RETURNS TO RESEARCH FOR BEEF CARCASS QUALITY IMPROVEMENT IN AUSTRALIA

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ABSTRACT

Dark-cutting (DC) in beef has become an important quality problem facing the Australian beef industry. DC beef appears dark, firm and dry (DFD), and compared with meat of normal pH, DFD meat has a lower organoleptic property (reduced meat flavour) and a poorer keeping quality which makes it unsuitable for vacuum packaging and export. It is rejected as high quality table beef by the meat industry. The average incidence of DC in Australia has been estimated to be in the range 8-10%.

DC is reducing the overall returns to Australian beef producers, and is redistributing income from producers whose production exhibits a relatively low incidence of DC to those whose production has a high incidence. Economic losses are incurred in the form of depressed prices for DFD carcasses, diversion of top quality primal cuts to mince or manufactured meat, and possibly lower demand due to loss of reputation for the beef industry.

The incidence of DC may be reduced by research into animal management (e.g. improved handling of animals) and alternative marketing systems (e.g. computer marketing). An inadvertent flow of DFD meat from the abattoir to consumers could be avoided if some form of sorting or objective classification were available.

There is a lack of scientific and economic research into meat quality for the Australian beef industry. Past research focused on shifting supply curves by reducing costs and raising yields. In the present paper, an economic framework based on the concept of economic surplus is developed to make an illustrative calculation of the size of economic gains accruing to producers and consumers as a result of improvement in meat colour in beef carcasses. Meat colour improvement in carcasses eliminates the price reduction effect caused by DC at carcass sales. It is estimated that, on a national basis, improvement in meat colour in beef carcasses resulting from 50% reduction in DC would contribute a gross annual saving averaging $10 million in table quality beef, of which 20% accrues to producers and 80% to consumers.

Our current analysis constitutes only a part of an overall assessment of reducing DC in beef. The present estimation only covers a certain percentage of dark carcasses acceptable at retail trade with appropriate price discounting. Due to DC and product heterogeneity, meat colour of beef carcasses varies widely from normal and mature-red meat to extremely dark coloured meat. A certain percentage of carcasses with very dark and dull meat colour may not be acceptable for retail trade even with price discounting. These carcasses could be diverted to alternative uses (e.g. the production of mince and processed meat) by wholesalers or abattoir operators. Our present analysis does not account for benefits and costs that a reduction in DC would cause through reducing the ‘diversion’ effect and the inadvertent flow of undetected DC meat from the abattoir to consumers. Further research is needed to allow for a full benefit-cost appraisal of reducing DC in beef.
1 An Economic Evaluation of Dark-cutting Beef in Australia

1.1 The Problem of Meat Colour Variation in Beef Carcasses

Quality is a collective attribute or characteristics which make a product what it is. It may be precisely expressed by the value of different traits which described the product. Past research revealed that meat colour has been an important trait. An empirical study by Porter and Todd (1985) showed that meat colour, fat colour, meat texture and fat texture were important explanators of carcass price variations. In a survey on the attitudes of retailers to beef carcass classification, Wilson and Wissemann (1981) discovered that meat colour was considered the most important characteristic to be included in future objective classification system. This view is supported by the results of Porter and Todd (1985).

Changes in meat colour could influence consumers' acceptability of the product. In the market place, buyers would naturally prefer fresh bright-red beef to either pale or dark coloured beef. This is due to the fact that most buyers presume that discoloured beef may be derived from old, sicked or diseased animals. Besides, buyers have a notion that discoloured beef may be stale, dated, unfresh or contaminated. This happens in spite of the fact that there seems to be no clear relationship between colour defects and meat spoilage. Buyers are willing to purchase more and/or pay a higher price for normal bright-red meat relative to the dark meat.

Colour variation in beef carcasses is mainly caused by the dark-cutting (DC) phenomenon and by the age of an animal (see Warner, 1988 for detail). The darker colour of meat due to dark-cutting and the more red colour of meat from older animals have traditionally conveyed messages of poor eating quality.

