A MULTIVARIATE ANALYSIS OF TWO COOKING METHODS FOR NINE MUSCLES FROM LIMOUSIN AND WAGYU STEERS

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of TERENCE CHRISTOPHER FARRELL find it satisfactory and recommend that it be accepted.

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Abstract

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Retail beef cuts are heterogenous due to their function and composition that influences sensory and mechanical attributes of meat products. The levels of attributes change for cooking methods, breed type and muscle type. The aim of this research was to develop a model for analysing variation in beef muscle attribute levels by muscle type, breed and cooking method, and to estimate an economic value for the attributes.

This dissertation contains three papers. The first addresses the issue of modelling meat demand by retail cuts rather than a whole carcass. The second examines attributes for two cooking methods on nine muscles from two cattle breeds. A trained sensory panel evaluated samples for initial tenderness, sustained tenderness, juiciness, beef flavour and off flavour. Shear force, cooking time and cooking loss were also recorded. Correlated attributes were analysed using factor analysis (FA). The FA model provided variables that were used in a hedonic model to derive price flexibilities that were discussed in the third paper.

Initial tenderness, sustained tenderness, juiciness, flavour and shear force loaded on the first factor and cooking time, cooking loss and off flavour loaded on factor 2. The sign and relationship between the attributes was consistent with expectations and other research.

When the factor scores were used in a hedonic equation the results revealed that increasing tenderness by one per cent would increase price by 10.6 cents per pound (c/lb). Similarly increasing juiciness and beef flavour scores would produce a price increase of 9.7 and 9.4 c/lb respectively. Increasing cooking loss and cooking time would lead to a decrease in price by 9 and 9.7 c/lb respectively. A reduction in off-flavour would raise price by 6 c/lb.

The contribution of this research was: to provide a method of analysing bundled attributes by reducing the attribute space from eight to two dimensions; to rank muscles according to their attribute scores on those two dimensions; to show that cooking methods and breed have a significant influence sensory scores; and to establish an economic value for beef sensory attributes.

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CHAPTER ONE

INTRODUCTION

Demand for retail beef cuts has been difficult to model in economic systems due to a lack of information on the degree of substitution between products. There are various methods available to classify retail cuts; however, those methods rely on carcass grades, which bear little relationship to the eating quality of particular muscles. The difficulty is to identify the circumstances for which one muscle will be a substitute for another. It is also important to identify muscles that have few or no substitutes. The consumer's choice of cooking method has an impact on the sensory attributes of various muscles and under various cooking regimes some muscles will be preferred; however, the rank of muscles changes with each cooking method.

In this dissertation multivariate statistical techniques for correlated sensory and mechanically measured data and economic models are employed to answer three questions. The first is, what muscles react similarly when fast cooking methods are used? The second is how can muscles be ranked while incorporating a bundle of attributes rather than examining each attribute in isolation? Finally, what is the economic value of increasing sensory attributes?

The first question arises from a benefit-cost approach to research on meat sensory attributes. Meat scientists have worked on improving the levels of sensory and mechanical measures of meat products; however, little work has been done on valuing the benefits of this work to establish whether the returns are greater than the costs. In this dissertation we develop a model for estimating returns from increasing or decreasing the level of an attribute by one per cent. This measure is called a price flexibility. Data were produced through a trained beef sensory panel and the data were evaluated through the application of statistical techniques and an economic hedonic model.

The second question addressed in this research is to examine the levels of attributes of a selection of muscles and then to collate those muscles that perform similarly over a bundle of attributes for two fast cooking methods.

The dissertation contains three manuscripts. Each manuscript is formatted in the style appropriate for the audience or journal to which it is targeted.

The first manuscript reviews economics and meat science literature as it relates to meat purchasing decision processes. A potential modelling process was presented for peer consideration. The manuscript was written primarily for an audience of agricultural economists and therefore elementary meat science concepts were presented. The purpose of the paper was to justify an analysis based on the demand and supply of retail cuts or muscles, rather than whole carcasses. Previous economic work in this area has identified multicollinearity as a potential problem when including sensory variables in hedonic equations. Furthermore, few authors have recognised the need to segregate muscles by their end use characteristics, which may reduce, but not eliminate the problem. The paper also explores the attribute space surrounding meat products and identifies important factors that cause demand for retail cuts to vary. The paper concludes with an outline of the model that is presented here in Chapter 4.

The second manuscript (Chapter 3) contains a statistical technique to identify muscles that produce similar sensory attributes for two fast cookery methods on nine muscles derived from two cattle breeds. In that paper the relationships between muscles, cooking method and breed type are examined in detail. The manuscript was aimed toward a meat science audience. In this paper past research on the relationships between muscles and cooking methods was reviewed. The objective of the paper was to map the attributes space of the beef muscles by breed, muscle type and cooking methods so that similar muscles could be grouped together for demand analysis. The cooking methods used were a griddle and grill. The protocols for the cooking techniques and for the trained sensory panel and mechanical measures for shear force were then explained. Factor analysis was used to identify the dimensional space in which eight attributes resided. Subsequent analysis of the factors revealed significant differences by breed, muscle type and cooking method. The results were similar to previous work conducted on independent attributes. Important conclusions were then drawn regarding the need to examine a number of muscles when testing the impact of cooking methods on beef rather than one or two muscles.

The third manuscript (Chapter 4) combines the results of a factor analysis with an economic hedonic model to derive values for meat quality attributes of nine selected beef muscles. This paper was also targeted to agricultural economists where the focus of the paper was the economic model and statistical methods. That paper dealt with the problem of mulitcolinearity in estimating hedonic functions of data with highly correlated attributes. The model was designed to identify relevant attributes by using factor analysis. The factors, once estimated, were then used as independent variables in a regression. The hedonic equation is estimated from a regression of a price dependant variable with factor scores included as independent variables. This two-step modelling processes then produces price flexibilities for the independent attributes. The factor loadings produced some significant relationships and theoretically correct signs between the eight attributes and price. The model enables researchers to better represent the consumers purchasing decision by modelling a collection of attributes rather than analysing one attribute at a time. The model also produces estimated price increases or decreases for changes in attribute levels.

The interdisciplinary nature of this dissertation is evident in each manuscript. Knowledge of meat and food science was necessary to first understand the organic relationships that exist between animals, their nutrition, slaughter treatments, handling methods, and muscle degradation through aging and cooking processes. Skills in food science were also necessary to design and conduct a trained sensory panel for product analysis. Science and statistical skills were necessary for the interpretation of the data and the results. Economics was the catalyst for this research and it features prominently in the first and third manuscript; however, the conclusions drawn in the second manuscript are very relevant to demand analysis and the development of a product substitution matrix. The attribute-pricing model would not have been developed without an understanding of the economic theory and knowledge of the value of that information when applied to meat demand analysis. A sound knowledge of statistics was vital to reviewing literature, critiquing previous models and choosing appropriate techniques to test the results of the sensory panel. The major contribution of this dissertation was the application multivariate techniques in conjunction with an economic model to address issues common to both meat science and economics.

The results contained in each manuscript are limited due to the limited data set derived from the available cattle. Nonetheless, the results could be validated through similar experiments with more animal breeds, muscles and cooking methods. One obvious limitation to this proposal is the cost of conducting such experiments. Several organizations have collected data that could be used with the techniques described and it may be more cost effective to validate the model with that data prior to conducting more sensory experiments. Thus this work could be accurately portrayed as a proof of concept for both ranking muscles by sensory attributes and then placing an economic value on those attributes.

CHAPTER TWO

MODELLING MEAT QUALITY ATTRIBUTES

Abstract

Recent meat demand models incorporate demand functions for cuts of meat rather than whole carcasses. However, parameters for “meat quality” are seldom included in such models. Modelling difficulty arises, as meat cuts are heterogeneous in their quality attributes. Meat quality may be assessed by measurement of attributes including tenderness, juiciness and flavour. Cooking method and cooking time are two important factors that affect meat-eating quality. The purpose of this paper is to show how meat quality parameters relate to one another for retail beef cuts. A quality index for tenderness, juiciness and flavour can be incorporated directly into hedonic price functions.

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2.1. Introduction

Economists seldom employ “quality variables” in meat demand analysis even though meat products are heterogeneous. Quality grades as they apply to carcasses do not satisfactorily reflect the same quality across meat cuts derived from the carcass. Quality differences between cuts of meat and the available cooking time may have more effect on retail prices than many other aspects of meat demand. In this paper, the components of meat quality are examined, particularly those components which differentiate cuts. The major quality indicators of meat include tenderness, juiciness and flavour. Some consideration is also presented in this paper as to the relationship between fat or marbling and meat quality. Throughout this study the material related to beef quality may be equally well applicable to lamb, veal, pork and chicken. The muscle structure and function of fish is extremely different to red meats and is not discussed here. See Schupp, Gillespie and Reed (1998) for an analysis of exotic red meats.

The paper proceeds with some justification of the need to consider meat substitutes in demand systems. In the section that follows, “quality” is discussed with particular emphasis on meat sensory characteristics. Brief evidence as to why carcass-grading schemes are poor predictors of meat eating quality are presented prior to some recent work on a grading system that is focused on individual cuts of beef. The relationship between marbling and tenderness is developed before a section on modelling meat demand with the addition of quality attributes.

2.2. Background

Meat demand analysis has become increasingly complicated during the past decade, as red meat is seldom sold as a whole carcass, side or quarter. The more recent industry trend is to supply meat as a primal or as a cut in retail ready packs. Cuts or primals that are derived from various grades of different carcasses may be distributed to a number of heterogeneous retail markets. The meat marketer's objective is to maximise profit from the carcass by allocating various quantities of the different cuts to the various markets. The typical equation to be maximised is:

$$\text{Max } \Pi = \Sigma_{ij} (p_{ij}q_j - c_{ij}q_j - FC) \qquad (2.1)$$

where i is the relevant market and j is the relevant cut, p is the price of the cut q in the particular market i, c is the cost of supplying the cut q, and FC is the fixed cost component associated with the processing or wholesaling business. In a competitive market this equation is maximised where the marginal revenue is equated with marginal cost. In the meat industry this approximation may not be satisfied, as revenue from some cuts is higher than the marginal cost whereas other cuts may be sold below cost. The price premium or discount arises from variation in expected eating quality and the quantity of premium cuts available to the market. The supply of high quality cuts from a carcass is a fixed proportion of the carcass weight. This relationship is relatively constant until mid maturity. The same analogy is true of low quality and intermediate cuts. This is a problem in industries where a raw product is dissected into components for sale rather than aggregated during production. For every high value loin cut produced, the processor is automatically supplied with a fixed proportion of low value product such as chuck. If an entire market is examined, cut quantities are not separable as they are supplied in some fixed proportion.

Thus,

$$\Sigma_{ij} q_j = Q \qquad (2.2)$$

where Q is the total quantity of retail cuts in a carcass. More particularly, the total supply of cuts in the market Q* can be simply represented by:

$$Q^* = \phi\, Q \;=\; \phi\,(\Sigma_{ij}\, q_j\,) \tag{2.3}$$

where ϕ is the number of animals slaughtered in the relevant period of time. Equation 2.3 can be employed as a constraint on the levels of q_i. The costs associated with each q_i are relatively straightforward for the processor:

$$\begin{gathered} c_i = \text{purchase price (cents/kg)} + \text{trim loss} + \text{labour} + \text{packaging} + \\ \text{labelling} + \text{delivery} + \text{overheads} \end{gathered} \tag{2.4}$$

where c_i is the unit cost in cents per kilogram and the purchase price is given below in Equation 2.5. See Hahn and Green (2000) for justification of fixed proportions and joint costs in meat retailing.

$$Pp = (CC\,/\,Q) \text{ x the weight of the untrimmed primal or cut } q_i \tag{2.5}$$

where Pp is the purchase price, CC is carcass cost in cents per kilogram and Q is total carcass weight in kilograms. The demand side of the market incorporates the consumer response to the supply of particular meats. See Hsu and Brester (1996) for an economic model in which demand for cuts is examined in preference to an aggregated carcass level system. The typical inverse demand function for meat cuts follows this format with some variation in the income or expenditure term.

$$\text{Price (A)} = f\,\{QA, QB, QC, OG, Y, S) \tag{2.6}$$

where Price (A) is a vector of wholesale or retail prices, QA is a vector representing the quantity of the meat product A, QB is matrix of quantities for substitute products derived from the same species class as A, and QC is a matrix of quantities for products selected from other species. If product A is a beef cut then product quantities in C may represent lamb, chicken or pork. OG is a matrix of other goods, Y is some income vector and S is some form of dummy variable for season, or month.

Problems are encountered when estimating meat demand for cuts by employing equations similar to Equation 2.5. Typically the quantity of meat type A and close substitutes B are highly correlated. This point is based on the fixed cut proportions discussion presented earlier. Naturally when imports to a particular region or market occur then the supply of cuts is no longer proportional to the number of animal slaughtered in the designated region and the degree of correlation between cuts would decrease. The necessity of examining demand for beef cuts rather than carcass level data, particularly in trade models, is outlined in Brester (1996).

Obviously the problem of high collinearity in the explanatory variables is less of a concern where there are many suppliers and products freely enter and exit the region according to consumer preferences. Fraser (1998) explains the use of maximum entropy for meat demand where the researcher is faced with problems with collinearity or unstable parameter estimates.

Another problem encountered with Equation 2.5 above is to accurately determine how the substitutes from other species are to enter the equation. If product A were beef ribs then we need to ask whether all cuts from each of the other species are substitutes for beef ribs (species substitution). There are at least 40 beef cuts, 30 pork cuts, 25 lamb cuts and 10 cuts of chicken, not to mention veal and other meat products. The question is, how to reduce the data set required in cut level estimation while ensuring that genuine substitutes have not been omitted from the equation? If we back up one step we may ask a similar question of whether similar cuts that are derived from different breeds of animals within the same species are substitutes (breed substitution). Finally, we may also ask whether similar cuts from the same animal are substitutes when the cuts are roasted versus grilled (cooking method substitution). To answer these questions we need to understand when a meat product is likely to be a close substitute and when it is not. Thus we need to carefully define "quality" in terms important to consumers and the conditions when a consumer is likely to substitute one cut for another. To do this we must understand the differences between cuts, by species, breed type and cooking method.

2.3. What is meat quality?

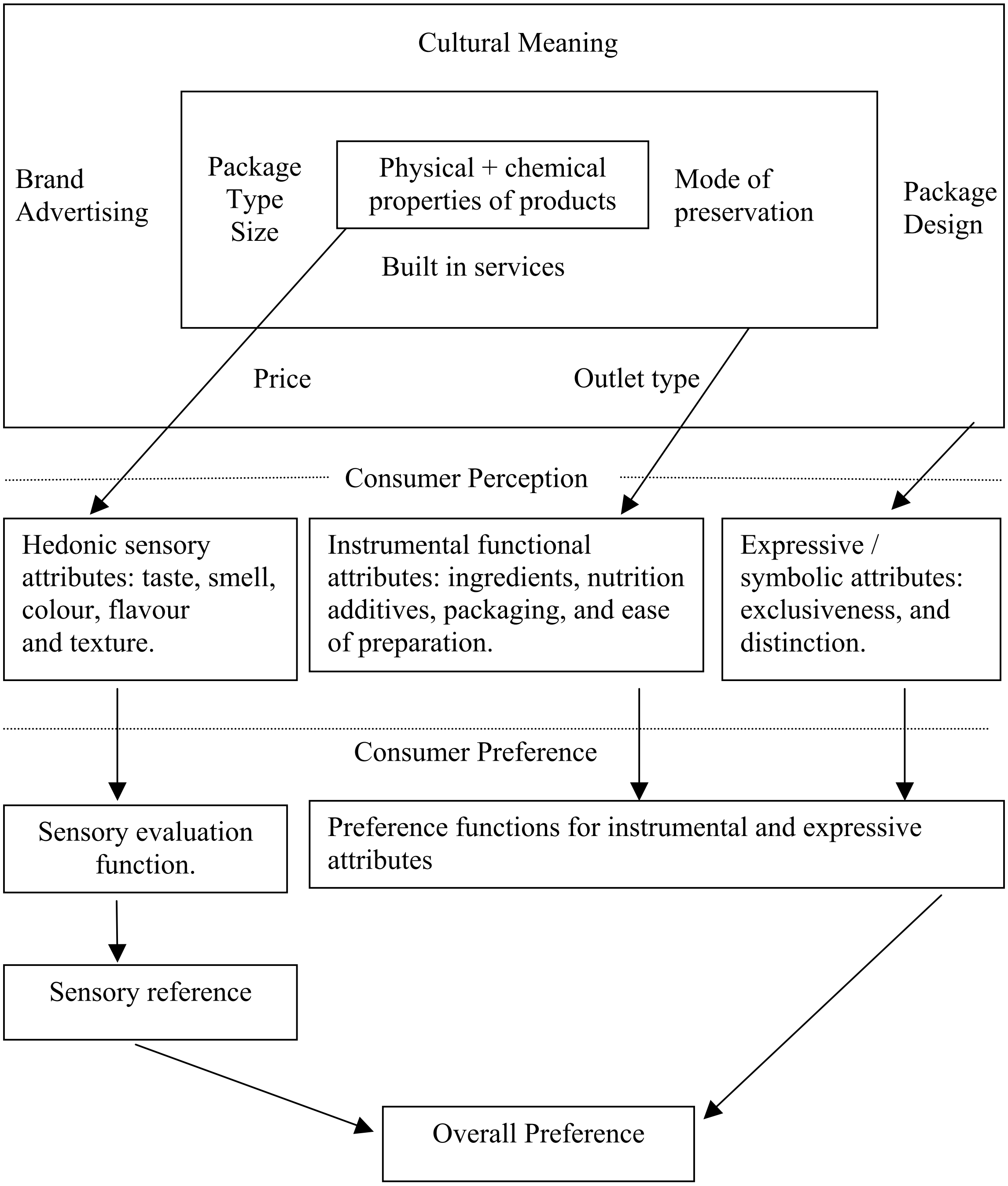
Kauffman et al. (1990) explain that quality as perceived by meat eaters means "nutrition, convenience, wholesomeness, appearance, health image and naturalness, and yes, palatability – and perhaps even price. It is the meat that looks good, smells good and tastes good, and is affordable. It must be repetitiously consistent, be price competitive, and be available and convenient" (p 160). Research by the Institute of Grocery Distribution nominates price as the most important attribute of meat followed by quality.

> Price seemed to be the key factor influencing these consumers' product choices. It provided the boundaries for both the type and cut of meat they could consider buying; then they would look for the piece of meat which best met their own quality standards. … Within these pricing boundaries, however, the quality of the meat was more important than price (Institute of Grocery Distribution 2000, p. 24).

The above research shows the importance of both price and quality to consumers. The price-quality relationship melds with many other attributes of a product such as the degree of doneness (Cox et al., 1997). Wierenga (1983) outlines a methodology for an analysis of consumer choice of food products.

