Australasian Agribusiness Review - Vol.17 - 2009

Paper 10

ISSN 1442-6951

Identification of substitute 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.

1. Introduction

The aim of this research was to identify beef muscles that were substitutes or complements and use this information to define appropriate demand equations.

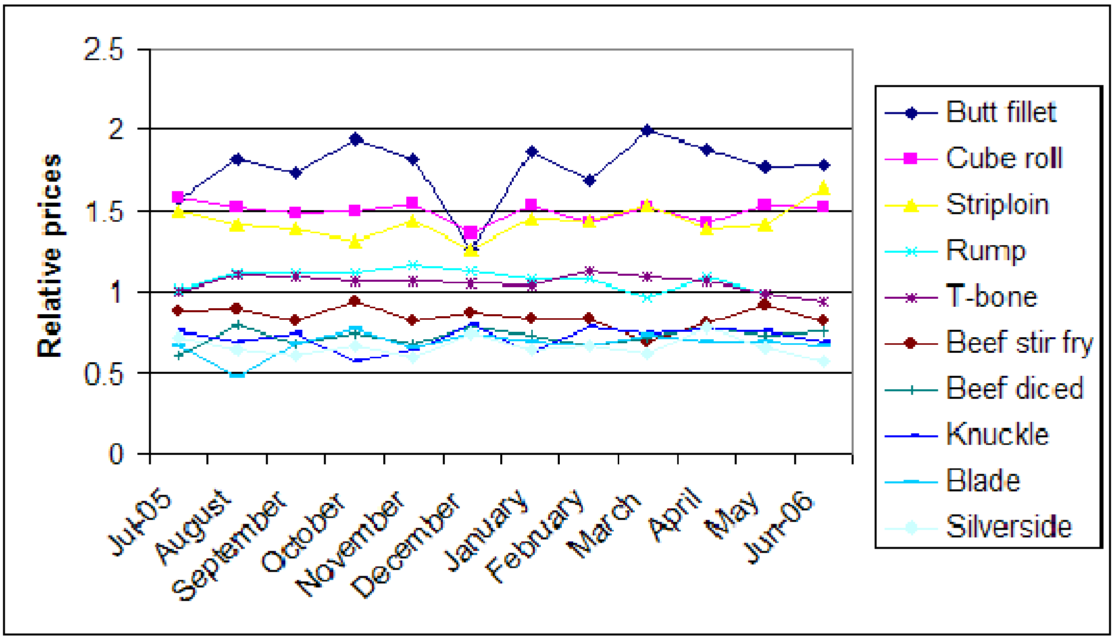
Many beef grading systems have been developed to rank beef carcasses into various quality grades and most use a cross sectional analysis of the longissimus dorsi muscle. The longissimus dorsi muscle alone does not provide a reliable indicator of the palatability of other muscles in the carcase. Muscle palatability is also affected by muscle preparation (steak, cube or thin sliced) and cooking method (roast, fry, grill etc.). The challenge then for market analysis is to identify muscles that are similar and different when a muscle-grading scheme includes cooking method.

Estimation of meat demand equations requires knowledge of which muscles or retail beef cuts are substitutes and which are complements. Cross price elasticities are typically used to assess these relationships. The normal sign rules that assist in the determination of the cross relationships do not apply in quantity-constrained markets. Similarly products cannot be simply aggregated by their retail or wholesale prices per kilogram as other factors such as cooking method also affect the muscle and its utility in the minds of consumers.

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 monthly prices for the New South Wales market 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 monthly price series for different muscles in Figure 1.

The price data for each muscle were extracted for the NSW series and indexed to the mean 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.

3. Hedonic equation

Hedonic functions have been widely used to value attributes of products on both the producer and the consumer sides of the market. The model dates back to Waugh's (1928) analysis of vegetable attributes. Lancaster (1966) and Rosen (1974) refined the model. Ladd and Martin (1976) and Ladd and Suvannunt (1976) have since shown the use of the model in assessing input and consumer characteristics respectively.

