	0.00	0.03	0	1	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.00	0	0
Best spinners	0.02	0.13	0	1	0.00	0.05	0	1	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.00	0	0
Spinners	0.13	0.33	0	1	0.08	0.27	0	1	0.01	0.08	0	1	0.00	0.03	0	1	0.00	0.02	0	1
Best	0.56	0.50	0	1	0.45	0.50	0	1	0.25	0.43	0	1	0.14	0.34	0	1	0.17	0.37	0	1
Good	0.28	0.45	0	1	0.43	0.49	0	1	0.65	0.48	0	1	0.72	0.45	0	1	0.75	0.43	0	1
Average	0.01	0.11	0	1	0.04	0.19	0	1	0.09	0.28	0	1	0.13	0.34	0	1	0.08	0.27	0	1
Inferior	0.00	0.00	0	0	0.00	0.06	0	1	0.01	0.08	0	1	0.01	0.09	0	1	0.00	0.05	0	1
Vegetable matter (type)																				
Burr	0.01	0.07	0	1	0.03	0.17	0	1	0.11	0.31	0	1	0.20	0.40	0	1	0.09	0.29	0	1
Seed	0.51	0.50	0	1	0.43	0.49	0	1	0.39	0.49	0	1	0.38	0.49	0	1	0.56	0.50	0	1
Shive	0.48	0.50	0	1	0.51	0.50	0	1	0.43	0.50	0	1	0.32	0.47	0	1	0.31	0.46	0	1
Noogoora Burr	0.00	0.00	0	0	0.00	0.03	0	1	0.01	0.08	0	1	0.01	0.08	0	1	0.00	0.04	0	1
Bathurst Burr	0.01	0.07	0	1	0.03	0.17	0	1	0.11	0.31	0	1	0.20	0.40	0	1	0.09	0.29	0	1
Moit	0.01	0.08	0	1	0.00	0.07	0	1	0.00	0.06	0	1	0.01	0.08	0	1	0.00	0.02	0	1
Bogan Flea	0.00	0.02	0	1	0.00	0.07	0	1	0.03	0.16	0	1	0.04	0.20	0	1	0.00	0.05	0	1
Unscourable colour																				
Light	0.06	0.24	0	1	0.04	0.20	0	1	0.07	0.26	0	1	0.08	0.27	0	1	0.14	0.34	0	1

Table 1 (*Continued*)

Variable	Ultrafine (5618 observations)				Superfine (24,419 observations)				Fine (34,709 observations)				Medium (33,605 observations)				Broad (12,999 observations)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Medium	0.00	0.05	0	1	0.00	0.05	0	1	0.01	0.07	0	1	0.01	0.08	0	1	0.02	0.13	0	1
Heavy	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.01	0	1	0.00	0.01	0	1	0.00	0.02	0	1
No colour	0.94	0.24	0	1	0.96	0.20	0	1	0.92	0.27	0	1	0.92	0.33			0.85	0.36	0	1
Branding contamination																				
Light	0.00	0.01	0	1	0.00	0.02	0	1	0.00	0.04	0	1	0.0029	0.05	0	1	0.003	0.05	0	1
Medium	0.00	0.00	0	0	0.00	0.02	0	1	0.00	0.03	0	1	0.0006	0.02	0	1	0.000	0.02	0	1
Heavy	0.00	0.00	0	0	0.00	0.02	0	1	0.00	0.03	0	1	0.0006	0.02	0	1	0.001	0.04	0	1
No brands	1.00	0.01	0	1	1.00	0.04	0	1	1.00	0.06	0	1	0.996	0.07	0	1	0.996	0.07	0	1
Quarter 1	0.19	0.40	0	1	0.28	0.45	0	1	0.24	0.43	0	1	0.26	0.44	0	1	0.23	0.42	0	1
Quarter 2	0.48	0.50	0	1	0.33	0.47	0	1	0.26	0.44	0	1	0.26	0.44	0	1	0.34	0.47	0	1
Quarter 3	0.22	0.42	0	1	0.23	0.42	0	1	0.28	0.45	0	1	0.26	0.44	0	1	0.26	0.44	0	1
Quarter 4	0.11	0.31	0	1	0.16	0.36	0	1	0.22	0.41	0	1	0.23	0.42	0	1	0.17	0.37	0	1
Sydney	0.21	0.40	0	1	0.32	0.47	0	1	0.36	0.48	0	1	0.25	0.43	0	1	0.35	0.48	0	1
Newcastle	0.35	0.48	0	1	0.23	0.42	0	1	0.05	0.22	0	1	0.02	0.14	0	1	0.04	0.19	0	1
Melbourne	0.42	0.49	0	1	0.39	0.49	0	1	0.37	0.48	0	1	0.48	0.50	0	1	0.58	0.49	0	1
Fremantle	0.01	0.11	0	1	0.06	0.23	0	1	0.22	0.41	0	1	0.25	0.43	0	1	0.03	0.17	0	1
Launceston	0.01	0.11	0	1	0.01	0.08	0	1	0.00	0.02	0	1	0.00	0.00	0	0	0.00	0.00	0	0

point in the joint distribution space. In this model, the supplier offers a fixed bundle of attributes at each price point, but the buyer has a large range of product bundles over varying qualities from which to choose.

