1 **The impact of genetics on retail meat value in**

2 **Australian lamb.**

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13 **Keywords**

14 Carcass value, muscling, breeding values, lean meat yield, allometric growth

15

16 **Abstract**

17 Lean (muscle), fat, and bone composition of 1554 lamb carcasses from **Maternal**,
18 Merino and Terminal sired lambs was measured using computed tomography scanning.
19 Lamb sires were diverse in their range of Australian Sheep Breeding Values for post
20 weaning c-site eye muscle depth (PEMD) and fat depth (PFAT), and post weaning
21 weight (PWWT). Lean value, representing predicted lean weight multiplied by retail
22 value, was determined for lambs at the same carcass weight or the same age. At the
23 same carcass weight, lean value was increased the most by reducing sire PFAT,
24 followed by increasing PEMD and PWWT. However for lambs of the same age,
25 increasing sire PWWT increased lean value the most. Terminal sired lambs, on average,

26 had greater lean value irrespective of whether comparisons were made at the same age
27 or weight. Lean value was greater in Merino compared to Maternal sired lambs at equal
28 carcass weight, however the reverse was true when comparisons were made at the same
29 age.

30

31 **1 Introduction**

32 Hot carcass weight (HCWT) and lean meat yield percentage (LMY%) are important
33 profit drivers across the entire value chain, but especially for processors. The value of
34 HCWT is relatively easy to understand as it represents increased volume of product per
35 fixed cost of slaughter and fabrication of cuts. Alternatively, the financial implications
36 of LMY% are more complex. For processors, leaner lambs require less fat trimming,
37 resulting in less wastage and decreased processing costs (Hopkins, 1989). Furthermore,
38 the location of lean in the carcass also influences carcass value, as the price of different
39 cuts vary at retail. Therefore a carcass with proportionately more lean within the higher
40 value loin cuts, will be worth more (Pethick, Ball, Banks, & Hocquette, 2011). To
41 reflect these profit drivers, Australian processors purchase lambs on the basis of HCWT
42 and GR tissue depth (tissue depth at the 12th rib 110mm from the midline) to crudely
43 reflect LMY% (Pethick et al., 2011).

44

45 To indirectly select for LMY% and HCWT, Australian lamb producers make use of
46 Australian Sheep Breeding Values (ASBVs) for sire post-weaning weight (PWWT), c-
47 site fat depth (PFAT) and eye muscle depth (PEMD). All three breeding values have
48 been shown to increase HCWT (Gardner et al., 2015), with PWWT having the biggest
49 impact producing heavier lambs at the same age, or enabling earlier slaughter at a
50 targeted weight. Producers also utilise the carcass breeding values to indirectly select
51 for LMY%, with a breeding value for direct selection for this trait not currently utilised

52 in Australian lamb breeding programs. A recent study by Anderson, Williams, Pannier,
53 Pethick and Gardner (2015a) used computed tomography (CT) to assess lamb carcass
54 composition and revealed that when compared at the same carcass weight, the progeny
55 of sires with increased PEMD and decreased PFAT had a greater proportion of lean in
56 the carcass. Additionally, it was observed that the increase in lean was preferentially
57 distributed to the saddle (mid) section of the carcass (Anderson, Williams, et al.,
58 2015a), a finding supported by earlier studies (Gardner et al., 2010; Hall, Gilmour,
59 Fogarty, & Holst, 2002; Hegarty et al., 2006). Sire PWWT ASBV was shown to
60 increase the proportion of lean in the saddle region, although the effect on carcass
61 LMY% was smaller and less consistent than that of sire PFAT and PEMD (Anderson,
62 Williams, et al., 2015a). The combined effect of these breeding values on LMY% and
63 distribution of lean and therefore carcass value has not been determined. When
64 comparing lambs at the same carcass weight we would expect sire PFAT to have the
65 greatest increase on carcass value, followed by sire PEMD and PWWT. Alternatively,
66 when comparing lambs at the same age HCWT will be the main profit driver, hence
67 PWWT is expected to have the biggest impact on carcass value.

68

69 Differences between sire types have also been shown to impact carcass composition
70 (Anderson, Pannier, Pethick, & Gardner, 2015; Anderson, Williams, et al., 2015a;
71 Anderson, Williams, Pannier, Pethick, & Gardner, 2015b; Ponnampalam, Hopkins,
72 Butler, Dunshea, & Warner, 2007). Terminal sired lambs have been shown to grow the
73 fastest (Gardner et al., 2015), and when compared at the same carcass weight, they also
74 have a greater proportion of carcass lean than Maternal and Merino sired lambs
75 (Anderson, Williams, et al., 2015a; Ponnampalam et al., 2008). Therefore their carcass
76 value should be higher irrespective of whether compared at the same weight or age.

77

78 This experiment analyses data from a large number of lamb carcasses (1554) from the
79 Information Nucleus Flock (INF) experiment which is run by the Australian
80 Cooperative Research Centre for Sheep Industry Innovation (Sheep CRC). Previous
81 analyses of the lamb carcasses from this experiment have examined the impacts of
82 genetic and non-genetic factors on carcass composition and distribution of fat, lean
83 (muscle) and bone and are reported in Anderson, Williams et al. 20015a,b.
84 Alternatively, this analysis expresses these changes in absolute mass and the equivalent
85 dollar value, thus focussing on the financial implications that genetic selection for sires
86 high in PWWT and PEMD and low in PFAT has on the value of lean in the carcass. We
87 hypothesise that when compared at the same carcass weight, selection of lambs for
88 increased sire PWWT and PEMD and decreased PFAT will result in a higher carcass
89 value through an increase in LMY%, with PFAT having the greatest impact. However,
90 when compared at the same age we hypothesise that PWWT will have the greatest
91 impact on carcass value. Finally, we hypothesise that the carcass value of Terminal
92 sired lambs will be greater compared to Merino and Maternal sired lambs when
93 compared at either the same weight or the same age.

94 **2 Materials and Methods**

95 *2.1 Experimental design and slaughter details.*

96 The design of the Sheep CRC INF is described by Fogarty, Banks, van der Werf, Ball,
97 and Gibson (2007). In brief, approximately 10,000 lambs were produced by artificial
98 insemination of Merino or Border Leicester-Merino (BLM) dams over a 5 year period
99 (year 2007-2011) at eight research stations (Katanning WA, Cowra NSW, Trangie
100 NSW, Kirby NSW, Struan SA, Turretfield SA, Hamilton VIC, and Rutherglen VIC).
101 The sire types used in the INF included: Terminal sires (Hampshire Down, Ile De
102 France, Poll Dorset, Southdown, Suffolk, Texel, White Suffolk), Maternal sires (Bond,
103 Booroola Leicester, Border Leicester, Coopworth, Corriedale, Dohne Merino, East

104 Friesian, Prime South African Meat Merino (SAAM), White Dorper), and Merino sires
105 (Merino, Poll Merino). The combinations of sire and dam crosses included: Merino,
106 Maternal x Merino, Terminal x Merino and Terminal x BLM. Lambs were weaned at
107 approximately 100 days of age, grazed under extensive conditions and supplemented
108 with feed at times when there was limited pasture, with availability of pasture and feed
109 varying between sites (Ponnampalam et al., 2014). All male lambs were castrated.

110

111 The lambs were divided into groups based on live weights, with each group killed
112 separately (kill groups) targeting a hot carcass weight at slaughter of between 21 to
113 24kg, irrespective of condition score. Lambs within kill groups were on average within
114 5 days of age of each other and within a year there was an attempt to represent all sire
115 types in each kill group. Within each site, the aim of selection of lambs for CT was to
116 include at least two progeny from each sire used at the site, selected across a live weight
117 strata. At all INF sites, lambs were yarded within 48 hours of slaughter, maintained off-
118 feed for at least 6 hours, and then weighed to determine pre-slaughter live weight.
119 Lambs were then transported for 0.5-6 hours via truck to one of 5 commercial abattoirs,
120 held in lairage at the abattoir for between 1 and 12 hours, and then slaughtered. All
121 carcasses were subjected to medium voltage electrical stimulation (Pearce et al., 2010)
122 and trimmed according to AUSMEAT standards (Anonymous, 2005) and HCWT was
123 then measured within 40 minutes of slaughter. All lambs were measured and sampled
124 for a wide range of carcass and meat quality traits (Pearce, 2009).