Wierenga's stylised version of the consumer model for food products is shown as Figure 1. For this study the important component is the track in which the hedonic attributes of the product are discovered, evaluated and modelled. Other marketing literature (Brinberg and Lutz, 1986) would suggest the addition of a feedback loop to consumer perception after a product selection and product evaluation stage. This schema would be especially true for fresh products that are purchased frequently as consumers will buy, consume, and evaluate the product against expected performance, readjust their perception of the product and then may or may not buy a similar product on their next shopping visit. Consumers buy and consume food products more often than many other products and therefore have more opportunities for repeated sampling to build their knowledge of intrinsic product attributes.

Wierenga (1983) proposes several different strategies to discover consumer preferences and mapping those against the preferences for other goods. An elementary survey tool in the marketing literature is the Fisbein Model. Consumers are asked to state the salient features of broad categories of products. The next step is to ask consumers whether a particular product has more or less of the salient features determined earlier.



Source: Wierenga (1983), p 123.

Figure 2.1. Model for the Choice of a Food Product.

The scale of salient features is used to score similar products in the brand group or competitors' products. The scores are then simply added to determine which product has higher scores for the salient features. When analysing food products consumers could be simply asked about some level of an attribute such as the level of flavour of a food product by drawing from their previous exposure to the product or they can partake in a sensory panel in which the product samples are not identified to the consumer and the consumer is asked to score or rank a number of samples for specific attributes of the product. Conducting sensory experiments with human subjects is very expensive; hence, the sample size tends to be small. Sensory data tends to be much more objective relative to memory recall data.

Often the sensory specialist does not know which attributes will separate products. Hence, discriminant analysis or factor analysis is often performed on the sensory results to identify the key variables. Product scores are then calculated using the levels for each significant attribute.

Horsfield and Taylor (1976) evaluated sensory characteristics of five cuts of beef (rump, shin, brisket, topside and stewing steak), three reformed meats, liver, pork leg and three textured vegetable proteins using a trained panel of meat experts and a consumer team of 390 housewives located in three cities. The parameters examined were resistance, resilience, initial juiciness, meat flavour, Soya flavour, other off-flavour, breakdown, uniformity, chewiness, final juiciness and bolus formation. Notably the study did not include raw product attributes such as meat colour or appearance. The attributes, which contributed to meat quality, were refined by factor analysis from eleven sensory properties down to just three dimensions that were described as toughness, succulence and flavour. These sensory descriptors have been further refined though many subsequent studies into the attributes of tenderness, juiciness and flavour.

Meat tenderness is partly related to the amount of connective tissue (perimysium) present in a muscle and partly related to the temperature at which meat cuts are cooked. Cuts that typically have lots of connective tissue will be tender, if they are cooked at a low temperature over a long period of time such as by roasting or stewing the cuts. See Burson and Hunt (1986) for the proportions of collagen (connective tissue) present in four beef muscles. If a cut with lots of connective tissue is cooked fast on a grill then the proteins in the cut shrink and toughen as cooking temperatures increase up to 60 ^{o}C. At cooking temperatures beyond 60 ^{o}C the myofibrillar portion of muscle fibres becomes denatured causing fluids to be exuded from the meat so that they become dry. The combination of high temperature cooking and prolonged cooking at temperatures above 60 ^{o}C will have a negative impact on the perceived quality of meats. See both Christensen et al. (2000) and Powell et al. (2000) for a more complete discussion of meat tenderness properties.

To satisfy food safety requirements meat is generally cooked for at least 15 seconds above 65 ^{o}C to destroy pathogens; hence, cooking at this temperature will have some detrimental effect on meat eating quality. For texture and colour changes in meat products due to cooking see Martens et al. (1982).

A second measure of tenderness is to cook a muscle sample to 71 degrees Celsius and shear a 2.47 cm by 1.27 cm meat sample across the grain and measure the resistance on the cutting blade in kilograms (kgs). This process is referred to as a Warner-Bratzler shear-force test (WBSF). Morgan et al. (1991) claim that shear force values less than 3.9 are acceptable to a majority of consumers. According to Miller et al. (1995) meat consumed at home should measure below a range of 4.6 to 5.0 kgs. They also report that a maximum range of 4.3 to 5.2 kgs shear force would be acceptable to consumers dining at restaurants. Huffman et al. (1996) suggest that 98 per cent of consumers would be satisfied if the shear-force values were less than 4.1 kgs.

A study conducted by Brooks et al. (2000) shows the percentage of beef cuts which satisfy the criteria set by Morgan et al. (1991) of shearing below 3.9 kgs. The results from the study by Brooks are shown below in Table 2.1. Approximately 68 per cent of the bottom round tested in excess of 3.9 kgs and 52 per cent of these rounds tested in excess of 4.6 kgs. Thus, according to the maximum tenderness limits stated above, this cut would not be suitable for either the at-home market or the restaurant market. Alternatively, 98 per cent of the t-bones examined tested less than 3.9 kgs and 100 per cent of the samples were less than 4.6 kgs. Thus, this cut would be suitable for either market. A problem with the shear-force test is that the samples have to be dry cooked and this procedure discriminates against cuts that are better suited to moist cooking or roasting.

Carmack et al. (1995) show the sensory results of a study including 12 beef muscles and the rank of the muscles for the attributes of tenderness, juiciness and flavour. The scores in the columns to the right of the attribute reveal that a cut may be ranked high or low for quality depending upon which attributes are considered important. For example, if flavour was considered to be the more important attribute then the best choice is biceps femoris (outside flat or silverside).

Table 2.1. Least square means for Warner-Bratzler shear-force (WBSF) and the percentage distribution of steaks with <3.9, ≥3.9 and ≥4.6 kilograms

			Percentage		
Muscle	N	WBS, kgs	< 3.9 kgs	≥ 3.9 kgs	≥4 .6 kgs
Triceps brachii	68.0	3.01 ef	92.6	7.4	5.9
Serratus V.	135.0	3.35 d	74.8	25.2	5.2
Psoas major	200.0	2.84 efg	94.5	5.5	1.5
Porterhouse	56.0	2.69 g	92.9	7.1	1.8
Longissimus T.	147.0	2.71 g	98.0	2.0	0.0
Longissimus D.	269.0	2.77 fg	94.1	5.9	0.7
Gluteus medius	118.0	3.04 e	89.0	11.0	0.8
Rectus femoris	91.0	3.74 c	60.4	39.6	15.4
Semitendinosus	177.0	4.19 b	44.1	55.9	26.6
Biceps femoris	97.0	5.09 a	32.0	68.0	52.6

a,b,c,d,e,f,g Within the same column, means with different letters are significantly different ($p<0.05$).
Source: adapted from Brooks et al. 2000.

Similarly if juiciness were most important then the serratus ventralis is the better muscle. In reality a combination of attributes is used to score muscles. One such weighting is shown in the last column where the weight is 0.5 x Tenderness + 0.3 x Juiciness + 0.2 x Flavour. Under this ranking system the psoas major is the preferred muscle. The subscripts in the column should not be ignored as these show the significant groupings for the muscles by attribute. In terms of tenderness the infraspinatus, longissimus, rectus femoris and serratus may be considered as substitutes. From this group the infraspinatus and the serratus are substitutes for juiciness and they are both also in the same group for flavour. By using these groupings by attribute we could identify cuts and organize them into groups of likely substitutes to model in demand analysis. Unfortunately the process is not so simple, as the ranks of the muscles change for different cooking methods.

Table 2.2. Tenderness, juiciness and flavour rankings for 12 beef muscles

Muscle	Tenderness (a)	Rank	Juiciness (b)	Rank	Flavour (c)	Rank	Wt.* Rank
Psoas major	8.5 d	1	5.9 ef	3	7.5 de	2	1
Infraspinatus	7.2 e	2	6.6 de	2	6.8 fgh	9	2
Longissimus lumborum	6.9 e	3	5.2 fe	4	7.1 efgh	7	4
Rectus femoris	6.9 e	4	4.8 gh	8	7.1 efgh	6	5
Serratus ventralis	6.5 ef	5	6.8 d	1	6.9 efgh	8	3
Gluteus medius	5.8 fg	6	4.7 gh	9	7.4 de	3	7
Triceps brachii	5.8 fg	7	4.9 gh	7	7.3 defg	5	6
Supraspinatus	5.1 g	8	5.1 fg	6	6.6 g	12	9
Semitendinosus	5.0 gh	9	4.2 h	11	6.9 fgh	10	10
Biceps femoris	4.9 gh	10	4.7 gh	10	7.8 d	1	8
Semimembranosus	4.0 hi	11	4.1 h	12	7.4 def	4	12
Pectoralis profundus	3.8 i	12	5.1 fg	5	6.7 fg	11	11

[a] Ease with which a sample is masticated until it can be swallowed.

[b] Moisture in sample perceived after 10 chews.

[c] Flavour generally associated with dry cooked beef.

defghi Column means with the same subscript are not significantly different ($P>0.05$).

* Sample means were weighted such that (Weight 0.5 x T + 0.3 x J + 0.2 x F) and the results which are not shown were ranked from 1 equals the highest score to 12 equals the lowest score.

Source: Adapted from Carmack et al. (1995) Table 2, p 146.

2.4. Carcass grades

Current meat grading systems that allocate carcasses to quality groups generally fail to adequately reflect the quality of the major muscles in a carcass. Brooks et al. (2000) studied the USDA beef grading system for tenderness, juiciness and flavour and overall liking for quality groups of Prime, Top Choice, Choice, Select and Lean. The category of Prime scored higher than each of the other categories for overall liking, tenderness, juiciness, and beef flavour. The mean for overall flavour was not significantly different to the Select category. The results for Top Choice through to Lean were not different to one another statistically (95 per cent confidence) with the exception of overall flavour. Interestingly the standard errors were larger for the Prime grade relative to each of the other grades. The quote below from Brooks et al. (2000) reveals the lack of difference between the muscles examined.

> Quality group had no effect on WBS values of retail clod, chuck roll, top round (Topside), bottom round (Silverside), eye of round (Eye of silverside), top loin, top sirloin (Rump) or rib eye steaks (Cube roll or Scotch fillet) Bracketed terms added (Brooks et al., 2000).

Table 2.3. Least square means and standard errors for sensory panel ratings for retail ribeye steaks (n=105 steaks)

Sensory Rating	Prime	Top Choice	Choice	Select	Lean
Overall like(a)	7.50 +- 0.48 b	6.12 +- 0.19 c	5.95 +- 0.18 c	6.42 +- 0.16 c	5.99 +- 0.30 c
Tenderness	8.15 +- 0.56	6.47 +- 0.22	6.45 +- 0.21	6.67 +- 0.19	6.48 +- 0.35
Juiciness	6.68 +- 0.61	5.63 +- 0.24	5.45 +- 0.23	5.79 +- 0.20	5.38 +- 0.39
Overall flavour	7.72 +- 0.46 b	6.05 +- 0.18 cd	5.92 +- 0.17 d	6.39 +- 0.15 bc	6.16 +- 0.29 cd
Beef flavour	6.90 +- 0.41	5.97 +- 0.16	5.89 +- 0.15	6.28 +- 0.13	6.08 +- 0.26

a. Overall like: 10=like extremely, 1=dislike extremely; tenderness:10=very tender, 1=not tender; juiciness: 10=very juicy, 1=not at all juicy; overall flavour: 10=like extremely, 1=dislike extremely; and beef flavour: 10 =extreme amount, 1=none at all.
b,c,d within a row, means lacking a common subscript differ ($p<0.05$).
Source: Brooks et al. (2000), Table 10, p. 1858.

In contrast to Brooks et al. (2000), Wheeler, Shackelford and Koohmaraie (2000) reported that pre-grading carcasses based on an early post-mortem measure of longissimus tenderness could predict the eating quality performance of four typically tender muscles. This result is a large step forward; however, Thompson et al. (1999) found that “the variation explained by muscles was approximately 60 times greater than that explained by the variation between animals for the same muscle.” The recent work by Wheeler, et al. contradicts their earlier work to some extent where they (Shackelford et al., 1997) found significant variation between different parts of muscles. Earlier, they concluded that shear-force testing should not be used to differentiate muscles for tenderness. Quality variation such as this, within and between muscles, warrants further modelling of individual muscle palatability.

Meat Standards Australia (MSA) developed a meat-grading scheme that assigns grades to individual cuts depending upon several carcass factors. The tenderness, juiciness and flavour of certain muscles is affected by cooking method, sex of the animal, phenotype (*bos indicus* content), ossification score, growth pattern, and the number of days the product is aged before reaching the consumer. A weighted index of these factors was used to produce a carcass meat quality score.

A scoring method (CMQ4), which is based completely on a weighted index for tenderness, juiciness, flavour and an overall score for cuts, was developed by Thompson et al. (1999). The index weights of the CMQ4 score are reported in Polkinghorn et al. (1999) as follows:

$$\text{CMQ4} = 0.4 \times \text{Tenderness} + 0.1 \times \text{Juiciness} + 0.2 \times \text{Flavour and } 0.3 \times \text{Overall Score.} \quad (2.7)$$

The weighted average score is awarded to each cut and then simplified into a consumer grade icon of unacceptable, 3 stars, 4 stars or 5 stars. See Thompson et al. (1999) for further details on the background to these grading standards.

The consumer's choice of cooking method can change the rank of muscles and the group of substitutes that a particular cut belongs with. In Table 2.4, for instance, the rump changes from being ranked third if it is roasted, to fifth if it is grilled. The fact that cooking method has an impact on sensory quality is not new knowledge. Cooking methods have changed and researchers need to assess the impact of new cooking techniques for a number of muscles.

Increased demand for meat products that cook quickly has resulted in fewer products being roasted relative to cuts being grilled, fried and in some cases micro-waved. This change in available cooking time may have caused a rightward shift in demand for cuts which can be cooked quickly and a reduction in demand for traditional slow cooking meats such as roasts, stew and casserole meats. Some of the slow cooking cuts have undoubtedly been downgraded to ground meat during the past decade. See Brester and Wohlgenant (1991) for changing consumption patterns associated with ground beef.

Table 2.4. Beef muscle by cooking method MQA scores and standard errors

Cut Name	Muscle Name	Grill	Rank	Roast	Rank	Total*
Spinalis	Spinalis dorsi	77.7 +- 2.0	1			78.2 +- 1.9
Tenderloin	Psoas major	75.0 +- 1.1	2	75.6 +- 1.1	1	75.8 +- 0.8
Cube roll	Longissimus thoracis	65.3 +- 1.2	3	65.9 +- 1.0	2	66.4 +- 0.8
Oyster blade	Infraspinatus	63.5 +- 1.2	4	59.3 +- 2.6	6	64.3 +- 1.1
Rump	Gluteus medius	58.8 +- 1.0	5	63.7 +- 1.0	3	61.2 +- 0.8
Strip loin	Longissimus lumborum	67.8 +- 0.7	6	56.8 +- 0.9	7	60.6 +- 0.6
Blade	Triceps brachii	60.0 +- 1.6	7	59.3 +- 1.1	5	59.9 +- 1.0
Knuckle	Rectus femoris	50.3 +- 1.8	8	62.1 +- 1.2	4	59.4 +- 1.0
Eye round	Semitendinosus			51.9 +- 1.1	8	52.7 +- 1.1
Topside	Semimembranosus			49.6 +- 1.0	9	49.7 +- 0.9
Outside flat	Biceps femoris			43.9 +- 1.0	10	44.4 +- 0.9

* Total is an average score that takes account of three different hanging methods including Achilles tendon, Tender-stretch or Tender-cut in addition to cooking method.
Source: Adapted from Meat Standards Australia (1998) Table 2.

2.5. Contribution of marbling to meat quality

Campion, Crouse and Dikeman (1975) show that the marbling percentage of different breeds of cattle has a small positive effect on the sensory scores for tenderness and juiciness (see Table 2.5). However, the scores for juiciness and flavour are virtually indifferent across breeds. The muscle selected for the Campion et al. study was the loin. A better comparison would have been to use a selection of muscles from each breed type. See Appendix A1, for the fat, water and protein content of 15 beef muscles that were studied by Brackebusch et al. (1991). Notice the amount of variation in the fat content reported for the various muscle types in that table.

Table 2.5. Marbling, shear force and taste panel scores by beef breeds

Breed Type	Marbling Fat %	Shear Force Kg/cm^2	Taste Panel Scores * Tenderness	Juiciness	Flavour
Jersey	7.2	2.3	7.5	7.3	7.6
Angus	6.4	2.5	7.4	7.1	7.5
Hereford	5.5	2.5	7.3	7.0	7.5
S. Devon	5.4	2.4	7.5	7.2	7.5
Charolais	5.0	2.5	7.4	7.1	7.5
Simmental	4.7	2.7	6.9	7.1	7.5
Limousin	3.9	2.7	7.0	7.0	7.5

* Using 1 - 9 hedonic scales, with 9 highest.
Source: Adapted from Campion, Crouse and Dikeman (1975).

Breeds such as the Japanese Wagyu and the Korean Hanwoo are renowned for their vast marbling abilities. To Japanese consumers, marbling symbolises product quality particularly when used in shabu-shabu cooking (Busboom, et al., 1993). Marbling appears to be important to the Japanese market. However, the sensory benefits come at a significant cost in terms of lower animal growth rates and reduced lean meat yields. The trade-off between the increase in sensory attributes and costs for these obese breeds needs to be examined more thoroughly.

Subcutaneous fat percentage and marbling are generally poorly correlated with tenderness, juiciness or flavour of beef cuts. The work by Wulf and Page (2000) demonstrates this point for three muscles as shown in Table 2.6. The intramuscular fat percentage for semimembranosus (topside), and gluteus medius (rump) are both correlated by 0.30 with tenderness. The correlation for marbling percentage is lower still in the range of 0.20 to 0.25.

The marbling score for longissimus (T-bone) has no more effect on meat quality than the marbling found in the gluteus medius (rump).

Table 2.6. Tenderness, juiciness and flavour correlations to marbling and intramuscular fat

Muscle	Longissimus		Gluteus medius		Semimembranosus	
Characteristic	Marbling Score	Intramusc. Fat %	Marbling Score	Intramusc. Fat %	Marbling Score	Intramusc. Fat %
Tenderness	0.25	0.25	0.26	0.30	0.20	0.30
Juiciness	0.03	0.05	0.19	0.13	0.27	0.23
Flavour intensity	0.17	0.30	0.10	0.09	0.20	0.19
Flavour desirability	0.27	0.22	0.27	0.29	0.20	0.13

Source: Adapted from Wulf and Page (2000) Table 8, p 2603.

According to Brackebusch, et al. (1991) the amount of fat in all beef muscles is linearly related to the amount of fat present in the loin (longissimus). The reason why cattle feeders over supply energy is to increase the marbling score in the loin as well as to increase fat deposits or marbling in other muscles. Research on fat deposition in particular muscles is quite complex and beyond the scope of this paper except to say that controlling fat deposition may be possible in subcutaneous regions of the carcass. However, the hormones and adipose cell receptors that control the deposition of fat in muscle tissue will strive to maintain their energy equilibrium and return surplus energy or fat to subcutaneous storage sites. Hence some muscles do not store more fat than they require to function adequately for metabolism. Thus a high marbling score in the loin (longissimus) is a poor indicator of marbelling for other muscles and resulting meat quality. See Schaefer (1995) for more on the relationship between animal growth and fat deposition in beef cattle.

