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Identification of substitute muscle groups for retail beef demand and supply equations

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Abstract

In modelling retail meat demand and supply equations it is difficult to identify close substitutes or competing products. However, close substitutes can be identified through a comparison of meat attributes, especially cooking method and sensory attributes. The Meat Standards Australia (MSA) grading system can be used to identify primals (whole muscles) with similar attributes. The MSA system is based on carcase attributes, cooking methods and sensory properties and it allocates 3, 4 or 5 stars to beef primals. Prices for different star grades are affected by the quantity of meat allocated into each grade and this is determined by cooking method, which is dependent upon season. Estimating demand and supply by MSA grades and cooking methods requires fewer variables and therefore reduces multicollinearity and increases model efficiency.

Key words MSA, beef cuts, sensory attributes and cooking methods.

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1. Introduction

The purpose of this paper is to identify beef products that are substitutes for demand and supply analysis. In analysing markets for new or altered meat products it is important to have a good understanding of the market groups into which the new products will be allocated. The usual method of determining substitutes and complements is to examine the signs of the cross price elasticities of each product; however, in a quantity constrained market, only relative prices change, and therefore the usual "sign" rules do not apply.

The current method of allocation is to group products by their designated cooking method. Unfortunately this method does not allow for discrete product classes as some muscles can be used in a number of cooking methods. An alternative rule is to allocate meat products to groups with similar retail prices. This allocation rule also has some problems in that prices are determined by both muscle weight and quality and it is has been unclear which of these two characteristics was driving prices.

Meat products can now be allocated to market groups on the basis of their levels of sensory properties. Meat Standards Australia (MSA) is a grading scheme that uses carcase grading, meat processing, product management, and cooking methods to score individual muscle products (Polkinghorn, Thompson, Watson, Gee and Porter 2008). The derived scores, called MQ4 scores, are then used to allocate muscles to market "star" grades. The current MSA system has four grade levels including "fail", "three", "four" and "five" stars. The MSA star grade correlates with MQ4 scores that were derived from independent consumer sensory testing. The MSA star ratings for new products can therefore be derived by testing new products in meat sensory trials to evaluate product tenderness, juiciness, flavour and overall liking on a 100-point scale. The new product can then be allocated to the most suitable star grade group. Quantities of product in each star grade can then be calculated and new prices determined from the supply and demand curves for each star group. The new price times quantity of the new product then provides the value (revenue) of the new product.

The process of mapping MSA quality grades into retail prices is still evolving (Polkinghorn, Watson, Thompson and Pethic 2008, and Dart, Griffiths, Rodgers and Thompson 2008). Currently each muscle within each star grade has a unique price. It may be argued that if the quality of a product is the same within each star grade then the price of each product within the star grade should also be the same. The solution to this problem is to also include the other factors that affect meat prices in addition to meat sensory qualities in demand and supply equations. Other factors include the quantity of each muscle, the visual characteristics and portion size.

The MQ4 scores explain much of the variation in prices for most beef muscles but for a small group of muscles other characteristics will need to be evaluated. Models relating muscle prices, quantities and quality were constructed to identify the functional relationships between these traits. The value of increasing the MQ4 scores was next calculated for eight muscles. A cluster analysis model was then used to identify muscles that were similar for price and quality traits. The limitations and suggested improvements to the model are presented prior to the conclusion.

2. Models

The relationship between muscle prices and MQ4 scores or quality scores can be expressed through a log-linear regression. Watson, Polkinghorne and Thompson (2008) show a table of MQ4 scores for various "muscle by cook" combinations derived from the MSA system. In their table Watson *et al* show MQ4 scores for five methods of cookery. The MQ4 scores for the grill method of cookery were combined with muscle prices for 3-star MSA products derived from an Australian wide survey conducted by Millward-Brown (2006). The relative prices for the New South Wales market in each month are shown in Figure 1.