125

126 2.2 *Computed tomography scanning*

127 Lambs used in the CT study of composition were slaughtered and carcasses transported
128 to either Murdoch University (Picker PQ 5000 spiral CT scanner) or the University of
129 New England (Picker, Bavaria, Germany) for scanning within 72 hours of slaughter to

determine the proportions of fat, lean and bone. Lamb carcasses were divided into three sections (fore, saddle (middle) and hind): the fore section separated from the saddle by a cut between the fourth and fifth ribs; the hind section was separated from the saddle by a cut through the mid-length of the sixth lumbar vertebrae. A detailed description of the CT scanning process and calculation of carcass composition is presented in Anderson, Williams et al. (2015a).

2.3 Data used

This experiment utilised the HCWT results obtained from an experiment described by Gardner et al. (2015) for the progeny born from 2007 to 2010. This included 7516 lambs, representing the progeny of 76 Maternal, 127 Merino and 135 Terminal sires for which breeding value data were available. The breeding values for PEMD and PFAT are based upon live ultrasound measurement at the c-site (located at the 12th rib 45mm from the midline), and PWWT is based upon live weight, all measured at the post weaning time point (about 240 days of age).

CT scanning data was available on 1554 of the lambs from an INF experiment described by Anderson, Williams et al. (2015a) using 7 site-year combinations where lean measurement was available within the fore, saddle, and hind sections of the carcass (Table 1). In this experiment there were a total of 23 kill groups, with the raw average age of lamb 280 days and the number of lambs within each kill group ranging from 20 to 99 lambs (Table 1). The mean weight (and range) of the lamb carcasses in this experiment was 23.3kg (13.3-40.0 kg), with the weight (and range) of fat being 6.3kg (2.1-15.3), lean 13.3kg (7.4-20.8), and bone 3.8kg (2.4-5.7) respectively. The full description of carcass weights of fat lean and bone across the three sections are reported in Anderson, Williams et al. (2015a). Of the 81 Maternal, 119 Merino and 144 Terminal

156 sires in the CT experiment, 67, 109 and 143 had ASBV values for PWWT, PEMD,
157 PFAT and Carcass Plus Index available with the mean and range of these breeding
158 values shown in Table 2.

159

160 In both the HCWT analysis and CT analysis, a percentage of sires selected in a year
161 were used in subsequent years to provide sire linkage between years. The ASBV values
162 were sourced from Sheep Genetics, which is Australia's national genetic evaluation
163 database for sheep (Brown et al., 2007). The sire breeding values and index estimates
164 were generated within 3 separate data-bases for Terminal, Maternal, and Merino sired
165 progeny and were from an analysis completed in April 2013. Some of the youngest sires
166 used in this experiment lacked industry records and therefore did not have ASBVs
167 available. For the CT analysis of lean distribution this meant that there were 1501 lambs
168 with known ASBVs for the analysis.

169

170 2.4 Data transformation

171 All data in the lean analysis were converted to natural logarithms in order to utilise
172 Huxley's allometric equation ($y = ax^b$) (Huxley & Teissier, 1936). Where x is the
173 independent variable (carcass weight), a is the proportionality coefficient and b the
174 growth coefficient of y (weight of each tissue within a section) relative to x . By
175 transforming all of the values to natural logarithms the equation becomes: $\log_e y = \log_e$
176 $a + b \cdot \log_e x$; which linearises the data and can then be solved for y by least squares
177 regression.

178

179 A significant advantage of using the $\log_e$ form of the equation is that it homogenises the
180 variance over the entire range of sample data. It also allows for the direct comparison
181 of the differences in $\log y$ values as percent differences (Cole, 2000) in lean weight of a

182 section at a given carcass weight or back-transformation to give the weight (kg) of the
183 tissue (lean) in each section. The $\log_e$ transformation introduces a systematic bias into
184 the calculations and it is well recognised that a correction factor is required to correct
185 for this bias when back-transforming predictions (Baskerville, 1972; Beauchamp &
186 Olson, 1973; Sprugel, 1983). Hence the correction described by Sprugel (1983) was
187 used when data were back-transformed from $\log_e$ lean weight to kg lean weight.

188

189 2.5 *Establishing models for predicting section lean weights.*

190 Linear mixed effects models in SAS (SAS version 9.0, SAS Institute, Cary, NC, USA)
191 were used to determine the factors affecting the weights of muscle, bone, and fat for
192 each carcass section. A series of 9 base models were established, where the dependent
193 variables were the $\log_e$ weights (kg) of these tissues within each section, including $\log_e$
194 (fore section fat, lean, bone); $\log_e$ (saddle section fat, lean, bone) and $\log_e$ (hind section
195 fat, lean, bone). The covariate (x) was $\log_e$ whole carcass weight (kg), fixed effects
196 included: site-year (combined effect of site and year of lamb birth: Katanning (2008,
197 2011), Kirby (2007, 2008,) Hamilton 2009, Turretfield 2009 and Struan 2010); birth
198 type and rearing type (combined effect of animals born as single, twin or triplet and
199 reared as single, twin or triplet); sire type (Maternal, Merino and Terminal); sex within
200 sire type (wether Merino, wether Maternal, female Terminal, wether Terminal); dam
201 breed within sire type (Merino x Merino, Maternal x Merino, Terminal x Merino,
202 Terminal x BLM) and kill group within site-year, and random terms included sire and
203 dam identification by lamb birth year. The 1554 carcasses with entries for sex, sire type,
204 birth-type rear-type, dam breed, and kill group were included in the base model (Table
205 3). It was initially established that there were no first order interactions of the b term
206 with and of the core terms (sire type, sex within sire type, dam breed within sire type,
207 birth type-rear type, site year, site year within kill group). The 9 base models were

208 constrained to maintain the same form allowing the relative increases and decreases in
209 carcass components within each section to offset each other so that the predicted
210 weights of the components would be additive to equal the weight of the carcass. To
211 identify this consistent form we initially used a single multivariate model which was
212 derived using all of the 9 $\log_e$ weights (kg) of the tissues within each section as the
213 dependent variables, and the covariate and fixed effects described above as independent
214 variables. All relevant interactions between fixed effects and the covariate ($\log_e$ carcass
215 weight) were tested within this multivariate model and removed in a stepwise manner if
216 non-significant ($P > 0.05$).

217

218 In a secondary analysis, the above procedure was repeated with the sire ASBVs for
219 PWWT, PEMD and PFAT included in the base model along with their first order
220 interactions with the fixed effects. This included the interaction between ASBVs and
221 sire type, which was particularly relevant given that the breeding values were derived
222 from 3 separate data-bases for Terminal, Maternal, and Merino sired progeny, and thus
223 their magnitudes may not be directly comparable. Non-significant ($P > 0.05$) terms were
224 removed in a stepwise manner. Although these ASBVs were correlated (PWWT vs
225 PEMD = 0.3; PWWT vs PFAT = 0.3; PEMD vs PFAT = 0.1) previous analysis has
226 demonstrated that their effects are still relatively independent when included
227 simultaneously in a model predicting CT composition (Anderson, Williams, et al.,
228 2015a, 2015b).

229

230 Finally, to determine the impact of sire Carcass Plus Index on carcass composition and
231 carcass lean value, the Carcass Plus Index values were included in the base model along
232 with their first order interactions with the fixed effects, and non-significant ($P > 0.05$)
233 terms removed in a stepwise manner. The Carcass Plus Index combines the three

234 breeding values (PWWT, PFAT and PEMD) into a single index value based on
235 estimated economic weightings for each trait, and therefore **was** included in the models
236 independently to the ASBVs of which it is comprised. Carcass Plus is designed to
237 simplify the selection for improved HCWT and LMY% for producers of Terminal sired
238 lambs in the Australian Sheep Industry, although the Index values are readily calculated
239 for the Maternal and Merino sired lambs based on their values for weaning weight,
240 PWWT, PFAT and PEMD. The Carcass Plus Index is currently based upon weightings
241 for positive weaning weight breeding value (0.30), PWWT (0.35), and PEMD (0.30),
242 and negative PFAT (0.05).