Based on the results of previous studies, it would be expected that fibre diameter would have the most important effect on price, as finer wools reduce fabric weight, have higher levels of comfort and produce more even yarn, especially in the worsted process (Cottle 2000; Australian Wool Innovation 2011). Staple length and strength could be expected to be the next most important factors as they are used to predict key processing and product properties.

Staple length may improve the spinning performance of wool, fabric abrasion resistance and the strength of knitted fabrics (Angel *et al.* 1990; Australian Wool Innovation 2011). However, wool that is too long is sold into specialist processing markets and may attract discounts, especially for superfine wools (Gordon *et al.* 2004). Wools that are too short for combing are sold into the carding market.

Staple strength is a measure of how much force is required to break a wool staple and has an influence on the efficiency with which wool is combed, and the amount of fibre breakage and wastage during this process. Weaknesses are particularly important in the early stages of processing where they will result in increased fibre breakages (Angel *et al.* 1990; Australian Wool Innovation 2011). The optimum strength of wool is greater than 45 Newtons per kilotext. Processors can trade off wools of low strength and produce more waste but will generally pay less for the wool. When wool lacks sufficient strength to comb then it is heavily discounted into the carding market. There are large price penalties for very tender wools (14–21 Nkt). The discounts become less significant as the strength increases, and premiums become evident once the wools test above 40 Nkt. Premiums and discounts are much larger for finer wools.

Midpoint breakage is related to the strength of the staple and is affected by the environmental conditions experienced by the sheep. Position of break is reported by the AWTA as the percentage of staples which break in the middle of the staple. This is of concern to processors, but only if staple strength is low (Cottle 2000). Buyers prefer wool of high staple strength and low mid-break percentage and will specify a strength minimum along with a maximum midpoint break percentage for their deliveries, thereby placing increased price pressure on low mid-break types (Australian Wool Innovation 2011).

The nonlinear relationships between attributes of wool have been well documented (see, for example, Bramma *et al.* 1985; Maddever *et al.* 1988). Length and strength interact with fibre diameter, producing a quadratic response surface. Generally, wool length increases as micron increases. Similarly, as micron increases so does wool strength. Technical constraints associated with processing machinery impose minimum and maximum length and strength tolerance requirements on the demand side of the market. Strength and percentage of midpoint break interact over parts of their ranges.

These relationships have been accounted for by the use of interaction variables. The effect on prices of length, strength, percentage of midpoint break and diameter may vary over their whole range. We have therefore included quadratic and cubic terms for these variables in some micron categories.

4.4.2. Discrete variables

The discrete variables were incorporated in the models as dummy variables. They include brand contamination and unscourable colour (whether branding or colour was present and at what level of severity), vegetable matter (VM) by type, and style (relative to inferior).

Wool style is a ranking based on a subjective appraisal of the overall look and feel of a wool lot and considers evenness of crimp along the length of a wool staple, the extent of tip damage, dust content and penetration, colour and lustre. All lots sold through the auction system by AWEX are assigned an appraised style, from inferior (7) to choice (1). While the literature suggests that purchases should not be based on appearance (Gleeson *et al.* 1993; Scrivener *et al.* 1999; Vizard and Hansford 1999), appearance is perceived as continuing to influence prices paid, especially for style 1 and style 2 (AWEX 2002). Ford and Cottle (1993) suggest that style is likely to have some significance in determining the processing potential and therefore price. The styles are included through the use of dummy variables, with style (7) as the base (style 6 for ultrafine and superfine).

The two most important fleece faults are unscourable colour and branding fluids. Presence of colour involves considerable scouring costs for processors, and discounts will be applied as severity of unscourable colour increases. Its presence in wool can be the product of a number of factors such as rainfall and humidity levels, diet, animal health and control of parasites. Greasy wool with unscourable colour will result in an end product that is off-white or yellow, thus limiting dyeing options (Australian Wool Innovation 2011). Unscourable colour is present in this sample in varying degrees from about 4 per cent of fine wools and up to 15 per cent of broad wools. The discounts for unscourable colour depend on its severity, and the finer the wool, the greater the discount.

Processors impose heavy penalties for the presence of branding fluids, and three levels of brand contamination, relative to no brand contamination, are included in the model. Lipson (1951) provides an overview of the processing problems, costs and proposed solution to the branding problem. Although improved branding fluids were introduced as long ago as the 1950s, presence of unscourable brands may be linked to farmers using home-made branding fluids to cut costs (AWEX 2006). While branding contamination is present in a very small proportion of the lots in this sample (<0.1 per cent in the fine wools and <0.5 per cent in the medium and broad groups) it could be expected that where it is present, price discounts would be substantial.

