

## Is the Australian wool industry efficient at converting wool into value?

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### Abstract

The marketing strategies of agricultural producers have become increasingly focussed on the sale of differentiated products to intermediary buyers rather than the sale of homogeneous commodities directly to retailers. The wool value chain in Australia fits the description of differentiated products being sold by wool producers to agribusiness firms that are intermediaries in the chain. The attributes of wool that are the source of this differentiation are used by firms to add value to their operations, reflected in higher retail prices paid for wool products.

We measure the overall efficiency with which wool is converted into value across different processing routes and end products in the Australian wool value chain and decompose it into its technical, scale and mix efficiency components. We find that wool price changes significantly with a change in fibre diameter, staple length and staple strength and employ a flexible functional form to capture the relations between these wool attributes and lot value. Results show that considerable scope exists to increase the value of most sale lots, and indicate that the overall efficiency in extracting value is lower for wool supplied to processes that produce high-value wool garments. We then ascertain that various factors related to wool production and product characteristics significantly influence the level of technical efficiency.

The mix of the three key attributes in wool lots was found not to be a major factor influencing overall efficiency whereas scale efficiency scores (which we measure as returns to wool attributes) were clearly much lower than those for technical and mix efficiency scores, a function of strongly increasing returns to wool lots as the levels of attributes increase. We test propositions about the skewness of distributions of efficiency scores in translating wool attributes into value. Most distributions of overall efficiency scores are positively skewed for production processes paying high prices for wool, and differences in overall efficiency were observed across selling centres. *Prima facie*, the results provide a strong case for wool producers to move to higher value levels of wool attributes by producing finer, stronger and longer wool fibres – especially the former. But such a strategy may not be an optimal one for producers to follow because the investments they make to implement such a strategy may entail high costs and take a long period to fruition that would lead to a heavy discounting of future benefits. A full benefit-cost analysis would be needed of any investments to raise the levels of wool attributes and otherwise improve wool quality at the farm level.

## Introduction

Innes, Kerr and Hobbs (2008, p. 2), among many other commentators, commented on ‘the trend away from trade in agricultural commodities and toward trade in more differentiated agricultural and food products’,<sup>1</sup> and noted the relative decline of commodities in agricultural trade. Marketing strategies aimed at differentiating products enable ‘market demand to be manipulated in ways which lead to sustained, or at least temporary, increases in profitability’ (Gordon, Hannesson and Kerr 1999, p. 2). Decisions and actions taken by agribusiness firms are now firmly rooted in the milieu of strategies aimed at selling differentiated products that achieve higher prices and generate higher profits. While Hofstrand (2007) observed that commodities tend to be raw materials whereas differentiated products tend to be final products, this is not always the case. Even as they leave the farm and enter the value chain, many raw materials possess different attributes that buyers throughout the value chain look for, and for which they are prepared to pay a higher price.

Wool in Australia clearly fits the category of a raw material that is a differentiated product that producers benefit from selling if the product contains attributes that are demanded by intermediaries in the wool value chain. Meeting the requirements of processors, in particular, to extract maximum value for a given quantity of wool output has been a major goal of wool producers. This goal is challenging in the sense that there are a number of wool attributes to consider and a variety of other factors that can influence wool quality. In this paper, we adapt a model developed for studying input-output relationships in production to measure the efficiency with which the wool industry converts wool into value and assess which factors influence the willingness of processors to pay for the wool that they use.

Two hedonic studies have recently been undertaken explaining factors influencing wool prices in Australia. Nolan et al. (2014) valued the quality attributes of Australian Merino wool for the 2008-2009 auction season using hedonic models for five wool categories ranging from ultrafine to broad wool. Their major findings were that the fibre diameter (FD) of wool influences its value most across all wool types, and that brand contamination, higher level of unscourable colour and vegetable matter contamination significantly influence wool value. Their study is subject to two main limitations. First, wool is processed via different routes (e.g. worsted, woollen and non-woven)<sup>2</sup> and is put to a variety of uses (e.g. suits, socks and underwear); hence it has different end-product processes (PPs). The classification of wool types by Nolan et al. (2014) does not adequately meet the challenges created by these different end uses. Second, Nolan et al. (2014) viewed valuation of wool according to quality differences from purely a demand perspective.

Cottle and Fleming (2015) also viewed valuation of wool according to quality differences from a demand perspective but made an important advance on the study by Nolan et al. (2014) by separating wool auction data on the basis of all fibre attributes that affect suitability for different PPs. They found that including information about PP groupings is more useful in understanding price formation than clustering by broad fibre diameter classes. We build on this approach by broadening the study to understand how well wool lots meet the differing requirements of the PP groups.

Alston, Norton and Pardy (1995, p. 244) noted that a change in product quality is a change in supply conditions, originating from the production process, rather than simply a change in demand conditions and should be modelled as such. Both supply and demand conditions need to be analysed because

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<sup>1</sup> According to Hofstrand (2007), commodities are fungible and homogeneous, can be mixed together, tend to be raw materials, and people who produce them are price takers. Differentiated products are uniquely different and enable producers to influence the price they receive.

<sup>2</sup> AWI (2009, pp. 7-16) describes the processes embedded in the worsted, woollen and non-woven woollen systems. The worsted system involves processes ‘to convert long wools ... into woven or knitted fabrics and materials’ (AWI 2009, p. 13). The woollen system involves the processes ‘to convert shorter wools or oddments ... into woven or knitted fabrics and materials’ (AWI 2009, p. 14). Products from the non-woven woollen system include ‘Felts (used for cleaning, polishing etc), wool quilts and doonas, sliver knitted woollen underblankets’ that ‘undergo a range of different processes’ with a common feature that the wool is either scoured or carbonised prior to further processing (AWI 2009, p. 16).

the valuation of an increase in quality from the perspective of suppliers does not always equal the additional amount of money that buyers will pay for a product. Alston et al. (1995, pp. 243-245) conceded that it can be difficult to establish an objective measurement of quality in output, but wool is one product where it is possible. Our major contribution is to show how efficiently wool quality from the supplier's perspective is being translated into value from the buyer's perspective given the variety of end uses to which it can be put.

## Research objectives

The aims of this study are to:

- *Measure the efficiency in creating value in wool auction sales in Australia.*  
The first objective is to determine the overall potential for increasing the value of wool sold through the auction system in Australia by supplying product of desired attributes and quality into the various PPs in which wool is the major raw material.
- *Decompose this efficiency into its core components.*  
The efficiency of adding value to wool inputs in processing can be decomposed into three components: technical efficiency (TE); attribute scale efficiency (ASE); and attribute mix efficiency (AME).
- *Ascertain which factors influence technical efficiency.*  
There are numerous actions that producers and others in the early stages of the wool value chain may take to improve the technical efficiency of wool in adding value. Actions by producers include managing the amount and type of vegetable matter in the wool, the practice of mulesing, the breed of sheep, and the style, colour, brand contamination, darkness, skin pieces, water stain and pigmentation contamination level of the wool. The type of test certificate used in the value chain can also alter the technical efficiency of wool in adding value according to the tasks and standards that need to be met in order to be granted a particular certificate.
- *Determine whether increasing returns to wool attributes are present.*  
The presence of attribute scale inefficiency would indicate that wool is being supplied for processing at sub-optimal levels of the main wool attributes. Either these levels are too high for the purpose at hand in processing or, more likely, they are not high enough. In the former case, lowering the attribute levels of the wool at the margin leads to a less-than-proportional decrease in wool value. In the latter case, raising the levels of wool attributes at the margin leads to a more-than-proportional increase in wool value, suggesting that more effort should be put into raising attribute levels.
- *Test the proposition that overall efficiency is lower for wool supplied to processes that produce high-value wool garments.*  
The opportunity for suppliers to earn higher premiums for wools used as inputs in certain PPs is expected to be associated with more stringent criteria used by buyers offering these higher premiums. A higher proportion of the wool is therefore unlikely to satisfy these criteria than would be the case for wool entering PPs with less stringent requirements and lower potential for premiums.
- *Test propositions about the skewness of distributions of efficiency scores in translating wool attributes into value.*  
A skewed distribution of overall efficiency scores in translating wool attributes into value according to whether the processes produce high-, medium- or low-value wool garments and other non-apparel products is expected because of variations in the degree of specialisation in fine wool production on farms and different levels of adoption of product innovations by producers. For the PPs producing high-value wool garments where higher premiums for wool are associated with more stringent buyer criteria, a positively skewed distribution of scores is expected because innovators and early adopters at the farm level, along with producers specialising in fine wool production, should out-perform the majority of producers in meeting buyer requirements. As buyer criteria become less stringent and premiums fall, more wool is

likely to achieve scores close to the value frontier<sup>3</sup>, leading to a more symmetric distribution of overall efficiency scores.