2.6. Qualitative models

The largest problem that economists encounter in building economic models that include quality components is the lack of data on quality attributes to combine with price, quantity and income data. The division of perceived quality into an attitude component and measurable attribute component is useful. Attitude components may be independent of measurable components such as the belief regarding the level of food safety associated with a particular product. Measurable quality components such as tenderness, juiciness and flavour are not typically independent of one another. The latter are more likely to require multivariate models and the former may be more suitable for limited dependent variable models or multiple regression models. In some cases mixed models that contain variables with fixed and random effects may be employed. A weakness of this route is that the error terms are no longer a function of mean square error alone and interactions therefore need to be considered which may use valuable degrees of freedom in statistical work.

Richardson, et al. (1994) present a broader view of United Kingdom (UK) consumer attitudes to meat consumption including healthiness, vegetarianism, meat avoidance and characteristics such as hormones and additives. Their paper included a survey of the attitudes of 1046 UK residents to broad product categories including a number of meat products. Issanchou (1996) presents an overview of factors affecting perceived meat quality for European consumers including convenience, animal welfare, safety, healthiness and a section on meat sensory analysis. These attributes of products are subjective and are difficult to measure in qualitative models.

2.6.1. Attitudinal models

Piggott and Wright (1992) suggest that consumer variety seeking behaviour, promotion and product convenience are potential variables to add to demand functions. Rimal, et al., (1999) provide an example of an exit interview survey for consumer attitudes to irradiated beef. There it is argued that consumers are unaware of the benefits of irradiation. Medina and Ward (1999) show a model of retail outlet selection for beef consumers. They conclude that the type of beef purchased and the quantity of the beef product are attitudinal factors that define where consumers shop. Verbeke, et al. (2000) explore food safety issues with BSE and television and the resulting impact that these images have on consumer attitudes. They find that there is a positive association between the perceived safety risk of food and hours of television viewing.

The home production model (Pollak and Watcher, 1975, and Deaton and Muellbauer, 1998) takes account of consumer inputs into preparing meals. Meat can be represented as an input to the home production function as there are time costs associated with preparation and cooking. Hence, preparation and cooking time should be included in meat demand systems if the analyst is considering the home market. Larson (1999) shows that between 1995 and 1996, 66 per cent of American consumers ate at home, 19 per cent ate at a restaurant, and 15 per cent ate ‘some place else.’ Of those who ate at home, 91 per cent still made the food themselves, whereas the other 9 per cent ate ‘take out.’ The results of a Pillsbury Foods study indicate that “the average meal preparation and clean up takes 36 minutes” (Duckworth, 1998). Bernstein (2001) reports that 40 per cent of meals prepared by U.S. households were prepared in 30 minutes or less in 1993 and that the figure has increased to 44 per cent in 2000. The growth of four per cent in fast meals may be coupled with other factors such as an increase in the number of discount food vendors.

Cooking time can be added as a variable to demand models by simply recording the minutes per kilogram of cooking time for each product. Recommended cooking times are available from meat marketing agencies. The cooking time variable can be multiplied by the opportunity cost of cooking time, i.e. wage rates or leisure time to produce a cost variable. Cooking time may be negatively correlated to meat tenderness or juiciness scores. The relationship is likely to be represented by a quadratic functional form rather than a liner function. However this depends on the muscle type and cooking method employed.

2.6.2. Measurable attribute models

Rosen's (1974) paper on pricing of hedonic attributes for differentiated products provides an understanding of interactions between the demand and supply of attributes. According to Rosen the consumer's demand for certain attributes can be modelled by dividing the price paid for the product, by a weighted index of quality indicators to derive the relative value of each attribute. The cost of supplying the attribute is calculated the same way with the supply cost rather than the sale price. A consumer will buy a product when the supply of attributes equals their demand for attributes. The model allows one attribute to cross subsidise another since consumers are paying for bundles of characteristics rather than attributes one at a time. The weight of preferences for certain attributes can be measured subjectively or objectively. A basic assumption of the model is that the attributes increase in constant proportion for increasing quantities of the product. This assumption works well for the supply of beef attributes.

Unnevehr and Bard (1993) estimated a hedonic price model for categories of beef cuts from data supplied through the US National Beef Market Basket Survey (Savell, et al., 1991). Their model expressed price as a function of a time dummy, city dummy, dummy for bone in or bone out cuts, external fat thickness, seam fat percentage and marbling percentage. Their general results are replicated in Table 2.7.

Table 2.7. Estimates of parameters for fat thickness and marbling percentage by retail cut

Class of Cuts	Bone-in	External Fat Thickness	Marbling Per cent	Seam Fat Per cent	Adjusted R^2
Chuck Roasts	-42.52	-0.91	-4.12	-2.59	0.56
Chuck Steaks	-75.92	NS	NS	-2.48	0.54
Round Roasts	NS	-1.19	NS	-7.51	0.23
Round Steaks	NS	-1.22	NS	-6.02	0.22
Rib Steaks	-110.76	1.76	NS	NS	0.5
Loin Steak	-90.8	-2.26	5.53	NS	0.51
Sirloin Steak	-29.94	-1.47	NS	NS	0.62
Miscellaneous	-141.61	-2.29	NS	NS	0.41

NS = Not Significant at α=0.05 level or better.
Source: Unnevehr and Bard (1993) p. 291.

The result for marbling was significant for only one type of cut, namely loin steak. The other parameter estimates indicated that consumers were adverse to bone-in products as well as products with significant amounts of external fat. The estimated model had some problem with the sign of the coefficients in that the parameters for rib steak and loin steak were mostly negative for each of the ten cities included in the study. Many of the estimated parameters for the cuts revealed different means and standard errors across cities. One might conclude from this result that the markets are heterogeneous or that the variable “city” may be a proxy variable for average consumer income and that may influence the model results.

Schupp et al. (1999) studied U.S. consumer knowledge of fat, cholesterol and protein levels in beef, pork, turkey and chicken. Consumers were reasonably accurate in selecting between cuts of different species for fat levels; however, they were less likely to correctly select cuts based on cholesterol and protein contents.

Belgian consumer perceptions of pork quality are provided by Verbeke, *et al.* (1999). In their paper, Verbeke *et al*. show that chicken was preferred to beef which was preferred to pork for attributes including leanness, healthiness, good taste and tenderness. They also showed that beef had fewer monousaturated fatty acids than mutton, chicken and pork. This result could be a function of the fatty acid content in the animal's diet. Nevertheless this is one quality factor that can be manipulated to some extent and may take on a more prominent role as feeding technology advances.

A more thorough list of physical attributes associated with meat demand was examined by Steenkamp and van Trijp (1996). Their study was conducted on 48 raw and cooked blade steaks that were analysed by 192 consumer respondents from Holland. Attributes of meat included in their model were: colour, fatness, pH, water binding capacity, shear-force, sarcomere length, freshness, visible fat, appearance, tenderness, non-meat components (fat and sinews), flavour, quality expectation and quality performance. Several of these attributes are correlated to some degree. Attributes that may be correlated include muscle pH with meat colour and water binding capacity, and sarcomere length with shear-force and tenderness. As with many factor-loading models the study produces some dubious results. For example, visible freshness was related to sarcomere length. The conclusion that fat has a positive effect on consumer flavour perceptions was interesting; however, the finding that flavour was not a significant variable for defining quality negates the earlier conclusion. The study has merit although some of the results are dubious. The fact that Steenkamp and van Trijp chose to use a blade steak for their analysis may have had a considerable impact on their results. The blade steak typically contains two large pieces of sinew plus there may be some variation in product toughness as the infraspinatus is typically more tender and juicy than the supraspinatus. The hierarchical modelling framework that they employ might be very useful if they were to compare attributes of several cuts.

The studies above are enlightening for the purpose of exploring the dimensions of attributes associated with product quality. The interaction of attitude to quality and measurable quality characteristics is discussed below.

2.7. Proposed method of deriving and modelling meat substitutes

The basic premise is that cuts with similar eating quality should be identified as substitutes. It is assumed that consumers choose among competing goods that provide the same level of utility. Utility is thus a function of measurable attributes. The identification process is to group cuts with similar scores for attributes including tenderness, juiciness and flavour. When sensory attributes are approximately equal then other variables such as cooking and preparation time, cost per unit and appearance may come into play to constrain the optimal set of cuts. The details of the product sampling procedures and basic statistical operations are presented below. Steps in identifying suitable meat substitutes are extended from Wierenga (1983).

1. Conduct a survey of consumers that identifies salient features of beef, lamb, pork, and chicken.
2. Use these salient features to run a small-scale trained panel for product from each species.
3. Use principal component analysis to identify the first two or three significant components and their loadings.
4. Use a trained sensory panel to evaluate the key components in step 3 as reference indicators for as many different products from each species as possible including a number of different cooking methods for each product.
5. Map the sensory scores for each of the products into either three or four-dimensional space and use cluster analysis to group cuts with similar sensory scores together. This procedure involves subjective interpretation of the cluster groups by the analyst. Hence the procedure should be done a number of times to the remove bias of initial starting points.
6. Once the clusters have been identified, list all the cuts within each group. These cuts will be the substitutes based on sensory quality that can be grouped together for demand analysis.
7. When the dependent variable in the equation is cut i from cluster k then simply add the quantity, price or income (expenditures) of the other i-1 variables in cluster k as the matrix of substitutes.

Potential problems with clustering techniques are that in some cases no unique cluster can be identified for the entire sample. There may also be cases where it remains uncertain as to whether a cut should be in one group or another if the sample is equidistant from the mean in each competing cluster. In many cases the cluster groups depend upon the seed point where different clusters will occur for different seed points. Pervaiz and Skinner (1992) provide tests for checking the independence of clusters identified in step 6 above.

Amemiya (1981) reviews qualitative models and the requirements of statistics, economics and biometrics in model building. Amemiya prefers discriminant analysis for classifying dependent variables, based on qualitative independent variables. Discriminant analysis works on the basis of finding the maximum difference between samples to identify groups. This technique thus puts more weight on attributes with more variation, rather than those variables with less variation. Hence it is least preferred relative to models which group cuts on close proximity in attribute space such as cluster analysis. It may be wise to check groups using discriminant analysis in addition to cluster analysis.

Næs, *et al*. (1996) used principle component analysis (PCA) to identify significant sources of variation in a comparison of ingredients in small goods. They also showed the use of partial least squares where the covariance between linear combinations of X and Y was optimised. One should check the data before employing these techniques for strong linear approximation between the variables, as these techniques are not suitable for alternate functional forms.

If one is using the hedonic approach, the attributes may be included in a regression directly; however, the analyst should be aware that the quality variables are likely to dependent rather then independent. Unfortunately Rosen's (1974) optimum result will not hold if the attributes are not independent or the attributes cannot be represented by smooth continuous functions.

Some linear or non-linear combination of the "quality" attributes may be formed to produce a single quality index for each cut that may then be used as an independent variable in a model or the quality variables may be added directly (Deaton and Muellbauer 1998, p263). The function of the index would be to raise or lower the price of a product based on its quality above or below the mean of a particular group. Other variables can also be added to the model as scalars. The following function (2.8) captures the essence of the price-scaling model.

$$P_i = P^* + - f (QI_i + \text{Other attributes}) + e \qquad (2.8)$$

where Pi is the price of the product to be calculated, P* is the price of a base product or the group mean m for which $\{i \subset m\}$, and QI_i is a quality index which scales product i against the quality of other products m, other attributes are factors such as cooking time, meat colour, and package type, etc, and e is an random normal error term.

The weakness with the whole process of sensory sampling is the associated cost of doing the sensory analysis for each market. There are however many benefits to the approach of defining substitutes by sensory properties. One benefit is that comparisons between cities or markets can be done to explore consumer preferences. The process is also useful for identifying the group of competitors for new products that are destined to enter a market according to their physical properties. Meat substitutes can also be tested in the same manner to examine the economic effects on selected items. The major benefit is that this approach to identifying product substitutes allows the analyst to use a smaller and more theoretically appropriate data set when modelling demand for cuts.

The process of mapping quality attributes is likely to be useful in assessing the benefits to breed societies and producer marketing groups as their products can be compared with the products of their competitors in quality terms.

The potential benefit to research organizations for including quality variables in models is that they can model returns to increasing quality factors by breed type, muscle or cooking method. A "quality" elasticity or flexibility estimate could be derived to show the price response to small changes in quality while accounting for the effect on competing products. Alternatively, a simple profit maximising model could include constraints on the quality index so that the algorithm is maximising over cuts, which implies that only the cuts that satisfy palatability constraints will be selected.

The next step in defining groups of substitute meat products is to test several models with actual sensory data. A project has been initiated which examines nine muscles for two cattle breeds and two cooking methods. An obvious extension to this work is to complete the same task for other meat producing species in an amalgamated sensory data set.

2.8. Conclusion

Meat quality was shown to be heterogenous across beef muscles. The same result applies to lamb, pork and chicken. The difficulty in modelling meat quality arrises from a lack of sensory data for cuts or muscles. In this study some of the common relationships between muscles and meat cuts were described for beef. The main indicators of objective quality include tenderness, juiciness and flavour of meat products. The consumers' choice of cooking method changes the parameters of these attributes. The contribution of marbling to sensory quality is not strongly correlated with sensory indicators. Consumers in previous attitudinal analysis work perceived seam-fat negatively. Multivariate techniques can be employed to group meat cuts with similar quality attributes. The market analyst can take these quality groupings and apply them, as they prefer in demand systems, keeping in mind that the quality variables are often collinear. The use of a quality index avoids some of the problems associated with including collinear variables in typical regression models. This approach to quality measurement allows the analyst to reduce the size of the competing products matrix, thus making the analysis more relevant in terms of assessing the impact of quality changes on competing cuts.

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CHAPTER THREE

A MULTIVARIATE ANALYSIS OF TWO COOKING METHODS FOR NINE MUSCLES FROM LIMOUSIN AND WAGYU STEERS

Abstract

To optimise the use and value of lower value beef muscles it is important to understand how the sensory attributes of individual beef muscles are affected by cooking methods. Our objective was to map attribute scores for two cooking methods of several muscles from two divergent cattle breeds to identify those muscles that respond similarly across sensory and mechanical attributes. A nine person sensory panel was engaged to test for variation in nine muscles from four Limousin and four Wagyu cattle for either a griddle or grill cookery method. Factor analysis was used to identify muscles that performed similarly over the eight attributes. The first factor explained 46.1 per cent of the variation and was dominated by initial tenderness, sustained tenderness, shear force, juiciness and beef flavour intensity while the second was dominated by cooking time, cook loss and off flavour and explained 18.1 per cent of the variation. The scores were significantly different for Wagyu and Limousin by breed, griddle and grill for cooking method and by muscle. In conclusion, cooking method affected sensory scores when evaluated across a range of muscles from two divergent cattle breeds. The results were consistent with prior research and the method shown offers researchers the opportunity to reduce the attribute space to just two dimensions when classifying beef muscles.

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3.1. Introduction

The identification of sources of variation in cooked muscles is important for ranking muscles. In this research a griddle or grill cookery method was applied to nine muscles from four Limousin and four Wagyu steers to produce sensory scores over eight attributes including initial tenderness, sustained tenderness, shear force, juiciness, flavour, off flavour, cooking time and cooking loss. Variation in sensory scores has been shown in other studies to arise from cooking method, animal breed and muscle type. These sources of variation are reported independently in the literature. Here we examine these factors jointly through factor analysis that accounts of the correlation that exists between sensory scores and represents a consumer's choice over a bundle of muscle attributes rather than one attribute at a time.

3.1.1. Background

Previous work examining the palatability of muscles from beef cattle has been documented by Morgan et al. (1991) in the National Beef Tenderness Survey. In their study Morgan et al. examined the shear force, juiciness, myofibrillar tenderness, connective tissue amount, overall tenderness and flavour intensity of eleven sub primals. Three cooking methods were employed. These were braise, broil and roast. Steaks were either braised or broiled. Roasts were cooked to an internal temperature of 60°C whereas the steaks were braised to 85°C or broiled to 67°C. This variation in end point cooking temperature may be responsible for some of the variation in sensory scores. Wheeler et al. (1994) reported that longissimus lumborum steaks that were broiled to an internal temperature of 70°C relative to those cooked to 65°C produced shear force means that were 5.99 and 5.79 kg, respectively. Seideman and Durland (1984) have shown that shear force increases in two significant steps for cooking temperatures between 40-50 °C and from 65 –80 °C. Thus for comparative purposes, end point temperatures should be consistent between samples by muscle type and cooking method.

In the study by Morgan et al. (1991), the roasts were more tender than the steak samples in all cases. The correlation between overall tenderness and juiciness was 0.52 for the roast samples and 0.86 for the steak samples. The correlation between juiciness and flavour intensity was 0.67 for the roasts and 0.54 for steaks. Finally the correlation between shear force and overall tenderness was –0.61 for the roasts and –0.91 for steaks.

Morgan et al. (1991) did not test each steak using both the broil and braise cookery methods. The broiled steaks had higher overall means for tenderness, juiciness and flavour relative to the braised steaks. Similarly, the shear force means for the broiled steaks were lower than those for the braised steaks. The correlation between juiciness and overall tenderness was 0.63 for the broiled steaks and 0.78 for the braised steaks. Notably the correlation between juiciness and flavour intensity was –0.39 for the broiled steaks and 0.20 for the braised steaks. This pronounced negative linear relationship between juiciness and flavour intensity for the broiled steaks contradicts the correlations produced from our data.

Carmack et al. (1993) examined 12 muscles from eight Select/Choice USDA grade steers and produced palatability scores for young cattle. They identified species and feed source as the most important of the genetic and environmental factors that influence sensory traits. The steers were all grain fed for 100-120 d grain fed and received A-maturity scores; however, breed type and grain type were not specified. Steaks were broiled to an end-point temperature of 70 °C.

Muscles were scored on a 10 point scale for tenderness, flavour and juiciness. The psoas major (PM) was found to be more tender than infraspinatus (IS), longissimus lumborum (LL), rectus femoris (RF) and the serratus ventralis (SV). The latter group was reported to be more tender than the supraspinatus (SS), semitendinous (ST), biceps femoris (BF), semimembranosus (SM) and pectoralis profundus (PP). Individual muscles were ranked for tenderness, flavour and juiciness. The rank of each of the twelve muscles was dependent upon which attribute was deemed more important. When juiciness was deemed the most important attribute then the serratus ventralis was preferred; however, if tenderness was most important then it was ranked fifth and for beef flavour intensity it would be eighth. This study emphasised the need to create sensory attribute weights over a mix of important attributes rather than a single attribute in order to rank muscles or define groupings of similar muscles by cooking method.

Shackelford, Wheeler and Koohmaraie (1995) conducted a comprehensive study of shear force and sensory attributes of 10 muscles from *Bos taurus* and *Bos indicus* cattle with known breeding histories and feeding regimes. Steaks from ten muscles were broiled to an end point temperature of 70 ^{o}C and six muscles were roasted in a fan forced convection oven at 135 ^{o}C to an end-point internal temperature of 70 ^{o}C. Shear force scores of the longissimus dorsi (LD), triceps brachii (TB), supraspinatus (SS), biceps femoris (BF) and quadriceps femoris (QF) steaks and QF, BF, TB and LD roasts were reported to be significantly higher for progeny of *Bos indicus* sires than progeny of *Bos taurus* sires. Roasting caused higher shear force scores for the ST, BF, SM and QF primals and lower scores for the LD and TB primals. Shackelford et al. concluded that, “Shear force of LD was not highly related to the shear force of the other muscles” (p. 3339). This conclusion supports earlier results by Shorthose and Harris (1990).