1.2 Economic Implications of Discolouration in Meat

Early studies on the effects of discolouration on consumers' demand for beef (round steak) was undertaken by Hood and Riordan (1973). The studies shows that the percent total sales of round steak at Dublin supermarkets decreased proportionately with increase in the extent of discolouration. In other words, consumers' demand for round steak dropped when the rate of discolouration rises. In a survey of 141 Dublin housewives, for instance, 72% stated that they disliked both dark-red and brown beef since they considered such discoloured meat to be of inferior quality. Consumers tend to be very sensitive to meat colour variation particularly at retail chains or big butcher shops where arrays of different types of red meat are displayed together. Supermarket operators would not normally accept discoloured meat unless it is discounted to a point at which profitability is not sacrificed.

Beef colour lies in the range of pale to very dark, with varying acceptability of texture. It is theoretically possible to speculate on relationships between consumers' utility (U) and the rate of discolouration (R) in meat (see Figure 1 to 3). The marginal utility functions (MU) are plotted in Figure 4 to 6. The optimum colour is bright-red, as denoted by R2 in Figure 1 to 6. R1 and R3 denotes extremely pale and extremely dark coloured meat respectively. Consumers' utility decreases with increases in the rate of discolouration on both sides. Consumers' utility can decrease linearly (Figure 1), with increasing rate of
Figure 1-3. RELATIONSHIPS BETWEEN CONSUMER UTILITY (U) AND RATE OF DISCOLOURATION (R) IN MEAT

Case 1

Case 2

Case 3
Figure 4.6. RELATIONSHIPS BETWEEN MARGINAL UTILITY (MU) AND RATE OF DISCOLOURATION (R) IN MEAT

Case 1

Case 2

Case 3
discolouration (Figure 2) or with decreasing rate of discolouration (Figure 3) depending on the type of meat, the nature of discolouration and individual tastes and preferences. For linear function (case 1), consumers' satisfaction drops in a constant fashion when meat either turns paler (towards the left) or darker (towards the right). For increasing function (case 2), consumers' utility drops very slowly in the beginning in either directions, that is consumers seem to be quite indifferent to or unaffected by initial colour change. When discolouration increases, however, consumers' utility begins to drop sharply. The opposite changes apply to the decreasing function (case 3) in which consumers' utility drops very rapidly in the beginning indicating that consumers are extremely sensitive to discolouration in meat. At points R1 and R3, the commodity could be completely discarded by consumers in the market place due to extreme discolouration. In the economists' point of view, case 3 phenomenon could yield a more severe economic repercussion than either case 2 or case 1 phenomenon because meat with even slight discolouration will be discriminated against by the buyers. Quality improvement in this case would increase consumers' utility markedly and this can be socially desirable. Thus, one of the criteria for quality (colour) improvement research may be based on the way in which consumers' utility or the consumption patterns fall relative to meat colour change.

The existence of linearity and non-linearity functions were investigated by Hayenga et al. (1985) in their studies on a carcass merit system for pork. Their studies were based on hedonic price variations in relation to incremental changes in carcass weight, backfat thickness and muscling. When the backfat and carcass weight variables are specified as continuous rather than discrete, carcass weight exhibits a non-linear relationship with carcass value, with increasing discounts appropriate as carcass weight increases. However, the backfat carcass value relationship did not exhibit any significant non-linearity. In analysis of meat colour, similar premium-discount matrix for assessing carcass values resulting from variations in meat colour can be obtained provided such data exist. This, however, warrants further research because as yet there is no objective system for appraising meat colour. Research priority should thus be devoted to studying as well as devising appropriate objective classification methods for assessing meat colour.