243

244 2.6 *Estimating weights of lean tissue within sections*

245 The models described above were used to estimate the lean weight for each carcass
246 section. These were initially calculated at a constant carcass weight of 23kg, which was
247 selected because this represents a relevant industry weight and lies well within the
248 bounds of this dataset. The base model was used to estimate lean weight for the fore,
249 saddle and hind section for the comparison between ewes versus wethers (within the
250 progeny of Terminal sires), BLM dams versus Merino dams (within the progeny of
251 Terminal sires), and Terminal versus Maternal or Merino sire types (within the wether
252 progeny of Merino dams). The model with the 3 ASBVs was used to estimate $\log_e$ lean
253 weights in each section for Maternal, Merino and Terminal sires at the extremes of their
254 breeding value ranges for PFAT, PWWT, and PEMD (Table 2). In all cases, the lean
255 weights estimated were back transformed to kilogram weight and the correction
256 described by Sprugel (1983) applied to account for log-transformation error. The
257 predicted weight of lean (kg) was subsequently used to determine the value of lean
258 across the range of breeding values (see 2.7 calculating lean value). Similarly, the model
259 containing the Carcass Plus index was used to estimate lean weights in each section for

260 Maternal, Merino and Terminal sires at the extremes of their Carcass Plus Index values
261 (Table 2).

262

263 This procedure was then repeated to make these same comparisons at a constant
264 slaughter age of 280 days. This age represents the raw mean age of lambs at the time of
265 slaughter. In this instance, carcass weight was not held constant, but instead allowed to
266 vary to reflect the true carcass weight for the comparisons being made. For example, the
267 section lean weight of ewes was predicted at 23.5kg carcass weight, and wethers at
268 24.6kg carcass weight. The carcass weights used to predict lean weights for each sire
269 type are summarised in Table 4 and were derived from the models described by Gardner
270 et al. (2015). These weights were converted to $\log_e$ values prior to analysis.

271

272 2.7 *Calculating lean value.*

273 To determine carcass lean value the estimates of lean weight for each carcass section
274 (kg), as described above, were multiplied by the average retail value of lean in each
275 section and summed to arrive at a whole carcass lean value. The average retail values
276 used were \$17.33, \$27.02 and \$20.25 per kilogram for lean from the fore, saddle and
277 hind sections. These values were determined using average retail prices of two major
278 Australian lamb retailers (April 2015) for a set of commercial cuts (AUS-MEAT
279 description codes (AUS-Meat Limited, 2015) in parenthesis) which included: 5 cuts
280 from the fore section, eye of shoulder (5151), boneless shoulder (5047), fore-shank trim
281 (5030), breast trim (5000), neck meat (5020), and fore-section lean trim (5290); 4 cuts
282 from the saddle section, eye of shortloin (5150), tenderloin butt off (5082), eye of rack
283 (5153), trimmed boneless flap (5173), and saddle section lean trim (5270); and 6 cuts
284 from the hind section, topside (5073), round (5076), silverside (5071), rump (5130), butt
285 tenderloin (5081), hind shank butt off (5031), and hind section lean trim (5270). Within

each carcass section the average of these prices was calculated, after being weighted by the proportion that each cut represented of the total mass of lean for that section. The commercial cuts described above contain a small amount of subcutaneous and inter-muscular fat, however this would have little effect on the proportion that each cut represents of the total lean in each section, therefore having little impact on the overall estimate of lean value for that section.

3 Results

3.1 Impact of sex on carcass composition and lean value.

A comparison between sexes was only able to be made within the Terminal sired lambs. When compared at the same carcass weight, the carcass composition varied between sexes ($P < 0.01$, Table 5), with wethers generally having more lean than ewes (Table 6). This was evident in the fore, saddle and hind sections where the wether progeny from BLM dams had 4.83%, 2.04% and 1.69% more lean than ewe lambs (Table 6). Likewise in lambs born to Merino dams, the wethers had 4.26%, 1.85% and 1.08% more lean than the ewe lambs in the fore, saddle and hind sections (Table 6). The decreased lean in the ewe lambs was largely offset by an increase in fat across all sections of the carcass (Table 6).

In a 23kg carcass, these compositional differences equated to an additional 0.38 kg and 0.31 kg of lean in wether lambs born to BLM and Merino dams, which was worth \$7.55 and \$6.27 per carcass more than ewe lambs (Table 7). The carcasses of wether lambs were also 1.07 kg heavier than ewe lambs at the same age (ie 280 days) (see Gardner et al. 2015). When this carcass weight difference was factored into the calculation the additional carcass lean was worth \$19.22 and \$16.81 for the wether lambs born to BLM and Merino dams (Table 7).

312

313 3.2 *Impact of genetics on carcass composition and lean value in the carcass.*

314 3.2.1 *Sire type*

315 Sire type comparisons were possible in wether lambs born to Merino dams. When
316 compared at the same carcass weight, the amount of lean in each section varied between
317 the Maternal, Merino and Terminal sired lambs ($P<0.01$, Table 5). For lean, 95% of the
318 sire estimates lay between $\pm 3.7\%$, $\pm 5.4\%$ and $\pm 3.9\%$ for the fore, saddle and hind
319 sections respectively at any given carcass weight.

320

321 Compared to the Terminal sired lambs, the Maternal and Merino sired lambs had
322 respectively 6.78% and 4.79% less lean in the saddle and 5.26% and 4.13% less lean in
323 the hind section (Table 6). The Maternal sired lambs had the least fore section lean with
324 2.08% and 2.42% less lean than the Merino and Terminal sired lambs (Table 6)
325 respectively.

326

327 When compared at the same carcass weight (23kg) these compositional differences
328 equated to an additional 0.42kg and 0.62kg of lean in Terminal sired lambs compared to
329 Merino and Maternal sired lambs, which was worth an extra \$9.57 and \$14.36 per
330 carcass (Table 7).

331

332 Carcasses of Terminal sired lambs were 4.27kg and 1.48kg heavier than Merino and
333 Maternal sired lambs at the same age (ie 280 days) (Gardner et al., 2015). When this
334 carcass weight difference was factored into the calculation the additional carcass lean
335 was worth \$53.85 and \$32.61 (Table 7).

336

337 3.2.2 Dam breed

338 A comparison of dam breeds was possible in the Terminal sired lambs. In the fore
339 section, differences only existed within ewe lambs ($P<0.01$, Table 5), where the
340 progeny of Merino dams had 1.46% more lean than those from BLM dams (Table 6). In
341 the hind section, differences were evident within both sexes ($P<0.01$, Table 5), where
342 lambs from Merino dams had 1.26% (wethers) and 1.90% (ewes) more lean than lambs
343 from BLM dams (Table 6). In the ewe lambs the increased lean in Merino lambs was
344 offset by reductions in fat within the fore, saddle and hind sections (3.1%, 4.28% and
345 2.41% **respectively**, Table 6) compared to lambs from BLM dams.

346
347 When compared at the same carcass weight (23kg), these compositional differences
348 equated to an additional 0.17kg more lean in the progeny of Merino dams (average of
349 wethers and females) compared to the progeny of BLM dams (Table 7). This resulted in
350 Merino dams producing lambs with a predicted carcass lean value of \$3.58 more, when
351 compared to those born to BLM dams (Table 7). When compared at the same age, (280
352 days) the BLM dams produced lambs that on average had more lean (0.95kg, Table 7)
353 and a carcass lean value that was \$20.12 greater than the lambs from Merino dams.

354

355 3.2.3 Australian Sheep Breeding Values

356 3.2.3.1 Impact of sire PWWT on carcass composition and lean value

357 Sire PWWT had a significant effect on lean weight of the saddle section ($P<0.01$, Table
358 5). The magnitude of this effect varied between site-years, however on average saddle
359 section lean weight increased at 0.28% per unit increase of PWWT ASBV (Table 6).

360

361 When lambs were compared at the same carcass weight (23kg), the lean value increase
362 due to sire PWWT was similar for all three sire types (Table 8). However, due to their

different breeding value ranges this meant that the impact of PWWT on lean value was greatest in Maternal sired lambs and worth an additional \$5.59, compared to only \$4.98 and \$4.31 for the Terminal and Merino sired lambs (Table 8) across their respective ranges of sire PWWT.