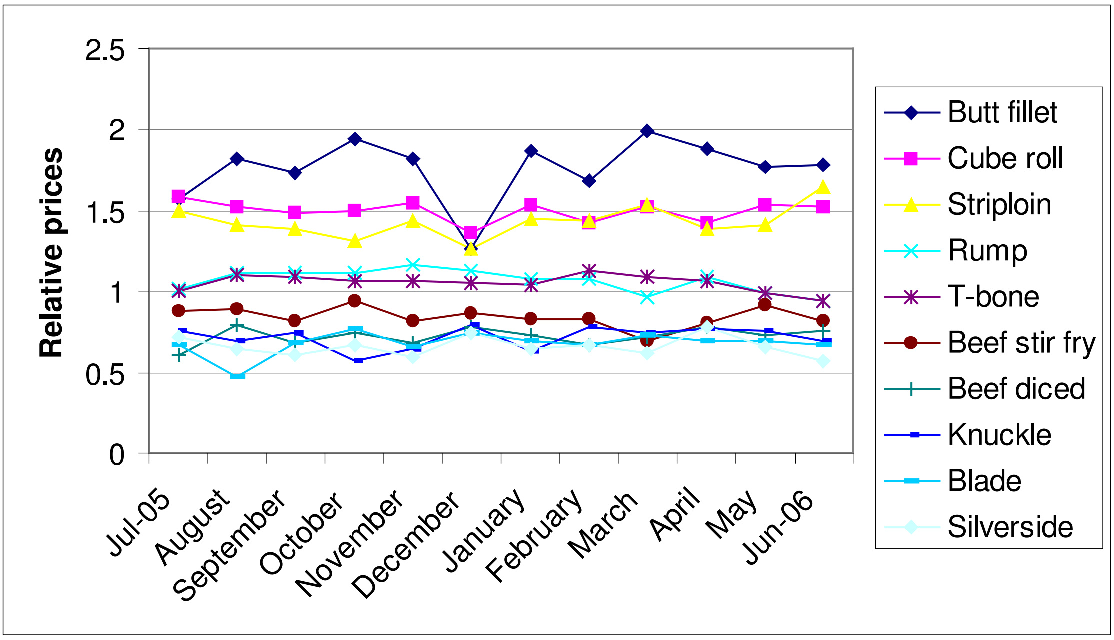

Figure 1 Relative prices for NSW markets for 10 muscles July 05 to June 06
Source: Calculated from Millward-Brown (2006).

Ewers, Pitchford, Deland, Rutley and Ponzoni (1999) have shown that muscles increase in weight at a relatively constant proportion of carcase weight when adjusted for fat. This accounts for the appearance of constant margins between most of the price series for different muscles in Figure 1.

The price data for each muscle were extracted for the NSW series and indexed to the average price for all ten muscles in each month. The monthly relative prices were then averaged over the period July 2005 to June 2006. This process therefore smoothed monthly prices and then averaged them over twelve months to remove seasonal fluctuations, but it retained relative prices between muscles. The data used for this analysis are replicated in Appendix 1.

The log of relative prices between muscles (i) equals the MQ4 scores of the muscles plus an error term (e). This relationship is shown as equation 1.

$$\text{Log Price}_i = a + b \text{ MQ4 score}_i + e \qquad (1)$$

The results for this regression are shown in Table 1. The adjusted R-square was strong at 0.90 and the model F-value was 29.75, which was significant at the 95 per cent level. The sign on the parameter for the MQ4 score was positive, as expected, and its T-value was significant at the 95 per cent level.

Table 1 Regression results for MQ4 scores on the log of relative prices

LN Price Variable	Parameter Estimate	Standard Error	DF	T-value	Pr > |t|		
						R-square	0.9370
						Ad R-square	0.9055
Intercept	-3.11655	0.55829	1	-5.58	0.0306	Model F	29.75
MQ4 score	0.06051	0.01109	1	5.45	0.0320	Prob > F	0.032

The flexibility (η_i) of the price MQ4 score regression is provided by equation 2.

$$\eta_i = (\exp^{(\alpha\beta MQ4i)} - 1) / \alpha \tag{2}$$

where α is 0.01 for a one per cent change in MQ4 scores$_i$ and β is the parameter estimate (0.06051). The calculated price flexibilities are shown in Table 2 along with the corresponding change in relative prices and monthly average prices for each muscle.