1.3 Economic Losses and The Alternative Uses of Dark-Cutting Beef

DC beef has the following characteristics: dark, firm and dry conditions; reduced shelf-life; reduced meat flavour; and the presence of spoilage odours. The extent to which economic losses are incurred from DC in beef depends on the specific methods used for measuring DFD meat, the ways in which beef are marketed and the ways in which DFD meat are used. Up to now, commercial assessment of DC beef has been subjectively based on individual appraisal of appearances, particularly meat colour. Measurement of pH values as a means for judging and confirming the occurrences of DC poses some technical problems to the beef industry. It is extremely difficult, for instance, to accurately determine a threshold point at which DC occurs. Due to the existence of intermediate stages between 'extreme' DFD meat and so-called normal meat, meat which is considered to be DFD may have normal appearance. Therefore, under current subjective assessment, DFD meat may be presumed to be normal by some traders and consequently this may lead to an under-estimation of economic losses.
Fresh beef in the form of carcasses is usually passed down from wholesalers or abattoir operators to retailers, particularly butchers and retailer chain operators. In this process, carcasses are transformed into primal cuts and various beef products to meet the market demand. Identification of DC beef carcasses commences at the wholesale or abattoir level. It is expected that DC incidence will be lower at wholesale than at retail level due to several reasons. First, difficulty still remains in assessing the occurrences of DC beef in the high quality domestic market because carcasses often leave the abattoir before reaching the ultimate pH. In this case, identification of DC beef may not occur at the wholesale level. Warner (personal communication, 1988) reported that abattoir management identified lower incidence (3.4%) of DC than the retail butchers (7.4%), indicating that DC carcasses could miss in detection at the abattoir and be detected by other traders down in the marketing chain. Second, the absence of absolute measurement for detecting DC beef means that some DFD meat with normal appearance will be passed on to the retailers without being identified. Unlike retailers, wholesalers seem to be concerned merely with characteristics associated with the initial outward appearance of beef carcasses. DFD carcasses with seemingly normal appearance at slaughter may deteriorate with time during which characteristics indicative of DC may emerge in retail beef cuts derived from carcasses or parts of the carcasses. Some retailers may consider their beef cuts or carcasses to be DFD so long as an undesirable characteristic associated with DC arises. In this regard, retailers tend to complain more frequently about, and report a higher incidence of DC than the wholesalers. Supermarket operators or retail butchers are the ultimate traders who actually confront the final consumers. Thus, discrimination against DC beef tends to affect the retailers directly.

The problems of DC in beef can also affect the consumers in an indirect manner. When DFD meat with seemingly normal appearance is purchased, cooked and tasted, experienced consumers might feel, for instance, that it yields less flavour, and hence is less satisfying to the palate, than the normal beef. Besides, DFD meat spoils faster and is thus a disadvantage to some restaurant operators and institutional buyers who tend to keep their meat defrosted for a longer time for seasoning and cooking purposes.

At the wholesale level, economic losses resulting from DC are due to the fact that prices paid for DFD carcasses are comparatively lower than prices paid for normal and good quality carcasses. Due to differences in colour intensity and severity of DC, a proportion of DC carcasses could be disposed off by wholesalers at discounted price but a proportion of very dark and dull coloured carcasses would be rejected even with price reductions. Some retailers who unintentionally receive unacceptably dark carcasses may send such carcasses back to their respective suppliers for fear of reduced saleability and the expectation of losses. Carcasses which appear unacceptably dark in colour at the abattoir and those returned by the retailers would be directed to alternative market outlets.

In some cases, only certain parts of the carcasses are DFD. Under such circumstances, sorting and culling are necessary in which only affected parts of the carcasses are diverted to other meat products or to markets where customers are less discriminating whereas less affected parts will be salvaged for high quality retail cuts. In the market place, the top quality primal cuts obviously fetch much higher prices and offer better profit margins than alternative meat products. Economic losses in this case are incurred in the form of profit forgone in diverting high quality fresh table beef to alternative products.