## Data

Most wool produced in Australia is sold through open-cry auctions (AWEX 2010). Wool auctions most closely resemble the asymmetric case of the independent-private-values model of English auctions (McAfee and McMillan 1987). Bidders, usually exporters, are assumed to know their production capabilities (specifically, the production capabilities of topmakers or spinners for whom they act as agents) if they win the bid. They also have their desired trading margins and export shipping schedules to meet, which influence the prices they bid. The asymmetry arises from inherent differences in these capabilities, where the PP groups using wool have different production costs and final product values at retail. McAfee and McMillan (1987) observed that the second-last bidder in an English auction will drop out of the bidding as soon as the price exceeds his or her own valuation of the item. Because this price is usually below the winning bidder's valuation of the item, they showed that this bidder earns economic rent: the difference between the amount bid and the successful bidder's own valuation of the wool. Where bidders have different valuations of the wool because of their different production capabilities, reflected in different derived demand functions for wool, the price of the successful bid should fall in the range between the maximum price that the bidder with the least production capability is willing to pay and the valuation placed on the wool by the bidder with the greatest production capability. On average, bidders with higher valuations of wool of the same quality and specifications would pay higher prices for it.

Data for 369,918 auction sale lots in 2010-2011 were obtained from the Australian Wool Exchange (AWEX). This was the latest year for which data were available at the time of the analysis. Data on 80,820 (21.8 per cent) lots not sold on the sale day (33,024 passed in and 47,796 traded lots), 132,903 (35.9 per cent) lots without staple length (SL) and staple strength (SS) measurements, and 111,762 (30.2 per cent) oddment lots (i.e. not fleece, pieces or bellies) were removed. These lots overlapped, so that 158,478 (42.8 per cent) sold, fully measured, non-oddment lots remained for analysis. A further 121 non-adult wools or lots with breed errors were removed, leaving 158,357 lots for analyses. The November 2010 and March 2011 data sets were then selected from these lots.

The filtered data set was segmented into 12 PP groups on the basis of the FD of the sale lots of wool, predicted hauteur (average fibre length in the top), vegetable matter and pigment (Maddever and Cottle 1999). Many sale lots were allocated to multiple PP groups. The numbers of lots, tonnage and average clean price respectively for each PP group are presented in Table 1. The two smallest PP groups and Crossbred sale lots were not analysed further.

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<sup>3</sup> The value frontier is based on the concept of a value function, which is defined as 'the present discounted value, in consumption or utility terms, of the choice represented by its arguments' (<http://economics.about.com/od/economicsglossary/g/valuef.htm>), where the arguments are the parameters on which the value of the function depends. For wool lots, the arguments determining value are expressed by its attributes and other factors influencing wool quality. The value frontier is defined by the parameters of the attributes and quality factors that attract the maximum value from buyers.

**Table 1. Number of lots, tonnage and average clean price of PP groups**

PP group	Lots (number)	Tonnage (t)	Ave clean price (c/kg)
Worsted, woven upholstery	20,677	27,908	930
Woollen woven blankets	452		
Non-woven, duvets, futons	2		
Non-woven apparel	24,899	24,918	1120
Worsted, handknitting yarn	20,723	27,947	928
Woollen, handknitting yarn	2,454	2,384	882
Shetland knitwear	80,905	102,764	1174
Lambswool knitwear	40,152	39,699	1059
Worsted knitwear	103,308	127,007	1074
Worsted, woven outerwear	122,192	137,981	1241
Woollen, woven outerwear	75,604	67,486	1254
Worsted, knitted underwear	117,757	138,236	1159

## Variables

The sale lot data consisted of: selling centre, storage centre, net weight, AWEX-ID code, greasy price (cents), sale outcome, FD ( $\square$ m), yield (%), vegetable matter (%), SL (mm), SS (N/ktex), position of break (POB%), predicted hauteur (mm), suffix for certification, mulesing, breed, weaner and fleece preparation codes, clean price (cents) and sale date. Quarterly or yearly macroeconomic influences such as exchange rates were not included in the analysis as only one year of data was analysed.

Subroutines were used to convert the AWEX-ID code into nominal variables for category (fleece, pieces, bellies), style (within-category choice, best spinners, spinners, best, good, average, inferior), subjective colour, vegetable matter type (burr, seed, shive, Noogoora burr, Bathurst burr, moit, bogan flea), brand, dark fibres, skin pieces, water stain and pigment. A glossary of efficiency variables included in the analysis of efficiency is presented in Appendix 1.

The price of the lot was the associated weekly market indicator reported for five selling centres. The AWEX Eastern Market Indicator (AWEX-EMI) is a basket of 128 wool types that reflect the offerings in selling centres on the eastern seaboard. There are two regional indicators, Northern Region and Southern Region, which are a subset of the AWEX-EMI. The Northern Region Indicator is the weighted average clean price of a basket of 54 types that reflect the offerings in Sydney and Newcastle (AWEX 2012a). The Southern Region Indicator covers Melbourne and Launceston and comprises 74 wool types (AWEX 2012a). The western (Fremantle) indicator was also used.

## Method

We slightly change the standard terminology used in efficiency analysis of production to suit our purpose of measuring the responsiveness of wool suppliers to buyers' needs. Instead of the process of transforming production inputs into outputs, we are concerned with the efficiency of the process of translating the three main wool attributes of fineness (measured as the inverse of FD), SL and SS into unit values (the clean price of wool in cents per kilogram). The willingness by buyers to pay for a

particular wool lot will depend on the levels of the three attributes and other quality criteria, modified by the specific needs of each process producing apparel and non-apparel products in which wool is the major raw material. We refer to the capacity of wool suppliers to produce the desired attributes and quality standards that buyers value as value efficiency.

To achieve this task, we need to be able to control for the various exogenous factors that shift the demand and supply functions for Australian wool, thereby influencing the price of clean wool in ways over which the suppliers have no control. A short period of analysis (one month) was chosen during which it is reasonable to assume that demand and supply shifters do not change appreciably. The months of November 2010 and March 2011 are selected because they were the months in the 2010-2011 wool trading season studied with the largest numbers of transactions.

The efficiency analysis is conducted employing the traditional approaches used to measure efficiency in production, namely data envelopment analysis (DEA) and stochastic frontier analysis (SFA). These methods have a long history in analysing efficiency in production and their merits and demerits have been well-studied (e.g. Coelli et al. 2005, pp. 312-313).

First, a DEA-based non-parametric method, *Decomposing Productivity Index Numbers* (DPIN) (O'Donnell 2011), is used to decompose overall efficiency, termed total factor productivity efficiency (TFPE) by O'Donnell (2011), into its technical, scale and mix components. Färe-Primont indices are calculated for each component. O'Donnell (2011) explains the suitability of Färe-Primont indices and why efficiency indices must lie between zero (perfectly inefficient) and unity (perfectly efficient).

Second, we use SFA (Coelli et al. 2005, pp. 241-261) for two specific purposes. The first purpose is to estimate partial value elasticities of wool attributes at their mean values to calculate returns to value of these attributes. The second purpose is to estimate the effects of a variety of factors on the TE with which wool is converted into value.

An input orientation is chosen to reflect the fact that the value of a wool lot is determined exogenously to the supplier in the auction system by the willingness of the buyer to pay according to its value as an input in the PP for which it is purchased.<sup>4</sup> The supplier can influence the price only by controlling the attributes and quality of the wool presented for sale at auction.

When applying DPIN, one of the three efficiency measures needs to be selected as the residual. We chose ASE in our analysis, which is an efficiency measure that is a parallel concept to scale efficiency widely used in studies of efficiency in production (Coelli et al. 2005). ASE provides a measure of how appropriately a wool lot is located in the continuum of wool attributes to meet the particular needs of a PP.

In addition to ASE, two other efficiency dimensions are directly estimated to determine whether a wool lot is efficient: TE and AME. The product of the three efficiency components provides an overall efficiency score for a wool lot. A wool lot that achieves full efficiency in all three dimensions is one that defines the frontier in attribute-value space, where a change in any of its attributes and other qualities would not result in a further increase in its value.

TE measures how well wool is translated into value for given levels and mixes of attributes. It is influenced by factors that are within the power of the wool supplier to change. AME measures the efficiency with which the FD, SL and SS attributes are combined in a single wool lot to extract value. Wools that exceed what is needed in a PP are not being used for their highest value purpose if they

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<sup>4</sup> In practice, the wool value chain is more complex than the buyer simply paying for wool according to its value as an input in the PP for which it is purchased. This value would not be known by the buyer in many or most cases. Exporters (the buyers at auction) in practice do not know the explicit PP in which the wool is required. Rather, they have their customer (for example, a top maker or a spinner) ask them to supply a quantity of wool meeting minimum specifications such as FD, SL and SS at least cost or under a price. It is their customer who may know the PP, although in some cases they would not know it as they on-sell their tops or yarns to later stage processors (weavers or knitters), so the wool could still be used in a variety of PPs. The woven or knitted fabric may still be used for different PPs by those further down the processing chain.



are used in a less stringent PP. The most efficient market is where all wools are used for PPs where they just meet the technical specifications of the PP: there is often no pay-off to the producer or exporter for exceeding specifications.