Sire PWWT breeding value also had a marked effect on carcass weight which differed between sire types (Gardner et al., 2015). Thus when these differences between carcass weights (Table 4) were factored into the calculation at a constant age (280 days) the additional carcass lean was worth \$3.95 per unit sire PWWT for the Merino sired lambs, compared to only \$2.07, and \$2.10 per unit sire PWWT for the Maternal, and Terminal sired lambs (Table 9). Across the range of sire PWWT breeding value for each sire type this equated to a total of \$62.46, \$38.39, and \$28.20 for the Merino, Maternal, and Terminal sired lambs (Table 9).

3.2.3.2 Impact of sire PFAT on carcass composition and lean value

When compared at the same carcass weight, decreasing sire PFAT increased lean ($P<0.01$, Table 5) in all carcass sections. The greatest magnitude of effect was in the saddle region where at any given carcass weight a decrease in sire PFAT by one unit increased saddle lean by 2.74%, compared to increases of only 1.72% and 1.84% for lean in the fore and hind sections (Table 6). The increases in lean were accompanied by changes in the proportion of fat and bone in all carcass sections ($P<0.05$, Table 5) with the proportion of fat decreasing and bone increasing (Table 6). The impact of PFAT for all sections of the carcass was consistent across sites and years, although varied between kill groups ($P<0.01$, Table 5) (data not shown).

388 When compared at the same carcass weight (23kg), the increase in carcass lean value
389 for each unit decrease in sire PFAT was similar for all three sire types (Table 6). Due to
390 the different ranges of breeding values between sire types, this meant that the Terminal
391 sired lambs had the greatest increase in carcass value (\$30.05, Table 8), followed by the
392 Maternal and Merino sired lambs (\$28.36 and \$22.70, Table 8).

393

394 Sire PFAT had a small impact on carcass weight that was consistent across sire types
395 (Table 4)(Gardner et al., 2015). Therefore when lambs were compared at the same age,
396 these increases in carcass weight resulted in a per unit value of lean of \$8.42, \$7.60 and
397 \$7.11 per unit decrease in PFAT for the Terminal, Maternal and Merino sire types
398 (Table 9). Across the sire range of PFAT values for each sire type this equated to an
399 increased lean value of \$40.42, \$35.71 and \$27.03 for the Terminal, Maternal and
400 Merino sired lambs (Table 9).

401

402 3.2.3.3 *Impact of sire PEMD on carcass composition and lean value.*

403 When compared at the same carcass weight, increasing sire PEMD increased lean in the
404 saddle and hind sections ($P<0.01$, Table 5). In the saddle each unit increase in sire
405 PEMD increased saddle lean by 1.99% (Table 6). In the hind section the effect varied
406 between sire types. PEMD had minimal impact on the proportion of lean in the Merino
407 sired lambs, however in the Terminal and Maternal sired lambs there was a 0.75 and
408 2.24% increase in hind section lean per unit of PEMD (Table 6). This increase in lean
409 was largely off-set by carcass fat ($P<0.01$, Table 5) which when averaged across sire
410 types was equivalent to a reduction in fat of 1.96%, 2.73% and 2.77% in the fore, saddle
411 and hind sections per unit of increasing sire PEMD (Table 6).

412

413 When compared at the same carcass weight, Maternal sired lambs had the greatest
414 increase in lean value per unit increase in PEMD (\$4.30, Table 8), which was greater
415 than both of the Terminal (\$2.98) and Merino (\$2.64) sired lambs (Table 8). Across
416 their respective ranges of PEMD breeding values this equated to an increase in carcass
417 lean value of \$18.51, \$23.22 and \$13.70 for the Maternal, Terminal and Merino sired
418 lambs (Table 8).

419

420 Sire PEMD had only a small impact on carcass weight which was consistent across sire
421 types (Gardner et al., 2015). Thus when this was factored into the calculation and
422 comparisons made at the same age, the Maternal sired lambs still had the greatest per
423 unit increase in carcass lean value (\$5.65, Table 9) compared to either the Terminal or
424 Merino sired lambs. However, when calculated across the range of sire PEMD values
425 within each sire type the Terminal sired lambs had the greatest increase in carcass lean
426 value at \$36.06 (Table 9), compared to \$24.30 and \$20.06 in the Maternal and Merino
427 sired lambs.

428

429 *3.2.3.4 Impact of sire Carcass Plus on carcass composition and lean value.*

430 The sire Carcass Plus Index impacted on the saddle and hind section lean, with the
431 impact on fore section dependent on sire type ($P<0.01$, Table 5). For every 10 units of
432 increase in Carcass Plus there was an increase of 0.35% and 0.49% in fore section lean
433 in the Maternal and Terminal sired lambs which amounted to a 4.2% and 3.7% increase
434 in lean across their respective ranges of the Carcass Plus Index values (Table 6). The
435 increase in lean for all sire types in the saddle and hind sections was 0.76 and 0.40% per
436 10 units of the Carcass Plus Index value (Table 6).

437

438 When lambs were compared at the same carcass weight (23kg), the Terminal and
439 Maternal sired lambs had similar increase in lean value per unit of Carcass Plus (\$0.15
440 and \$0.13, Table 8), with a smaller impact on the lean value of Merino sired lambs
441 (\$0.09/ unit Carcass Plus). Across the range of Carcass Plus this equates to an increase
442 of \$11.27, \$8.47 and \$16.19 for the Terminal, Merino and Maternal sired lambs (Table
443 8).

444

445 Sire Carcass Plus Index also impacted on lamb carcass weight, although this varied
446 across the three sire types (Table 4) with the Merino sired lambs having the greatest
447 increase in HCWT per unit Carcass Plus (Table 4). When lambs were compared at the
448 same age, the Merino sired lambs had the greatest increase in lean value of \$0.54 per
449 unit Carcass Plus (Table 9), compared to \$0.48 and \$0.37 for the Maternal and Terminal
450 sired lambs (Table 9). When compared across their respective ranges of Carcass Plus
451 this resulted in the greatest increase in lean value of \$57.59 in the Maternal sired lambs
452 (Table 9).

453 **4 Discussion**

454 *4.1 The impact of genetics on the value of the lamb carcass.*

455 *4.1.1 The impact of sire type and dam breed on the value of the lamb carcass.*

456 In support of our hypothesis, Terminal sired lambs had the greatest lean value when
457 compared at the same carcass weight. This was a reflection of their greater lean weight
458 across all three carcass sections compared to both Merino and Maternal sired lambs,
459 consistent with their larger mature size and therefore reduced maturity when compared
460 at the same weight (Huisman & Brown, 2008). On the basis of these differences the
461 carcasses of Terminal sired lambs were worth \$9.57 and \$14.36 more than the Merino
462 and Maternal sired lambs.

463

464 When compared at the same age, the difference between sire types was much
465 greater due to their marked difference in carcass weights (Gardner et al., 2015). Thus
466 the lean from the carcasses of Terminal sired lambs were worth \$53.84 and \$32.60 more
467 than the Merino and Maternal sired lambs. These values also highlight the re-ranking of
468 Merino and Maternal sired lambs, with Merino's more valuable when compared at the
469 same carcass weight, but less valuable when carcass weight (and therefore growth rate)
470 is factored in to the calculation. This partly contradicts the conclusions of
471 Ponnampalam, Hopkins, Dunshea, et al. (2007) who stated that purebred Merino lambs
472 will always be less productive in terms of carcass weight and muscle related
473 productivity traits than Maternal sired lambs.

474

475 It should be noted that sire type comparisons are based on the mean of the sires in each
476 sire type group. However within these groups considerable genetic variation exists
477 between sires. This is well demonstrated by the breeding values described in Table 2,
478 such that considerable overlap exists between the sires in each sire type group.
479 Therefore while average differences exist between these groups, individual sires can
480 still achieve the performance reported for other sire type groups.

481

482 Compared at the same carcass weight, Merino dams produced lambs that had more fore
483 and hind lean compared to the BLM dams. This difference in lean weight was worth
484 \$3.58, and aligns well with the sire type effect discussed above where the lean from
485 Merino lambs was worth \$4.80 more than lambs from Maternal dams. Although not
486 previously compared on a dollar basis, the mass differences align well with previous
487 studies where, after correcting for carcass weight, lambs from BLM dams had less
488 carcass lean (Anderson, Williams, et al., 2015a; Ponnampalam et al., 2008) and a higher
489 proportion of fat (Anderson, Williams, et al., 2015b) than lambs from Merino dams.

490 The increased fatness of lambs from BLM genetics may be linked to their selection for
491 improved reproduction capacity (Ferguson et al., 2010).