At the retail level, however, economic losses are not so clear-cut. Retailers may face
the problems arising from reduced saleability of DFD meat due to abnormal appearances. Quality deterioration of a product would certainly lead to a lower demand for that product. It is nevertheless very difficult to quantify economic losses resulting from reduced saleability of a product unless data are available indicating the actual loss in sales. There are instances where losses are due to reduced shelf-life of DC beef particularly when it is vacuum-packed. DC beef with seemingly normal appearance poses some problems for the retailers as well. Indirect losses are incurred from reduced storability and unexpected discolouration. In cases where DC beef is sent back to the wholesalers, retailers may still liable to unnecessary transportation charges and may face the difficulties of filling orders or meeting demand of their customers.

Consumers could also be affected by the incidence of DC directly and indirectly via unexpected consumption of meat which yields less flavour (less tasty) or meat which appears darker in colour. Consequently, the beef industry may, to a certain extent, suffer from lower domestic and export sales due to loss of reputation for not being able to constantly supply beef with expected quality standards. In maximising their utility or satisfaction, affected consumers would subsequently select their bundle of goods with a smaller quantity of beef in it. This, however, depends on individual taste and preferences. The demand for meat is price and perhaps quality elastic implying that the substitution effect is strong. The case where overall table quality beef consumption is depressed by an unexpected and unsatisfactory consumption of some poorer quality beef can happen as a result of information asymmetries and previous unpleasant experiences. The possible occurrences of depressed demand due to loss of industry reputation and reduced consumers' utility could ultimately cause greater economic losses.

Theoretically, economic losses resulting from an inadvertent flow of DC beef from abattoir to consumption point may be avoided if an objective measurement for DC beef is available and if quality control is being enforced. The way in which this may be accomplished warrants further research.

As a consequence of apparent rejection of DC beef at the retail and consumption levels, wholesalers may divert DFD meat to the production of mince beef, small-goods, processed meat and meat products (e.g. canned beef, corned beef, ground beef, meat pie, quick-frozen beef and some pre-cooked meat) or to markets where customers are less discriminating (e.g. in the preparation of ready-to-cook dishes). The main reason for using DFD meat in cooking or curing processes is its high water-holding capacity and this is important when meats are finally comminuted for mince or for use in meat emulsions. It is nevertheless unsuitable for the manufacture of dry sausages or other dry processed meat products.

1.4 Economic Implications of Dark-Cutting Beef in Australia

The severity of DC in beef varies from area to area and from country to country due to differences in the ways in which beef cattle are produced and marketed, differences in climatic conditions, infrastructure and pre- and post-slaughtering management. In Victoria, the mean incidence of DC beef has been estimated to be 9.6% based on pHu greater than or equal to 5.8 (Warner et al., 1988). An estimated average of 8% of cattle (excluding mature bulls and animals younger than 1 year) slaughtered in Australia have ultimate pH values greater than 6.0 (Shorthose, 1988). In Australia, most regard the M. Longissimus dorsi (LD) muscle, from 18 month old animals, as 'dark' once its pHu exceeds 5.7-5.8 (Shorthose, 1988).
A Victorian study on a supermarket purchasing behaviour revealed that 30% of carcasses inspected by an experienced supermarket meat buyer had unacceptable muscle colour (Truscott, unpublished). The assessment was based on visual colour rating between 1 and 10 (with 1 being pale and 10 being very dark); scores from 7 to 10 were unacceptable for his requirements. Visual colour score was moderately correlated with pH ($r = 0.57$). A visual colour score of 6.5 (i.e. the mid-point between acceptable and unacceptable) being equivalent to a pH value of 5.8 ($pH = 4.8 + 0.153\times VCS$). These results show that, at times, the incidence of unacceptable colour associated with high pH can be quite high in, otherwise, high quality Victorian carcasses. Because of the way meat is displayed for consumers in supermarkets, supermarket operators are very sensitive to the need to have meat that is of consistent colour and appearance.

The studies referred to above provide solid evidence on the severity of the DC problem in Australia.