ASE estimates are based on how close a wool lot is to constant returns to scale of attributes. A general view of returns to wool attributes across the full sample of wool lots can be gauged from the estimated returns to scale parameter derived from the SFA model. Returns to scale of attributes for average wool lots were estimated using ordinary least squares (OLS) regression and returns to scale of attributes for wool lots on the frontier were estimated using the 'Frontier' option in the software package, *Stata*, version 12 (StataCorp 2012).

The parameter for returns to wool attributes is calculated as the sum of the individual attribute elasticities of wool value. This parameter measures the percentage change in the unit value of wool for a 1 per cent change in all attributes at their mean values and fulfils the same role as the traditional measure of returns to scale in production. In our study, it positions a particular wool lot entering into processing in the range of value propositions<sup>5</sup> from low attribute values to high attribute values. Different PPs require different levels of the attributes of wool and its other qualities to suit their processing or product needs; hence, the value proposition will vary according to the use to which the wool is put.

A returns-to-attributes parameter estimate that is significantly greater than unity indicates increasing returns to value of attributes. That is, a 1 per cent increase in all three attributes combined results in an increase in the unit value of wool of more than 1 per cent. Decreasing returns to value of attributes prevail when a 1 per cent increase in all three attributes combined results in an increase in the unit value of wool of less than 1 per cent. Perfect efficiency in value creation from wool attributes occurs when constant returns to value prevail; that is, a 1 per cent increase in all wool attributes results in an increase in the unit value of wool of exactly 1 per cent.

## Results

### Overall efficiency estimates

The distributions of efficiency estimates for each PP are presented in Appendix 2 for November 2010 and Appendix 3 for March 2011. They are ordered vertically by mean clean wool price per PP from highest mean price to lowest mean price. The horizontal ordering by selling centre is Fremantle, Melbourne, Launceston and Sydney in Appendix 2 and Fremantle, Melbourne, Newcastle and Sydney in Appendix 3. Mean efficiency estimates of wool lots, reported in Table 2, are reasonably stable across selling centres but there are variations between efficiency measures and across the ten PPs.

Two key findings relating to the research objectives arise from the results reported in Table 2 and Appendices 2 and 3. They are exemplified by a sample of distributions of overall efficiency scores for three PPs taken from the Fremantle March 2011 results that are presented in Figure 1 (from the top, the distributions are for the woollen woven outerwear PP, which had the highest mean value of wool, the non-woven apparel PP, which had the fifth-highest mean value of wool, and the woollen handknitting yarn PP, which had the lowest mean value of wool). The first key finding is that, in general, overall efficiency increases as the mean clean wool price per PP declines (exceptions are lower efficiency scores for woollen handknitting yarn PP than overall efficiency for the non-woven apparel PP in Melbourne and Sydney for March 2011). This finding accords with the expectation that processors demand better wool attributes if they are to pay higher premiums for wool inputs in PPs.

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<sup>5</sup> A value proposition in the context of this study is an affirmation why a wool buyer should purchase a particular wool lot based on the rationale that this wool lot will add more value in the PP for which it is destined than would other wool lots. There are a series of value propositions for each PP.

**Table 2. Efficiency estimates by PP**

(a) November 2010

PP by selling centre	TE	ASE	AME	PP by selling centre	TE	ASE	AME
1. Woollen woven outerwear:				6. Worsted knitwear:			
Fremantle	0.920	0.745	0.976	Fremantle	0.946	0.851	0.985
Launceston	0.894	0.646	0.986	Launceston	0.925	0.799	0.989
Melbourne	0.930	0.714	0.985	Melbourne	0.966	0.786	0.996
Sydney	0.918	0.698	0.992	Sydney	0.931	0.835	0.989
Average	0.915	0.701	0.985	Average	0.924	0.814	0.988
2. Worsted woven outerwear:				7. Lambswool knitwear:			
Fremantle	0.922	0.805	0.989	Fremantle	0.946	0.851	0.985
Launceston	0.894	0.712	0.988	Launceston	0.925	0.799	0.989
Melbourne	0.929	0.730	0.994	Melbourne	0.966	0.786	0.996
Sydney	0.912	0.742	0.988	Sydney	0.931	0.835	0.989
Average	0.910	0.740	0.989	Average	0.924	0.814	0.988
3. Shetland knitwear:				8. Worsted woven upholstery:			
Fremantle	0.910	0.725	0.989	Fremantle	0.970	0.912	0.989
Launceston	0.892	0.704	0.986	Launceston	0.958	0.917	0.990
Melbourne	0.918	0.692	0.981	Melbourne	..	..	..
Sydney	0.890	0.592	0.987	Sydney	0.958	0.835	0.985
Average	0.900	0.683	0.986	Average	0.955	0.902	0.990
4. Worsted knitted underwear:				9. Worsted handknitting yarn:			
Fremantle	0.943	0.805	0.943	Fremantle	0.965	0.912	0.985
Launceston	0.937	0.712	0.937	Launceston	0.954	0.926	0.987
Melbourne	0.946	0.730	0.946	Melbourne	..	..	..
Sydney	0.931	0.742	0.931	Sydney	0.955	0.834	0.980
Average	0.939	0.740	0.939	Average	0.949	0.911	0.987
5. Non-woven apparel:				10. Woollen handknitting yarn:			
Fremantle	0.950	0.868	0.981	Fremantle	..	..	..
Launceston	0.936	0.829	0.988	Launceston	0.960	0.895	0.978
Melbourne	0.962	0.850	0.989	Melbourne	..	..	..
Sydney	0.947	0.863	0.989	Sydney	..	..	..
Average	0.935	0.840	0.986	Average	0.956	0.865	0.982

Notes: .. signifies too few observations to give reasonable estimates.

TE is technical efficiency; ASE is attribute scale efficiency; AME is attribute mix efficiency.