Vegetable matter is the percentage of vegetable matter found in the greasy wool sample. The level and type of vegetable matter generally limit the number of available processing options and increase the costs of processing (Angel *et al*. 1990). Where vegetable matter content is >2–3 per cent, the wool may need to undergo additional expensive processing (carbonising). Industry sources estimate the cost of carbonising at 140 cents per kg, and carbonising will usually lead to higher fibre loss than other processing methods. Seven types of vegetable matter are reported in the data. Fibrous types, such as seed and shive, are the most difficult to remove in combing and carry the largest discounts. Burry types are easier to remove. The raw data describe vegetable matter as a percentage and then list the types of vegetable matter in each lot. In our models, vegetable matter type is nested within vegetable matter content which produces a discrete discount value for the presence of each matter at all levels of contamination.

Weaner wool comes from animals that are in their first full season of wool production. Because of the animal's age, the wool may differ from that of adult sheep and therefore attract a premium or discount. We control for the possible difference in price by the use of a dummy variable, 1 for weaner and 0 for an adult sheep.

4.4.3. Location and quarter of sale

The third group of dummy variables was included to control for the possible effect of sale location, with Sydney as the base, and for possible seasonal influences, with Quarter 4 (April–June) as the base. Although the results for these variables are in general found to be statistically significant, they are not reported in detail.

4.5. Functional form

The appropriate form of the hedonic function was debated in the literature from the early 1970s (see, for example, Rasmussen and Zuehlke 1990). The semi-log form is typically used for hedonic pricing analyses because homogeneity and curvature properties are better satisfied when using a log dependent variable, relative to linear dependent variables. It becomes more important to use nonlinear price measures when the rate of attribute substitution is variable. Its nonlinear properties are required of quasi-utility functions in order to produce a continuous first derivative and minimise the problem of identification (Rasmussen and Zuehlke 1990; Ekeland *et al.* 2002). The hedonic model, estimated in semi-log functional form is:

$$\ln P_i = \alpha_0 + \sum_{h=1}^{m} \beta_h x_{ih} + \sum_{j=1}^{n} \gamma_j z_{ij} + \sum_{k=1}^{r} \delta_i d_{ik} + \varepsilon_i \tag{1}$$

where $\ln P_i$ is the log of clean price for lot i (c/kg), α_0 is the constant term, x_{ih} is the set of h linear and nonlinear objectively measured quantitative characteristics and includes a set of quadratic, cubic and interaction variables, z_{ij} is the set of j dummy variables representing the qualitatively assessed discrete characteristics of lot i, and d_{ik} is the set of dummy variables which control for location of sale, and quarter of sale, thus accounting for changes in price at different locations and over the year, and ε_i is the error term. The model was estimated for each of the five different micron groups, using generalised least squares (GLS) multiple regression. Given the difference in the nature of each of the groups, different attributes were evaluated for each micron range model. SAS® was used to run the regressions.

5. Results

Statistics for each of the five models are presented in Table 2. All models are statistically significant with F-values ranging from 709.02 for the ultrafine model to 5781.7 for the fine model. The R-squared is between 0.70 for the medium model and 0.94 for the broad model. These values are very high for cross sectional data, implying that the models explain a large part of the variation in each of the five models. The lower R-squared for medium wool may be attributable to the fact that there is a larger range of substitute products such as cotton and synthetic fibres for wools in this micron group. There are likely to be other macroeconomic market factors that affect prices but are not analysed in this model.

The results for each of the five models are reported in Tables 3 and 4. The final column for each model shows the price flexibilities for each characteristic. In the case of continuous variables, price flexibilities are defined as the percentage change in price for a one per cent change in an attribute when evaluated at the price and attribute means. For the general form of the model,

$$\mathrm{LN}\,P = a + bX + cX^2 + dX^3 + e, \tag{2}$$

the price flexibility for a cubic variable is

$$\text{Flexibility} = \left(b + 2cX + 3dX^2\right) * X = bX + 2cX^2 + 3dX^3 \tag{3}$$

We have estimated flexibilities by taking a total derivative for each attribute and the interactions where they occur. For a discrete variable, the flexibility is reported as the percentage change in price if an attribute is

Table 2 Model statistics

Model statistics	Ultrafine	Superfine	Fine	Medium	Broad
Observations	5618	24,419	34,709	33,695	12,999
R-squared	0.81	0.75	0.86	0.70	0.94
F-value	709.02	1934.74	5781.70	2509.36	1427.91
Pr > |F|	<0.001	<0.001	<0.001	<0.001	<0.001
Root MSE	0.20	0.10	0.06	0.05	0.07