These results across breed type, muscle type and cooking method support the examination of at least these three factors when assessing the levels of sensory traits associated with various cooking methods. The correlation between tenderness and juiciness within their study was 0.53.

Wheeler, Koohmaraie, Cundiff and Dikeman (1994) tested longissimus lumborum steaks using two cooking protocols. A total of 57 paired steaks were cooked to 70 ^{o}C on a Farberware broiler (protocol 1) or were oven broiled to an end point temperature of 65 ^{o}C in a Kaycee gas oven (protocol 2). The shear force mean for the broiled steaks was 6.29 kgs versus 3.60 kgs for the oven broil method. A smaller sample of 26 steaks was compared using both cooking methods at 65 ^{o}C and 70 ^{o}C temperatures. At 70 ^{o}C the broil shear force mean was 5.99 kgs versus 6.62 kgs for the oven broil method. Interestingly the shear force results of protocol 2 were not repeated when steaks were cooked at 65 ^{o}C as the mean for the broiled steaks was 5.79 kgs and the mean for oven-broiled steaks was 5.72 kgs rather than near 3.60 kgs. Wheeler et al. reported that the difference in shear force means for these two cooking methods was inconclusive.

Dugan and Aalhus (1998) examined longissimus lumborum steaks from A-grade carcasses that were cooked to 72 ^{o}C by using a single sided grill, double sided grill, or a water bath. They reported that cooking method did not affect shear force when steaks were cooked to the same internal temperature. Dugan and Aalhus made reference to Boleman, Boleman and Savell (1995) who reached a similar conclusion. Boleman, et al. (1995) cooked strip loin steaks to 65, 70 or 75 ^{o}C using the following methods: pan broil, out door grill and oven broil. They found that these three methods “exert relatively no effect on tenderness and cooking loss.”

3.1.2. Justification

Cattle breed has been shown to be a source of variation for cooked muscles. Shackelford, Wheeler and Koohmaraie (1995) conducted a comprehensive study of shear force and sensory attributes of 10 muscles from *Bos taurus* and *Bos indicus* cattle with known breeding histories and feeding regimes. Muscles derived from cattle from various breeds were shown to be significantly different within their study. This would indicate the need to include a number of breeds and muscles in an analysis of sensory variation on muscles.

Sensory scores vary considerably for steaks of different muscles when cooked using the same cooking method (Carmack, et al., 1993). Results of other studies indicated that the variability extended to a range of fast cooking methods (Morgan et al., 1991). However, it has also been reported that some muscles, in particular the longissimus lumborum, were not significantly different when cooked using a broil or oven broil methods (Wheeler, Koohmaraie, Cundiff and Dikeman, 1994) a pan broil, out door grill or oven broil methods (Boleman, Bolman and Savell, 1995) or the single sided grill, double sided grill, or water bath methods (Dugan and Aalhus, 1998). Specifically, Dugan and Aalhus (1998) found that shear force values on longissimus lumborum steaks were not significantly different across three cooking methods when the samples were cooked to an internal temperature of 72^{o}C. These results demonstrate the need to examine sensory attributes over a range of muscles and a number of cooking methods.

When valuing research into *ante* or *post* mortem muscle fabrication techniques that improve meat sensory characteristics, it is important to identify cuts with similar attributes (substitutes) as these play a vital role in determining the quantity of meat within a particular product class, and this may in turn influence the price of that class of meat (Freebairn, 1973; Boleman et al., 1997). Cooking time was one form of classification used to aggregate similar muscles for demand analysis (Farrell, 1999). The rank order of muscle was shown to differ for a number of muscle attributes (Carmack, et al., 1993); hence, the cohort of muscles changed for different attributes. A classification system that ranked muscles over a number of important attributes to standardise the scoring process was required. This process had to account for potential variation in breed, muscle and cooking method. It was the purpose of this project to develop a classification system that accommodated these requirements.

3.1.3. Objective

The objective of this study was to use a griddle or grill methods on cookery for nine muscles from four Limousin and four Wagyu cattle with recorded backgrounds to identify and rank those muscles that respond similarly across sensory and mechanical attributes.

3.2. Methods

Nine muscles derived from four Wagyu and four Limousin steers were either pan-fried (Griddle) or grilled (Farberware). For each cooking method sample palatability was assessed on five sensory attributes including: Initial Tenderness (IT), Beef Flavour (BF), Juiciness (J), Off-flavour (OF), and Sustained Tenderness (ST). Cooking loss (CLS) and cooking time (MINS) were recorded and Warner-Bratzler shear force tests conducted on all muscles for each cooking method and both breed types. The nine muscles sampled were the serratus ventralis (SV), infraspinatus (IS), psoas major (PM), longissimus thoracicus (LT), biceps femoris (BF), triceps brachii (TB), rectus femoris (RF), gluteus medius (GM) and semimembranosus (SM). These muscles were selected to enable a comparison with prior studies as the data set employed here was limited to samples from eight animals.

3.2.1. Beef samples

Mir et al. (2002) conducted a nutrition study involving Limousin and Wagyu cattle. One side from four Limousin and four Wagyu cattle was purchased from the control groups of that project. The steers were backgrounded on a 35% (dry matter basis) barley diet for 140 days. When the cattle reached 400 kg for Wagyu and 450 kg for Limousin, the diet was changed to a high barley diet (78 % on dry matter basis). The cattle were maintained on that diet until they weighed 500 kgs for the Wagyu, and 560 kg for the Limousin. The steers were slaughtered at these weights. Animal care procedures were approved by the Washington State University Laboratory Animal Care Committee (LARC Project # 2823). The carcass grading data are shown in Table A2 within the appendix.

3.2.2. Sample cutting protocol

The left side of each carcass was suspended by the Achilles tendon and aged at 0-2 ^{o}C for 14 days. The Semitendinosus (ST) and Longissimus Dorsi (LD) were removed at day 2 for other research (Kuber, et al., 2004a). On day 14 post mortem, the left side of the carcass was dissected into primal muscle groups and the muscles were trimmed of excess fat and then placed into storage tubs, covered with plastic film, and stored overnight at 1 ^{o}C.

On day 15 post mortem the nine primal muscles were weighed. The weights of the primals are shown in Table A3 within the appendix as a proportion of the total carcass weight. All remaining subcutaneous and intermuscular fat was removed prior to slicing the muscles into four or more 2.5 cm steaks for the trained panel and shear force tests. One of the four steaks was randomly designated for shear force testing. The objective in cutting the steaks was to remove a sample from across the centre of the lateral plane of each muscle. The steak samples were wrapped individually in a plastic film barrier and paper, and stored at –40 ^{o}C until the sample was required by the taste panel or for shear force testing.

3.2.3. Cooking protocol

One steak from each of nine muscles derived from the four Limousin and four Wagyu cattle carcasses was assigned to the Farberware® grill (Model R455N, Bronx, NY 10461, 1650 Watts) and another steak assigned to the Dainty Maid® griddle (Model 46877A, Boonville, MO 65233, 1500 Watts) (n=144). The pair of steaks was then randomly assigned to one of eighteen tasting sessions.

The steak samples were thawed for 72 h at 1 ^{o}C prior to cooking. In the 30-minute period prior to cooking, the thawed samples were unwrapped of paper and barrier film, and allowed to stand at room temperature on stainless steel trays. The two cooking devices were turned on 25 minutes prior to cooking to preheat the cooking surfaces. A single probe attached to a Digi-Sence® (Model Number 92800-00, Cole Parmer, Niles IL, 60714) scanning thermocouple thermometer was inserted into the centre of each steak and the steaks were then placed randomly on the designated cooking device.

The surface temperature of the two cooking devices was measured with a Raytek® infrared thermometer (Model number RAYST6lXU - Santa Cruz CA USA). The mean unloaded surface temperature for the Dainty Maid® griddle was 255.25 ^{o}C with a standard deviation of 13.8 ^{o}C. The surface temperature mean for the Farberware® grill was 232 ^{o}C with a standard deviation of 20.8 ^{o}C. Six temperatures were recorded on the Farberware grill from inside the top rim that supports the wire grill. The temperature at the centre of the wire grill was 184 ^{o}C.

The steaks were turned at 32 ^{o}C and removed from the cooking device at an end point temperature of 71 ^{o}C. Once cooked, the steaks were immediately wrapped in aluminium foil and held at room temperature for up to five minutes prior to dissecting the steaks into sample portions for the panelists. A 1 cm x 1 cm x 2.5 cm sample was cut from each cooked steak. Samples that were free of significant connective tissue and fat were impaled with a toothpick and placed in individual randomly numbered Dixie® cold cups (89 ml) and then served immediately to the trained sensory panel.

3.2.4. Sensory panel protocol

Nine adult panelists, 5 females and 4 males, who commonly consumed beef were selected and trained (AMSA, 1995) using various samples of lamb and beef muscles to develop an experience spectrum for each attribute that was tested. The majority of the panelists had prior experience on other panels involving beef products in the weeks leading up to this panel.

In training the panel, off-flavours were created via the saturation of samples in saline solution for 24 hours (10 grams per 500 millilitres) (AMSA, 1995). Juicy and dry samples were created by cooking meat to rare or well done respectively. Tough and tender samples were selected from a stock of samples that had been previously rated as such in other experiments.

The panelists sat in individual booths in a well-ventilated room under white lights. Unsalted crackers (Nabisco® Unsalted Tops Premium Saltine Crackers) and distilled ice water were provided to each panelist. Each panelist was provided with a cooked sample that was impaled with a toothpick parallel to the fibre orientation and served in a Dixie cup. The panelists were instructed to place the sample between their teeth and bite; however, the orientation of the first bite was not specified.

The panelists scored their samples for the attributes of initial tenderness, juiciness, beef flavour intensity, off-flavour, and sustained tenderness. The samples were scored on a 100 mm line scale with anchored end points. The scale end points were labelled as tough-tender, dry-juicy, bland-intense, none detectable-pronounced and tough-tender. The panelists were served eight samples per session at two sessions per day (10 am and 2 pm) for a total of nine days. The sampling period was spread over a two-week period with a three-day break following the fifth day. The panelists were rewarded for their participation and debriefed on the objective of the study at the conclusion of the sampling period.

3.2.5. Shear force protocol

The shear force sample steaks were thawed and cooked using the same protocol as the trained panel. The cooking time was recorded in minutes from when the sample was placed on the cooking device until the sample was removed at 71 ^{o}C. The samples were weighed immediately prior to cooking and were reweighed 3.5 h after being removed from the cooking device to monitor cooking loss. The cooking loss was recorded as a percentage of the initial weight. Post cooking, the steaks were cooled at a room temperature (16 ^{o}C) for four hours after which at least six 2.5 cm by 1.27 cm diameter cylindrical cores were removed from each of the sample steaks with the 2.5 cm length being parallel to the fibre orientation. The cores were inspected for excessive connective tissue and fat depositions. A final set of six cores per sample steak were selected and were then shorn once through the centre of the 1.27 cm diameter using a Texture Analyser TA-XT2 (Texture Technologies Corp. Scarsdale, NY 10583) shear force machine with a TA-7 WB (Stable Micro Systems) blade attached. The cross-head speed was set at 3.33 mm/Sec. The peak force was recorded for each of the six cores per sample and then averaged to attain the mean peak shear force for the sampled steak.

3.2.6. Statistical Methods

Factor analysis was performed using Proc Factor with a Varimax rotation in SAS Version 8. (2001) SAS Institute Inc., Cary, NC, USA. The data were structured in a completely randomised design with doubly repeated measures. That is, two cooking methods were analysed for nine muscles, from eight animals, which included two cattle breeds. The four animals were nested within each breed. The main effects and interactions are shown in equation 3.1.

Attribute score = breed + animal(breed) + muscle + muscle x breed +

muscle x animal(breed) + cook + cook x breed +

cook x muscle + cook x muscle x breed (3.1)

The breed effect was tested via an F-test using animal within breed the as error terms. The muscle effect was tested using muscle times breed, or muscle times animal within breed, as the error term. Cooking methods was tested using the overall error term, as the cooking method interactions were not significant.

3.3. Results

The means and standard errors for each attribute are shown in Table 3.1. The mean for initial tenderness was shown to be higher than sustained tenderness producing 68.6 points relative to 61.9 points on a 100 point scale. The standard error was slightly higher on sustained tenderness relative to initial tenderness. Beef flavour, juiciness and off flavour each produced means of 55.8, 32.6 and 91.4 respectively. The standard error on beef flavour was low at 10.5. Alternatively the standard error for juiciness was larger than expected at 17.2 when compared to the error for beef flavour. A high off flavour score indicated a lack of off flavours whereas a low score would indicate the presence of off flavours. Thus the mean of 91.4 with a standard error of 6.1 indicated an absence of off flavours in many of the samples. The mean shear force score across all samples was 4.07 kgs. The standard error was 1.5 kgs which was high but not unexpected due to the variation in breed and muscle types. The mean cooking loss was 32.7 %. The average time to cook a sample was 29.8 minutes with an error of 11.1 minutes, which is considered high since steaks were cut to the same width (2.5 cm).

Table 3.1. Means and standard errors by attribute

Variable	IT	STD	SHEAR	BFL	JCY	CLS	MIN	OF
Mean	68.63	61.96	4.07	51.56	55.87	32.68	29.81	91.44
S. Error	18.78	20.19	1.56	10.55	17.12	5.21	11.10	6.13

IT=Initial Tenderness, STD=Sustained Tenderness, Shear=Shear Force, BFL=Beef Flavour, JCY=Juiciness, CLS=Cooking Loss, MINS=Cooking Time and OF=Off Flavour.

3.3.1. Factor Analysis

Factor analysis is a technique that creates uncorrelated variables from correlated data. The procedure relies on orthogonal rotations of the attribute vectors to identify factor scores. This technique is therefore suitable only for correlated variables. A correlation statistic refers only to the degree of linear association. The statistic does not identify non-linear associations such as a quadratic, log or exponential functional forms.

The correlation matrix for the eight attributes is reported below in Table 3.2. The highest correlation is that between initial tenderness and sustained tenderness at 0.97. Juiciness and beef flavour were also highly correlated (0.76) which indicated that juiciness and beef flavour moved in the same direction. There was a negative relationship between initial tenderness with shear force (-0.60) and sustained tenderness with shear force (-0.61) that was expected as shear force increases for tougher meats. Cooking time (MINS) was positively related to cooking loss; however, the correlation was low against the remaining attributes. The signs and magnitudes of these correlations were consistent with *a priori* expectations. Off flavour produced low correlations with each of the other variables.

Table 3.2. Correlation matrix by attribute

Attribute	IT	STD	SHEAR	BFL	JCY	CLS	MIN	OF
IT	1.00							
STD	**0.97**	1.00						
SHEAR	**-0.60**	**-0.61**	1.00					
BFL	**0.60**	**0.57**	-0.37	1.00				
JCY	**0.58**	**0.55**	-0.31	**0.76**	1.00			
CLS	-0.36	-0.38	0.32	-0.33	-0.16	1.00		
MIN	-0.14	-0.11	0.07	-0.18	0.10	**0.50**	1.00	
OF	0.18	0.18	-0.22	0.14	0.01	-0.20	-0.16	1.00

IT=Initial Tenderness, STD=Sustained Tenderness, Shear=Shear Force, BFL=Beef Flavour, JCY=Juiciness, CLS=Cooking Loss, MINS=Cooking Time and OF=Off Flavour. **Bold** indicates a correlation greater than 0.50.

The Eigen values for the attributes are reported in Table 3.3. The Eigen values show that approximately 46 % of the variation in the correlation matrix can be explained by one component. The second component accounted for an additional 18 % of the variation to explain 64 % of the total variation. The remaining 23.7 % of the total variation was explained by six additional components. This result indicates that between two and three factors would be required to explain 64 to 76 % of the total variation in these eight attributes.

Table 3.3. Eigen values for 8 attributes

Attribute Number	Eigen Values	Difference	Proportion	Cumulative
1	3.688	2.235	0.461	0.461
2	1.453	0.495	0.182	0.643
3	0.958	0.171	0.120	0.763
4	0.787	0.312	0.098	0.861
5	0.475	0.049	0.059	0.920
6	0.427	0.242	0.053	0.974
7	0.185	0.159	0.023	0.997
8	0.026		0.003	1.000

The Proc Factor procedure was used in SAS (2001) with a Varimax rotation. The Varimax rotation provides more weight to variables with high communality scores without affecting the variance of the variables (Johnson, 1998). The factor scores are shown in Table 3.4 for each of the eight attributes.

Table 3.4. Rotated factor scores by attribute

	IT	STD	SHR	JCY	BFL	MIN	CLS	OF
Factor 1	0.897	0.881	-0.641	0.828	0.799	0.055	-0.280	0.104
Factor 2	-0.219	-0.227	0.266	0.181	-0.132	0.834	0.769	-0.476

IT=Initial Tenderness, STD=Sustained Tenderness, Shear=Shear Force, BFL=Beef Flavour, JCY=Juiciness, CLS=Cooking Loss, MINS=Cooking Time and OF=Off Flavour.

Initial tenderness, sustained tenderness, shear force, juiciness and beef flavour dominated the first factor. The second factor was dominated by cooking time, cooking loss and off flavour. Each of the eight attributes loaded with a high value onto either the first or second factor but did not have a high score on both factors. This enabled the dimensional space to be reduced from eight planes (eight attributes) to two planes (factors 1 and 2) for subsequent analysis.

Factor scores for factors 1 and 2 were used as dependant variables in an ANOVA model. The results for factor 1 are shown in Table 3.5. In that table it was shown, using an F-test, that the means among breed, muscle and cooking method were significantly ($P < 0.05$) different. The remaining interactions were not significantly different. The breed x muscle interaction effect was not significant when the mean square for animal x muscle(breed) was used as the divisor.

Table 3.5. Type III ANOVA results with factor 1 as the dependent variable

Source	DF	Type III Sum of Squares	Mean Square	F Value	Pr > F
Breed[a]	1	7.83	7.83	8.36	0.0277
Animal (Breed)	6	5.62	0.93	2.20	0.0604
Muscle[b]	8	65.07	8.13	22.58	<.0001
Breed*Muscle[b]	8	1.68	0.21	0.59	0.7846
Animal*Muscle (Breed)	48	17.29	0.36	0.85	0.7131
Cook	1	5.71	5.71	13.44	0.0007
Breed*Cook	1	0.21	0.21	0.51	0.4771
Muscle*Cook	8	2.26	0.28	0.67	0.7175
Breed*Muscle*Cook	8	2.23	0.28	0.66	0.7264

[a] Animal (Breed) used as the mean squares error term.

[b] Animal*Muscle (Breed) used as the mean squares error term.

