Modelling Meat Quality Attributes.

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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 the two primary factors that affect meat-eating quality. The purpose of this paper is to show how meat quality parameters relate to one another for beef cuts. A quality index for tenderness, juiciness and flavour can be incorporated directly into demand functions.

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Introduction:

Economists seldom employ “quality variables” in meat demand analysis even though meat products are heterogeneous. Quality grades as they apply to carcasses are not consistent with the eating quality of all 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 concept of meat quality is 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.

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:

$$\text{Max } \Pi = \Sigma_{ij} (p_{ij}q_j - c_{ij}q_j - FC) \quad (1)$$

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, and 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,

$$\Sigma_{ij}\, q_j = Q. \tag{2}$$

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:

$$Q^* = \phi\, Q = \phi\, (\Sigma_{ij}\, q_j) \tag{3}$$

Where ϕ is the number of animals slaughtered in the relevant period of time. Equation 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:

$$c_i = \text{purchase price (cents/kg)} + \text{trim loss} + \text{labour} + \text{packaging} + \text{labelling} + \text{delivery} + \text{overheads.} \tag{4}$$

Where c_i is the unit cost in cents per kilogram and the purchase price is given below in Equation 5. See Hahn and Green (2000) for justification of fixed proportions and joint costs in meat retailing.

$$Pp = (CC / Q) \text{ x the weight of the untrimmed primal or cut } q_i \tag{5}$$

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.

$$\text{Price (A)} = f\ \{QA, QB, QC, OG, Y, S) \tag{6}$$

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 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 well 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 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). Keep in mind that 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 with cuts being roasted versus grilled are substitutes (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.

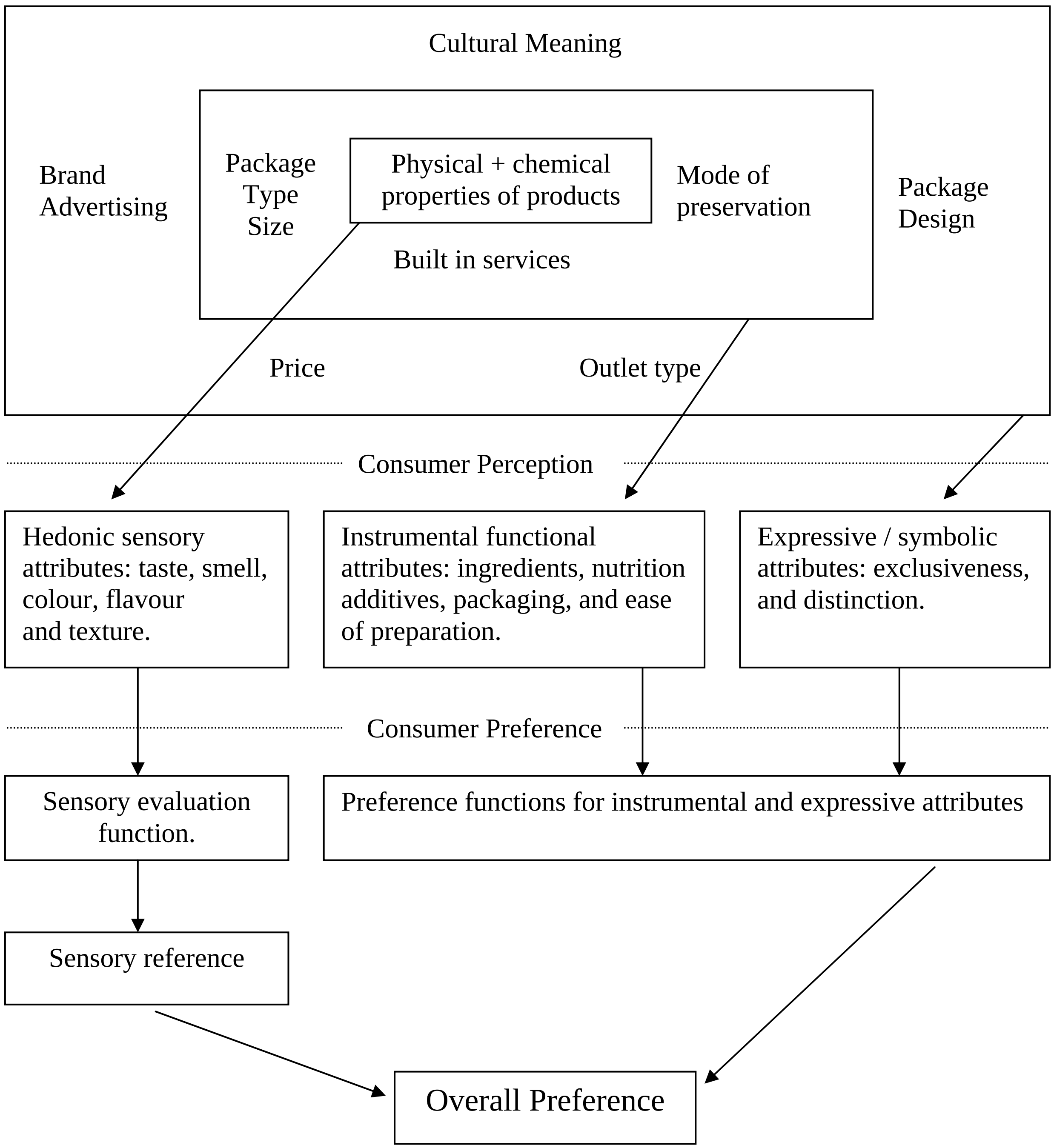
What is meat quality?

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). British research 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 quotes show 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 a consumer 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. With fresh products consumers have more opportunities for repeated sampling and building their product attribute knowledge base.

Figure 1. Model for the Choice of a Food Product.



Source: Wierenga (1983), p 123.