Table 3 Results for ultrafine, superfine and fine models

Parameter	Ultrafine				Superfine				Fine			
	Estimate	*t*-Value	Pr > |t|	Price flexibility	Estimate	*t*-Value	Pr > |t|	Price flexibility	Estimate	*t*-Value	Pr > |t|	Price flexibility
Micron	3.903	1.180	0.239	−3.963	−0.038	−2.540	0.011	−2.140	−1.206	−29.860	<0.0001	−3.4792
Micron squared	−0.559	−2.540	0.011						0.028	27.330	<0.0001	
Micron cubed	0.020	4.060	<0.0001									
Micron* Length	−0.008	−8.530	<0.0001		−4.59E–04	−2.950	0.003					
Micron* Strength	−0.020	−30.090	<0.0001		−0.001	−9.190	<0.0001		−0.002	−33.560	<0.0001	
Length	0.125	8.830	<0.0001	0.395	0.028	10.030	<0.0001	0.109	0.011	22.460	<0.0001	0.010
Strength	0.309	19.470	<0.0001	0.578	0.056	16.130	<0.0001	0.234	0.065	40.980	<0.0001	0.096
Length squared					−1.12E–04	−15.160	<0.0001		−6.20E–05	−22.560	<0.0001	
Strength squared	0.001	1.500	0.133		−0.001	−12.820	<0.0001		−0.001	−17.480	<0.0001	
Strength* POB	2.50E-05	1.430	0.152		1.33E-05	3.620	0.000		1.26E-05	7.400	<0.0001	
Strength cubed	−5.24E-06	−1.640	0.102		8.20E-06	13.650	<0.0001		3.99E-06	14.070	<0.0001	
POB	−0.001	−2.290	0.022	−0.025	−0.001	−5.380	<0.0001	−0.010	−0.001	−12.910	<0.0001	−0.015
Unscourable colour (no colour as base)												
Light	−0.064	−5.410	<0.0001	−6.171	−0.014	−4.280	<0.0001	−1.391	−0.009	−7.170	<0.0001	−0.861
Medium	−0.076	−1.350	0.178		−0.043	−3.270	0.001	−4.167	−0.042	−9.820	<0.0001	−4.121
Heavy	N/A				N/A				−0.168	−2.970	0.003	−15.454
Brand contamination (No brand contamination as base)												
Light	0.289	1.420	0.155		−0.081	−3.160	0.002	−7.772	−0.020	−2.740	0.006	−1.967
Medium	N/A				−0.198	−7.180	<0.0001	−17.942	−0.155	−15.710	<0.0001	−14.326
Heavy	N/A				−0.223	−5.500	<0.0001	−19.958	−0.170	−14.440	<0.0001	−15.652

Table 3 (*Continued*)

Parameter	Ultrafine				Superfine				Fine			
	Estimate	*t*-Value	Pr > |t|	Price flexibility	Estimate	*t*-Value	Pr > |t|	Price flexibility	Estimate	*t*-Value	Pr > |t|	Price flexibility
Style		(Style 6 as base)				(Style 7 as base)				(Style 7 as base)		
Style 1	0.195	4.580	<0.0001	21.590	0.315	11.850	<0.0001	37.037	N/A	N/A	N/A	N/A
Style 2	0.182	5.340	<0.0001	19.914	0.343	19.340	<0.0001	40.938	N/A	N/A	N/A	N/A
Style 3	0.108	3.910	<0.0001	11.399	0.242	21.840	<0.0001	27.418	0.185	33.580	<0.0001	20.297
Style 4	0.049	1.870	0.061	5.013	0.136	12.670	<0.0001	14.618	0.100	25.080	<0.0001	10.502
Style 5	0.042	1.610	0.108	4.285	0.122	11.420	<0.0001	13.013	0.097	24.630	<0.0001	10.172
Style 6					0.095	8.500	<0.0001	9.950	0.082	20.380	<0.0001	8.575
Vegetable matter												
VM (Burr)	−0.035	−2.400	0.016	−3.435	−0.029	−20.860	<0.0001	−2.844	−0.020	−45.540	<0.0001	−1.948
VM (Seed)	−0.049	−6.530	<0.0001	−4.761	−0.035	−23.250	<0.0001	−3.471	−0.023	−27.240	<0.0001	−2.239
VM (Boganflea)	−0.080	−1.750	0.080	−7.649	−0.033	−6.990	<0.0001	−3.208	−0.017	−16.040	<0.0001	−1.716
VM (Moit)	−0.027	−2.800	0.005	−2.672	−0.027	−12.040	<0.0001	−2.637	−0.022	−16.700	<0.0001	−2.175
VM (Shive)	−0.050	−13.190	<0.0001	−4.903	−0.027	−4.290	<0.0001	−3.200	−0.024	−24.840	<0.0001	−1.987
VM (Bathurst Burr)	−0.033	−6.070	<0.0001	−3.263	−0.033	−44.320	<0.0001	−2.365	−0.020	−47.450	<0.0001	−1.682
Weaner	−0.040	−6.440	<0.0001	−3.920	−0.024	−12.890	<0.0001	−2.359	−0.005	−3.870	<0.0001	−0.526
Intercept	6.376	0.380	0.702		6.330	24.160	<0.0001		18.662	47.020	<0.0001	