492

493 When compared at the same age, the opposite trend was evident, with lean value of the
494 lambs from the BLM dams worth \$20.12 more than that of the Merinos. Again, this
495 aligns well with the sire type comparison between Merino and Maternal sires, reflecting
496 the marked difference in carcass weights of lambs from these two dam breeds (Gardner
497 et al., 2015)

498

499 *4.1.2 The impact of Australian Sheep Breeding Values on carcass value*

500 *4.1.2.1 Post weaning C-site fat depth.*

501 In support of our hypothesis, when comparing lambs at the same carcass weight,
502 decreasing sire PFAT increased lean weight, corresponding with a substantial increase
503 in the value of carcass lean. Furthermore, this increase in the value of lean across the
504 range of PFAT ASBVs in the sired used, was substantially larger than the
505 corresponding effects of PEMD or PWWT. This aligns well with previous work which
506 showed that PFAT not only caused substantial increases in the mass of lean across the
507 entire carcass, but also a favourable distribution of lean to the more highly valued
508 saddle region (Anderson, Williams, et al., 2015a). This is in contrast to PEMD where
509 only the weight/value of the saddle and hind sections were increased.

510

511 When lambs were compared at the same age, the difference in carcass lean value was
512 still quite similar across the PFAT range. This reflects the relatively small effect of the
513 PFAT breeding value on carcass weight, thus the main impact of PFAT on carcass value
514 is via its effect on composition. The potential impact of PFAT on the retail lamb value
515 through its impacts on eating quality (Pannier, Gardner, et al., 2014) and intramuscular

516 fat (IMF) % (Pannier, Pethick, et al., 2014) in addition to the value of the lean meat are
517 yet to be quantified.

518

519 4.1.2.2 *Post weaning weight*

520 The impact of PWWT on lean was predominantly focused on the saddle region, with no
521 effects evident in the fore or hind sections, contrary to our initial hypothesis. Thus lean
522 weight within the saddle increased across the PWWT range when compared at the same
523 carcass weight, resulting in a small increase in carcass lean value. Previous analyses
524 have demonstrated no overall increase in carcass lean weight due to the PWWT
525 breeding value (Anderson, Williams, et al., 2015a), most likely because the small
526 increases in saddle lean were masked by the lack of effect elsewhere.

527

528 In contrast to these small effects, when compared at the same age, sire PWWT had a
529 marked impact on the lean value within the carcass, largely reflecting the substantial
530 impact of this breeding value on carcass weight. Furthermore, lean value of the Merino
531 sired lambs was almost twice the per unit increase evident within the Maternal and
532 Terminal sired lambs. This is due to the greater impact of PWWT on carcass weight
533 within the Merino sired lambs compared to the Terminal and Maternal sired lambs
534 (Gardner et al., 2015).

535

536 4.1.2.3 *Post weaning eye muscle depth*

537 At any given carcass weight, increasing sire PEMD increased the weight of lean in the
538 saddle and hind sections, with no significant increase in the fore section. These
539 combined effects lead to a substantial increase in lean value, aligning well with our
540 initial hypothesis. Earlier studies by Anderson, Williams et al. (2015a) showed that
541 PEMD preferentially increased lean weight in the saddle at the expense of the fore

542 section. Therefore it would be expected that the combined effects of the overall increase
543 in lean weight and the lean redistribution away from the fore section would result in no
544 net change to fore section lean weight. Likewise the overall increase in carcass lean
545 weight, and the redistribution of lean to the saddle region would amplify the increase in
546 lean weight in the more expensive saddle region cuts – as was evidenced in this study.
547 The Maternal sired lambs had the greatest increase in carcass lean value per unit PEMD
548 which was at least 1.5 times that of the Terminal and Merino sired lambs. The Merino
549 sired lambs had only a small increase in hind section lean weight and therefore the
550 smallest increase in lean value.

551

552 There was a significant increase in carcass weight caused by PEMD (Gardner et al.,
553 2015), although this was a small in magnitude and consistent across all sire types,
554 compared to the impact of sire PWWT. When lambs were compared at the same age
555 the increase in lean value resulting from increasing sire PEMD for all sire types was
556 greater than when lambs were compared at the same carcass weight.

557

558 4.1.2.4 Carcass plus

559 This breeding value index represents a way for lamb producers to select their Terminal
560 sires on the basis of a weighted combination of PEMD, PWWT, and PFAT. This
561 optimises the production of lambs that reach slaughter weights early, while maximising
562 lean meat and maintaining a lean carcass. It is not used by Merino breeders as it does
563 not incorporate selection for wool traits, with index selection in Maternal sires having
564 more emphasis on traits such as number of lambs weaned and ewe resilience, including
565 maintaining fat to optimise fertility. Despite these different selection pressures this
566 analysis provides important information that quantify the effect of the Carcass Plus
567 index on lean value in all sire types.

568

569 When lambs were compared at the same carcass weight, the Maternal and Terminal
570 sired lambs had a similar increase in lean value per unit of Carcass Plus. The Merino
571 sired lambs had less increase due to the negligible impact of Carcass Plus on the fore
572 section of the carcass.

573

574 However, when lambs were compared at the same age, the Merino sired lambs had the
575 greatest per unit increase in lean value compared to the other sire types. This is due to
576 the heavy weighting of PWWT in the Index and the increased impact of PWWT on the
577 carcass weight of the Merino sired lambs (Gardner et al., 2015).

578

579 This analysis provides important information regarding the impact of the Carcass Plus
580 index on the value of lean in the carcass. In the future, similar analyses may provide
581 some basis for restructuring the Carcass Plus Index to maximise lamb profitability. This
582 was well demonstrated in one of our previous analyses (Anderson, Williams, Pannier,
583 Pethick, & Gardner, 2013) which calculated the loss in retail carcass value when the
584 emphasis on PFAT within the index was reduced from 30% to 5%, which was
585 performed in order to maintain intramuscular fat at a level that did not negatively impact
586 eating quality (Pannier, Gardner, et al., 2014; Pannier, Pethick, et al., 2014).

587

588 4.2 *The impact of sex on the value of the lamb carcass*

589 At the same carcass weight the wether lambs had more lean in all carcass sections
590 resulting in greater carcass value equivalent to \$6.46 within a 23kg carcass. The largest
591 differences in lean weight were seen in the fore section, with the hind section showing
592 the least differences in lean weight between the wethers and ewe lambs. However, given
593 the high value of the saddle lean the difference within this tissue was amplified when

594 expressed in dollar terms. The increase in lean in wethers when lambs are compared at
595 the same weight (Anderson, Williams, et al., 2015a; Lee, Harris, Ferguson, & Jelbart,
596 1990; Ponnampalam et al., 2008) and age (Ponnampalam et al., 2008) has been reported
597 previously, although not quantified holistically across carcass regions or expressed in
598 dollar terms. These effects on composition are a reflection of the impact of sex on
599 mature composition, with ewes being fatter than wethers (Anderson, Williams, et al.,
600 2015b; Ponnampalam et al., 2008) and a reflection of mature size, with wethers being
601 less mature and therefore leaner when compared at the same weight (Butterfield, 1988).

602

603 When comparisons were made at the same age, the mass difference between wethers
604 and ewes was amplified, due to the more rapid growth rate and therefore heavier
605 slaughter weights of wether lambs compared to ewes at the same age (Gardner et al.,
606 2015). This leads to an even greater financial difference with lean value of wethers
607 being \$18.01 greater than ewes. This difference represents an important advantage for
608 self-replacing ewe flocks where all wether lambs are slaughtered while the bulk of ewes
609 are retained for breeding.

610

611 *4.3 Comparison of effects*

612 When compared at the same carcass weight, the biggest influence on carcass lean value
613 was through the two breeding values, PFAT and PEMD. Reducing PFAT and
614 increasing PEMD both increased carcass lean value, although the impact of both was
615 greatest in Terminal sired lambs. This effect when assessed across the breeding value
616 range was at least double the next largest factor – in this case the sire type difference
617 between Terminal and Maternal sired lambs. It is possible that reducing sire PFAT and
618 increasing PEMD has an even greater impact beyond its impact on lean weight and
619 carcass weight due to the substantial decrease in carcass fat (Anderson, Williams, et al.,

2015b; Gardner et al., 2010). These carcasses are less likely to attract penalties at processing plants for being over fat. The impact of gender was the next largest effect, with the difference between ewes and wethers only half the difference between Terminal and Maternal sired lambs. The PWWT breeding value had a relatively small effect, particularly when compared to the other two breeding values. The magnitude of effect of PWWT across the breeding value range was just over half the magnitude of the difference between genders. Lastly dam breed had a relatively small effect which was similar in magnitude to the impact of PWWT.