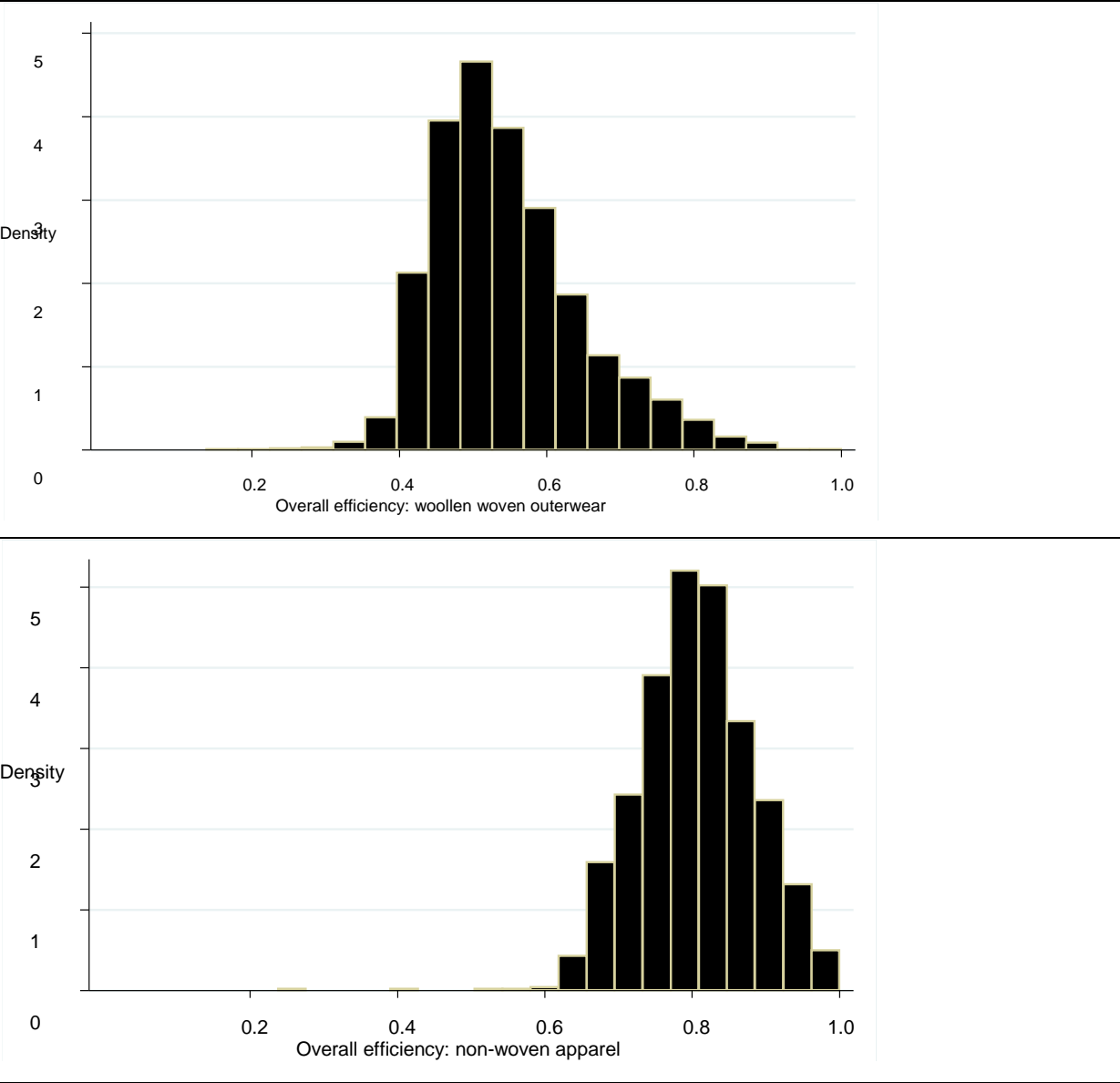
(b) March 2011

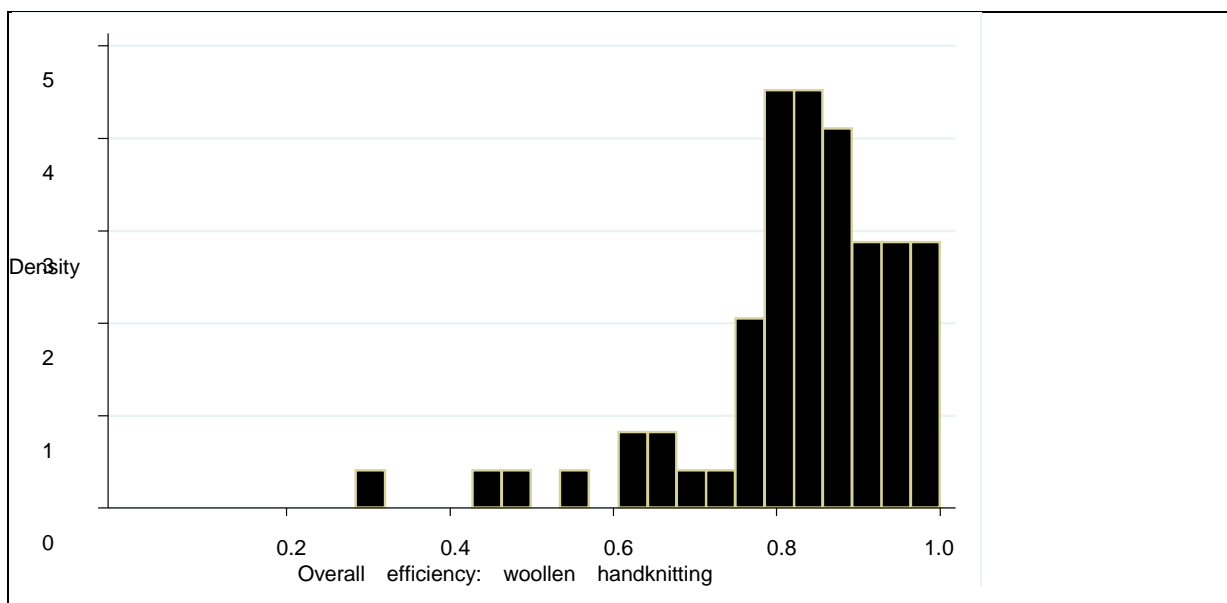
PP by selling centre	TE	ASE	AME	PP by selling centre	TE	ASE	AME
1. Woollen woven outerwear:				6. Worsted knitwear:			
Fremantle	0.903	0.623	0.970	Fremantle	0.894	0.794	0.981
Melbourne	0.899	0.607	0.985	Melbourne	0.902	0.788	0.979
Newcastle	0.943	0.752	0.984	Newcastle	0.940	0.812	0.988
Sydney	0.914	0.675	0.988	Sydney	0.923	0.876	0.979
Average	0.915	0.664	0.982	Average	0.915	0.818	0.982
2. Worsted woven outerwear:				7. Lambswool knitwear:			
Fremantle	0.886	0.669	0.980	Fremantle	0.939	0.850	0.988
Melbourne	0.900	0.638	0.985	Melbourne	0.922	0.788	0.973
Newcastle	0.944	0.787	0.987	Newcastle	0.957	0.763	0.990
Sydney	0.912	0.703	0.990	Sydney	0.929	0.837	0.985
Average	0.911	0.699	0.986	Average	0.937	0.810	0.984
3. Shetland knitwear:				8. Worsted woven upholstery:			
Fremantle	0.880	0.703	0.993	Fremantle	0.952	0.923	0.982
Melbourne	0.879	0.532	0.988	Melbourne	0.899	0.682	0.977
Newcastle	0.937	0.700	0.989	Newcastle	0.984	0.883	0.991
Sydney	0.860	0.629	0.982	Sydney	0.959	0.827	0.981
Average	0.889	0.641	0.988	Average	0.949	0.829	0.983
4. Worsted knitted underwear:				9. Worsted handknitting yarn:			
Fremantle	0.923	0.771	0.983	Fremantle	0.950	0.923	0.984
Melbourne	0.928	0.729	0.982	Melbourne	0.898	0.682	0.978
Newcastle	0.944	0.694	0.990	Newcastle	0.984	0.883	0.991
Sydney	0.929	0.749	0.980	Sydney	0.953	0.842	0.980
Average	0.931	0.736	0.984	Average	0.946	0.833	0.983
5. Non-woven apparel:				10. Woollen handknitting yarn:			
Fremantle	0.940	0.865	0.988	Fremantle	0.955	0.878	0.987
Melbourne	0.917	0.836	0.984	Melbourne	0.938	0.770	0.973
Newcastle	0.962	0.832	0.982	Newcastle	..	..	..
Sydney	0.940	0.878	0.983	Sydney	0.962	0.786	0.981
Average	0.940	0.853	0.984	Average	0.952	0.811	0.980

Notes: .. signifies too few observations to give reasonable estimates.

TE is technical efficiency; ASE is attribute scale efficiency; AME is attribute mix efficiency.

**Figure 1: Sample distribution of overall efficiency from Fremantle celling centre in March 2011**





The second key finding is that, with the exceptions of Melbourne selling centre in November 2010 and Newcastle selling centre in March 2011, distributions of overall efficiency scores are positively skewed for PPs paying high prices for wool. This result suggests that innovators and early adopters at the farm level plus producers specialising in fine wool production out-perform the majority of producers in meeting buyer demands. Distributions tend towards symmetry as buyer requirements become less stringent, then become negatively skewed for wool destined for low-value PPs as indicated in Figure 1. The negative skewness of overall efficiency scores for wool destined for low-value PPs reflects the fact that most wool lots used as inputs in these PPs are located close to the value frontier, suggesting that it is relatively easy to meet buyers' requirements.

The negative skewness for Melbourne in November 2010 and Newcastle in March 2011 can be explained by the predominance of superfine wool lots passing through the two selling centres in those months. In November 2010, the proportion of superfine wool lots auctioned in the Melbourne selling centre was 54.8 per cent. This percentage was many times higher than the proportions of superfine wool lots in the other three centres during this month (18.6 per cent for Sydney, 10.5 per cent for Fremantle and 7.7 per cent for Launceston) and many times the proportion of superfine wool for the Melbourne selling centre in March 2011 of just 4.1 per cent. A picture emerges for Newcastle selling centre in March 2011 that is similar to that for Melbourne in November 2010, with superfine wool lots accounting for 39.7 per cent of wool lots auctioned. This proportion is much higher than the proportions for Fremantle (2.3 per cent), Sydney (5.6 per cent) and Melbourne. The higher premiums attracted by superfine wool meant that a substantial amount of the wool auctioned would be close to the value frontier.

### TE estimates and factors influencing TE

Mean TE estimates for the ten PPs in November 2010 were high, varying from 0.90 to 0.96 (Table 2), but indicate that there is still some room for overall efficiency improvement by increasing TE. Mean TE estimates for the ten PPs in March 2011 were similarly high, varying from 0.89 to 0.95 (Table 2). As a general rule, TEs in both months were higher for the lower-value PPs.