Table 2 Price flexibilities with relative and average prices for each muscle

Primal	Price Flexibility	Relative Prices	Average Prices
Butt fillet	4.789	0.084	1.630
Cube roll	3.835	0.057	1.105
Strip loin	3.440	0.049	0.948
T-bone	3.309	0.035	0.668
Beef stir fry	2.128	0.018	0.344
Beef diced	3.303	0.024	0.461
Knuckle	2.885	0.021	0.395
Silverside	2.673	0.018	0.339
Average	3.295	0.038	0.589

The change in average prices reported in Table 2 shows the price increase in dollars per kilogram for a one per cent increase in the MQ4 score for each muscle. The average increase in MQ4 score was 59 cents per kilogram for a one per cent increase in the MQ4 scores. The average increase in relative prices was 3.8 cents per kilogram.

3. Relationship between muscle weight and quality

It is useful to understand the relationship between the quantity of muscles and the quality of muscles. Muscle quantity is correlated with muscle quality as determined by MQ4 scores. The relationship between the quantities of muscle, as a proportion of carcase weight, and quality, expressed as MQ4 scores, is described by a linear-log regression shown as equation 3.

$$\text{Quantity}_i = a - b \log \text{Quality}_i + e \quad (3)$$

where the relative quantity of each muscle *i* is a function of the quality of each muscle, as determined by their grill MQ4 scores, and *e* is the error term.

Table 3 Regression results for the log of MQ4 scores on 10 muscle weights

Weight Variable	Parameter Estimate	Standard Error	DF	T-value	Pr > |t|	R-square	0.8864
						Ad R-square	0.8637
Intercept	0.69548	0.10716	1	6.49	0.0013	Model F	39.01
LN MQ4	-0.17324	0.02774	1	-6.25	0.0015	Prob > F	0.0015

The regression statistics in Table 3 show the negative relationship between MQ4 scores and muscle weights as a proportion of carcase weight. The adjusted R-square value was strong at 0.86 and the model F-value was 39.01, which was significant at the 99 per cent level. The parameters each had the expected signs and their T-values were both significant at the 99 per cent level. Thus as muscle weight increases then muscle quality decreases.

The strong relationship between muscle weights and MQ4 scores may cause multicollinearity issues if they are used together as independent variables with price as the dependent variable and therefore any model including the two variables would need to be constructed to minimise that problem.

The quantity-quality regression shows an important relationship, which is that muscle quality is primarily determined by muscle quantity. This result is similar to other sensory panel data where it has been shown that muscle tenderness decreases with increasing muscle size (Farrell *et al.* 2009). The strength of the quantity-quality relationship (R-square 0.70) decreases when highly variable muscles such as the gluteus medius, infraspinatus, triceps brachii and serratus ventralis are included in the analysis. The first three of these muscles were not included in the MSA MQ4 grill data set used in this analysis.

Some retail cuts contain more than one muscle and sometimes the quality of the two or more muscles is vastly different. This is particularly the case with the rump, which contains portions of the relatively tough biceps femoris and gluteus medius. The chuck and blade cuts have similar problems with composite muscles.

The strength of the weight-quality relationship indicates that further research is required to model this effect for other muscles and different cattle weights. Other meat quality factors may be responsible for the weight-quality effect when it is weak. These other factors may include the content of sinew, connective tissues or the texture.

4. Cooking methods

The selected method of cookery affects the strength of the price-quality relationship. The cooking methods assessed to date under the MSA system include grill, roast, stir-fry, thin-slice, slow cook and corn (Watson *et al.* 2008). The R-square value decreased to 0.37 for the thin-slice method; however, the T-statistic on the MQ4 score for that cooking method was not significant. The price-quality relationship was not modelled well by any of the alternate methods of cookery other then the grill method, which is the method used for most meat quality assessments. A price index incorporating cookery methods could better explain the price-quality relationship, relative to the grill series; however, prices are not regularly available for alternate cooking methods and no research has been identified that describes the percentage use of different cookery methods by Australian consumers from which to construct a cooking method index.