When carcasses with DFD meat are identified, wholesalers or abattoir operators have the options of reducing prices, using the affected parts of carcasses for mincing or manufacturing of small goods, diverting the carcasses to their own shops or delivering the carcasses to alternative outlets.

Beef constitutes one of the largest traded commodities in Australia. Of Australian beef production, approximately half of the total is exported and the other half is consumed domestically. Under the Export Meat Regulations, export meat orders prohibit the export of excessively dark meat unless in a boneless manufacturing form or as an ingredient of a meat product (Brownlie, 1988). Apart from low organoleptic properties (poor flavour) and reduced storage life, DC beef has a sulfmyoglobin greening syndrome during transportation, making it unsuitable for packing for export, particularly meat with an ultimate pH of 6.0 or above. There were instances in the past of bacteria-induced greening in vacuum-packed beef during transportation to Japan and the product was returned to Australia. This implied that substantial financial losses may be incurred in the form of depressed overseas demand due to loss of reputation for the beef export industry. Loss of reputation means that the meat export industry is unable to meet overseas’ demand for expected quality beef. This can jeopardise the international trade between Australia’s meat exporters and oversea importers of fresh, vacuum-packed and chilled/frozen export quality beef. Quality control is therefore needed to ensure beef satisfies a minimum quality standard before shipping. The current subjective means of identification for DC beef should, if possible, be replaced by a more objective method of appraisal. Through an objective assessment, DFD meat, when detected prior to shipping, may be put into a boneless manufacturing pack to be exported for manufacturing purposes. Following the abolition of quota on Japanese beef import by 1991, Australia’s market share in the total quantity of beef exported to Japan is likely to increase. The beef industry, however, should be well informed of the type and quality of beef the Japanese are eating. Co-ventures between Australian beef producers and the Japanese importers may be helpful in this respect. More stringent quality control would be necessary in order to establish a stronger export reputation and to maintain consistent export demand for Australian export quality beef.
2 Quality Improvement and Demand Shift

2.1 Introduction

A better quality beef carcass is equivalent to altering one or more of the amount of a characteristic in each unit of the product. In some cases, quality improvement is perceived as adding one or more of unique and desirable characteristics (i.e. characteristics which previously did not exist) to the product. Such innovations would give rise to a ‘new’ product; a product which has a different form and is more desirable than the one prior to innovations.

Quality improvement can be depicted as a rightward or upward shift of consumer demand function. Figure 7 showed a parallel rightward shift of linear demand function. A rightward shift of demand for a product implies that consumers are willing to purchase an increased quantity of that product at each price level (denoted by \( v \) in Figure 7), or alternatively, consumers are willing to pay higher prices for that product at each quantity level (denoted by \( w \) in Figure 7). The increase in quantity demanded or increase in willingness to pay is reflected by a rise in consumer’s utility obtained from each unit of the product. From Figure 7, the price premium resulting from quality improvement, as denoted by \( w \), is equivalent to \( P_i(X^*_i - X_i) \), where \( P_i \) is the implicit price of characteristic \( j \); \( X^*_i \) is the new amount of characteristic \( j \) obtained from one unit; and \( X_i \) is the old amount of characteristic \( j \) obtained from one unit before the technical change.

When demand shift is measured as the consumption increase, that is, the projected output change \( v \) (Figure 7), rather than the premium \( w \), then,

\[
v = n Q w / P,
\]

where \( n \) is the own price elasticity of demand, and \( P \) and \( Q \) are equilibrium price and quantity. Let \( k = w / P \), then,

\[
v = knQ.
\]

2.2 Differences Between Demand-shifting and Supply-shifting Research

There are two distinct types of supply-shifting research, the output expanding research (e.g. improved animal breeds and high-yielding crop variety) and the cost-reduction research (e.g. technological changes resulting in lower cost of production). In the former, the output per unit input is increased and in the latter, the same previous output is possible with reduced input. Nevertheless, the desired level of production can be adjusted according to market demand by the desired level of inputs. Thus, an output expanding research advance can be interpreted as a cost-reduction, for instance, a 10% higher production rate from a new breed of cattle or a higher yielding variety can be interpreted as a 10% reduction in per unit output cost of production.