628

When lambs were compared at the same age this allowed for the differences in lamb size and therefore carcass weight at a given age to be included in the calculation of the weight and value of lean. There was marked re-ranking of magnitudes between the factors affecting value, predominantly driven by those which had the greatest impact on carcass weight. As such, the difference between Terminal and Merino sire types and the effect of the PWWT across its breeding value range, particularly within the Merino sires, had the largest impact on carcass lean value. The differences between genders and dam breeds also increased when differences in carcass weight at a given age were accounted for, yet these differences were still less than the effect of the PFAT and PEMD across their respective breeding value ranges.

639

640 *4.4 Limitations and future work*

This analysis enables the relative effects of gender and genetics on carcass lean to be evaluated without relying solely on a selected few cuts like the topside, and loin to indicate this value. However, allocating prices to this lean based on market prices as of April 2015 immediately exposes this analysis to currency issues due to price fluctuations. However, the ranking of prices for each cut within the lamb carcass has

646 remained relatively constant over time (Pethick, Ball, Banks, & Hocquette, 2010),
647 hence the results can still be interpreted with respect to the ranking of fore, saddle, and
648 hind quarter lean within the carcass. Likewise, the effects identified in this paper are
649 also likely to maintain their relative proportional differences.

650

651 Other limitations to this work are the additional factors that are impacted upon by the
652 traits examined – particularly the carcass breeding values. For example the magnitude
653 of the changes observed in bone and fat have not been incorporated into this financial
654 evaluation which was instead restricted to the value of lean within the carcass. Indeed,
655 this value differential could also be extended to include the costs of trimming of
656 excessive fat from carcasses in the retail market. Likewise, this analysis does not
657 capture the impact of genetic selection (carcass breeding values, dam breed, sire type)
658 on the number of lambs weaned, feed efficiency, wool growth or ewe longevity. This
659 more detailed economic analysis is beyond the immediate scope of this study, yet would
660 certainly be of value to the industry when attempts are made to justify the introduction
661 of new technologies to capture this value.

662

663 Lastly, the introduction of eating quality assessment through Meat Standards Australia
664 (Meat Standards Australia, 2013), creates an opportunity for the associated effect on
665 eating quality to be incorporated into the economic values. Work by Pannier, Gardner,
666 et al. (2014) showed that selection for improved LMY% using increased sire PEMD and
667 reduced sire PFAT had a negative impact on the eating quality of longissimus and
668 semimembranosus samples, partially through their impact on intramuscular fat
669 percentage. Therefore future multi-trait indexes are required that balance eating quality
670 (reflected through intramuscular percentage) with the existing growth and carcass traits
671 (Mortimer et al., 2014; Swan, Pleasants, & Pethick, 2015). More widespread

672 introduction of technology that accurately assesses LMY%, IMF% and eating quality
673 commercially and in breeding programs, alongside payment schemes that reward
674 producers, would encourage the use of these multi index selection tools.

675

676 **5 Conclusion**

677 The results of this study enable the direct comparison of carcass lean value of different
678 sire types, sexes and breeding values at the same carcass weight and at the same age.
679 When compared at the same carcass weight sire PFAT had the greatest impact on
680 carcass lean value, its magnitude of effect across the PFAT range being 1.5 times
681 greater than the next most influential breeding value, PEMD. However when compared
682 at the same age increasing sire PWWT had the greatest impact on carcass lean value,
683 due to largely to its effect on carcass weight. Compared to lambs from other sire types,
684 Terminal sired lambs had, **on average**, the greatest lean value irrespective of whether
685 compared at the same weight or age, closely followed by Merinos when compared at the
686 same weight, and Maternal sired lambs when compared at the same age.

687

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697

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827

1 Table 1. Average age of lambs at slaughter and number of carcasses scanned using computed
 2 tomography in each lamb kill group at each site.

Site-Year	Kill group	Average age (days)	Carcasses (n)
Kirby 2007	1	235	72
	2	270	63
	3	352	96
Kirby 2008	1	269	97
	2	345	99
	3	408	99
	4	420	96
Rutherglen 2010	1	198	55
	2	254	59
Hamilton 2009	1	229	53
Struan 2010	1	260	67
	2	287	67
	3	322	27
Turretfield 2009	1	235	58
	2	262	63
	3	310	29
Katanning 2008	1	235	20
	2	242	29
	3	319	28
Katanning 2011	1	168	87
	2	238	96
	3	280	99
	4	355	95
Total	23	-	1554

3 Table 2. Number of sires and mean (min, max) for the Australian Sheep Breeding Values for
 4 post weaning weight (PWWT), post weaning c-site fat depth (PFAT) and post weaning eye
 5 muscle depth (PEMD) for each sire type of lamb carcasses undergoing computed
 6 tomography.

Sire type	No. of sires	PWWT (kg)	PFAT (mm)	PEMD (mm)	Carcass Plus
Maternal	67	4.7 (-6.1, 12.4)	-0.3 (-2.1, 2.6)	0.1 (-2.5, 1.8)	125 (63,184)
Merino	109	1.9 (-5.0, 10.8)	-0.2 (-1.9, 1.9)	0.0 (-2.6, 2.6)	112 (68,160)
Terminal	143	12.7 (5.3, 18.6)	-0.7 (-2.5, 2.3)	1.2 (-2.8, 5)	179 (133, 209)

7 Table 3. Number of lamb carcasses analysed in the base model according to sex, sire type, birthing and rearing type and dam breed.

	Sex		Birth type-rearing type						Dam breed	
	Female	Wether	Single born and raised	Born as twin- raised as single	Born as twin- raised as twin	Born as triplet- raised as single	Born as triplet- raised as twin	Born and raised as triplet	Merino	BLM ¹
Maternal	0	332	152	25	141	2	8	4	332	0
Merino	0	251	129	38	79	1	0	4	251	0
Terminal	475	496	379	91	447	8	24	22	457	514
Total	475	1079	660	154	667	11	32	30	1040	514

8 ¹ BLM: Border Leicester-Merino

9

10 Table 4. Predicted carcass weights (kg) $\pm$ SE of the Maternal, Merino and Terminal sired wether lambs born to Merino dams at an average age of
 11 280 days.

Sire type	Base model (no breeding values) Carcass weight (kg)	PWWT (kg)			PEMD (mm)			PFAT (mm)			Carcass Plus		
		Range (low, high)	PWWT low Carcass weight (kg) ¹	PWWT high Carcass weight (kg) ¹	Range (low, high)	PEMD low Carcass weight (kg) ¹	PEMD high Carcass weight (kg) ¹	Range (low, high)	PFAT low Carcass weight (kg) ¹	PFAT high Carcass weight (kg) ¹	Range (low, high)	Carcass plus low Carcass weight (kg) ¹	Carcass plus high Carcass weight (kg) ¹
Maternal	21.9 $\pm$ 0.18	(-6.1, 12.4)	20.0 $\pm$ 0.53	23.3 $\pm$ 0.36	(-2.5, 1.8)	21.5 $\pm$ 0.23	22.1 $\pm$ 0.21	(-2.1, 2.6)	22.2 $\pm$ 0.24	21.3 $\pm$ 0.26	(64,184)	19.0 $\pm$ 0.60	24.6 $\pm$ 0.52
Merino	19.1 $\pm$ 0.22	(-5.0, 10.8)	16.3 $\pm$ 0.32	21.9 $\pm$ 0.33	(-2.6, 2.6)	18.3 $\pm$ 0.25	19.1 $\pm$ 0.25	(-1.9, 1.9)	19.1 $\pm$ 0.25	18.3 $\pm$ 0.26	(69,160)	17.2 $\pm$ 0.42	21.2 $\pm$ 0.32
Terminal	23.4 $\pm$ 0.19	(5.3, 18.6)	22.2 $\pm$ 0.29	24.6 $\pm$ 0.28	(-2.8, 5)	22.9 $\pm$ 0.26	24.1 $\pm$ 0.26	(-2.5, 2.3)	23.9 $\pm$ 0.21	22.9 $\pm$ 0.27	(134, 209)	22.4 $\pm$ 0.31	24.5 $\pm$ 0.30

12 PWWT: post weaning weight; PFAT: post weaning c-site fat depth; PEMD: post weaning eye muscle depth

13 ¹ The carcass weight for each sire type has been predicted at the maximum and minimum Australian Sheep Breeding Value range for that particular sire type as described in
 14 Table 2 using models and data from Gardner et al. (2015).