Results of the analysis of the factors influencing the TE of wool lots are presented in Table 3. Sydney was arbitrarily set as the base selling centre. Fremantle and Launceston dummy variables have mainly positive effects on TE while Melbourne and Newcastle have mainly negative effects. These estimates indicate that although wool in Melbourne on average had a higher value frontier than wool in Sydney for most PPs, its lots were more widely spread below their value frontier indicating that more variable wools were being supplied to this centre. Conversely, wool in Fremantle on average had a lower value

**Table 3(a). Effects on TE by production process, November 2010**

Variable	1	2	3	4	5	6	7	8	9	10	Base
Fremantle	↓	↑	↑	↑	↓	→	→	↑	↑	→	Sydney
Launceston	↑	↑	↑	↑	→	→	→	↑	↑	→	
Melbourne	↑	↓	↓	↓	↓	→	→	→	→	→	
In VM	→	↓	↓	→	↓	↓	↓	↓	↓	↓	
CS B	→	→	→	→	→	→	→	→	→	→	CS Q
CS D	↑	↑	↑	↑	↑	↑	↑	→	→	→	
CS I	→	→	→	→	→	→	→	→	↓	→	
CS M	→	→	→	→	→	→	→	→	→	→	
CS P	↑	↑	↑	↑	↑	↑	↑	↑	↑	→	
Mules CM	→	→	→	↓	↑	→	→	→	→	→	Mules PR
Mules ND	↑	→	→	→	↑	→	→	→	→	→	
Mules NM	→	→	→	↓	↑	→	→	→	→	→	
Breed 0	↑	↑		↑	↑						Breed 7
Breed 1	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	
Breed 3	↓	→		↓	↓	↓	↓	→	→	→	
Breed 4	↓		↓	↓	↓		↓	↓	↓	→	
Bellies	↓	↓	↓	→	↑	→	↓	↓	↓	→	Category pieces
Fleece	↑	↑	↑	→	↑	↑	→	→	→	↑	
Style fav		→	→	→	→	→	→	→	→	→	PB stain
Style fbe		↑	→	→	↑	→	→	→	→	→	
Style fbsp	↓	→	→	→	→	→	→	→	→	→	
Style fch		↑	→	→	↑	→	→	→	→	→	
Style fgoo		↑	→	→	→	→	→	→	→	→	
Style finf		→	→	→	→	→	→	→	→	→	
Style fspi		↑	→	→	→	→	→				
Style pbe		→	→	→	↑	→	→	→	→	→	
Style pgoo		↓	→	→	↑	→	→	→	→	→	
Style pinf		→	→	→	→	→	→				
Style pspi		→	→		↑	→	→				
Colour good	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	Colour H3
Colour H1	↑	↑	↑	↑	↑	↑	↑	↑	↑	→	
Colour H2	→	→	→		↑	→	→				
VM 1		→	→		→	→					Shive
VM bath	↑	↓	↓	↓	→	→	→	→	→	→	
VM bogan	→	↑	↑	→	→	↑	→	→	→	→	
VM burr	↑	→	→	↑	↑	↑	↑	→	→	→	
VM clump	→	↓	↓	↓	↓	↓	→	↑	↑	→	
VM moit	↓	↓	↓	↓	→	→	→	→	→	→	
VM noog	→	↓	↓	↓	→	↓	→	↓	↓	→	

VM seed	↑	↓	↓	→	→	↓	↓	→	→	→	
Brand 0	↑	↑	↑	↑	↑	↑	↑	↑	↑	→	Brand R3
Brand R1	↑	↑	↑	↑	↑	↑	→	→	→		
Brand R2	→	→	→			→	→				
Dark 0	→	→	→	↓	→	↑	↑	→	→	→	Dark S3
Dark S1	→	→									
Dark S2	→	→	→		→	→	→				
Sk piece 0	→	→	→	→	→	→	→	→	→		Skin pieces V3
Sk piece V1		→	→		→	→					
Sk piece V2											
Wat. Stn 0	↑	↑	↑	↑	↑	→	↑	→	→		Wat. Stn N3
Wat. Stn N1	↑	↑	↑	↑	↑	→	→	→	→		
Wat. Stn N2											
Pigment 0	↑		↑	→	↑	↑	↑				Pigment Y3

Note: ↑ positive effect on TE  
↓ negative effect on TE  
→ no effect on TE  
Blank no observations.

PP numbers:

- 1 Woollen woven outerwear
- 2 Worsted woven outerwear
- 3 Shetland knitwear
- 4 Worsted knitted underwear
- 5 Non-woven apparel
- 6 Worsted knitwear
- 7 Lambswool knitwear
- 8 Worsted woven upholstery
- 9 Worsted handknitting yarn
- 10 Woollen handknitting yarn

**Table 3(b). Effects on TE by production process, March 2011**

Variable	1	2	3	4	5	6	7	8	9	10	Base
Fremantle	↑	→	↓	→	↓	↓	↑	→	→	→	Sydney
Melbourne	→	↓	↓	↑	↓	↓	→	↓	↓	→	
Newcastle	→	↓	↓	↓	→	→	→	→	→	→	
In VM	↓	↑	→	↓	↓	↓	↓	↓	↓	↓	
CS B	→	→	→	→	→	→	→	→	→	→	CS Q
CS D	→	→	→	→	→	→	→	↑	→	→	
CS F	→										
CS I	→	→	→	→	↑	→	→	→	→	→	
CS M	→	→	→	→	→	→	→	→	→	→	
CS P	↑	↑	→	↑	↑	↑	↑	↑	↑	→	
Mules CM	→	→	→	→	→	→	→	→	→	→	Mules PR
Mules ND	↑	→	→	↓	↑	↓	→	→	→	→	
Mules NM	↓	↓	↓	→	→	→	→	↓	↓	→	
Breed 7	↓		→	↓	↓		↓	↓	↓	→	Breed 0
Breed 1	→	↑	↑	→	→	↑	→	↑	↑	→	
Breed 3	↓	↓	↓	↓	↓	↓	↓	→	→	→	
Breed 4	↓	↓	↓	→	↓	↓	↓	↓	↓	→	
Bellies	→	→	→	→	↓	↑	→	→	→	→	Category pieces
Fleece	→	→	→	→	→	→	→	→	→	→	
Style fav	→	→	↓	↓	→	↓	→	→	→	→	PB stain
Style fbe	↑	↑	→	↑	→	→	→	→	→	→	
Style fch	↑	↑	→	→	→	→	→	→	→	→	
Style fgoo	↑	→	→	→	→	→	→	→	→	→	
Style finf	↓	→	→	→	→	↓	→	→	→	→	
Style fspi	→	→	→	→	→	→	→	→	→	→	
Style pbe	→	→	→	→	→	→	→	→	→	→	
Style pgoo	→	→	→	→	→	→	→	→	→	→	
Style pinf	→	→		→	→	→	↓	→	→	→	
Style pspi	→	→		→		→					
Colour good	↑	↑	↑	↑	↑	↑	↑	↑	↑	→	Colour H3
Colour H1											
Colour H2											
VM 1	→			→							Shive
VM bath	→	↓	↓	→	→	↓	→	→	→	→	
VM bogan	↑	→	↓	→	→	→	↑	→	→		
VM burr	↑	→	↓	↑	→	↓	↑	→	↓	→	
VM clump	→	→	→	→	→	→	→	→	→	→	
VM moit	→	→	→	→	→	→	→	→	→	→	
VM noog	→	→	↓	→	→	↓	→	→	→	→	
VM seed	→	→	↓	→	→	↓	↓	→	→	→	



Brand 0	↑	↑	→	↑	↑	↑	↑	→	→	Brand R3	
Brand R1	↑	↑	→	↑	↑	↑	↑	→	→		
Brand R2	→	→	→	→	→	→	→	→	→		
Dark 0	→	→	→	→	→	→	→	→	→	Dark S3	
Dark S1	→	→		→	→	→	→	→	→		
Dark S2	→	→		→			→				
Sk piece 0	↑	→	→	→	→	→	→			Skin pieces V3	
Sk piece V1	↑			→		→	→				
Sk piece V2	→			→							
Wat. Stn 0	↑	↑	↑	↑	→	↑	↑	↑	↑	→	Wat. Stn N3
Wat. Stn N1	↑	↑	↑	↑	→	↑	→	↑	↑	→	
Wat. Stn N2	→	↑	→	→	→	→	→				
Pigment 0	↑			↑	↑	↑	↑				Pigment Y3
Pigment Y1				↑							

Note: ↑ positive effect on TE  
↓ negative effect on TE  
→ no effect on TE  
Blank no observations

PP numbers:

- 1 Woollen woven outerwear
- 2 Worsted woven outerwear
- 3 Shetland knitwear
- 4 Worsted knitted underwear
- 5 Non-woven apparel
- 6 Worsted knitwear
- 7 Lambswool knitwear
- 8 Worsted woven upholstery
- 9 Worsted handknitting yarn
- 10 Woollen handknitting yarn

frontier than wool in Sydney for most PPs but its lots were on average closer to their value frontier indicating that less variable wools were being supplied. The value frontier for wool in Launceston was little different from that for wool in Sydney across PPs and its lots were on average closer to their value frontier. Lots in Newcastle were not only more widespread below their value frontier than those in Sydney but their frontier was also below the Sydney frontier for most PPs. The Newcastle result is likely to be volume-related because prices are usually higher when more buyers attend an auction and Newcastle is a smaller centre.