The ANOVA F-test results for factor 2 are presented in Table 3.6. In that table it is shown that breed, animal within breed, muscle and cooking method are significant ($P<0.05$). Since animal within breed was significant the error mean square was replaced by the mean square error of the nested term. None of the other interaction terms were significant ($P<0.05$).

Table 3.6. Type III ANOVA results with factor 2 as the dependent variable

Source	DF	Type III Sum of Squares	Mean Square	F Value	Pr > F
Breed[a]	1	9.61	9.61	2.35	0.1758
Animal (Breed)	6	24.48	4.08	8.44	<.0001
Muscle[b]	8	15.92	1.99	5.45	0.0001
Breed*Muscle[b]	8	3.22	0.40	1.10	0.3778
Animal*Muscle (Breed)	48	17.52	0.36	0.76	0.8289
Cook	1	35.66	35.66	73.79	<.0001
Breed*Cook	1	0.007	0.007	0.02	0.9025
Muscle*Cook	8	4.58	0.57	1.19	0.3287
Breed*Muscle*Cook	8	2.99	0.37	0.77	0.6273

[a] Animal (Breed) used as the mean squares error term.

[b] Animal*Muscle (Breed) used as the mean squares error term.

Breed was not significant (P <0.05) for factor 2 and it was concluded that the Limousin and Wagyu results were not different. The F-test result for muscle indicates that the muscle results were significantly different (P <0.0001). The breed x muscle interaction was not significant (P <0.05).

Table 3.7 shows the means and standard errors for breed for each factor. The mean for the Limousin cattle (-0.263) was lower than the mean for Wagyu cattle (0.26) for factor 1 and that the means were not statically different by breed for factor 2. Thus we conclude that breed influenced the elements of factor 1 including initial tenderness, sustained tenderness, shear force and beef flavour; however, breed did not influence the elements of factor 2 including cooking time, cooking loss or off flavours.

Table 3.7. Means and standard errors for breed effect from factors 1 and 2

	Factor 1		Factor 2	
Breed[a]	Limousin	Wagyu	Limousin	Wagyu
Mean	-0.263	0.259	0.19	-0.38
S.E.	0.12	0.133	0.25	0.27

[a] Animal (Breed) used as the mean squares error term.

The means and standard errors for cooking method for each factor were shown in Table 3.8. The griddle cookery method produced a significantly lower mean (-0.22) relative to the mean for the grill method (0.22) for factor 1. Hence for that factor, grill was preferred to griddle. Alternatively, for factor 2, the griddle method was lower (-0.65) relative to the grill (0.45) indicating that the griddle method was superior. Hence the grill cookery method may potentially increase cooking loss and produce more off flavours relative to the griddle method. Thus cooking method with the same end point temperature had a significant effect on the sensory and mechanical scores.

Table 3.8. Means and standard errors for cooking effect from factors 1 and 2

	Factor 1		Factor 2	
Cook Method	Griddle	Grill	Griddle	Grill
Mean	-0.22	0.22	-0.65	0.45
S.E.	0.09	0.07	0.1	0.08

The means and standard errors by muscles for each factor are shown in Table 3.9. The muscles were ranked differently for each factor. The infraspinatus produced a superior score on factor 1 indicating that it was more tender, juicy and flavourful relative to the remaining muscles. There was no significant difference for PM, SV, LT, TB and GM as indicated by the "b" against the score for the factor 1 scores. The GM was in a group of three muscles including the RF and SM that produced negative scores for tenderness, juiciness and flavour. The BF was ranked last and was significantly different to each of the other muscles for factor 1.

Factor 2 represents cooking time, cooking loss and off flavours. The PM and LT scored slightly higher relative to the SM and BF; however there was no significant difference between the LT, IS, GM, SM, RF and TB for factor 2 as shown by the means in Table 3.9.

Table 3.9. Means and standard errors for muscle effect from factors 1 and 2

	Factor 1			Factor 2	
Muscle	LSMEAN	S.E.	Muscle	LSMEAN	S.E.
.IS	1.152a	0.184	PM	-0.716ab	0.195
PM	0.484bc	0.194	LT	-0.561bc	0.151
SV	0.429bc	0.15	IS	-0.239bcd	0.185
LT	0.369bc	0.15	GM	-0.214bcd	0.214
TB	0.105bc	0.15	SM	-0.211bcd	0.151
GM	0.036bcd	0.212	RF	0.168cde	0.163
RF	-0.445cde	0.162	TB	0.213cde	0.151
SM	-0.705de	0.15	BF	0.318de	0.151
BF	-1.441f	0.15	SV	0.348de	0.151

IS=Infraspinatus, PM=Psoas Major, SV=Serratus Ventralis LT=Longissimus Thoracicus, TB=Triceps Brachii, GM=Gluteus Medius, RF=Rectus Femoris, SM=semimembranosus and BF=Biceps Femoris.
LSMean is the Least Squares Mean. Animal*Muscle (Breed) used as the mean squares error term. Muscles with the same letter in the same column are not statistically different ($P<0.05$).

The results indicate that breed, cooking method and muscle were different for factor 1 which was represented by initial tenderness, sustained tenderness, shear force, juiciness and beef flavour. Alternatively breed was not significant for factor 2. Cooking method and muscle type were different for factor 2 that was dominated by cooking time, cooking loss and off flavour.

3.4. Discussion

The use of factor analysis has reduced the set of explanatory variables from eight to two. Factor one explains 46.1 % of the variation and factor two explains 18.2 % and together they explain a total of 64.2 % of the variation in the eight attributes. The results for factor one are consistent with the tenderness and juiciness results produced in other studies where single attributes were examined.

The breed effect may be a function of intramuscular fat content. Adipose cells are ruptured during cooking. When meat is served warm the melted fat "increases palatability of the product by giving a desirable mouth feel, especially at the end of the chewing period when most of the aqueous juices have been lost" (Fennema, 1985 p. 773). Differences in intramuscular fat levels between the Wagyu and Limousin muscles may affect the levels of the tenderness, sustained tenderness, juiciness and flavour attributes.

The results for a study by Carmack et al. (1995) are reproduced in Table 3.10. In that table it was shown that the PM, IS, SV, and LL score highly on tenderness and juiciness, which was consistent with factor 1.

Table 3.10. Means and rankings for tenderness, juiciness and flavour for 9 beef muscles

Muscle	Tenderness[a]	Rank	Juiciness[b]	Rank	Flavour[c]	Rank	Wt.* Rank
Psoas major	8.5 d	1	5.9 ef	3	7.5 de	2	1
Infraspinatus	7.2 e	2	6.6 de	2	6.8 fgh	9	2
Serratus ventralis	6.5 ef	5	6.8 d	1	6.9 efgh	8	3
Longissimus lumborum	6.9 e	3	5.2 fe	4	7.1 efgh	7	4
Rectus femoris	6.9 e	4	4.8 gh	6	7.1 efgh	6	5
Triceps brachii	5.8 fg	7	4.9 gh	5	7.3 defg	5	6
Gluteus medius	5.8 fg	6	4.7 gh	7	7.4 de	3	7
Biceps femoris	4.9 gh	8	4.7 gh	8	7.8 d	1	8
Semimembranosus	4.0 hi	9	4.1 h	9	7.4 def	4	9

Source: Adapted from Carmack et al. (1995) Table 2, p 146.

[a] Ease with which a sample is masticated until it can be swallowed.

[b] Moisture in sample perceived after 10 chews.

[c] Flavour generally associated with dry cooked beef.

defghi Column means with the same subscript are not significantly different ($P > 0.05$).

* Sample means were weighted such that (Weight 0.5 x T + 0.3 x J + 0.2 x F) and the results which are not shown were ranked from 1 equals the highest score to 12 equals the lowest score.

The TB, GM and RF were placed toward the middle of the range of muscles studied by Carmack et al. (1995), which is consistent with factor 1. Similarly, the SM and BF scored toward the lower end of the muscle range in factor 1 and the range produced by Carmack et al. (1995). Factor 1 did not agree with the flavour results produced by Carmack et al. (1995) as the rank order shown in that study for flavour was reversed with the one exception of the PM.

Results from a study by McKeith et al. (1985) have been scaled up from an 8-point scale to a 10-point scale and are shown in Table 3.11. The results of that study are more consistent with factor 1 scores across the four variables including flavour. A notable exception within the study by McKeith et al. (1985) is the result produced by BF. BF ranks toward the middle of the muscle range shown by McKeith et al. (1985); however, it was clearly ranked last by its factor 1 score. In their study the BF was reported with a high shear force value and yet it had a middle rank for tenderness, juiciness and flavour scores.

Table 3.11. Means for tenderness, shear force, juiciness and flavour by muscle

Muscle	Tenderness	WB Shear	Juiciness	Flavour
Psoas major	9.13 a	2.64 a	7.28 bc	8.19 a
Infraspinatus	8.43 b	3.28 ab	8.04 a	8.10 a
Longissimus thoracicus	8.08 bc	3.78 bc	7.28 bc	7.94 ab
Longissimus lumborum	8.28 cd	3.46 abc	7.59 ab	7.96 a
Rectus femoris	7.35 de	3.68 bc	7.36 abc	7.74 abc
Biceps femoris	7.29 e	5.49 d	7.73 ab	7.50 bcd
Gluteus medius	7.04 e	3.48 abc	6.28 de	7.34 cde
Semitendinosus	6.85 e	3.57 abc	5.99 e	7.08 de
Triceps brachii	6.85 e	3.89 bc	7.39 abc	7.30 cde
Semimembranosus	6.75 e	3.94 bc	6.84 cd	7.05 de

Source: adapted from McKeith et al. (1985) Table 3 by scaling from 8 point scores to 10 point scores for tenderness juiciness and flavour. Means in the same column with the same subscript are not significantly different (P >0.05).

Ramsbottom and Strandine (1948) used a water bath to cook muscles to 76.7 °C. They reported the shear force score of BF at 4.3 kg, which was specified to be a medium tenderness rating. Alternatively, Wheeler, Shackelford and Koohmaraie (2000) reported that BF had a 0.43 correlation with LD tenderness scores relative to a correlation of 0.68 for GM and 0.58 for SM that would indicate that the BF should be ranked low. However Wheeler et al. (2000) used a continuous belt grill set to 163 °C for 5.5 minutes to cook their samples and this difference in cooking method may have affected the tenderness scores. Reuter, Wulf and Maddock (2002) systematically evaluated shear force on 22 sequential steaks derived from the BF. They used a Farberware grill and cooked their samples to 71 °C; however, their samples were turned every four minutes. In their study the shear force scores ranged from a low of 2.80 kgs in the dorsal end to a high of 5.62 kgs in the centre and 4.44 kgs at the distal end. The samples for this present study were drawn from the centre of the muscle and this may explain the high shear force scores and the resulting low score for BF in factor 1.

Factor 2 represents cooking time, cooking loss and off flavours. In Table 3.9 it was shown that PM was different than RF, TB, BF and SV. However LT, IS, GM, SM, RF and TB were not significantly different for this factor. If muscle moisture were driving this factor then the order of the factor scores would be expected to be similar to the order reported in Brackebusch, McKeith, Carr and McLaren. (1991). Brackebusch et al. (1991) show the relationship between fat, water and protein content for fifteen muscles from cattle of various marbling levels. Results for the nine comparable muscles were selected from their study and are shown in Table 3.12.

Table 3.12. Fat, water and protein composition of selected muscles

Muscle	Water[a]	Rank[c]	Protein[a]	Rank[c]	Fat[a]	Rank[b]
SV	67.08	1	18.33	1	14.57	1
PM	69.25	2	20.37	3	10.26	3
LT	69.95	3	21.34	7	8.61	4
IS	70.5	4	18.9	2	10.43	2
BF	71.22	5	21.2	6	7.23	5
GM	71.85	6	21.66	8	6.6	6
SM	71.97	7	22.56	9	5.06	9
RF	72.55	8	21.17	5	6.16	8
TB	72.56	9	21.02	4	6.36	7

[a] Source: Adapted from Brackebusch et al. (1991).
[b] Highest fat level = 1, lowest = 9
[c] Lowest water and protein level =1, highest = 9.
BF= Biceps Femoris, GM=Gluteus Medius, IS=Infraspinatus, LT=Longissimus Thoracicus, PM=Psoas Major, RF=Rectus Femoris, SM=Semimembranosus, SV=Serratus Ventralis, and TB=Triceps Brachii.

The results shown in Table 3.12 from Brackebusch et al. (1991) indicate that the SV has a lower water component relative to the other muscles but the percentage value was not vastly different from the PM, LT or IS values. The factor 2 score however, ranks PM and SV at opposite ends of the muscle range. The factor scores were also not consistent with either the protein or fat percentage rankings. The SV was of particular interest in this factor as it was separated from the muscles that it has been typically grouped with.

Table 3.13 shows the means and standard deviations of the Limousin SV for each attribute and cooking method. The off flavour score for the grill method of cookery was 79.6 relative to the griddle method where the mean was 91.4. Importantly the grill cookery method produced a higher cooking loss (37.7); however, at the same time it produced a higher juiciness score (77.5) relative to the griddle method (54).

Table 3.13. Attribute means and standard deviations for Limousin SV by cooking method

Breed	Muscle	Cooking method	Scale	IT 100	ST 100	SHR kg's	BFL 100	OF 100	JCY 100	CLS %	MIN mins
L	SV	Griddle	Mean	60.5	49.2	3.89	53.8	91.4	54.0	32.6	24.3
			S.D.	15.3	15.1	0.31	2.79	6.40	7.43	6.54	4.90
L	SV	Grill	Mean	71.1	57.9	4.17	53.8	79.6	77.5	37.7	37.5
			S.D.	5.85	6.99	0.26	3.09	9.54	6.72	2.83	11

L=Limousin, SV = Serratus Ventralis, IT=Initial Tenderness, STD=Sustained Tenderness, SHR=Shear force, BFL=Beef Flavour, OF=Off-Flavour, JCY=Juiciness, CLS=Cooking Loss and MINS=cooking time.

T-tests on the off flavour means for the SV indicated that the difference between the grill and griddle methods of cookery was significant. The differences were more pronounced among the Limousin muscles relative to the Wagyu muscles; however, the F-test on breed was not significant for factor 2. Boylston et al. (1995) found no difference in the effect of cooking method on lipid content when either a roast (air temperature175 ^{o}C & internal temperature 70 ^{o}C) or boil method (100 ^{o}C: no internal cooking temperature was reported) was used for Wagyu LD versus other domestic breeds. Kazala et al. (1999) reported a significant correlation for extracted lipid content between the LD and the pars costalis diaphragmatis (PCD) of Wagyu crossbred cattle. This may explain the smaller degree of variation in off-flavours for the Wagyu muscles; however, this does not explain the level of off-flavour between the grill and griddle methods for the Limousin muscles.

The degree of correlation between off-flavour and cooking loss was shown in Table 3.2 to be -0.196, which would indicate that as cooking loss increased then off-flavour would decrease. Crocker (1948) argues the point: “cooking developed meaty flavour, apparently owing to chemical changes taking place in the fibre rather than in the juices” (p.180). Thus with a reduction in moisture then flavours may be more concentrated. The negative relationship between the cooking loss and off flavour factor scores would support this conclusion. Brackebusch et al. (1991) show that the SV has the lowest water content of the muscles sampled and therefore it may potentially produce more beef flavour as well as off-flavour; hence, its ranking at the lower end of the factor 2 score.

During heating, proteins and amino acids on the surface of meats change, with the production of volatile products. "Sulfur containing compounds are produced, including hydrogen sulfide, mercaptans, sulfides, disulfides, as well as aldehydes, keytones, alcohols, volatile amines and others" (Fennema, 1985 p. 773). The "lipid component may also break down into volatile products such as aldehydes, ketones, alcohols, acids and hydrocarbons" (Fennema, 1985 p. 773). Short chain hydrocarbons are very volatile due to their higher number of double bonds. Amino acids may interact with glucose and/or ribose of meats in the Maillard reaction, which produces the browning effect and flavour. Some of these volatile compounds, in both the fat and lean portions of the meat, contribute to the flavour and odour of cooked meats" (Fennema, 1985 p. 773). Thus variation in the amount of fat, air and level of oxidation of meats may produce flavours and off flavours during cooking. In addition to this variation, the cooking surface temperatures may also produce variation in the samples and may be responsible for some of the variation in cooking method and the levels of off flavour.

In this study breed type, muscle type and cooking method were found to produce significant variation in the sensory and mechanically measured attributes of beef. This result enables us to draw four conclusions:

1. The eight attribute variables loaded onto two factors thus reducing the dimensionality of the attribute space. This more realistically represents the choice that consumers make when purchasing beef products over bundles of attributes rather than one attribute at a time;

2. The breed effect was significant in this study. Wagyu muscles produced overall higher scores than Limousin muscles. This result was supported by other studies on the longissimus dorsi (Busboom et al. 1993; Kuber et al. 2004a) and the semitendinosus (Kuber et al. 2004b). The results shown here indicate the need to examine a broader range of muscles for each cooking method;

3. The ranking of muscles in this study was similar to those reported in other studies and was not affected by breed or cooking method; and

4. The results of this study would indicate that marketers of beef products should promote grill rather than griddle cookery methods to increase sensory ratings.

The results of this study are limited due to the number of animals and the number of cattle breeds from which the samples were derived. Nonetheless the method demonstrated is applicable to larger data sets including more animals, breeds, cooking methods and muscles.

The method demonstrated will become increasingly important for situations where more effects are introduced such as where additional cattle breeds or products from other animal breeds or species are considered for each cooking method.

3.4.1. Further research

The model should be validated with larger data sets such as the Meat Standard Australia set, to review the parameters of the factor analysis particularly those attributes residing in factor 2. This study has shown the importance of including a number of animal breeds and muscle types when cooking methods are evaluated. Further work is required to identify the factor leading to the variation in off-flavour between the two cooking methods, particularly for muscles with lower moisture levels and marbling scores.

3.5. Conclusion

The objective of this research was to test for sensory and mechanical variation in attributes across muscles derived from two cattle breeds and for two cooking methods and to produce a simple method of muscle classification. A nine person trained sensory panel was engaged to evaluate the sensory attributes of initial tenderness, sustained tenderness, juiciness, beef flavour and off-flavour. Additional attributes including cooking loss, cooking time and shear force were also measured.

A factor analysis model was used to accommodate the high level of correlation that exists between sensory variables and mechanically measured variables. The main effects of the model were tested via a randomised repeated measures ANOVA. The animal within breed effect proved to be significant; however, the interactions were not significant. Tenderness, sustained tenderness, shear force, juiciness and flavour dominated the first factor. Cooking loss, cooking time and off flavour dominated the second factor.

The breed effect, muscle effect and cooking effect were significant for the first factor. Only the muscle effect and cooking effect were significant for the second factor. The results of the factors are relatively consistent with other research with the notable exception of the biceps femoris muscle in the muscle ranking for the first factor and the serratus ventralis that unexpectedly loaded at the opposite end of the spectrum for factor 2.

This technique reduces the dimensionality of the attribute scores from eight to two, which enables researchers and marketers to identify muscles that demonstrated equivalent performance over the two factors.