Without verification with market data it is not possible to estimate the change in cooking method mix due to different seasons throughout the year. It is expected that during summer barbeques, grills, thin-sliced and stir-fries would be common. In winter stews (slow cook), roasts and corn meats might be preferred more. To properly account for the quantity of meat in each MSA star grade it will be essential to model changes in cooking methods due to seasons as the MQ4 scores change for the same muscle depending on the cooking method used. The chuck muscle is a good example. The muscle can score three stars when roasted or stir fried, or four stars when it is grilled, thin sliced or slow cooked. Alternatively the knuckle will score three stars for grill and slow cook but four stars for roast and stir-fry (Watson *et al* 2008). Hence as the cooking methods change with seasons the mix of muscles and therefore the quantities and prices of each star grade will subsequently change.

The MQ4 scores for muscles change with different carcase and manufacturing treatments and therefore the levels will change for different animals, process treatments and management conditions. The supply side of the market will need to incorporate expected animal numbers, weights, ages (ossification), marbling scores and source locations (Bos *indicus* content) to adequately model the input muscle quantities into each star grade.

The MSA MQ4 scores for the grill method of cookery are at present the best available index to use to allocate muscles to market groups for demand and supply analysis. The derivation of market groups based on the grill MQ4 scores and log relative prices for the NSW market is described below.

5. Cluster analysis

Cluster analysis is a method of grouping data across a number of correlated variables. The procedure in SAS® allows for the program to form clusters by several methods and the one used here was the nearest neighbour approach (Johnson 1998). That is, the program identifies muscles that have similar attribute levels across each of the correlated input variables. In this analysis the input variables were log relative prices and MQ4 scores for the grill set. Table 4 shows the eigen values which indicate the number of orthogonal vectors required to map the variance of the variables. The eigen values for the covariance matrix of these two variables shows that 99.97 per cent of the variation was explained by the first eigen vector.

Table 4 Eigen values of the covariance matrix for Log price and MQ4 scores

	Eigen value	Difference	Proportion	Cumulative
1	162.659	162.605	0.9997	0.9997
2	0.054		0.0003	1

Root Mean Square of the total sample deviation 9.019.
Mean distance between sample observations 14.9264.

The variance-covariance matrix is used to produce groups of similar muscles across the two input variables. A hierarchical cluster tree is presented as Figure 2. That figure shows up to seven clusters working from one at the top to seven at the bottom of the figure. The vertical axis shows the unit distance between cluster groups. Clusters that are similar are closer together vertically and those further apart are dissimilar. Hence T-bone and diced meat are similar whereas cube roll and butt fillet are dissimilar.