Vegetable matter had a negative effect on TE for almost all PPs. This result is expected and is consistent with that reported by Nolan et al. (2014), given that the amount of vegetable matter in wool has a negative impact on its value. There are, however, two exceptions: for the worsted woven outerwear and Shetland knitwear PPs in both months. It is surprising that there is not a negative coefficient for these two PPs, especially as these PPs tend to use finer wools for which vegetable matter discounts are more severe (AWI 2012).

It is expected that vegetable matter types that are hard to remove such as seed would depress price more than vegetable matter that is relatively easy to remove. Shive (barley grass, wild oats) was the base for the seven vegetable matter dummy variables included in the estimated model. It belongs to the vegetable matter type that is most difficult for processors to remove and carries the largest discounts according to AWI (2012). Yet, surprisingly, results suggest that the presence of Bathurst burr, Noogoora burr and seed tends to have a more depressing effect on wool price than the incidence of other vegetable matter, reflecting higher discounts to these categories after controlling for severity.

AWI (2012) expects the burr type (barrel and medic) to have the smallest discount because of its greater ease of removal during processing. Results support this expectation for the November observations but not for the March observations for which there are both positive and negative coefficients on the dummy variable. No consistent effects were revealed for other forms of vegetable matter. In general, results are at odds with the discounts reported by AWI (2012).

Test certificate suffix Q was selected as the base for determining the effect of rigour in woolclassing certification on wool value. There was a positive effect on TE for all but the Shetland knitwear and worsted woven upholstery PPs for the dummy variable for the suffix P test certificate. This result is expected because it is the most rigorous certification process in that wool is from a single source, prepared on-farm, classed by a registered woolclasser and meets or exceeds the standards defined in the Woolclassers Code of Practice. The dummy variable for the second-most rigorous suffix D certificate had a largely positive effect on TE in November and an occasional positive effect in March. No consistent effects on TE are revealed for dummy variables of other certificate suffixes, whose coefficients are almost all insignificantly different from zero in both months. Most other categories are for smaller lots that are bulk-classed or lot-built by the broker. These lots can include very high- or low-quality wools so they are not well related to more rigorous classing.

Mules PR (mulesing with pain relief) is the base for mulesing effects on wool price. The NM (no mulesing) dummy variable had a negative effect on TE for some PPs in March suggestive of a price premium for wool shorn from non-mulesed sheep. But there is no consistent effect for the other dummy variables, which mostly had insignificant effects on TE. This result indicates that concerns expressed through the media about the practice of mulesing have not been translated widely into price premiums for not mulesing.

Dummy variables for Breeds 3, 4 and 7 had a mainly negative effect on TE while breed 1 had a predominantly positive effect. These results indicate that wool from Merinos (superfine and other) fetch higher prices than wool from the other breeds of sheep for given attribute levels and other quality effects, possibly because of better staple tip.

No consistent effect was observed for any dummy variable representing style. This set of variables aims to pick up all intangible effects after controlling for the objective traits, and it is not surprising that style has minimal impact other than for some PPs producing high-end garments. For example, there were positive effects on TE for Style fbe and Style fch for the Worsted woven outerwear, Woollen woven outerwear and Worsted knitted underwear PPs.

The category, pieces, with the lowest expected wool value, was selected as the base for wool categories. The dummy variable for bellies had a mainly negative effect on TE and fleece mainly had a positive effect on TE in November but surprisingly no effect in March given that both bellies and fleece were expected to fetch higher prices than pieces for given attribute levels. There was no consistent effect on TE of dark wool or the different types of skin pieces.

Results for colour, brand contamination, water stain and pigmentation are in line with expectations. Colour H3, with the lowest expected wool value, was the base for colour in wool. There were consistently positive effects on TE for no colour and Colour H1. Brand R3, with the lowest expected wool value, was the base for branding effect on wool quality. Positive effects on TE by no branding and Brand R1 occurred for most PPs. Waterstain H3, with the lowest expected value, was the base for water stain. There were consistently positive effects on TE for no water stain and Waterstain H1. Pigment Y3, with the lowest expected wool value, was the base for fibre pigmentation. Consistently positive effects on TE were evident for no pigmentation and Pigment Y1.

## **AME estimates**

The universally high AME estimates indicate that the mix of the three attributes in wool lots is not a major factor influencing overall efficiency. The mean estimates vary over a small range between 0.97 and unity. The most likely explanation of the insubstantial impact on wool value of different attribute mixes is that FD dominates value creation almost regardless of the levels of SL and SS within the range of the latter two attribute values in wool offerings.

## ASE estimates

ASE estimates were clearly much lower than those for TE and AME in both months. Mean ASE was particularly low for wool used as an input in the high-value PPs of woollen woven outerwear (0.70 for November 2010 and 0.66 for March 2011), worsted knitted underwear (0.74 for both months), worsted woven outerwear (0.70 for both months) and Shetland knitwear (0.68 for November 2010 and 0.64 for March 2011) (Table 2). This result indicates that suppliers of wool could increase their overall efficiency markedly by scaling up to a higher wool value proposition. Higher mean prices are paid for wool used in these four processes. But with this greater willingness to pay comes the need to supply wool with the right attributes; to date, suppliers have not adequately exploited the additional value generated by accomplishing this task.

The mean price paid for wool used in the non-woven apparel PP was in the same range as the mean prices for wool used in the above four high-value PPs, while the mean price for wool used in the worsted knitwear was a little lower. However, because the differences in scale-of-attributes parameters between average and frontier wool lots were very small in both cases, higher mean ASEs were recorded for these two processes (0.84 and 0.83, respectively, in November 2010 and 0.85 and 0.82, respectively, in March 2011) than for the other four processes producing high-value garments.

The mean ASE indices were substantially higher for the other PPs where the willingness to pay extra for higher attribute levels and qualities is less. Wool used as an input in these processes is being valued by buyers at well below what is achievable with higher levels of attributes, especially fineness. This result shows that less scope exists in these lower-valued PPs to convert wool into value because of the less demanding needs of processors.

## Estimates of returns to wool attributes

The low ASE scores suggest there is either endemic increasing or decreasing returns to wool attributes across lots. Estimates of the returns to scale of attributes for November 2010 and March 2011 are reported in Table 4 for (1) wool lots that lie on the frontier – that is, lots that achieve perfect efficiency in converting attributes into value – and (2) the average wool lot, which is typically less than fully efficient in that it is located below the value frontier. Because exogenous factors that vary spatially and other non-attribute factors may have influenced prices in different selling centres, estimates were made for the individual selling centres of Fremantle, Launceston, Melbourne, Newcastle and Sydney in addition to the overall estimates, but only the overall estimates are reported in Table 4 (estimates for individual selling centres are available on request). The combination of strongly increasing returns to scale of attributes and higher returns to scale of attributes for average wool lots than for wool lots on the frontier explains why there are relatively low mean ASE indices among wool lots destined for the higher-value PPs. All scale-of-attribute parameters except the parameters for the worsted woven upholstery process and the woollen handknitting yarn process are greater than unity for both the frontier and average wool lots, indicating increasing returns. In November 2010, the scale-of-attributes parameter for the worsted handknitting yarn PP was only slightly greater than unity for frontier wool lots but much greater than unity for average lots. In March 2011, only the scale-of-attributes parameter for the worsted handknitting yarn PP for frontier wool lots was less than unity.

**Table 4. Estimated returns to value in each production process aggregated across selling centres**

(a) November 2010

Attribute by PP	Average	Frontier	Attribute by PP	Average	Frontier
1. Woollen woven outerwear:			6. Worsted knitwear:		
Fineness (Inverse FD)	2.735	2.592	Fineness (Inverse FD)	1.645	1.858
Staple length	0.250	-0.002	Staple length	0.236	0.061
Staple strength	0.279	0.093	Staple strength	0.170	0.061
Average	3.264	2.683	Average	2.051	1.980
2. Worsted woven outerwear:			7. Lambswool knitwear:		
Fineness (Inverse FD)	2.496	2.096	Fineness (Inverse FD)	2.152	2.152
Staple length	0.155	0.066	Staple length	0.266	0.024
Staple strength	0.145	0.065	Staple strength	0.229	0.080
Average	2.796	2.227	Average	2.647	2.256
3. Shetland knitwear:			8. Worsted woven upholstery:		
Fineness (Inverse FD)	2.526	2.068	Fineness (Inverse FD)	1.605	1.238
Staple length	0.045	0.047	Staple length	0.240	0.039
Staple strength	0.115	0.057	Staple strength	0.148	0.085
Average	2.686	2.172	Average	1.993	1.362
4. Worsted knitted underwear:			9. Worsted handknitting yarn:		
Fineness (Inverse FD)	2.087	1.974	Fineness (Inverse FD)	1.851	1.441
Staple length	0.264	0.081	Staple length	0.253	0.048
Staple strength	0.178	0.069	Staple strength	0.163	0.099
Average	2.529	2.124	Average	2.267	1.588
5. Non-woven apparel:			10. Woollen handknitting yarn:		
Fineness (Inverse FD)	1.948	2.072	Fineness (Inverse FD)	1.475	0.824
Staple length	0.072	-0.009	Staple length	0.096	-0.070
Staple strength	0.101	0.056	Staple strength	0.136	0.088
Average	2.121	2.119	Average	1.707	0.842