Table 4 Results for medium and broad models

Parameter	Medium				Broad			
	Estimate	*t*-Value	Pr > |t|	Price flexibility	Estimate	*t*-Value	Pr > |t|	Price flexibility
Micron	−0.021	−61.120	<0.0001	−0.451	−0.100	−7.640	<0.0001	−2.076
Micron squared					0.001	4.070	<0.0001	
Micron cubed								
Micron*Length					−5.18E-05	−1.190	0.233	
Micron*Strength					−0.001	−8.830	<0.0001	
Length	0.007	17.250	<0.0001	−0.006	0.002	1.370	0.171	0.011
Strength	0.024	32.600	<0.0001	0.050	0.028	7.140	<0.0001	−0.009
Length squared	−3.70E-05	−17.450	<0.0001					
Strength squared	−0.001	−25.880	<0.0001		−3.06E-04	−3.170	0.002	
Strength*POB	1.87E-05	12.910	<0.0001		2.87E-05	3.890	<0.0001	
Strength cubed	4.30E-06	20.390	<0.0001		2.32E-06	2.450	0.014	
POB	−0.001	−17.850	<0.0001	−0.011	−0.001	−5.010	<0.0001	−0.012
Unscourable colour								
Light	−0.006	−6.820	<0.0001	−0.648	−0.006	−1.230	0.218	−0.577
Medium	−0.039	−11.980	<0.0001	−3.818	−0.047	−3.750	0.000	−4.579
Heavy	0.062	1.350	0.177					
Brand contamination								
Light	−0.011	−2.490	0.013	−1.142	−0.008	−0.390	0.697	−8.361
Medium	−0.175	−16.650	<0.0001	−16.046	−0.392	−5.280	<0.0001	−32.436
Heavy	−0.199	−19.920	<0.0001	−18.057	−0.293	−6.850	<0.0001	−25.405
Style (Style 7 (Inferior) as base								
Style 3	0.066	6.820	<0.0001	6.857	0.064	1.610	0.108	6.642
Style 4	0.058	21.300	<0.0001	5.998	0.058	3.840	<0.0001	5.960
Style 5	0.059	22.230	<0.0001	6.079	0.058	3.980	<0.0001	5.921
Style 6	0.047	17.130	<0.0001	4.760	0.042	2.880	0.004	4.312
Vegetable matter								
VM (Burr)	−0.015	−46.190	<0.0001	−1.482	−0.015	−7.700	<0.0001	−1.479
VM (Seed)	−0.015	−20.930	<0.0001	−1.486	−0.009	−2.150	0.031	−0.916

Table 4 (*Continued*)

Parameter	Medium				Broad			
	Estimate	*t*-Value	Pr > |t|	Price flexibility	Estimate	*t*-Value	Pr > |t|	Price flexibility
VM (Bogan Flea)	−0.013	−13.900	<0.0001	−1.243	−0.034	−4.040	<0.0001	−3.369
VM (Moit)	−0.021	−21.390	<0.0001	−2.095	−0.012	−0.840	0.403	−1.198
VM (Noogoora)	−0.018	−21.610	<0.0001	−1.746	−0.013	−1.870	0.061	−1.288
VM (Shive)	−0.015	−35.160	<0.0001	−1.440	−0.009	−3.150	0.002	−0.867
VM (Bathurst Burr)	−0.014	−41.360	<0.0001	−1.438	−0.033	−20.950	<0.0001	−3.288
Weaner					−0.174	−4.08	<0.0001	−15.973
Intercept	6.418	297.650	<0.0001		8.083	35.380	<0.0001	

present as compared with the price when the variable is absent (Halvorsen and Palmquist 1980; Kennedy 1981). The equation for estimating flexibility for a discrete term is

$$f_{\mathrm{i}} = 100 * \{\exp(\beta_i) - 1\} \quad (4)$$

Most coefficients were statistically significant, but those variables with the most influence on price were fibre diameter, high vegetable matter content, medium to heavy branding fluid and colour. Increasing staple length and strength attracted a premium in most cases (the exceptions are for length for medium wool and strength for broad wool), and a very large premium was paid for choice and best spinner style fleeces in the ultrafine and superfine models. We discuss some selected results in more detail in the following sections.

5.1. Fibre diameter, length, strength and percentage of midpoint break

The results show that the responsiveness of clean price to a small change in fibre diameter, other factors held constant, varies across wool categories. This is expected because the demand response differs for the different wool types due to their respective end uses and the number and type of substitutes available.

Price responsiveness could be expected to be higher for finer wools, and this is demonstrated by the price flexibilities for diameter for the three fine wool categories. Price responsiveness is particularly high for ultrafine wool, where a one micron decrease in diameter is found to result in a 3.963 per cent increase in price. This result is in line with industry findings that micron premiums increase rapidly as micron diameter decreases.

Because of the type of processing undergone by medium fleeces, demand is relatively unresponsive across this micron range, and there is comparatively little difference in terms of the quality of the final product. This is demonstrated by a price flexibility for medium wool of only −0.451. Broader wools, on the other hand, incorporate a much larger micron range, implying that price will be more responsive to change as fibre diameter approaches the upper end of the category, and again, this is illustrated by a price flexibility of −2.076.