It is recommended for future comparisons of cooking methods that more muscles in including the Longissimus Dorsi and the Semitendinosus be analysed and that muscles be sourced from at least two breeds of cattle.

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CHAPTER FOUR

A HEDONIC MODEL OF CORRELATED SENSORY ATTRIBUTES OF RETAIL BEEF CUTS

Abstract

Hedonic models are typically used to value attributes of food products. The sensory data in such models are sometimes highly correlated. Factor analysis (FA) can be employed to create uncorrelated variables from correlated sensory attributes. The parameters of the factor score can then be estimated in conjunction with other independent normally distributed variables in a hedonic equation.

The parameters on the variables derived from factor analysis can then be used to estimate price flexibilities for the set of correlated sensory variables. The results show that the factor analysis produces parameters with the expected sign and that deriving price elasticities from the factors is achievable. The price flexibility for initial tenderness was 10.6 cents per pound (c/lb) and 10.4 c/lb for sustained tenderness. Juiciness and beef flavour were 9.7 and 9.4 c/lb respectively. Increasing cooking time and cooking loss would decrease prices by 9.7 and 9 c/lb respectively. A decrease in off flavours would lead to a 6 c/lb increase in price. Further research is required to validate the parameter estimates produced in this model.

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4.1. Introduction

Quality attributes have been valued through the application of hedonic models and applications can be readily found for products such as vegetables (Waugh, 1928) and housing (Rasmussen and Zuehlke, 1990). More recent work in hedonic modelling has included sensory data to analyse implicit prices for food attributes of products such as apples (Carew, 2000), wine (Oczkowski, 2001), and Tuna (McConnell and Strand, 2002). Sensory attributes are often correlated; hence, the variables need to be examined carefully to determine the relationship between them prior to employing these in hedonic functions.

In this paper, the development of the hedonic model is reviewed. A semi-log functional form is compared against a linear form to examine sensory data derived from two cooking methods on nine muscles of Wagyu and Limousin cattle. Two variables generated via factor analysis are analysed in a hedonic model. The paper concludes by presenting price flexibilities for the significant variables identified via factor analysis and a discussion of these values.

4.2. Background

Waugh (1928) pioneered the hedonic method in a simple model for vegetable products' attributes. Rosen (1974) defines hedonic prices as "the implicit prices of attributes [that] are revealed to economic agents from observed prices of differentiated products and the specific amounts of characteristics associated with them" (p. 34). Lancaster (1971) discusses the idea of a set of characteristics replacing quantity in demand estimation and there are some references to the supply equation; however, the point is not elaborated upon. Lancaster has referenced these ideas back to earlier work by Griliches (1961). Ladd and Suvannunt (1971) credit Lancaster with the development of a model that specifies demand as a function of income, product prices and yields of product characteristics. In this paper we shall work with a traditional hedonic model for attributes of meat products. That is, price as a function of attributes.

Sherwin Rosen (1974) developed the theory of employing the marginal price/quality relationship of a hedonic price function to derive a producer's profit function and a consumer's utility function. The technique relies on tangency between a supplier's offer function in terms of marginal prices for attributes and the buyer's bid function.

The theory developed by Rosen has sparked considerable debate in three key areas. The first question surrounds the issue of functional form of the hedonic equation. The second issue focuses on identity in simultaneous equations. The third issue is the deployment of instrumental variables within the model. In this paper we focus on a fourth issue. That is, the case of collinearly among sensory variables.

The inclusion of sensory attributes in hedonic functions is a relatively recent trend. Studies that include sensory attributes have been noted for wine (Schamel and Anderson, 2003) and apples (Carew, 2000) and beef (Steenkamp and van Trijp, 1996). Food sensory attributes often tend to be highly correlated and as such would decrease the precision of parameter estimates. In this paper factor analysis (FA) is used to accommodate collinearity between the explanatory sensory variables in a hedonic model for nine beef muscles.

4.3. Models of meat attributes

Previous hedonic work on meat products has focused on pricing attributes of beef carcasses (Porter and Todd, 1985, Lin and Mori, 1991, Wahl, Shi and Mittelhammer, 1995) and different muscles derived from cattle (Unnevehr and Bard 1993, SteenKamp and Van Trijp 1996). A problem with assessing attributes of meat cuts was that some of the sensory attributes have been reported as being highly correlated (Horsfield and Taylor 1976 and Wierenga 1982) which would lead to multicollinearity in a hedonic equation.

Unnevehr and Bard (1993) analyse attributes of retail meat cuts. They applied Ladd and Suvannuant's (1976) model to the analysis of eight retail beef cuts. In their study they modelled the presence of bone, external fat thickness, marbling percentage and seam fat percentage. The last three variables would often be correlated for particular cuts from known cattle breeds on specific quantities of feed. Their results show that the presence of bone and subcutaneous fat in retail cuts has a negative impact on beef prices. Their parameter for intramuscular fat (marbling) was not significant. Marbling is a difficult attribute to value as it has both negative and positive price associations. The relationship between subcutaneous and intramuscular fat is typically non-linear. Unnevehr and Bard report that based on diagnostics by Belsley, Kuh and Welsch (1980),"the estimates are not degraded by multicolinearity (p. 291).

In the presence of multicolinearity ordinary least squares (OLS) estimators remain the best linear unbiased estimators (BLUE) even though these estimators will have larger variances for small data sets (Mittelhammer, 1996). The multicolinearity problem diminishes with larger sample sizes. This may explain why Unnevehr and Bard did not detect multicolinearity.

Steenkamp and van Trijp (1996) analyse meat colour, fatness, pH, water binding capacity, shear force, sarcomere length, visible fat, appearance, tenderness, non-meat components, flavour, quality expectation and quality performance using a partial least squares model. In their study they analysed these attributes for blade steak. Many of these attributes are typically correlated, namely colour with pH, appearance and possibly flavour; shear force with sarcomere length and tenderness; and flavour with fatness. Steenkamp and van Trijp conclude that colour and sarcomere length were identified as two important characteristics that could be modified to increase quality. It was surprising that the tenderness attributes were not significant in their results.

Factor analysis is a technique that accommodates correlated variables. The process reduces the dimensionality of the attribute space and forms independent variables from correlated variables. The new variables are factor scores that are then used in subsequent analysis with a hedonic equation.

After identifying two factor scores the aim is to derive a set of price-flexibilities for the meat quality attributes of tenderness, sustained tenderness, shear force, juiciness, beef flavour, cooking time and lack of off-flavour. The data source and methods are described in detail below.

4.4. Data

A nine person trained taste panel was engaged to produce the sensory data for this research. Nine muscles from eight cattle consisting of two breeds (Wagyu and Limousin) were randomly assigned to one of two fast cooking methods (panfry (PF) or grill (G)) and a shear-force test. The muscle preparation, cooking protocol, and taste panel protocol are standard techniques and are detailed in Farrell, Busboom, Evans and McCurdy (unpublished). The taste panel consisted of nine members who sampled a random cross section of each steak over a period of two weeks. Each of the nine panel members recorded scores on a 100-point scale for the sensory attributes listed below. Note that the panel was trained and rated the presence and level of particular attributes which contrasts with a non-trained panel which is typically asked to rank attributes on a like or dislike basis. The sensory data produced are therefore more objective rather than subjective.

4.4.1. Carcass Data

The left side from each of four Limousin and four Wagyu cattle were purchased from the control groups of a feed trail project (Mir et al., 2002). The steers were backgrounded on a 35% (dry matter basis) barley diet for 140 days. When the cattle reached 400 kg for Wagyu and 450 kg for Limousin, the diet was changed to a high barley diet (78 % on dry matter basis). The cattle were maintained on that diet until they weighed 500 kilograms for the Wagyu, and 560 kilograms for the Limousin. The steers were slaughtered at these weights. Animal care procedures were approved by the Washington State University Laboratory Animal Care Committee (LARC Project # 2823). The carcass grading data are shown in appendix A2. These data include animal number, breed, live carcass weight, rib eye area, maturity score, yearling grade, marbling score, marbling value, and assessed quality grade.

4.4.2. Muscle Data

The nine muscles sampled were the serratus ventralis (SV), infraspinatus (IS), psoas major (PM), longissimus thoracicus (LT), biceps femoris (BF), triceps brachii (TB), rectus femoris (RF), gluteus medius (GM) and semimembranosus (SM). These muscles were selected to enable a comparison with other sensory data sets reported in studies for other cattle breeds.

4.4.3. Sensory Data

The sensory attributes examined were initial tenderness (IT), sustained tenderness (STD), juiciness (JCY), beef flavour (BFL) and off-flavour (OF). Attributes that were mechanically measured were cooking loss (CLS), cooking time (MINS) and shear force (SHR). The means and standard errors for these variables are shown below.

4.4.4. Price Data

Price data for various retail cuts by grade were derived from the USDA (2005) weekly wholesale price summary. This data is provided in appendix A10.

4.5. Factor Analysis

For a given p variate response vector x with mean μ and variance-covariance matrix Σ the aim is to identify m underlying factors denoted by $f_1, f_2, \ldots, f_m$ such that:

$$x_j = \mu_j + \lambda_{j1} f_1 + \lambda_{j2} f_2 + \ldots + \lambda_{jm} f_m + \eta_j \tag{4.1}$$

for j =1,2,…, p and for m = 1,2,…, k.

and η_j are independently distributed with mean 0 and variance ψ_j.

With the assumption $\mu_j = 0$ and var $(x_j) = 1$ for every j, then we can rewrite the FA equation in matrix form as:

$$x = \Lambda f + \eta \tag{4.2}$$

The factor analysis equation is provided by the following equation where the aim is to identify Λ and Ψ so that:

$$\Sigma = \Lambda\Lambda' + \Psi \tag{4.3}$$

where Ψ_j's are the diagonal elements of the residual term.

Since the true variance-covariance matrix Σ is unknown, the correlation matrix ρ is used and then Λ is the matrix of correlations between the z_j's and f_k's.

The standardised z scores are provided by:

$$Z_{ij} = \frac{x_{ij} - \hat{\mu}_j}{\sqrt{\sigma_{ij}}} \tag{4.4}$$

Given $\sigma_{ii} = \mathrm{Var}(x_i) = E[(x_i - \mu_i)]^2$ for i = 1,2,…,p, and

$\sigma_{ij} = \mathrm{Cov}(x_i, x_j) = E[(x_i - \mu_i)(x_j - \mu_j)]$ for $i \neq j = 1,2,\ldots,p$,

then the correlation coefficient between x_i and x_j is given by:

$$\rho_{ij} = \frac{\sigma_{ij}}{\sqrt{\sigma_{ii}\,\sigma_{jj}}} \tag{4.5}$$

Once the FA model is solved, then:

$$z = \hat{\Lambda} f + \eta \tag{4.6}$$

Bartlett's Method can be used to attain the weighted least squares to find *f*, which minimises:

$$(z_r - \hat{\Lambda} f)\Psi^{-1}(z_r - \hat{\Lambda} f) \tag{4.7}$$

For a given z, the above expression is minimised when:

$$f_r = (\hat{\Lambda}'\hat{\Psi}^{-1}\hat{\Lambda})^{-1}\hat{\Lambda}\hat{\Psi}^{-1}z_r \qquad (4.8)$$

The factors scores are thus provided by the vector f_r for r = 1,2,…,N. Here the vector is a weighted sum of correlated variables of the initial matrix of x_{jm} responses. Two factors were identified and these enter the hedonic function as independent variables.

4.6. Hedonic Function

The hedonic function is specified in the following general form:

$$P = (Zi,) \qquad (4.9)$$

where Zi is a matrix of attributes variables. The attribute vectors can be replaced by factor scores; hence, Zi is replaced by:

FA1 is the first factor score produced via factor analysis

FA2 is the second factor score produced via factor analysis.

The semi log specification of the hedonic function is:

$$\text{Log}(P) = \beta_o + \Sigma\, \beta_i Z_i \qquad (4.10)$$

where Z_i are the attribute i variables and β_o and β_i are the parameters to be estimated. Zi in this function is replaced by f_i for i = 1 and 2.

Prior to estimating the model the data is analysed for homogeneity between the variables.

Table 4.1. Least square means and standard errors by attribute and breed

Breed	Initial Tenderness	Sustained Tenderness	Juiciness	Beef Flavour	Off-Flavour	Cooking Loss	Cooking Time	Shear Force
Wagyu	73.04	67.37	59.09	55.02	92.28	30.65	25.96	3.76
Limousin	64.64	57.54	52.36	48.19	90.58	34.20	30.98	4.33
S.E.	2.66	2.43	1.37	1.30	0.94	1.80	2.28	0.26

[a] S.E. is the standard error.

The results for differences between the cooking method means are shown in Table 4.2. The results indicate that the means for initial tenderness (IT), beef flavour (BFL), cooking loss (CLS) and shear force (SHR) on the flat cooker and the grill are not significantly different. Alternatively, the means for sustained tenderness (STD), juiciness (JCY), off-flavour (OF), and cooking minutes (MIN) were significantly different at the 95 per cent level.

Table 4.2. Least square means and standard errors by attribute and cooking method

Cooking Method	Initial Tenderness	Sustained Tenderness	Juiciness	Beef Flavour	Off-Flavour	Cooking Loss	Cooking Time	Shear Force
Flat	67.40	60.65	51.25	51.95	92.35	31.93	19.98	4.13
Grill	70.28	64.26	60.19	51.26	90.51	32.92	36.95	3.96
S.E.	1.25	1.24	1.66	0.95	0.63	0.45	0.79	0.11

[a] S.E. is the standard error.

4.6.1. Correlation Matrix

A correlation matrix was generated to examine the relationship between the attributes gained from the sensory panel and the mechanically measured tests.

Table 4.3. Correlation matrix for sensory and mechanical variables

Attribute	IT	STD	SHEAR	BFL	JCY	CLS	MIN	OF
IT	1.00							
STD	**0.97**	1.00						
SHEAR	**-0.60**	**-0.61**	1.00					
BFL	**0.60**	**0.57**	-0.37	1.00				
JCY	**0.58**	**0.55**	-0.31	**0.76**	1.00			
CLS	-0.36	-0.38	0.32	-0.33	-0.16	1.00		
MIN	-0.14	-0.11	0.07	-0.18	0.10	**0.50**	1.00	
OF	0.18	0.18	-0.22	0.14	0.01	-0.20	-0.16	1.00

Bold indicates attributes with a correlation value greater than 0.50.
IT=Initial Tenderness, STD=sustained tenderness, SHR=Shear force, BFL=Beef Flavour, JCY=Juiciness, MINS=cooking time, CLS=Cooking Loss and OF= Lack of Off-flavour

The correlation matrix reveals a 0.97 correlation between initial tenderness (IT) and sustained tenderness (STD). Shear force score would typically be highly correlated with initial tenderness and sustained tenderness. These were shown to be –0.607 and –0.607 respectively. The sign is negative as expected indicating that as tenderness increases the amount of pressure required to shear through a 1.27 cm meat sample decreases.

The correlation of 0.76 between juiciness (JCY) and beef flavour (BFL) was expected, as it is the juice in meat that carries beef flavour. The correlation between beef flavour (BFL) and initial tenderness (IT) is 0.60. This relationship is stronger than expected. There is a similar (0.57) relationship between beef flavour (BLF) and sustained tenderness (STD). Furthermore there are parallel relationships between juiciness (JCY) and initial tenderness (IT) 0.58 and sustained tenderness (STD) 0.54.

Cooking loss (CLS) and cooking time (MIN) have a relatively low correlation of 0.50. They both exhibit poor correlations with the tenderness, juiciness and flavour variables. The highest correlation on the lack of off flavour attribute was –0.22 with shear force.

There are clearly interactions between the tenderness attributes and the juiciness/flavour attributes in the correlation matrix. Shear force displays a negative relationship with the tenderness attributes as expected; however, it is poorly correlated with the juiciness/flavour attributes. These results would indicate that a maximum of two factors should be employed for subsequent analysis.

4.7. Eigen Values

The first Eigen value explains approximately 46 per cent of the variation in the data and the first two attributes contribute approximately 64 per cent of the variation. The remaining factors contribute approximately 36 per cent of the variation. These results suggest that two or three factors should be formed. This expectation is confirmed by the likelihood ratio test.

Table 4.4 Eigen values for 8 attributes

Factor	Eigen Values	Difference	Proportion	Cumulative
1	3.688	2.235	0.461	0.461
2	1.453	0.495	0.182	0.643
3	0.958	0.171	0.120	0.763
4	0.787	0.312	0.098	0.861
5	0.475	0.049	0.059	0.920
6	0.427	0.242	0.053	0.974
7	0.185	0.159	0.023	0.997
8	0.026		0.003	1.000

The likelihood ratio test of no common factors was rejected at the 99 per cent level; however, the test that two factors were sufficient was also rejected at the 99 per cent level. The model was rerun with three factors. The test that three factor were sufficient was accepted (P> 0.1370). The model with three factors produced two factors that were similar to the two-factor model and did not appear to add further information. Thus the two-factor model was retained for subsequent analysis.

4.8. Factor weightings

The factor weightings for the two-factor model are shown in Table 4.4. The first factor was explained primarily by initial tenderness (0.89), sustained tenderness (0.88), shear force (-

0.64), juiciness (0.82) and beef flavour (0.79). The second factor was explained by cooking time (0.83), cooking loss (0.75) and lack of off flavour (-0.47). The first factor was primarily made up of the tenderness attributes so we call this factor mastication. The second factor is dominated by cooking loss and cooking time; hence, this factor is referred to as moisture. These terms, mastication and moisture, were used to avoid confusion between the factor analysis variables and the original variables that they explain.

Table 4.5. Rotated factor scores by attribute

	IT	STD	SHR	JCY	BFL	MIN	CLS	OF
Factor 1	0.897	0.881	-0.641	0.828	0.799	0.055	-0.280	0.104
Factor 2	-0.219	-0.227	0.266	0.181	-0.132	0.834	0.769	-0.476

IT=Initial Tenderness, STD=Sustained Tenderness, Shear=Shear Force, BFL=Beef Flavour, JCY=Juiciness, CLS=Cooking Loss, MINS=Cooking Time and OF=Lack of Off Flavour.

These composite factor variables, mastication and moisture, were analysed within a typical hedonic function framework. The dependent variable was estimated with either price or the log of price as a function of mastication and moisture.

$$\text{Log Price} = \text{intercept} + \text{masticate} + \text{moisture} + \text{error} \tag{4.11}$$

The results both forms of the price dependent hedonic equations are shown in Table 4.6. Non-linear functions were estimated, however, none of the higher order variables were significant. A linear-log and double-log function was not analysed as the factor scores include negative values, which exclude log transformations.