(b) March 2011

Attribute by PP	Average	Frontier	Attribute by PP	Average	Frontier
1. Woollen woven outerwear:			6. Worsted knitwear:		
Fineness (Inverse FD)	2.60	2.42	Fineness (Inverse FD)	1.46	1.71
Staple length	0.19	-0.06	Staple length	0.21	0.03
Staple strength	0.21	0.10	Staple strength	0.14	0.06
Average	3.01	2.45	Average	1.82	1.80
2. Worsted woven outerwear:			7. Lambswool knitwear:		
Fineness (Inverse FD)	2.40	2.07	Fineness (Inverse FD)	2.03	1.89
Staple length	0.15	0.04	Staple length	0.27	0.04
Staple strength	0.17	0.09	Staple strength	0.18	0.08
Average	2.72	2.20	Average	2.48	2.02
3. Shetland knitwear:			8. Worsted woven upholstery:		
Fineness (Inverse FD)	2.37	2.09	Fineness (Inverse FD)	1.53	0.75
Staple length	-0.02	-0.02	Staple length	0.15	-0.07
Staple strength	0.09	0.06	Staple strength	0.13	0.04
Average	2.44	2.13	Average	1.80	0.72
4. Worsted knitted underwear:			9. Worsted handknitting yarn:		
Fineness (Inverse FD)	2.04	2.17	Fineness (Inverse FD)	1.94	1.05
Staple length	0.24	0.04	Staple length	0.21	0.04
Staple strength	0.16	0.07	Staple strength	0.12	0.01
Average	2.45	2.27	Average	2.27	1.10
5. Non-woven apparel:			10. Woollen handknitting yarn:		
Fineness (Inverse FD)	1.76	1.91	Fineness (Inverse FD)	-0.42	-1.01
Staple length	0.14	-0.04	Staple length	0.49	-0.10
Staple strength	0.13	0.05	Staple strength	0.31	0.12
Average	2.03	1.93	Average	0.38	-0.99

Wool lots on the frontier bought for PPs that have very high scale-of-attributes parameters are: woollen woven outerwear (2.68 and 2.45 for November and March, respectively); worsted knitted underwear (2.12 and 2.27 for November and March, respectively); worsted woven outerwear (2.24 and 2.20 for November and March, respectively); and Shetland knitwear (2.17 and 2.13 for November and March, respectively). The estimated mean scale-of-attributes parameter for average wool lots is greater than the corresponding parameter for efficient wool lots for all these processes, indicating the greater scope for gains in value for lots below the frontier.

## Discussion

Prima facie, the ASE estimates reported above provide a strong case for wool producers and others in the wool value chain, including breeders, to raise the levels of wool attributes by producing and trading finer, stronger and longer wool fibres – especially the former. But such a strategy may not be the optimal one for chain participants to follow because the investments they make to implement such a strategy may entail high costs and take a long period to fruition that would lead to a heavy discounting of future benefits. Evidence from simulation modelling by Cottle and Bowman (1990) and Bowman et al. (1993) indicates that implementing management strategies to improve the quality of wool can be challenging. Therefore, a full benefit-cost analysis would be needed of any investments to raise the levels of wool attributes at the farm level. It may be that other endeavours to improve wool quality that increase TE are more cost-effective.

Relatedly, another caveat concerns the representativeness of the production and market situations in the selected period. Wool prices are influenced by a range of exogenous demand and supply shifters that can alter the relative prices of wool lots with different attributes. For example, AWEX (2012b) reported that prices of finer wools suffered proportionately greater declines than the prices of medium and broader wools in the 2012 fiscal year, just one year after the 2011 fiscal year used in this study. It provided the example of prices for 17 micron clean wool declining by 40 per cent over the year compared with declines of 25 per cent for 19 micron wool and 15 per cent for 21 micron wool.

A low premium for superfine wools has persisted, as observed by the NSW Department of Primary Industries (2015). It highlights the potential links between value-adding opportunities within the wool value chain by meeting buyers' demands and supply shifts for different wool types generated by the prospect of gaining a substantial premium, and how these shifts influence relative wool prices over time.

Superfine wool premiums have been low, largely due to a sharp increase in production of superfine wool, not because of a collapse in demand. Demand for most categories of superfine wool has actually increased.

(NSW Department of Primary Industries 2015, p. 6)

But there are prospects for a return to a higher premium:

The premium for superfine wool is likely to return towards the 10-year average once the short-term, drought-induced aspect of the increased superfine wool production wanes, although the long-term trend towards finer wool will mean higher production relative to a decade ago. The increased demand for superfine wool and the potential growth in demand for garments which use superfine wool (such as active leisurewear) justifies a continued (but not increased) emphasis on producing sound superfine wool. This may not be traditional Australian superfine wool ('spinners' style) but more general 'good topmaking' styles.

In contrast, the very low level of production of wool of 21 to 24 microns has been the reason for the better prices across this range. Demand for this wool does not appear to have increased. As well, this wool faces the most competition from man-made fibres (as it can be substituted for this wool in blends). A significant increase in production of this wool is likely to result in markedly lower prices.

(NSW Department of Primary Industries 2015, p. 6)

The main implication for the industry is to ensure accurate forecasting of relative wool price changes and the effective transmission of price information throughout the value chain.

Actions by producers and others in the value chain to limit the discounts on wool by increasing technical efficiency, thereby achieving higher prices, are less susceptible to the depressing effects on price of supply increases in fine wool caused by producers seeking higher returns to wool attributes. While potential gains are more modest, efforts to increase technical efficiency may also be cheaper to attain than improving wool attributes by paying closer attention to matters such as reducing the amount of vegetable matter in the wool and avoiding price qualifiers such as brand contamination, unscourable colour, darkness, skin pieces, water stain and pigmentation contamination in the wool.

On the surface it appears there is little scope for improving returns to the wool value chain by reducing mix inefficiency among the three main attributes. Estimates of mix inefficiency may nevertheless be understated depending on the strength of an assumption we made in applying our estimation procedures to the data. As indicated above, we filtered the data set on the basis that sale lots of wool could go into PP groups if they fell within specified ranges of FD, predicted hauteur (mm), VM and pigment percentage (Maddever and Cottle 1999). While we consider this assumption to be reasonable, any departures from this procedure – especially in relation to FD - may result in higher mix inefficiency than we have reported. It would be useful to conduct a separate study to assess whether wool is allocated to PPR groups strictly within the set ranges.

## Conclusion

We decomposed the overall efficiency with which wool is converted to value in the Australian wool value chain into its TE, ASE and AME components. The findings in this paper improve on those reported by Nolan et al. (2014) and Cottle and Fleming (2015). We segmented lots into their suitability for different PP groups and, similarly to these two studies, found that wool price changes significantly with a change in FD, SL and SS. Cottle and Fleming (2015) found significant interactions between the main wool attributes and wool price that are exploited in this study by employing a flexible functional form to capture the relations between these wool attributes and lot value.

The added value of the approaches used in this study compared with the results reported by Nolan et al. (2014) rests in identifying and measuring the efficiency with which the Australian wool industry converts wool into value across different PPs. Overall efficiency estimates reveal that there is considerable scope to increase the value of most sale lots. Estimates increase as the mean clean wool price per PP declines, reflecting the fact that processors demand better wool attributes if they are to pay higher premiums for wool inputs. Most distributions of overall efficiency scores are positively skewed for PPs paying high prices for wool and differences in overall efficiency were observed across selling centres.

Turning to the efficiency components, first, TE estimates indicate that there is still some room for overall efficiency improvement by increasing TE, and that various factors related to wool production and product characteristics were found significantly to influence the level of TE. Second, AME estimates show that the mix of the three attributes in wool lots is not a major factor influencing overall efficiency, with mean estimates varying over a small range. Third, ASE estimates were clearly much lower than those for TE and AME, a function of strongly increasing returns to scale of attributes. Mean ASE was particularly low for wool used as an input in the high-value PPs.