The coefficient for staple length was positive in micron categories, except for medium, where the flexibility was negative by 0.64 per cent. The price flexibility for strength is positive for all micron bands except broad. The price flexibility for percentage of midpoint break is negative in all cases. Therefore, price generally increases as strength increases; however, price decreases as the percentage of fibres that break in the centre increases. Generally, it was expected that beyond 36 Nkt, the POB would become less relevant as the wool is sufficiently sound for the majority of processing methods. In this case, the strength premium substantially dominates the POB discount in the interaction. This occurs at all levels of strength not just the means (which were all above 31.3 Nkt). The same result would be recognised lower down the strength curve due to the magnitude of strength relative to POB in the interaction term.

5.1.1. Quadratic and interaction terms

Previous studies have found nonlinear interactions between attributes of wool. We find the interaction between micron and length to be statistically significant and having an economic effect for ultrafine. The interaction was statistically significant, but had a very small economic effect for superfine wool, and was not statistically significant for the other categories. The interaction of micron and strength was statistically significant in all but the medium model, while the interaction of length and strength was not significant in any of the models.

The linear variable for diameter was positive but statistically insignificant for ultrafine wool. The negative parameter for the quadratic model implies that price will decrease at a decreasing rate as micron increases. The fine and broad micron ranges models produced a significant positive quadratic function for micron implying that as micron increases price decreases less rapidly. The quadratic variables for micron were not significant in the superfine and medium models. Although there was a significant quadratic effect for length, it had almost no economic value.

5.2. Vegetable matter

The discrete variables for vegetable matter contamination were estimated from the percentage of vegetable matter conditional on the type of contamination. Their coefficients reflect both the effect of the amount of vegetable matter and of the type. Since vegetable matter content is a percentage, the change is for a one per cent change of the vegetable matter percentage when a particular vegetable matter is present. For example, for ultrafine, for a one per cent change in vegetable matter content with burrs present, the price change was −0.034 or a decrease of 3.4 per cent. While it would be expected that the discounts for the presence of seed and shive would be greater than for burrs, the results were mixed. Seed and shive were both the most common and the heaviest faults, and their statistically significant effects on price were most important in the ultrafine and superfine categories. Discounts for bogan flea were also high in those categories.

5.3. Branding fluid

Although the proportion of lots where branding fluid is reported is very small (<0.5 per cent for the finer categories and <1.5 per cent for the broader wools), the discounts that apply when it is present are large. There is no significant presence of branding fluid in the ultrafine category, but in the superfine model the discounts range from 7.77 per cent for light contamination to 19.96 per cent for heavy contamination. The discounts range from 1.97 per cent to 15.65 per cent for fine wool and 1.14 per cent to 18.05 per cent for medium wool as severity increases. Light branding contamination resulted in a 0.84 per cent discount on the price of broad wool, but medium and heavy contamination attracted discounts of over 20 per cent. In general, this wool is used for lower grade products where colour constraints are less stringent.

5.4. Unscourable colour

Discounts would be expected for the presence of unscourable colour given that whiter wools are preferred by spinners for their superior ability to hold dye (Turk 1993). As is the case with branding fluid, where unscourable colour is present, discounts increase as wool becomes finer. In the ultrafine model, light unscourable colour attracted a discount of 6.17 per cent compared with 1.39 per cent and 0.86 per cent for superfine and fine wools, respectively. For medium wool, light colour attracted a discount of 0.65 per cent, and in the broad category, 0.58 per cent. In the ultrafine model, medium colour attracted a discount of 7.35 per cent and for superfine, fine, medium and broad wools the discounts were 4.17, 4.12, 3.82 and 4.58 per cent, respectively. There were no statistically significant discounts for heavy unscourable colour for ultrafine or superfine wools as these contaminants are generally removed from these lots during classing. The discount was 15.45 per cent for fine wool. Broad wools, in general, contain more colour, and the end use of these wools is less dependent on colour constraints.

5.5. Style

Only 3 per cent of wool lots in the ultrafine category were ranked as style 1 (choice) and style 2 (best spinners), and the proportion was only 0.27 per cent for superfine wool. However, where present, these style rankings attracted, as would be expected, substantial premiums. The premiums for these styles were greater for superfine wool than for ultrafine even when the difference in the base of S6 for ultrafine and S7 for superfine is taken into account. The style grades S3–S6 were statistically significantly different from the base case (S7) in all models except for the broad model where style 5 was only marginally significantly different from style 7 at the 10 per cent level of significance. The higher levels of style became less significant as fibre diameter increased. This was expected, given that style is loosely based on a number of visual characteristics that are mostly related to micron, dust and colour.

6. Conclusions

In this paper, we have used a hedonic pricing model to estimate the implicit prices of wool attributes present in all lots of fleece wool sold at auction in

Australia in 2008–2009. Our analysis of the price premiums and discounts that arise from certain raw wool characteristics is based on a cross section of data for the 2008–2009 selling season. The micron profile of the wool clip has changed in response to higher prices for finer wool, and China is now the major importer of Australian wool. Growers can now be made aware of the wool characteristics that command premiums and discounts and of the benefits that may result from modification of production practices to better meet the requirements of processors. The implicit values reported here have implications for wool growers, buyers, processors, marketers and policy-makers along the wool supply chain.