Table 4.6. Regression results for the hedonic equation for masticate and moisture

Dependent = Price Variable	Parameter Estimate	Standard Error	T-value	Pr > |t|	R-Square	Adj. R-Sq
Intercept	303.72	15.81	19.21	<.0001	0.102	0.0899
Masticate	46.80	16.31	2.87	0.0048		
Moisture	-41.77	15.38	-2.71	0.0075		

Dependent = Log Price Variable	Parameter Estimate	Standard Error	T-value	Pr > |t|	R-Square	Adj. R-Sq
Intercept	5.56	0.042	131.57	<.0001	0.103	0.0894
Masticate	0.11	0.043	2.58	0.0111		
Moisture	-0.12	0.041	-2.98	0.0035		

The log price and price dependent models produced similar results. The independent variables are significant on the T-test at the 98 per cent level, the variables have the correct signs, but the adjusted R-square values are both low at 0.089 for each model. The positive sign on mastication would indicate that as it increased then price would increase. Alternatively the negative sign on the moisture factor indicates that as it increased price would decrease. The moisture factor is dominated by cooking time, cooking loss and lack of off flavour. Hence if cooking time increases, cooking loss increases or lack of off flavour decreases then price would decline. The signs on these factor scores are consistent with expectations. The log price dependent model is consistent with curvature requirement of the utility and production functions; hence, it is retained for subsequent analysis.

The results from the hedonic equation are used below to calculate the price flexibilities for the attributes contained in each of the factors. These prices are obtained by replacing the value Z_i in the price flexibility equation shown by Wahl et al., (1995) with the factor scores f_i for each attribute in the factor.

4.9. Price Flexibilities

Wahl, Shi and Mittelhammer (1995) show the derivation of the price flexibility for the semi-log specification. The case for continuous and discrete variables is shown below:

$$\rho_i = (\exp^{(\alpha i \beta i Z i)} - 1) / \alpha_i \qquad \text{if } Z_i \text{ is continuous} \qquad (4.12)$$

$$\rho_i = \exp^{\beta i} - 1 \qquad \text{if } Z_i \text{ is discrete} \qquad (4.13)$$

where α_i is the per cent change in Z_i such that $\alpha_i = (Z^*-Z_i)/Z_i$ and Z^* is the new level of Z. The variables in this analysis were measured continuously; thus (4.12) was used to calculate the price flexibilities that are shown in Table 4.7.

Table 4.7. Price flexibilities by attribute

Attribute	Masticate Cents per lb	Moisture Cents per lb
Initial Tenderness	10.62	2.72
Sustained Tenderness	10.42	2.82
Shear Force	-6.96	-3.21
Juiciness	9.77	-2.19
Beef Flavour	9.41	1.63
Cooking Time	0.62	-9.72
Cooking Loss	-3.10	-9.00
Lack of Off Flavours	1.18	6.01

The price flexibilities show the percentage change in price for a one per cent change in the level of the specified attribute. The prices for the attributes show that if initial tenderness was increased by one per cent then the price would be expected to rise by 10.6 cents per pound (c/lb). The result for sustained tenderness is similar and would increase by 10.4 c/lb. If shear force were to increase by one per cent then price would fall by almost 7 c/lb. Increasing juiciness and beef flavour by one per cent would lead to an increase of 9.7 and 9.4 c/lb respectively. The remaining attributes did not load highly on the mastication factor.

The price flexibilities for cooking time and cooking loss show that if these attributes were to increase by one percent then the price would decrease by 9.7 and 9 c/lb respectively. A one per cent increase in the lack of off flavours would lead to a 6 c/lb increase in price.

The results of this study are consistent for the sign of the expected price flexibility. The factors in this model explained approximately 64 per cent of the variation in the attributes. However over all the regression model only explained 0.11 of the variation in price. This would indicate that other factors are also important in the consumer's decision-making process. These other factors may include colour, portion size, visual fat (marbling) and risk (Steenkamp and van Trijp, 1996). Risk would impose a negative value on the function where the probability of receiving a lower quality product is high (Beardsworth and Keil, 1991).

The fact that tenderness, juiciness and flavour each have similar values is important. It suggests that the value of juiciness and flavour are almost as important as tenderness and yet tenderness has received the majority of attention in major surveys (Morgan, Savell, Hale, Miller, Griffin, Cross, & Shackelford, 1991). It may also be true that as animal handling, processing and cooking methods improve that tenderness may have become less of an issue to consumers (Killinger, Calkins, Umberger, Feuz and Eskridge, 2004).

The results for cooking time show a 9 c/lb decrease in price; however, this was primarily related to the impact of time on the sensory properties of meat. Convenience and speed of cooking is also important to consumers and this may reduce the cost if convenience was added to the model as an explanatory variable.

The use of factor analysis was shown to be useful for analysing correlated attributes. Factor analysis increases the efficiency of estimation by reducing the number of explanatory variables from eight to two. It would be expected that factor analysis would prove very useful when the number of correlated attributes to be examined rises. The method of examining factors in hedonic equations shown here may be suitable for other food products with correlated sensory variables.

The results of this study clearly indicate that tenderness, juiciness and flavour have a significant positive effect on the price of Limousin and Wagyu beef. Similarly cooking time, cooking loss and off flavours have a negative effect on price. These results would suggest that the costs of research that influences these attributes should be considered against the potential to increase the price of specific retail cuts or carcasses by the proposed method.

4.10. Limitations of the results

The results of this paper are limited due to the small data set for the factor analysis, which in turn limited the size of the variable vectors in the hedonic equation upon which the marginal implicit prices are based. Furthermore, the cattle breeds used in this data are vastly different in terms of their growth rates and maturity scores. A more in-depth analysis would incorporate more breeds with at least eight cattle per breed rather than four. There is a significant expense to this option in terms of animal costs as well as the vast amount of time and resources required to perform sensory analysis. It is expected that data derived from alternate sensory projects may be available to validate these results.

4.11. Conclusion

Research in this article is focused on dealing with collinear explanatory variables that arise from the use of sensory panel data in latent price analysis for food attributes. A semi-log hedonic function is specified for correlated variables though the use of factor analysis. The results for the model showed that factor analysis provided parameters with the expected sign and that both factors were significant.

The results of the beef data employed for this study indicated that the attributes of initial tenderness and sustained tenderness have positive implicit prices. If initial tenderness was increased by one per cent then the price could be expected to rise by 10.6 cents per pound (c/lb) and 10.4 c/lb for sustained tenderness. Increasing juiciness and beef flavour by one per cent would lead to a price increase of 9.7 and 9.4 c/lb respectively. Price flexibilities for cooking time and cooking loss show that if these attributes were to increase by one per cent then the price would decrease by 9.7 and 9 c/lb respectively. A decrease in off flavours would lead to a 6 c/lb increase in price.

It is suggested that parameters of the model be validated with a larger data set. The results in this study are limited due to the small number of cattle involved and caution must be advised prior to generalising these results to other breeds and or cooking methods. Attaching a hedonic model to factor scores is nonetheless a suitable technique to assess the value of correlated sensory attributes.

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CHAPTER FIVE

CONCLUSION

Meat quality was shown to be heterogenous across cooking methods, breeds and muscles. This conclusion implies that retail cuts produce different consumption properties and that some muscles should be treated as heterogenous goods in demand systems. To define a product as being homogeneous or heterogenous one needs to know the attributes that are important for the product and then identify the levels of those attributes. The difficulty in modelling meat quality arises from a lack of sensory data for a range of muscles over a range of product uses such as different cooking methods.

In this study some of the common relationships between muscles and meat cuts were described for beef. The main indicators of objective quality for beef include tenderness, juiciness, flavour, cooking loss, cooking time and off flavour of meat products. The choice of cooking method changed the scores for these attributes. Breed was thought to influence sensory attributes through variation in genetic factors. For instance marbling, which was commonly associated with Wagyu beef was thought to influence both flavour and tenderness of beef; however, previous research has shown that marbling was not strongly correlated with sensory indicators. Furthermore previous attitudinal analysis research showed that consumers perceived fat negatively. Hence the value of marbling in Wagyu muscles was not immediately apparent without an understanding of the sensory attributes of the muscles of this breed relative to the Limousin breed or other breeds that demonstrate lower marbling scores. Multivariate techniques were proposed to test effects and group muscles that produced similar quality attribute levels across both breed and cooking method.

The aim of Chapter 3 was to map sensory and mechanical variation in attributes across muscles derived from the two cattle breeds and for two cooking methods. Other authors found that for some muscles, cooking method did not significantly affect sensory attribute levels when the muscles were cooked to the same end point temperature.

A nine person trained sensory panel was engaged to evaluate the attributes of initial tenderness, sustained tenderness, juiciness, beef flavour and off-flavour. Cooking loss, cooking time and shear force were also measured. The trained panel produced the data that were used for the analysis shown in manuscripts two and three. A full explanation of the methods was provided in the second manuscript (Chapter 3).

A factor analysis model was used to account for the correlations reported between attributes. Factor analysis also enabled the attribute space to contract from eight to two dimensions. The attributes of initial tenderness, sustained tenderness, shear force, juiciness and flavour loaded on the first factor that explained 46 per cent of the variation in the eight attributes. Cooking loss, cooking time and off flavour loaded the second factor which explained 18 per cent of the variation. Each of the eight attributes loaded the factors with the expected signs.

An ANOVA model was used to tests the main effects and interactions between effects. The model was described as a completely randomised design with doubly repeated measures. The interaction terms were not significant and thus enabled the main effects to be explained independently. The mean of the grill cooking method was shown to be higher than the griddle method for factor 1 and the reverse was true for the second factor. It was suggested that the grilling method of cookery should be promoted in preference to the griddle method; however, the griddle method produced lower cooking times, cooking losses and fewer off flavours relative to the grill method.

The mean scores for Wagyu were shown to be higher than Limousin for factor 1. Breed was not significantly different for factor 2. The rank of muscles was different for both factors; however, the Infraspinatus and Psoas major were ranked high and the Biceps femoris was ranked low for factor 1.

The infraspinatus produced a superior score on factor 1 relative to the remaining muscles. There was no significant difference for Psoas major, Serratus ventralis, Longissimus thoracicus and Triceps brachii for the factor 1 scores. The Gluteus medius was in a group of three muscles including the Rectus femoris and Semimembranosus that produced negative scores. The BF was ranked last and was significantly different to each of the other muscles for factor 1.

Overall the results of this research were consistent with previous studies. The notable difference for factor 1 was the low ranking of the Biceps femoris relative to previous studies. The site within the biceps femoris muscle from which samples were drawn had been reported elsewhere as being toughest at that location relative to other parts of the same muscle.

The Serratus ventralis ranked low for factor 2 and was separated from the group of muscles commonly reported in its cohort such as the Psoas major and Longissimus thoracicus. It was suggested that the lower level of initial moisture contained in this muscle as reported elsewhere may have influenced the off flavour scores.

It was recommended for future comparisons of cooking methods that a number of muscles are examined, rather than one or two which was common. The muscles should be sourced from at least two diverse cattle breeds for marbling. Further research was recommended to analyse the production of off-flavours in muscles with low initial moisture content and lower marbling scores, in particular, the Serratus ventralis when grilled.

The third manuscript provided a brief review of the development of hedonic models. Multicollinearity among the explanatory variables that arises from the use of sensory panel data in latent price analysis for food attributes was identified as a potential problem. To address this issue, a semi-log hedonic function was proposed for correlated variables via the use of factor analysis. The results for the model demonstrated that factor analysis produced the expected signs and that each of the attribute variables loaded highly onto either factor 1 or factor 2 but not highly on both factors.

The results of the beef data employed for this study indicated that the attributes of initial tenderness and sustained tenderness have positive implicit prices of approximately 10.6 cents per pound (c/lb) for a one per cent increase in the level of the sensory variables. Similarly a one per cent increase in the levels juiciness and beef flavour attributes would produce a price increase of 9.7 and 9.4 c/lb respectively. Increasing cooking loss and minutes of cooking time by one per cent would lead to a decrease in price by 9 and 9.7 c/lb respectively. A one per cent reduction in off-flavour would raise price by 6 c/lb. Other studies were not available to compare these price estimates and it was suggested that market price research be conducted and the data analysed in conjunction with larger data sets on sensory analysis to validate these results.

The major contribution of this research was:

1) to provide a method of analysing bundled attributes by reducing the attribute space from eight down to two dimensions;
2) to rank muscles according to their attribute scores on those two dimensions;
3) to show that cooking method has a significant influence sensory scores if several muscles are examined;
4) to show that Wagyu cattle produced significantly higher scores for attributes in factor 1 such as tenderness, juiciness and flavour relative to Limousin cattle; and
5) to provide an economic value for increasing or decreasing the levels of each sensory and mechanically measured attribute.

APPENDIX

Table A1. Percentage of protein, water and fat in 15 major beef muscles

Muscle	% Fat	Std. Error	% Water	Std. Error	% Protein	Std. Error
Spinalis	16.06	1.39	65.49	1.19	18.46	0.27
Serratus ventralis	14.57	1.22	67.08	1.08	18.33	0.23
Rectus abdominis	14.42	1.33	66.45	1.06	19.15	0.36
Infraspinatus	10.43	0.81	70.50	0.69	18.90	0.17
Psoas major	10.26	0.78	69.25	0.71	20.37	0.25
Longissimus	8.61	0.82	69.95	0.70	21.34	0.22
Biceps femoris	7.23	0.61	71.22	0.56	21.20	0.23
Supraspinatus	6.39	0.52	72.86	0.51	20.26	0.14
Deep pectoral	6.37	0.63	72.05	0.55	21.08	0.20
Triceps brachii	6.36	0.51	72.56	0.49	21.02	0.19
Rectus femoris	6.16	0.56	72.55	0.53	21.17	0.17
Gluteal group	6.06	0.53	71.85	0.48	21.66	0.18
Semimembranosus	5.06	0.40	71.97	0.33	22.56	0.21
Adductor	4.44	0.31	72.28	0.35	22.85	0.21
Semitendinosus	4.41	0.36	72.90	0.32	22.19	0.21
Average	8.33	0.86	70.62	0.59	20.84	0.18

Source: Brackebusch, S.A., McKeith, F.K., Carr, T.R. & McLaren, D.G. (1991) Relationship between Longissimus composition and the composition of other major muscles of the beef carcass. *Journal of Animal Science, 69,* 631-640.

Table A2. Carcass attribute scores

Animal #	Breed	LiveWt	HCWT	REA	Maturity	YG	Mb Score	Mb Value	Actual QG
13BR	Wagyu	1084	688	13.7	A 70	2.2	Md 90	790	Choice +
16BR	Wagyu	1070	686	13.3	A 60	2.9	Ab 0	1000	Prime +
17BR	Wagyu	1020	646	12.9	A 70	2.2	MA 80	980	Prime o
22BR	Wagyu	1074	690	14.3	A 70	1.9	Ab 0	1000	Prime +
3	Limo	1356	908	17.5	A 70	1.7	Sl 50	450	Select +
5	Limo	1261	837	13.9	A 60	2.4	SL 60	460	Select +
9	Limo	1234	825	16.7	A 70	1.1	Sl 80	480	Select +
12	Limo	1400	925	19.2	A 70	1.2	Sl 20	420	Select -

Wt=weight, HCWT= Hot Carcass Weight, REA= Rib Eye Area, YG=Yearling Grade, Mb=Marbling, QG=Quality grade.

Table A3. Mean and standard deviation of primal weight by breed as a percentage of hot weight (Kilograms)

Muscle	Mean Wagyu	S.D. Wagyu	Mean Limousin	S.D. Limousin
SM	3.46	0.14	4.09	0.38
BF	3.46	0.06	4.22	0.34
RF	3.05	0.07	3.43	0.20
GM	1.82	0.12	1.94	0.13
PM	0.96	0.06	1.02	0.15
LT	1.80	0.12	2.02	0.24
IS	1.32	0.12	1.21	0.07
TB	1.67	0.11	1.85	0.09
SV	1.44	0.14	1.65	0.14

Note: Mean values refer to muscle from one side against whole carcass hot weight.
SM=semimembranosus, BF=Biceps Femoris, RF=Rectus Femoris, GM=Gluteus Medius, PM=Psoas Major, LT= Longissimus Thoracicus, IS=Infraspinatus, TB=Triceps Brachii and SV=Serratus Ventralis.

Table A4. Mean and standard deviation by breed, muscle and cooking method

Breed	Muscle	Cooking method	Scale	IT 100	ST 100	SHR kg's	BFL 100	OF 100	JCY 100	CLS %	MIN mins
L	BF	Griddle	Mean	37.03	28.08	6.62	37.74	91.32	43.57	39.90	31.30
			S.D.	11.66	6.68	1.50	9.11	1.74	14.33	6.52	16.00
L	GM	Griddle	Mean	61.06	50.40	4.15	46.62	94.87	44.13	35.85	20.50
			S.D.	11.80	12.52	0.66	9.46	4.12	14.15	3.17	3.50
L	IS	Griddle	Mean	87.93	83.64	3.35	63.78	91.48	74.80	31.27	19.30
			S.D.	2.13	3.76	0.34	5.88	3.34	8.37	5.52	2.10
L	LT	Griddle	Mean	79.31	73.60	3.23	50.34	96.40	49.15	29.18	19.80
			S.D.	8.49	6.06	0.93	10.87	1.72	2.61	5.34	4.50
L	PM	Griddle	Mean	79.84	78.76	3.57	43.66	86.06	36.57	32.42	20.70
			S.D.	8.07	9.75	1.25	6.33	7.23	14.69	4.22	9.50
L	RF	Griddle	Mean	55.88	50.45	5.46	47.22	91.28	46.10	37.99	30.00
			S.D.	15.38	18.35	0.72	12.88	10.45	17.77	4.82	8.60
L	SM	Griddle	Mean	43.34	35.49	4.45	39.18	95.82	30.35	31.97	21.00
			S.D.	20.57	20.80	0.97	9.45	2.92	13.43	0.27	5.20
L	SV	Griddle	Mean	60.48	49.18	3.89	53.81	91.36	54.02	32.59	24.30
			S.D.	15.31	15.10	0.31	2.79	6.40	7.43	6.54	4.90
L	TB	Griddle	Mean	60.31	55.94	4.98	50.17	88.76	40.74	35.40	29.00
			S.D.	12.21	7.78	1.73	8.12	4.71	17.83	5.66	6.10
L	BF	Grill	Mean	31.32	23.23	6.62	35.04	83.71	36.34	37.36	35.30
			S.D.	11.38	9.47	1.29	7.21	5.79	14.76	5.96	6.30
L	GM	Grill	Mean	64.47	54.96	4.54	51.45	89.43	63.23	36.02	34.30
			S.D.	13.03	13.23	1.13	4.28	5.73	5.33	4.29	6.40
L	IS	Grill	Mean	85.11	81.09	3.14	58.56	89.53	71.39	30.00	35.00
			S.D.	5.85	4.84	0.62	1.79	1.97	9.43	3.57	3.90
L	LT	Grill	Mean	78.89	71.84	3.47	42.01	92.66	48.98	34.69	38.50
			S.D.	11.75	12.11	1.17	9.69	5.83	7.14	2.88	9.90
L	PM	Grill	Mean	89.75	87.78	3.78	50.41	92.47	60.76	30.94	39.50
			S.D.	3.03	4.31	1.11	12.87	5.51	23.69	7.52	7.60
L	RF	Grill	Mean	60.18	51.99	3.86	46.30	85.21	56.43	34.11	37.00
			S.D.	9.34	7.94	0.80	4.58	7.24	16.51	4.39	8.60
L	SM	Grill	Mean	52.05	42.81	4.05	47.71	95.32	55.21	34.77	41.30
			S.D.	16.45	14.82	1.22	8.93	1.81	15.46	9.79	13.30
L	SV	Grill	Mean	71.10	57.93	4.17	53.77	79.59	77.49	37.70	37.50
			S.D.	5.85	6.99	0.26	3.09	9.54	6.72	2.83	11.00
L	TB	Grill	Mean	65.60	58.61	4.35	49.70	95.21	53.29	37.04	49.00
			S.D.	21.32	21.65	1.33	9.54	2.45	18.44	5.09	9.70

Note: these means were summed over the four animals for each breed type.
W= Wagyu, L=Limousin, BF=Biceps Femoris, GM=Gluteus Medius, IS=Infraspinatus, LT=Longissimus Thoracicus, PM=Psoas Major, RF=Rectus Femoris, SM=semimembranosus, SV=Serratus Ventralis, and TB=Triceps Brachii. IT=Initial Tenderness, STD=Sustained Tenderness, SHR=Shear force, BFL=Beef Flavour, OF=Off-Flavour, JCY=Juiciness, CLS=Cooking Loss and MINS=cooking time.