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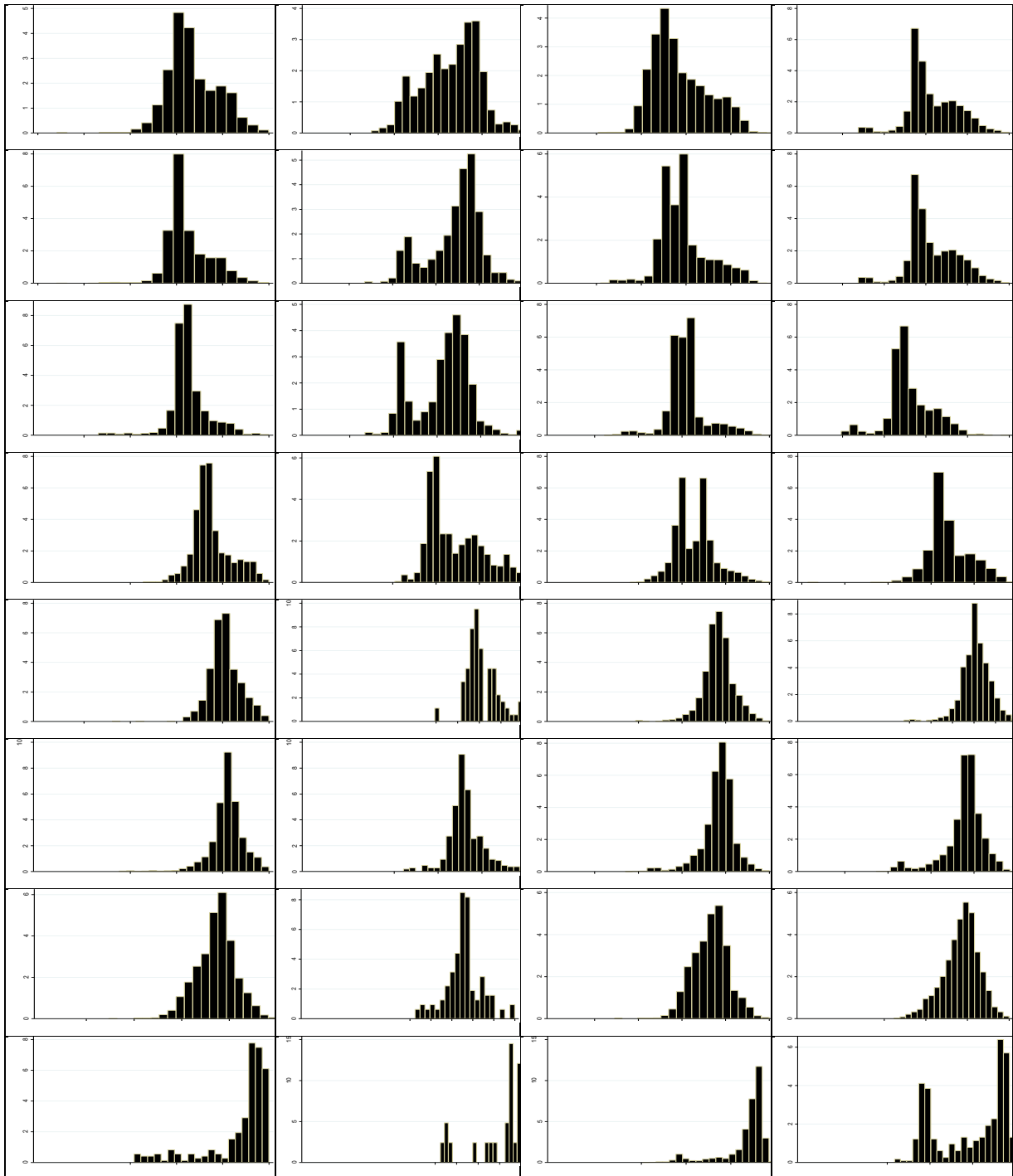
## Appendix 1. Glossary of efficiency variables

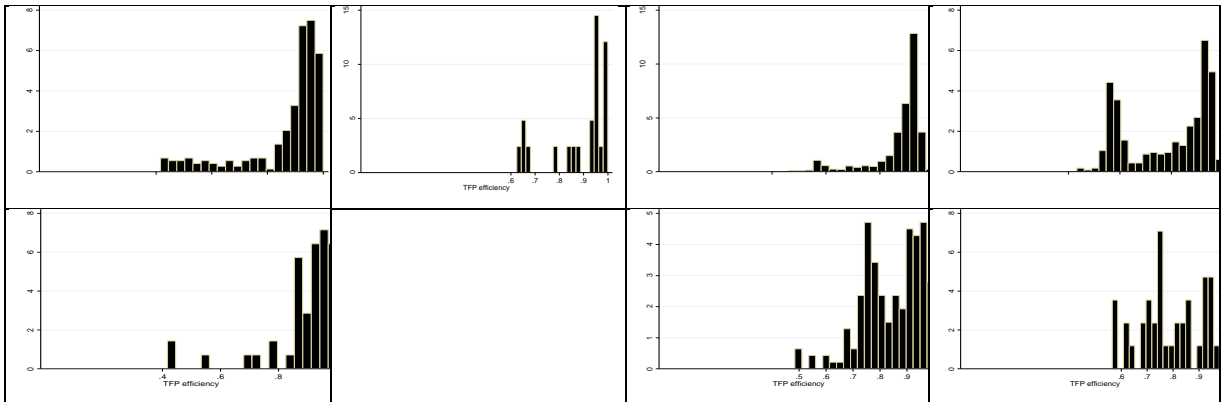
Variable name	Details
CS Q	Contains wool from multiple or unknown sources, prepared off farm, classed by a registered classing house and meets or exceeds the standards defined in the classing house code of practice
CS B	Contains wool from multiple or unknown sources, prepared off farm and not classed by a registered classing house or assessed as a non-conforming lot
CS D	Wool is from a single source, prepared on the farm and not classed by a registered woolclasser or, if so, assessed as a non-conforming lot
CS F	Superfine test certificate
CS I	Objectively matched interlot combination certificate
CS M	Objectively matched lot certificate
CS P	Wool is from a single source, prepared on the farm, classed by a registered woolclasser and meets or exceeds the standards defined in the classing house code of practice
Mules PR	Mulesing with pain relief
Mules CM	Ceased mulesing
Mules ND	Mulesing – no declaration submitted or signed
Mules NM	No mulesing
Breed 0	Wool from Merino – Australian Superfine(AS)
Breed 1	Wool from Merino (M)
Breed 3	Wool from crossbred (X)
Breed 4	Wool from downs (D)
Breed 7	Wool from Risk Merino (RM) (a line of Merino breed run with a sheds fibre breed such as Dorper)
Category pieces	Wool sold as pieces
Bellies	Wool sold as bellies
Fleece	Wool sold as fleece
PB stain	Pieces/bellies stain (7)
Style <sup>6</sup> fav	Fleece average style(6)
Style fbe	Fleece best style(4)
Style fbasp	Fleece best spinners style(2)
Style fch	Fleece choice style (1)
Style fgo	Fleece good style(5)
Style finf	Fleece inferior style(7)
Style fspi	Fleece spinners style(3)
Style pbe	Pieces best style(4)
Style pgo	Pieces good style(5)
Style pinf	Pieces inferior style(7)
Style pspi	Pieces spinners style(3)
Colour good	Good wool colour
Colour H1	Light/odd unscourable wool colour
Colour H2	Medium unscourable wool colour
Colour H3	Heavy unscourable wool colour
VM shive	Vegetable matter – shive
VM I	Vegetable matter – clumpy
VM bath	Vegetable matter – Bathurst burr
VM bogan	Vegetable matter – bogan flea
VM burr	Vegetable matter – burr

<sup>6</sup> AWEX-ID (2011) uses style codes related to the visual appearance of wool, ranked from highest (1) to lowest (7).

VM clump	Vegetable matter – clump
VM moit	Vegetable matter – moit
VM noog	Vegetable matter – noogoora burr
VM seed	Vegetable matter – seed
Brand 0	No branding fluid contamination in wool
Brand R1	Light/odd branding fluid contamination in wool
Brand R2	Medium branding fluid contamination in wool
Brand R3	Heavy branding fluid contamination in wool
Dark 0	No dark stain in fibres
Dark S1	Light/odd dark stain in fibres
Dark S2	Medium dark stain in fibres
Dark S3	Heavy dark stain in fibres
Skin pieces 0	No skin pieces
Sk piece V1	Light/odd skin pieces
Sk piece V2	Medium skin pieces
Sk piece V3	Heavy skin pieces
Wat Stn 0	No water stain
Wat. Stn N1	Light/odd water stain
Wat. Stn N2	Medium water stain
Wat. Stn N3	Heavy water stain
Pigment 0	No pigmentation
Pigment Y1	Light/odd pigmentation
Pigment Y3	Heavy pigmentation

## Appendix 2. Overall efficiency distributions by selling centre and production process, November 2010





**Appendix 3. Overall efficiency distributions by selling centre and production process, March 2011**