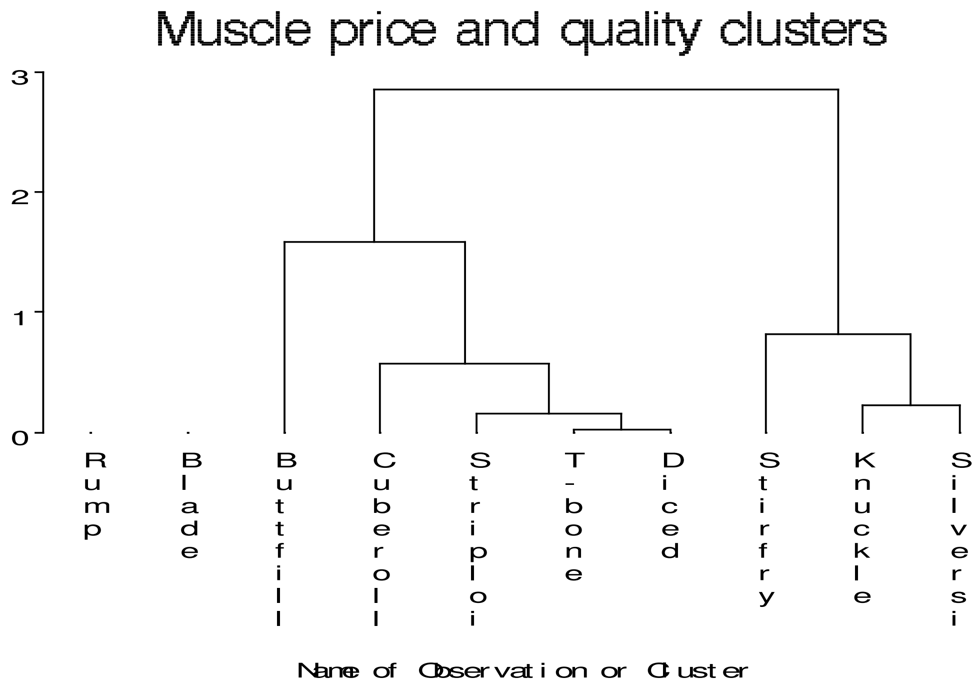

Figure 2 Clusters for muscles over log price and MQ4 scores

There are two tests available to determine the number of clusters to retain from the seven available (Johnson 1998). The pseudo Hotelling's T^2 test compares the means of two clusters to determine if the means are significantly different from one another. For example, if the mean for two clusters is significantly different to the mean for three clusters then the T^2 statistic is large. If the difference in the means is small then the T^2 statistic indicates that the number of cluster groups can be increased. The T-statistic (PST^2) for this sample indicates that five clusters are superior to four, but six are not superior to five, therefore five clusters are deemed appropriate. The statistics for this test are provided in Table 7, which also shows the members of each cluster, frequency, R-square and distance to the nearest cluster.

Table 5 Pseudo Hotellings T^2 test (PST^2) for up to seven clusters

Cluster	Member 1	Member 2	FREQ	R-Square	PST^2	Distance
7	T-bone	Diced	2	1.000	0.0	0.0259
6	Strip loin	CL7	3	0.997	43.5	0.1543
5	Knuckle	Silverside	2	0.992	0.0	0.2278
4	Cube roll	CL6	4	0.953	27.1	0.5715
3	Stir fry	CL5	3	0.888	12.7	0.8174
2	Butt fillet	CL4	5	0.581	21.7	1.5822
1	CL2	CL3	8	0.000	8.3	2.8477

The second test for the appropriate number of clusters is Beale's pseudo F-statistic. Beale's pseudo F-statistic minimises the residual sums of squares of the distance that observations are away from their cluster means. The results for the residual sum of squares, F-values and critical F-values for each of the seven clusters are shown in Table 6.

Table 6 Beale's Residual sum of squares and f-values for up to seven clusters

Clusters	RS Squares	P F-value	Crit F (0.25)	Cluster test
7	0.12	49.29	2.75	7 vs 6
6	3.32	3.48	2.75	6 vs 5
5	9.11	9.88	6.30	5 vs 4
4	54.07	3.46	2.75	4 vs 3
3	157.90	2.83	7.50	3 vs 2
2	477.24	1.11	8.58	2 vs 1
1	1139.29			

The results in Table 6 show the pseudo F-values from amalgamating the muscles into seven clusters down to one cluster. The pseudo F-value for the test of four versus three clusters is larger than the critical F-value; therefore four clusters would be preferred to three. The F-value is larger for each of the comparative tests above four clusters indicating that more clusters are preferred. There is a peak F-value for the test of five versus four clusters and this number of clusters (five) corresponds with Hotellings T^2 value result as discussed above. This result supports the conclusion that five clusters are appropriate for this data set. Table 7 shows the muscle membership to five cluster groups.

The grouping of muscles shown in Table 7 can be used to identify substitute muscles or product groups. Three products including butt fillet, cube roll and stir-fry each require individual market assessments. Strip loin, T-bone and diced meat can be analysed together. Similarly knuckle and silverside can be added into the same product grouping. The scores for blade and rump, which were not analysed for the grill cookery method data here, are consigned to group 6 as other research (Farrell *et al* 2009) has indicated that these muscles are similar but they require further analysis.