The signs and magnitudes of coefficients for variables that have been measured previously are consistent with those reported in earlier studies (for example, Angel *et al.* 1990; Beare and Meshios 1990; Gleeson *et al.* 1993; Hansen and Simmons 1995; Simmons and Hansen 1997). The results for those variables not previously measured are generally in line with expectations and indicate that discounts accrue to lots contaminated with branding fluids, unscourable colour and vegetable matter. Percentage of midpoint break will also have a negative effect on price in some wool categories. However, specific analyses of the costs and benefits of related factors are required to broaden the scope of the conclusions.

The results suggest that changes to current practice could include an increased emphasis on effective clip preparation. Growers need to be aware of the importance of minimising branding. Although only a small proportion of the clip (from 0.02 per cent for ultrafine wool to 0.44 per cent for broad wool) was contaminated with branding fluid, its presence still implies substantial price penalties. Penalties for heavy branding fluid presence range from 19.96 per cent for superfine wool to 15.65 per cent for medium wool. As greater penalties accrue to more severely contaminated wool, the emphasis should be on eliminating medium to heavy branding contamination. Price penalties for the various types of vegetable matter will provide classers with a useful guide to the level of skirting required for each contaminant type. As the type and concentration of vegetable matter tends to vary seasonally, it may be possible to adjust the timing of shearing and crutching to minimise its presence in fleece wool. Integrated weed management could also reduce the incidence of some contamination. It is difficult to minimise colour contamination, as it is mostly a function of the amount of sweat and moisture in the wool and this is dependent on feed availability, feed type and weather. However, growers may be able to reduce problems with tenderness through managing lambing time, avoiding rapidly changing feed types and shearing at times that will force breaks to be at the tip of the fibre (for example shearing in late autumn if the major stresses in the farm system occur in winter).

While our results imply that wool producers should direct investment to producing the quality attributes that have the greatest market value, we have considered only the demand side. The costs involved in making adjustments to production and selling practices must also be taken into consideration.

Growers will only adopt practices to meet the requirements of processors if the returns are perceived to exceed costs.

It should also be noted that, as was the case with the study conducted by Gleeson *et al*. (1993), the estimates of price premiums and discounts are for a single year, with its particular patterns of supply and demand for specific wool types. A more comprehensive study that utilises data over a number of selling seasons would enhance the robustness of the findings.

References

ABARES (2011). *Australian Commodity Statistics 2010*. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Ahmadi-Esfahani, F. and Stanmore, R.G. (1994). Values of Australian wheat and flour quality characteristics, *Agribusiness: An International Journal* 10, 529–536.

Angel, C., Beare, S. and Zwart, A.C. (1990). Product characteristics and arbitrage in the Australian and New Zealand wool markets, *Australian Journal of Agricultural Economics* 34, 67–79.

Australian Wool Innovation (2011). The Australian Wool Industry. Available from URL: http://www.wool.com/default.htm [accessed 3 June 2011].

Australian Wool Testing Authority (2011). Statistical Information. Available from URL: http://www.awta.com.au/en/Home/Statistics/ [accessed 3 June 2011].

AWEX (2002). *AWEX-ID: Non-measured characteristics*. Australian Wool Exchange (AWEX) Ltd., Sydney.

AWEX (2006). Branding Analysis Project. Available from URL: http://www.awex.com.au/publications/branding-fluid-analysis-project.html [accessed 7 August 2011].

Bardsley, P. and Olekalns, N. (1996). Wool price variability in the long run, *Australian Journal of Agricultural Economics* 40, 51–61.

Beare, S. and Meshios, H. (1990). Substitution between wools of different fibre diameter, *Australian Journal of Agricultural Economics* 34, 56–66.

Bowman, K. and Ethridge, D. (1992). Characteristic supplies and demands in a hedonic framework: US market for cotton fibre attributes, *American Journal of Agricultural Economics*, 99, 1–1001.

Bramma, K., Curran, B. and Gilmore, B. (1985). *Non-linearity and market segmentation in hedonic price analysis of greasy wool*, ABARE paper presented to the 29th Annual Conference of the Australian Agricultural Economics Society, Armidale, NSW, 13-14 February.

Chang, H.S.C. (2000). *A Cointegration Analysis of Wool Prices*. University of New England, Armidale.

Cottle, D.J. (2000). *Australian Sheep and Wool Handbook*. WRONZ Developments, Christchurch.

Drummond, T. (1993). Measurement and its relationship to processing, *Wool Technology and Sheep Breeding* 41, 317–329.

Ekeland, I., Heckman, J.J. and Nesheim, L. (2002). Identifying hedonic models, *American Economic Review* 92, 304–309.

Espinosa, J. and Goodwin, B. (1991). Hedonic price estimation for Kansas wheat characteristics, *Western Journal of Agricultural Economics* 7, 293–300.

Ethridge, D.E. and Davis, B. (1982). Hedonic price estimation for commodities: an application to cotton, *Western Journal of Agricultural Economics* 7, 293–300.