15

Table 5. F-values and degrees of freedom for the numerator(NDF) and denominator (DDF) for factors affecting the weight of fat, lean and bone in the fore, saddle and hind sections of the lamb carcass.

		Fore-section			Saddle section			Hind section		
Effect	NDF,DDF	Fat	Lean	Bone	Fat	Lean	Bone	Fat	Lean	Bone
Core model										
Site-year	7,171	13.24**	82.05**	43.13**	49.31**	38.24**	29.33**	54.11**	35.82**	85.21**
Sex(sire type)	1,171	35.86**	156.21**	43.30**	151.57**	19.84**	3.37	41.65**	21.52**	31.89**
Sire type	2,171	21.31**	5.13**	17.46**	8.56**	26.13**	1.31	13.67**	30.86**	14.8**
Kill group(site-year)	15,171	3.21**	9.15**	11.86**	9.88**	11.12**	6.95**	9.53**	4.89**	11.46**
Dam breed(sire type)	1,171	5.83*	8.33**	2.24	11.07**	1.78	0.19	2.76	9.04**	0.09
Site-year x sire type	12,171	2.82**	1.24	0.76	2.57**	3.11**	1.16	4.01**	3.00**	1.90*
Site-year x dam breed (sire type)	5,171	2.08	5.88**	2.29*	4.42**	1.89	0.32	3.32**	2.50*	1.96
log _e (CT whole carcass wt (kg))	1,171	2308.07**	3729.09**	1109.13**	2446.08**	2383.67**	615.23**	2332.49**	4582.8**	1525.07**
Australian Sheep Breeding Values										
PWWT	1,153	3.41	0.01	0.09	0.35	8.67**	0.48	3.69	0.6	0.06
PWWT x site-year	7,153	2.84**	1.67	1.27	3.88**	3.43**	1.14	3.84**	4**	3.48**
PFAT	1,153	44.4**	29.17**	9.2**	70.12**	49.65**	6.06*	58.53**	48.56**	8.77**
PFAT x Kill group(site-year)	22,153	1.34	1.28	1.33	1.33	1.75*	1.78*	1.93*	1.75*	1.79*
PEMD	1,153	14.75**	3.24	1.96	24.33**	53.23**	0.12	42.16**	31.64**	0.09
PEMD x sire type	2,153	2.07	1.47	0.46	8.13**	2.84	1.12	4.48*	6.14**	1.60
Carcass plus										
Carcass plus	1,167	12.14**	1.31	0.17	5.05*	22.53**	0.16	14.2**	12.64**	0.01
Carcass Plus x sire type	2,167	1.65	3.61*	1.03	2.72	2.24	0.44	1.15	1.60	1.48

NDF, DDF: numerator and denominator degrees of freedom.

* $P < 0.05$, ** $P < 0.01$

20 Table 6. The relative change (% change in weight) for fat, lean and bone in the fore, saddle and hind sections of the carcass due to sex, sire type,
 21 dam breed and Australian Sheep Breeding Value effects for lambs slaughtered at 23kg.

Effect	Level	Fore section (% change in weight)			Saddle section (% change in weight)			Hind section (% change in weight)		
		Fat	Lean	Bone	Fat	Lean	Bone	Fat	Lean	Bone
Sex dambreed (sire type) ¹	Maternal x Merino M	10.92^d	-2.42^c	1.36^c	10.05^b	-6.78^a	-0.58^{ab}	8.17^d	-5.26^a	0.23^c
	Merino x Merino M	6.31^c	-0.35^d	5.63^d	1.08^a	-4.79^b	1.80^b	4.00^{bc}	-4.13^{ab}	4.37^d
	Terminal x BLM F	6.61^c	-5.64^a	-4.32^a	14.38^c	-3.01^{bc}	-1.9^a	6.19^{cd}	-2.93^b	-2.76^a
	Terminal x Merino F	3.30^b	-4.26^b	-2.90^{ab}	9.48^b	-1.85^{cd}	-0.10^{ab}	3.63^b	-1.08^c	-1.89^{ab}
	Terminal x BLM M	1.74^{ab}	-0.81^d	0.25^c	2.92^a	-0.97^{de}	0.96^{ab}	0.19^a	-1.24^c	0.32^c
	Terminal x Merino M	0.00^a	0.00^d	0.00^{bc}	0.00^a	0.00^e	0.00^{ab}	0.00^a	0.00^d	0.00^{bc}
<i>Australian Sheep Breeding Values²</i>										
PWWT		-0.28	-0.01	-0.04	-0.10	0.28	0.13	-0.32	0.05	0.02
PWWT x site-year	Kirby 2007	-0.97	0.13	0.28	-0.89	0.37	0.03	-0.39	0.31	0.47
	Kirby 2008	-0.11	0.06	0.05	-0.45	-0.05	0.15	0.18	0.07	-0.01
	Rutherglen 2010	-0.47	0.12	-0.12	-0.33	0.41	-0.19	-1.42	0.38	0.16
	Hamilton 2009	0.28	-0.09	0.09	0.42	-0.14	0.28	0.14	-0.18	-0.17
	Struan 2010	-0.40	-0.22	-0.31	0.22	0.25	-0.38	0.02	-0.06	-0.06
	Turretfield 2009	0.23	-0.21	-0.22	0.83	0.21	0.05	0.34	-0.29	-0.50
	Katanning 2008	-0.49	0.02	-0.28	-0.65	1.06	0.79	-1.31	0.15	0.22
	Katanning 2011	-0.31	0.13	0.15	0.00	0.11	0.32	-0.14	0.01	0.08
PFAT		3.87	-1.72	-1.56	6.25	-2.74	-1.75	5.15	-1.84	-1.07
PEMD		-1.96	0.62	-0.40	-2.73	1.88	-0.19	-2.77	1.16	-0.19
PEMD x sex dambreed (sire type)	Maternal x Merino M	-3.17	0.61	-0.63	-6.27	2.89	1.16	-5.30	2.24	0.74
	Merino x Merino M	-0.69	-0.07	-0.98	-0.39	2.39	0.01	-3.25	0.40	0.10
	Terminal x BLM F	-2.29	1.00	0.24	-2.71	1.35	-1.61	-1.46	1.28	-0.49
	Terminal x Merino F	-1.77	0.40	-0.29	-2.37	1.46	-0.10	-1.83	1.07	-0.31
	Terminal x BLM M	-2.31	0.87	-0.32	-2.88	1.51	0.09	-2.64	1.23	-0.28
	Terminal x Merino M	-1.51	0.91	-0.42	-1.75	1.71	-0.71	-2.12	0.75	-0.93

*Carcass Plus*³

Carcass Plus		-0.96	0.25	-0.09	-0.80	0.76	-0.03	-0.88	0.40	-0.15
Carcass Plus x sex dambreed (sire type)	Maternal x Merino M	-0.90	0.35	-0.43	-1.39	0.88	0.03	-1.43	0.56	-0.10
	Merino x Merino M	-0.23	-0.22	0.21	0.08	0.14	0.28	-0.34	0.12	0.30
	Terminal x BLM F	-1.54	0.47	0.13	-0.67	0.93	-0.81	-0.58	0.63	-0.42
	Terminal x Merino F	-1.00	-0.04	0.17	-0.80	0.85	0.59	-0.71	0.36	-0.18
	Terminal x BLM M	-1.31	0.43	-0.54	-1.12	1.07	0.07	-1.43	0.53	-0.32
	Terminal x Merino M	-0.79	0.49	-0.05	-0.93	0.71	-0.35	-0.80	0.20	-0.20

M = wether; F = ewe; BLM: Border Leicester- Merino

PWWT: post weaning weight; PEMD: post weaning eye muscle depth; PFAT: post weaning c-site fat depth

¹ a-e Within columns for sexdambreed(sire type), % change values without a common superscript differ significantly at $P < 0.05$ and represents the difference in $\log_e y$ values for each fixed effect compared to the fixed effect with coefficient 0.00 expressed as a percentage.