Table 7 Muscle groups for demand and supply analysis

Group	Member 1	Member 2	Member 3
1	Butt fillet		
2	Cube roll		
3	Strip loin	T-bone	Diced
4	Stir fry		
5	Knuckle	Silverside	
6*	Blade	Rump	

* Blade and rump were not included in this analysis of the MQ4 scores for the grill cookery method. Both muscles have MQ4 scores reported for other cookery methods.

The process is now relatively simple to analyse dollar values for new muscle products. The MQ4 score of a new product can be aligned with the products in any of the five market groups and by adding the quantity of the new product to that group a new price can be estimated and thus the price times quantity will provide the potential revenue of the new product for each carcase.

The process for estimating the added value to lower grade muscles from further treatments is similar to that for new products. Consider the case of adding value to the silverside muscle (outside flat) through a new manufacturing process that tenderises the muscle. If the silverside were to be tenderised then it could potentially rise from a group 5 product to a group 4 product. In that case the quantity of silverside would be subtracted from group five and then the group five price would be recalculated. The quality of tenderised silverside would then be added to group four and a new price would then be estimated for that group.

6. Limitations of this model

This model is limited by the available knowledge of cooking methods in each season and the other quality factors that affect market prices such as visual characteristics including meat and fat colour, sinew, cartilage, fat, bone and portion size.

The supply side of the model will require data for environmental factors that affect cattle production and quality, and therefore the MSA scores, which are used to calculate the quantity of product in MSA star group that in turn affect the prices of each group.

7. Conclusion

The aim of this research was to identify muscles that are close substitutes in terms of quality and prices. The identification of these variables was determined by first relating quality to prices through MQ4 scores and then using cluster analysis to collect muscles into unique market groups. The price flexibility derived from the price-quantity relationship indicated that the average benefit from increasing MQ4 scores by one point was 59 cents per kilogram. A benefit of 163 cents per kilogram was calculated for the butt fillet muscle. The smallest benefit from increasing the MQ4 score by one point was for the silverside muscle at 34 cents per kilogram.

The grill method of cookery provided the only MQ4 data set to correlate well with relative market prices for each muscle. The regressions for the other cookery methods were poor. This research clarified the negative relationship between muscle quantity and quality. Cuts that are composed of composite muscles such the rump and chuck, will require further analysis to ensure that they are allocated to the correct market groups.

The number of unique muscle products was reduced from eight to five where butt fillet, cube roll and stir-fry meats were significantly different to the other muscle groups and will need to be modelled separately. Strip loin, T-bone and diced meat were grouped together as were knuckle and silverside. The use of the MSA system has enabled the number of market groups to be reduced for demand and supply analysis. This is important for modelling efficiency and it reduces the extent and cost of data collection and analysis. The model could be improved by collecting cooking method data for each month or season and, thus, incorporating seasonality into the demand side of the model. The model is useful for allocating new products to market groups once they have been evaluated for their sensory scores.

References

Dart, C., Griffiths, G., Rodgers, H., Thompson, J. (2008). The aggregate economic benefits at the wholesale level from the adoption of Meat Standards Australia. First estimates. *Australasian Agribusiness Review,* no. 16, in press.

Ewers, A., Pitchford, W., Deland, M., Rutley, D. and Ponzoni, R. (1999). Breed differences and prediction equations for saleable beef yield across a broad range of genotypes. Research Report; The University of Adelaide.

Farrell, T.C., McCluskey, J.J., Busboom, J.R., and Wahl, T.I. (2009). A hedonic model of sensory attributes of retail beef cuts. Paper in review, School of Economic Science, Washington State University.

Johnson, D.E. (1998). Applied multivariate methods for data analysis. Duxbury Press: A division of the International Thompson Publishing Company, Pacific Grove, CA, USA.

Millward-Brown (2006). Prices series: Dart, C., Griffiths, G., Rodgers, H., Thompson, J. (2008). The aggregate economic benefits at the wholesale level from the adoption of Meat Standards Australia. First estimates. *Australasian Agribusiness Review* no. 16, in press.