Ethridge, D.E. and Neeper, J.T. (1987). Producer returns from cotton strength and uniformity: an hedonic approach, *Southern Journal of Agricultural Economics* 19, 91–97.

Ford, K.L. and Cottle, D.J. (1993). A review of the use of sheep coats to improve the processing potential of wool, *Wool Technology and Sheep Breeding* 41, 161–172.
Gillmeister, W., Yonkers, R. and Dunn, J. (1996). Hedonic pricing of milk components at the farm level, *Applied Economic Perspectives and Policy* 18, 181–192.
Gleeson, T., Lubulwa, M. and Beare, S. (1993). *Price Premiums for Staple Measurement of Wool*. ABARE Research Report 93.4. Australian Bureau of Agricultural and Resource Economics, Canberra.
Gordon, R.V., Lee, G.J., Cox, R.J. and Johnson, S. (2004). *Characteristics of fleeces of fine-wool merino weaners shorn at either 9- or 12- months of age*, Proceedings of the 25th Biennial Conference of the Australian Society of Animal Production, University of Melbourne, Victoria, 73-76 4-8 July.
Halvorsen, R. and Palmquist, R. (1980). The interpretation of dummy variables in semilogarithmic equations, *American Economic Review* 70, 474–475.
Hansen, P. and Simmons, P. (1995). Measures of buyer concentration in the Australian wool market, *Review of Marketing and Agricultural Economics* 63, 304–310.
Hill, L.D. (1988). Grain grades: they lack economic rationale, *Choices* 1, 24–27.
Jackson, B. and Spinks, M. (1982). Price effects of wool marketing innovations: some empirical analysis, *Australian Journal of Agricultural Economics* 26, 14–22.
Kennedy, P.E. (1981). Estimation with correctly interpreted dummy variables in semilogarithmic equations, *American Economic Review* 71, 801.
Ladd, G. and Martin, M. (1976). Prices and demands for input characteristics, *American Journal of Agricultural Economics* 58, 21–30.
Lancaster, K. (1966). A new approach to consumer theory, *Journal of Political Economy* 74, 132–157.
Lenz, J.E., Mittelhammer, R.C. and Shi, H. (1994). Retail level hedonics and the valuation of milk components, *American Journal of Agricultural Economics* 76, 492–503.
Lipson, M. (1951). The problem of brands in wool, *The Textile Journal of Australia* 26, 295–298.
Maddever, D.C., Carnaby, G.A., Ross, D.A. and Cottle, D.J. (1988). *Vector space concepts in price relativity analysis*, in Proceedings of the advanced workshop on the application of mathematics and physics in the wool industry. Lincoln, Canterbury, New Zealand, pp. 439–445.
Perrin, R.K. (1980). The impact of component pricing of soybeans and milk, *American Journal of Agricultural Economics* 62, 445–455.
Rasmussen, D.W. and Zuehlke, T.W. (1990). On the choice of functional form for hedonic price functions, *Applied Economics* 22, 431–438.
Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in pure competition, *Journal of Political Economy* 82, 34–55.
Scrivener, C.J., Vizard, A.L. and Hansford, K.A. (1999). The valuation of superfine wools in relation to their topmaking performance, *Wool Technology and Sheep Breeding* 47, 241–247.
Simmons, P. (1980). Determination of grade prices for wool, *Review of Marketing and Agricultural Economics* 48, 37–46.
Simmons, P. and Hansen, P. (1997). The effect of buyer concentration on prices in the Australian wool market, *Agribusiness* 13, 423–430.
Skinner, J. (1965). Some factors affecting the clean price of greasy wool, *Australian Journal of Agricultural Economics* 9, 176–187.
Spinks, M. and Lehmer, C. (1986). An economic evaluation of additional measurement in wool processing, *Australian Journal of Agricultural Economics* 30, 162–172.
Stanley-Boden, I.P., Carnaby, G.A. and Ross, D.A. (1986). *An Analysis of the Relative Price Paid for New Zealand Wools*. Wool Research Organisation of New Zealand, Christchurch, Communications C100. April.
Stott, K.J. (1990). *An analysis of premiums for staple measurement, and price differentials for length and strength properties of merino combing wool*, AWC paper presented to the 34th

Annual Conference of the Australian Agricultural Economics Society Brisbane, 12-15 February.

Teasdale, D.C. (2005). *The Wool Handbook: The A-Z of Fibre to Top*, 2nd edn. Wild & Woolley, Sydney.

Templeton, D., Griffith, G., Piggott, R. and O'Donnell, C. (2004). *Measuring the impact of staple strength-enhancing technologies on Australian woo producer profits: a duality based approach*. University of New England Graduate School of Agricultural and Resource Economics and School of Economics, Working Paper Series in Agricultural and Resource Economics No. 2004-5, Armidale. August.

Turk, J. (1993). Requirements of an early stage processor, *Wool Technology and Sheep Breeding* 41, 51–55.

Vizard, A.L. and Hansford, K.A. (1999). A comparison of the topmaking performance of wool from sheep selected by index and visual methods, *Australian Journal of Experimental Agriculture* 39, 941–948.