The practice of using hedonic models to value attributes of carcasses is well developed (Porter and Todd, 1985, Lin and Mori, 1991, Wahl, Shi and Mittelhammer, 1995 and Hopkins and Farrell, 2007). The model has also been adapted to value attributes of beef muscles (Unnevehr and Bard 1993, SteenKamp and Van Trijp 1996 and Griffith, Rogers, Thompson and Dart, 2009).

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	Parameter	Standard				R-square	0.9370
Variable	Estimate	Error	DF	t-Value	Pr > |t|	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 price flexibility (ηi) for each muscle in the MQ4 score regression is provided by equation 2.

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

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.

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.

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

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 3 shows the eigen values which indicate the number of orthogonal vectors required to map the variance of the total variable space. The eigen values for the covariance matrix of these two variables showed that 99.97 per cent of the variation was explained by the first eigen vector.

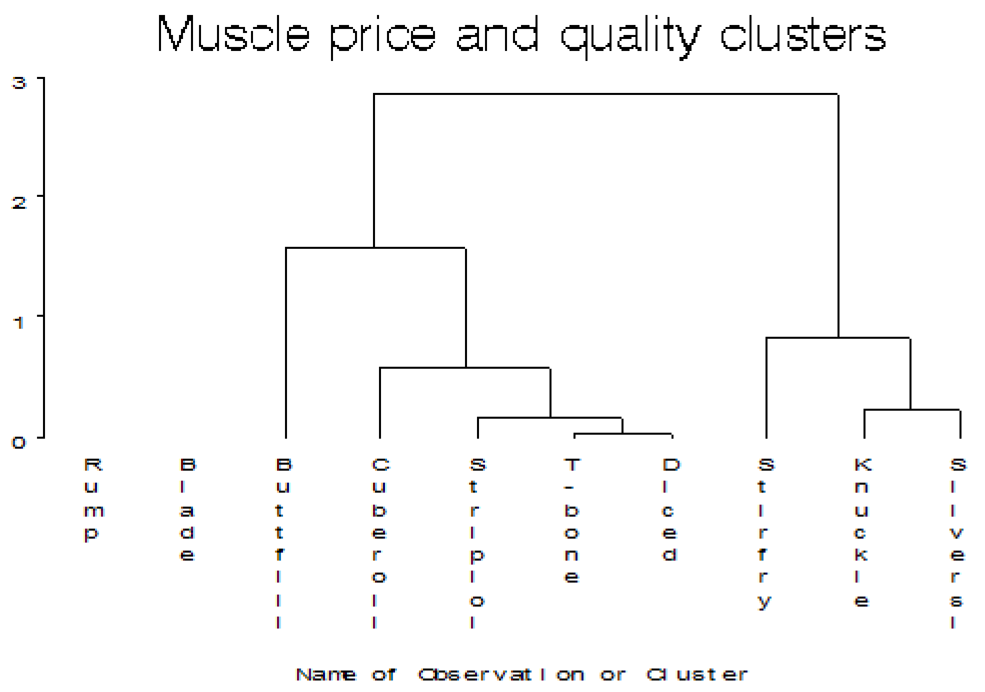
Table 3 Eigen values of the covariance matrix for Log price and MQ4 scores

	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 4, which also shows the members of each cluster, frequency, R-square and distance to the nearest cluster.

Table 4 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 5.

Table 5 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 5 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 6 shows the muscle membership to five cluster groups.

The grouping of muscles shown in Table 6 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 6 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.

7. 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 groups that in turn affect the prices of each group.

8. 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. 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.

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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. Pers Comm. Griffith, G. (2008).

Appendix 2 Index weight and MQ4 scores for five cooking methods

	Index	MQ4	MQ4	MQ4	MQ4	MQ4
Primal	Weights	Grill	Roast	Stir fry	Thin slice	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 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.