Polkinghorne, R., Philpott, J., Gee, A., Doljanin, A. and Innes, J. (2008). Development of a commercial system to apply the Meat Standards Australia grading model to optimise the return on eating quality in a beef supply chain, *Australian Journal of Experimental Agriculture*, Vol. 48, No.11, pp. 1451-1458.

Polkinghorne, R., Thompson, J.M., Watson, R., Gee A. and Porter, M. (2008). Evolution of the Meat Standards Australia (MSA) beef grading system, *Australian Journal of Experimental Agriculture*, Vol. 48, No.11, pp. 1351-1359.

Polkinghorne, R., Watson, R., Thompson, J. M. and Pethick, D.W. (2008). Current usage and future development of the Meat Standards Australia (MSA) grading system, *Australian Journal of Experimental Agriculture*, Vol. 48, No.11, pp. 1459-1464.

Watson, R. Polkinghorne, R. and Thompson, J.M. (2008). Development of the Meat Standards Australia (MSA) prediction model for beef palatability, *Australian Journal of Experimental Agriculture*, Vol. 48, No.11, pp. 1368-1379.

Appendix 1 Relative muscle prices by muscle for NSW markets 2005-2006

Muscle	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Ave
Butt fillet	1.576	1.825	1.735	1.940	1.823	1.259	1.867	1.682	1.988	1.883	1.768	1.781	1.761
Cube roll	1.590	1.521	1.483	1.504	1.548	1.363	1.534	1.429	1.526	1.422	1.530	1.522	1.498
Strip loin	1.494	1.408	1.391	1.311	1.433	1.266	1.452	1.439	1.535	1.385	1.411	1.648	1.431
Rump	1.014	1.113	1.115	1.108	1.164	1.131	1.081	1.073	0.970	1.089	0.984	0.944	1.066
T-bone	1.000	1.095	1.086	1.064	1.060	1.053	1.037	1.125	1.088	1.060	0.990	0.944	1.050
Stir fry	0.877	0.896	0.818	0.936	0.811	0.870	0.832	0.827	0.692	0.808	0.911	0.815	0.841
Diced	0.603	0.796	0.684	0.744	0.682	0.783	0.735	0.665	0.722	0.779	0.728	0.757	0.723
Knuckle	0.754	0.697	0.748	0.570	0.645	0.792	0.630	0.778	0.742	0.765	0.759	0.697	0.715
Blade	0.669	0.473	0.676	0.763	0.656	0.744	0.698	0.663	0.725	0.692	0.688	0.672	0.677
Silverside	0.712	0.647	0.608	0.672	0.592	0.744	0.645	0.671	0.617	0.779	0.653	0.568	0.659

Source: Milward-Brown 2006.

Appendix 2 Index weight and MQ4 scores for five cooking methods

Primal	Index Weights	MQ4 Grill	MQ4 Roast	MQ4 Stir fry	MQ4 Thin slice	MQ4 Slow cook
Butt fillet	0.016	77.3	76.4	79.3	74.1	NA
Cube roll	0.017	62.2	62	61.8	64.2	NA
Strip loin	0.022	55.9	56.6	58	58.5	NA
Rump	0.038	NA	39.6	41.7	54.9	52.5
T-bone	0.022	53.8	54.5	57.1	57.6	NA
Beef stir fry #	0.062	34.8	43.4	43.4	56.3	47.4
Beef diced +	0.045	53.7	55	55.8	59.2	62
Knuckle	0.037	47	60.1	55	58.6	42.8
Blade	0.055	NA	48.1	50.4	52.6	53.5
Silverside *	0.057	43.6	47.4	45.2	47.7	44.5

Index weight is the muscle weight as a proportion of the hot standard carcase weight. Source Dart, Griffiths, Rodgers and Thompson (2008). MQ4 scores. Source: Watson, Polkinghorne and Thompson (2008), Table 10, page 1376. * The semitendinosus was used for the analysis of silverside rather than the biceps femoris. # Semimembranosus was used for stir-fry. + Serratus ventralis was used for diced meats.