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. 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. The cost of conducting 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 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 temperature 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 a short period of time above 70 ^{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 sample to 71 degrees Celsius and shear a 2.47 cm by 1.0 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 (WBS). 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 percent 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 1. Approximately 68 percent of the bottom round tested in excess of 3.9kgs and 52 percent 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 percent of the t-bones examined tested less than 3.9kgs and 100 percent 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.

Table 1 Least Square means for Warner-Bratzler shear-force (WBS) and the percentage distribution of steaks with <3.9, >3.9 and >4.6 kilograms

				Percentage	
Steak	N	WBS, kgs	< 3.9 kgs	> 3.9 kgs	> 4.6 kgs
Clod	68	3.01 ef	92.6	7.4	5.9
Chuck roll	135	3.35 d	74.8	25.2	5.2
Ribeye	200	2.84 efg	94.5	5.5	1.5
Porterhouse	56	2.69 g	92.9	7.1	1.8
T-bone	147	2.71 g	98	2	0
Top loin	269	2.77 fg	94.1	5.9	0.7
Top sirloin	118	3.04 e	89	11	0.8
Top round	91	3.74 c	60.4	39.6	15.4
Eye of round	177	4.19 b	44.1	55.9	26.6
Bottom round	97	5.09 a	32	68	52.6

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

Carmack et al. (1995) show the sensory results of a study including 12 beef muscles and the rank of the muscle for the attributes of tenderness, juiciness and flavour. The rank 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). 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 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 bachii	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).
* This ranking is mine based on the following. 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.

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 percent 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 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 is used to produce a carcass MQA 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:

$$\text{CMQ4} = 0.4 \times \text{Tenderness} + 0.1 \times \text{Juiciness} + 0.2 \times \text{Flavour and } 0.3 \times \text{Overall Score.} \quad (7)$$

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 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 meat quality is not new knowledge. However, the 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 gravitated toward the ground meat supply during the past decade. See Brester and Wohlgenant (1991) for changing consumption patterns associated with ground beef.

Table 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 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.

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 5, next page). 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 1, 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.

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.

Table 5 Marbling, shear force and taste panel scores by beef breeds

	Marbling	Shear Force	Taste Panel Scores *		
Breed Type	Fat %	Kg/cm^2	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).

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 6 below. The intramuscular fat percentage for semimembranosus (topside), and gluteus medius (rump) are both correlated by 30 percent to tenderness. The correlation for marbling percentage is lower still in the range of 20 to 25 percent. The marbling score for longissimus (T-bone) has no more effect on meat quality than the marbling found in the gluteus medius (rump).

Table 6 Tenderness, juiciness and flavour correlations to marbling and intramuscular fat

Muscle	Longissimus		Gluteus medius		Semimembranosus	
	Marbling	Intramusc.	Marbling	Intramusc.	Marbling	Intramusc.
Characteristic	Score	Fat %	Score	Fat %	Score	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
Flavor intensity	0.17	0.30	0.10	0.09	0.20	0.19
Flavor 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 not to increase the marbling score in the loin but to increase fat deposits or marbling in other muscles. The 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 muscles may not store any more fat than they require to function adequately for metabolism. Thus a high marbling score is a poor indicator of meat quality for muscles other than the loin (longissimus). See Schaefer (1995) for more on the relationship between growth and fat deposition in beef cattle.

Richardson, et al. (1994) present a broader view of United Kingdom (UK) consumer attitudes to meat consumption including healthiness, vegetarianism and meat avoidance and characteristics such as hormones and additives. Their paper is a survey of the attitudes of 1046 UK residents to broad product categories including a number of meat products. A very nice paper by 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.

Qualitative Models:

The largest problem that economist 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 later 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 errors terms are no longer a function of mean square error alone.

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) provides an example of an exit interview survey for consumer attitudes to irradiated beef. It appears as if 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) explores 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 percent of meals prepared by U.S. households were prepared in 30 minutes or less in 1993 and that the figure has increased to 44 percent in 2000. The growth of four percent 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.

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 consumers 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 7 below.

Table 7 Estimates of parameters for fat thickness and marbling percentage by retail cut

Class of Cuts	Bone-in	External Fat Thickness	Marbling Percent	Seam Fat Percent	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. (1999) show that chicken was preferred to beef which was preferred to pork for attributes including leanness, healthy, 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 animals 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 typically contains two large pieces of sinew plus there may be some variation in product toughness as the infraspinatus is typically more tender than the supraspinatus. The hierarchical modelling framework that they employ might be very useful if they were to compare attributes of different 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.

Proposed method of deriving and modelling meat substitutes:

My 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 factor analysis to identify the first two or three significant factors and their loadings.
4. Use a trained sensory panel to evaluate the key factors 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 some tests for checking the independence of clusters identified in step 6 above.

Amemiya (1981) has a nice review of qualitative models and 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 less 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 were 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 it quality above or below the mean of a particular group. Other variables can also be added to the model as scalars. The following function (8) captures the essence of the price-scaling model.

$$P_i = P^* + - f\ (\ QI_i + \text{ Other attributes }) + e \qquad (8)$$

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: and 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 terms of quality and revenue. For example, a study of branded beef products by Wolf and Thulin (2000) would be more convincing if the study included a sensory analysis of each of the product brands in conjunction with the attitude data which they analysed.

The potential benefit to research organization for including quality variables in models is that they can model returns to increasing quality factors by muscle, cut or breed type. 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 if the algorithm is maximising over cuts so that only the cuts that satisfy palatability constraints will be selected.

The next step in defining the groups of substitute meat products is to actually test run 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.

Conclusion:

Meat quality was shown to be heterogenous across cuts of beef. The same analogy 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 for 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.

Appendix 1.

Table 8 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 et al. (1991).

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