Table A4. Cont. Mean and standard deviation by breed, muscle and cooking method

Breed	Muscle	Cooking method	Scale	IT 100	ST 100	SHR kg's	BFL 100	OF 100	JCY 100	CLS %	MIN mins
W	BF	Griddle	Mean	51.56	38.61	7.64	46.78	92.76	45.35	31.95	20.00
			S.D.	15.46	15.72	3.03	3.96	3.74	6.82	1.95	4.80
W	GM	Griddle	Mean	77.99	72.99	3.61	57.70	94.37	63.79	30.82	16.00
			S.D.	4.99	4.32	2.04	3.09	2.04	4.56	2.79	5.70
W	IS	Griddle	Mean	80.18	79.28	2.91	60.55	90.95	67.45	30.48	18.00
			S.D.	5.34	5.32	0.38	11.94	4.38	10.78	1.47	1.40
W	LT	Griddle	Mean	87.18	80.27	2.50	55.94	95.89	51.96	26.77	15.80
			S.D.	3.54	7.13	0.25	6.47	1.04	11.75	3.39	3.60
W	PM	Griddle	Mean	82.82	80.20	2.78	58.17	95.58	50.45	29.83	13.50
			S.D.	6.71	6.97	0.81	5.41	1.94	14.99	5.85	0.70
W	RF	Griddle	Mean	65.71	56.61	4.16	50.95	89.14	45.16	32.56	14.30
			S.D.	14.11	8.89	1.04	9.97	7.08	13.51	3.02	1.20
W	SM	Griddle	Mean	58.88	50.94	3.54	52.29	95.19	47.32	32.56	20.50
			S.D.	11.79	12.09	0.66	8.82	5.49	9.13	3.73	6.60
W	SV	Griddle	Mean	69.55	59.49	3.12	61.69	85.99	66.99	29.17	20.80
			S.D.	20.91	17.44	0.21	18.96	6.38	24.25	4.56	6.90
W	TB	Griddle	Mean	74.24	67.96	3.61	58.56	95.08	64.76	31.07	21.80
			S.D.	6.66	8.64	0.62	2.67	3.62	7.51	5.49	6.00
W	BF	Grill	Mean	47.10	40.92	6.16	49.08	91.28	47.27	30.94	35.80
			S.D.	12.07	13.05	1.01	7.87	4.01	13.76	7.88	7.60
W	GM	Grill	Mean	73.50	67.86	3.52	55.36	94.76	63.64	32.08	37.80
			S.D.	7.32	4.90	0.93	7.99	1.45	7.19	3.32	5.70
W	IS	Grill	Mean	87.23	86.50	2.45	62.03	88.28	77.73	27.79	30.50
			S.D.	4.99	4.35	0.23	7.45	5.11	8.68	3.63	4.70
W	LT	Grill	Mean	88.71	84.48	2.52	47.26	92.78	62.29	31.82	36.30
			S.D.	7.24	7.85	0.63	5.62	4.87	11.48	1.89	6.20
W	PM	Grill	Mean	90.16	89.37	2.65	57.26	96.37	66.02	30.32	33.80
			S.D.	8.58	9.37	0.68	12.40	2.68	22.25	4.89	8.20
W	RF	Grill	Mean	61.29	59.36	4.38	48.70	91.66	53.02	33.55	37.80
			S.D.	17.54	15.03	2.24	13.08	1.90	20.79	3.13	13.10
W	SM	Grill	Mean	58.33	50.05	3.74	45.21	92.26	54.23	32.66	38.50
			S.D.	12.15	13.27	0.37	10.15	6.94	11.54	2.25	4.10
W	SV	Grill	Mean	83.63	77.37	4.30	62.98	86.58	77.86	30.35	30.50
			S.D.	11.04	12.58	1.16	12.26	13.61	19.93	4.59	4.40
W	TB	Grill	Mean	76.73	70.59	3.68	59.91	92.28	58.41	30.66	37.30
			S.D.	10.10	9.30	0.85	5.24	5.63	10.86	6.94	10.30

Note: these means were summed over the four animals for each breed type.
W= Wagyu, L=Limousin, BF=Biceps Femoris, GM=Gluteus Medius, IS=Infraspinatus, LT=Longissimus Thoracicus, PM=Psoas Major, RF=Rectus Femoris, SM=semimembranosus, SV=Serratus Ventralis, and TB=Triceps Brachii. IT=Initial Tenderness, STD=Sustained Tenderness, SHR=Shear force, BFL=Beef Flavour, OF=Off-Flavour, JCY=Juiciness, CLS=Cooking Loss and MINS=cooking time.

Table A5. Least square means and standard errors by attribute and breed

Breed	Initial Tenderness[a]	Sustained Tenderness[b]	Juiciness[c]	Beef Flavour[d]	Off Flavour[e]	Cooking Loss (%)	Cooking Time (min)	Shear Force (kgs)
Wagyu	73.04	67.37	59.09	55.02	92.28	30.65	25.96	3.76
Limousin	64.64	57.54	52.36	48.19	90.58	34.20	30.98	4.33
SEM[f]	2.66	2.43	1.37	1.30	0.94	1.80	2.28	0.26
Pr>|t|	0.07	0.03	0.01	0.01	0.25	0.20	0.15	0.15

100 mm line scale with anchored end points labelled as [a] tough-tender, [b] tough-tender, [c] dry-juicy, [d] bland-intense and [e] none detectable-pronounced.

[f] SEM is the standard error of the least squares mean.

IS=Infraspinatus, PM=Psoas Major, LT=Longissimus Thoracicus, SV=Serratus Ventralis, GM=Gluteus Medius, TB=Triceps Brachii, RF=Rectus Femoris, SM=semimembranosus and BF=Biceps Femoris.

Table A6. Least square means and standard errors by attribute and cooking method

Cooking Method	Initial Tenderness[a]	Sustained Tenderness[b]	Juiciness[c]	Beef Flavour[d]	Off Flavour[e]	Cooking Loss (%)	Cooking Time (min)	Shear Force (kgs)
Griddle	67.40	60.65	51.25	51.95	92.35	31.93	19.98	4.13
Grill	70.28	64.26	60.19	51.26	90.51	32.92	36.95	3.96
SEM[f]	1.25	1.24	1.66	0.95	0.63	0.45	0.79	0.11
Pr>|t|	0.11	0.04	0.00	0.61	0.04	0.17	<.0001	0.33

100 mm line scale with anchored end points labelled as [a] tough-tender, [b] tough-tender, [c] dry-juicy, [d] bland-intense and [e] none detectable-pronounced.

[f] SEM is the standard error of the least squares mean.

IS=Infraspinatus,PM=Psoas Major, LT=Longissimus Thoracicus, SV=Serratus Ventralis, GM=Gluteus Medius, TB=Triceps Brachii, RF=Rectus Femoris, SM=semimembranosus and BF=Biceps Femoris.

Table A7. Least square means and standard errors by attribute and muscle

Muscle	Initial Tenderness[a]	Sustained Tenderness[b]	Juiciness[c]	Beef Flavour[d]	Off Flavour[e]	Cooking Loss (%)	Cooking Time (min)	Shear Force (kgs)
IS	85.10a	82.62a	72.84a	61.22a	90.05bc	30.00a	25.31abc	2.98abc
PM	85.64a	84.02a	53.45bc	52.37bc	92.62ab	30.19a	24.66abc	2.98abc
LT	83.52a	77.54a	53.09bc	48.88bc	94.43a	30.60a	27.56abc	2.93ab
SV	71.19b	60.99cb	69.09a	58.05ab	85.88c	32.45b	28.25abc	3.86bcd
GM	69.25b	61.55cb	58.70b	52.78b	93.35ab	32.50b	25.87abc	4.07bcd
TB	69.21b	63.27b	54.29bc	54.58ab	92.83ab	33.54c	34.25a	4.15cd
RF	60.76c	54.59c	50.17bcd	48.29bcd	89.32bc	34.58d	29.45abc	4.74cd
SM	53.14c	44.82d	46.77cd	46.09cd	94.64a	32.98bc	30.31ab	3.94cd
BF	41.75d	32.71e	43.13cd	42.16cd	89.76b	35.04d	30.56ab	6.76e
SEM[f]	2.75	2.67	3.44	2.35	1.30	0.86	1.68	0.30

Muscles with the same letter in the same column are not statistically different (P<0.05).
100 mm line scale with anchored end points labelled as [a] tough-tender, [b] tough-tender, [c] dry-juicy, [d] bland-intense and [e] none detectable-pronounced.
[f] SEM is the standard error of the least squares mean.
IS=Infraspinatus, PM=Psoas Major, LT=Longissimus Thoracicus, SV=Serratus Ventralis, GM=Gluteus Medius, TB=Triceps Brachii, RF=Rectus Femoris, SM=semimembranosus and BF=Biceps Femoris.

Table A8. Correlation matrix for Limousin sensory and mechanical variables

Attributes	IT	STD	SHR	BFL	JCY	MIN	CLS	OF
IT	1.000	**0.974**	**-0.595**	**0.603**	**0.554**	-0.095	-0.306	0.108
STD		1.000	**-0.558**	**0.585**	**0.504**	-0.103	-0.319	0.099
SHR			1.000	-0.335	-0.219	0.033	0.359	-0.251
BFL				1.000	**0.751**	-0.139	-0.296	-0.009
JCY					1.000	0.151	-0.080	-0.154
MIN						1.000	**0.510**	-0.145
CLS							1.000	-0.201
OF								1.000

Bold indicates attributes with a correlation value greater than 0.50.

IT=Initial Tenderness, STD=Sustained Tenderness, SHR=Shear force, BFL=Beef Flavour, JCY=Juiciness, MINS=cooking time, CLS=Cooking Loss and OF=Off-Flavour.

Table A9. Correlation matrix for Wagyu sensory and mechanical variables

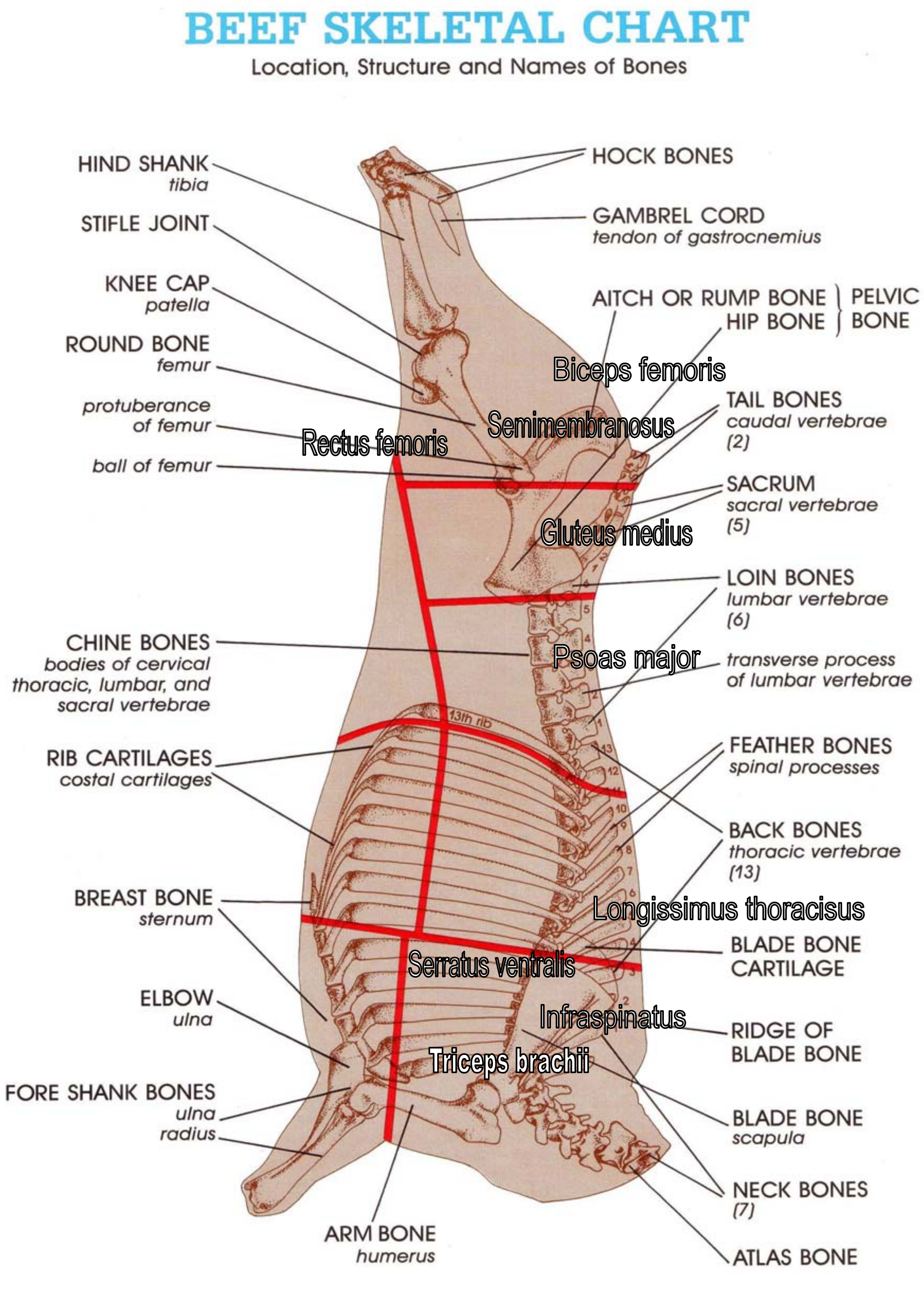
Attributes	IT	STD	SHR	BFL	JCY	MIN	CLS	OF
IT	1.000	**0.964**	**-0.606**	**0.550**	**0.586**	-0.110	-0.324	0.221
STD		1.000	**-0.646**	0.497	**0.556**	-0.043	-0.350	0.228
SHR			1.000	-0.347	-0.360	0.050	0.202	-0.161
BFL				1.000	**0.767**	-0.115	-0.184	0.241
JCY					1.000	0.111	-0.144	0.186
MIN						1.000	0.431	-0.129
CLS							1.000	-0.078
OF								1.000

Bold indicates attributes with a correlation value greater than 0.50.
IT=Initial Tenderness, STD=Sustained Tenderness, SHR=Shear force, BFL=Beef Flavour, JCY=Juiciness, MINS=cooking time, CLS=Cooking Loss and OF=Off-Flavour.

Table A10. Weekly wholesale beef prices by retail cut and quality grade (US cents/lb)

Animal	Number	L3	L5	L9	L12	W13	W16	W17	W22
	Grade	Select +	Select +	Select +	Select -	Choice +	Prime +	Prime o	Prime +
Retail No.	Muscle	c/lb	c/lb	c/lb	c/lb	c/lb	c/lb	c/lb	c/lb
171B	BF	215.00	215.00	215.00	173.25	215.25	223.25	221.25	223.25
185C	GM	287.65	287.65	287.65	253.05	282.00	325.00	322.00	325.00
114A	IS	215.37	215.37	215.37	165.06	215.37	215.37	215.37	215.37
112A	LT	448.01	448.01	448.01	446.46	456.00	511.00	506.00	511.00
189A	PM	688.77	688.77	688.77	689.98	836.00	891.00	886.00	891.00
167A	RF	225.50	225.50	225.50	174.50	225.00	233.00	231.00	233.00
168	SM	181.12	181.12	181.12	167.29	181.94	189.94	187.94	189.94
130	SV	134.64	134.64	134.64	94.00	135.00	135.00	135.00	135.00
114E	TB	260.00	260.00	260.00	202.20	260.00	260.00	260.00	260.00

Source: USDA, 2005, ‘National comprehensive boxed beef cut out’, *Market News Service*, Week ending 21/Jan/05, http://www.ams.usda.gov/mnreports/LM_XB463.



Courtesy of National Live Stock and Meat Board

Figure A1. Location of nine muscles in a beef carcass

Table A11. SAS input for factor analysis and ANOVA tests

```
options linesize=85 pagesize=60 pageno = 1 date;
 data Beef ;
input Breed $ Animal $ Muscle $ Cook $ Code $ Period $ Attrib $ Judge $ Score;
Title 'Beef Sensory Set';
Cards;
<DATA HERE>
;
Title2 "Analysis of a Completely Randomized Design with Doubly Repeated
Measures";
proc sort data = beef; by breed animal muscle cook attrib; run;
proc means data = beef noprint;
  by breed animal muscle cook attrib;
  var score;
  output out = average mean = meanscore; run;
proc sort data = average;
by attrib; run;
Title3 "Analysis of the Average Score for Each Sensory Attribute";
proc glm data = average ;
by attrib;
class Breed Animal Muscle Cook;
model meanscore = breed animal(breed) muscle muscle*breed muscle*animal(breed)
cook cook*breed cook*muscle cook*breed*muscle;
test h = breed e = animal(breed);
test h = muscle muscle*breed e = muscle*animal(breed);
LSMeans breed / PDIFF stderr e = animal(breed);
LSMeans muscle / PDIFF stderr e = muscle*animal(breed);
LSMeans cook / PDIFF stderr; run;
proc sort data = average; by breed animal muscle cook; run;
proc transpose data = average out = new;
by breed animal muscle cook;
var meanscore;
id attrib; run;
Title3 "Factor Analysis of the Sensory Attribute Averages to Extract the
Factor Scores";
proc factor data = new scree  rotate = varimax simple corr n = 2 out = scores;
var BF IT J OF ST MIN SHR CLS; run;
Title4 "Analysis of the Factor Scores for the First and Second Factors";
proc glm data = scores;
class Breed Animal Muscle Cook;
model factor1 factor2 = breed animal(breed) muscle muscle*breed
muscle*animal(breed) cook cook*breed cook*muscle cook*breed*muscle;
test h = breed e = animal(breed);
test h = muscle muscle*breed e = muscle*animal(breed);
LSMeans breed / PDIFF stderr e = animal(breed);
LSMeans muscle / PDIFF stderr e = muscle*animal(breed);
LSMeans cook / PDIFF stderr; run;
proc print data = scores; run;
Proc Plot Data=scores;
Plot factor1*factor2;
Run;
```