² % change in weight: the % increase or decrease in each tissue type per unit of Australian Sheep Breeding Value (PWWT, PFAT, PEMD)

³ % change in weight: the % increase or decrease in each tissue type per 10 units of the Carcass Plus breeding value

Effects in bold are significant $P < 0.05$

30 Table 7. Weight (kg) and value (\$) of lean in the fore, saddle and hind sections of the lamb carcass at the same weight (23 kg) and the same age
31 (280 days).

		Fore-section		Saddle-section		Hind-section		Whole carcass	
Effect	Level	Lean weight (kg)	Lean value (\$)	Lean weight (kg)	Lean value (\$)	Lean weight (kg)	Lean value (\$)	Lean weight (kg)	Lean value (\$)
Lambs compared at the same carcass weight (23kg)									
Sexdambreed (sire type)	Maternal x Merino M	4.28	74.13	3.45	93.29	5.10	103.36	12.83	270.79
	Merino x Merino M	4.37	75.71	3.53	95.28	5.16	104.59	13.06	275.58
	Terminal x BLM F	4.14	71.69	3.59	97.07	5.23	105.90	12.96	274.66
	Terminal x Merino F	4.20	72.73	3.64	98.23	5.33	107.92	13.17	278.88
	Terminal x BLM M	4.35	75.36	3.67	99.11	5.32	107.75	13.34	282.21
	Terminal x Merino M	4.38	75.97	3.70	100.08	5.39	109.10	13.47	285.15
Lambs compared at the same age (280 days)									
Sexdambreed (sire type)	Maternal x Merino M	4.10	71.04	3.19	86.19	4.91	99.45	12.20	256.68
	Merino x Merino M	3.72	64.46	3.00	81.06	4.44	89.93	11.16	235.44
	Terminal x BLM F	4.40	76.24	3.81	102.94	5.54	112.21	13.75	291.39
	Terminal x Merino F	4.10	71.04	3.55	95.92	5.21	105.53	12.86	272.48
	Terminal x BLM M	4.80	83.17	4.04	109.16	5.84	118.29	14.68	310.61
	Terminal x Merino M	4.45	77.10	3.76	101.59	5.46	110.59	13.67	289.29

32 M = wether; F = ewe; BLM: Border Leicester-Merino

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35 Table 8. Predicted carcass value for the fore, saddle and hind sections of carcass for the Maternal, Merino and Terminal sired lambs for the range
36 of post weaning weight (PWWT), c-site fat depth (PFAT), c-site eye muscle depth (PEMD) and Carcass Plus Index values – wether progeny of
37 Merino dams at 23kg carcass weight.

Sire type	Breeding value	Fore section lean value (\$)	Saddle section lean value (\$)	Hind section lean value (\$)	Carcass value (\$)	\$ difference (high-low)	\$ per unit breeding value
<i>PWWT</i>							
Maternal	Low (-6.1)	74.65	92.11	103.52	270.28		
Maternal	High (12.4)	74.52	96.88	104.48	275.87	5.59	0.30
Merino	Low (-5)	76.70	96.31	106.53	279.54		
Merino	High (10.8)	76.58	100.57	107.38	284.52	4.98	0.32
Terminal	Low (5.3)	75.46	98.52	106.30	280.28		
Terminal	High (18.6)	75.36	102.22	107.01	284.58	4.31	0.32
<i>PFAT</i>							
Maternal	PFAT low (-2.1)	76.93	99.67	107.55	284.15		
Maternal	PFAT high (2.6)	70.71	86.83	98.25	255.79	-28.36	-6.03
Merino	PFAT low (-1.9)	76.64	98.17	106.89	281.69		
Merino	PFAT high (1.9)	71.63	87.94	99.41	258.99	-22.70	-5.97
Terminal	PFAT low (-2.5)	77.78	105.64	110.26	293.68		
Terminal	PFAT high (2.3)	71.36	91.75	100.52	263.63	-30.05	-6.26
<i>PEMD</i>							
Maternal	PEMD low (-2.5)	73.72	89.45	96.69	259.85		
Maternal	PEMD high (1.8)	75.68	96.68	106.00	278.36	18.51	4.30
Merino	PEMD low (-2.6)	75.76	92.56	106.40	274.71		
Merino	PEMD high (2.6)	78.20	101.61	108.61	288.42	13.70	2.64
Terminal	PEMD low (-2.8)	74.07	91.86	105.40	271.33		
Terminal	PEMD high (5.0)	77.65	105.33	111.57	294.54	23.22	2.98
<i>Carcass Plus</i>							

Maternal	Carcass Plus low (64)	72.29	90.51	102.04	264.84		
Maternal	Carcass Plus high (184)	75.32	98.76	106.94	281.03	16.19	0.13
Merino	Carcass Plus low (69)	76.30	90.79	102.23	269.32		
Merino	Carcass Plus high (160)	74.77	97.07	105.96	277.80	8.47	0.09
Terminal	Carcass Plus low (134)	74.36	94.64	104.70	273.69		
Terminal	Carcass Plus high (209)	77.09	100.03	107.84	284.96	11.27	0.15
38	PWWT: post weaning weight; PEMD: post weaning eye muscle depth; PFAT: post weaning c-site fat depth						

39 Table 9. Predicted carcass value for the fore, saddle and hind sections of carcass for the Maternal, Merino and Terminal sired lambs for the range
40 of post weaning weight (PWWT), c-site fat depth (PFAT), c-site eye muscle depth (PEMD) and Carcass Plus Index values – wether progeny of
41 Merino dams at 280 days of age.

Sire type	Breeding value	Fore section lean value (\$)	Saddle section lean value (\$)	Hind section lean value (\$)	Carcass value (\$)	\$ difference (high-low)	\$ per unit breeding value
<i>PWWT</i>							
Maternal	Low (-6.1)	66.10	81.70	92.26	240.06		
Maternal	High (12.4)	75.23	97.79	105.42	278.44	38.39	2.07
Merino	Low (-5)	57.33	72.30	80.87	210.50		
Merino	High (10.8)	73.38	96.44	103.13	272.96	62.46	3.95
Terminal	Low (5.3)	73.30	95.75	103.42	272.47		
Terminal	High (18.6)	79.73	108.06	112.88	300.67	28.20	2.10
<i>PFAT</i>							
Maternal	PFAT low (-2.1)	74.74	96.88	104.65	276.28		
Maternal	PFAT high (2.6)	66.15	81.32	93.09	240.57	-35.71	-7.60
Merino	PFAT low (-1.9)	65.27	83.79	91.81	240.87		
Merino	PFAT high (1.9)	58.85	72.46	82.52	213.84	-27.03	-7.11
Terminal	PFAT low (-2.5)	80.39	109.13	113.76	303.28		
Terminal	PFAT high (2.3)	71.14	91.48	100.23	262.86	-40.42	-8.42
<i>PEMD</i>							
Maternal	PEMD low (-2.5)	69.47	84.38	91.41	245.27		
Maternal	PEMD high (1.8)	73.23	93.60	102.74	269.57	24.30	5.65
Merino	PEMD low (-2.6)	62.32	76.37	88.44	227.14		
Merino	PEMD high (2.6)	66.76	86.94	93.50	247.20	20.06	3.86
Terminal	PEMD low (-2.8)	73.82	91.56	105.07	270.45		
Terminal	PEMD high (5.0)	80.89	109.65	115.97	306.51	36.06	4.62
<i>Carcass Plus</i>							

Maternal	Carcass Plus low (64)	66.10	81.70	92.26	240.06		
Maternal	Carcass Plus high (184)	79.89	104.67	113.08	297.64	57.59	0.48
Merino	Carcass Plus low (69)	57.33	72.30	80.87	210.50		
Merino	Carcass Plus high (160)	69.69	90.55	99.12	259.36	48.86	0.54
Terminal	Carcass Plus low (134)	73.30	95.75	103.42	272.47		
Terminal	Carcass Plus high (209)	81.33	105.48	113.45	300.26	27.79	0.37

42 PWWT: post weaning weight; PEMD: post weaning eye muscle depth; PFAT: post weaning c-site fat depth

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