In contrast to supply shifting research, demand-shifting research is caused by quality improvement and technical changes in marketing processes. Quality improvement increases willingness of consumers to consume more of a product and or to pay a higher price for it. An upward shift of demand for a product implies that consumers are willing to allocate greater budget (\( I = PQ \)) for consumption of that product relative to other products.
Figure 7. PARALLEL RIGHTWARD SHIFT OF LINEAR DEMAND CURVE
to increased level of satisfaction. Therefore, willingness to consume 10% more of a product can be interpreted as willingness to pay a 10% higher per unit price of a product in order to achieve the same level of satisfaction.

Changes in marketing processes, on the other hand, reduce the marketing costs (the marketing margin) of a product and cause an upward shift in the farm demand function. The magnitude of a demand shift is represented either by \( w \) (the vertical distance between the two demand functions) or \( v \) (the horizontal distance between the two demand functions). Unlike yield raising, quantity data associated with \( v \) are often not available. In the case of supply, scientists are able to measure quantity increase per unit input resulting from improved breed or high yielding variety, but in the case of demand, extra quantity which consumers are willing to consume resulting from quality improvement is often not measurable. The price data \( w \), however, may be determined from cross-sectional data showing variation in prices with product quality. Regression of prices against quality characteristics with respect to a standard yields respective premiums and discounts for different grades of the product. In Unnevehr's paper, supply of rice was assumed to be perfectly elastic and rice grain quality improvement led to an absolute increase in consumption. Benefits from quality improvement were empirically quantified by the estimation of implicit price \( w \). For beef carcasses, saleyard auction data (Porter and Todd, 1985) showed that prices of carcasses varied with differences in various quality characteristics. Poorer quality carcasses were heavily discounted whereas better quality carcasses received certain premiums.

### 2.3 The Implications of Elastic and Inelastic Demand Shift

Given the same vertical shift in demand represented by \( w \) and a fixed supply \( S \), the relative change in price \( (dP) \) and quantity of a product \( (dQ) \) depends on the price elasticity of demand (Figure 8). For beef, retail demand is relatively elastic with respect to it's own price and substitution effect between other meats and beef is great as price relativity changes. However, farm demand for beef carcasses is relatively price inelastic. An upward shift in farm demand resulting from beef carcasses quality improvement would theoretically result in relatively large increase in consumption but small increase in price. Calculation on relative changes in price \( (dP) \) and quantity \( (dQ) \) is shown in the appendix. These price and quantity changes are represented by:

\[
dP = w\left(\frac{n}{e + n}\right),
\]

\[
dQ = wQ_0/P_0\left(\frac{en}{e + n}\right).
\]

where \( w \) is the implicit price, \( n \) is own price elasticity of demand, \( e \) is own price elasticity of supply, \( P_0 \) and \( Q_0 \) are the price and quantity at initial equilibrium point respectively. Compared with inelastic demand, elastic demand gives rise to higher equilibrium price and quantity level (\( e_2 \) versus \( e_1 \) in Figure 8) except when supply is perfectly inelastic. When demand is relatively elastic, higher equilibrium price and quantity levels are obtained, and producers derive a greater surplus.

In the short-run, supply of a commodity is usually inelastic but becomes increasingly elastic in the long-run as producers are able to alter both their fixed and variable costs in the long run. When supply is perfectly inelastic, a rightward shift of demand results in an absolute price rise (Figure 9) and the change in economic surplus accrues entirely to the
Figure 8 PARALLEL RIGHTWARD SHIFT IN DEMAND WITH TWO DIFFERENT ELASTICITIES BUT WITH AN IDENTICAL CHANGE IN PREMIUM ($w$)
Figure 9. PARALLEL RIGHTWARD SHIFT IN DEMAND RESULTING FROM QUALITY IMPROVEMENT
producers; consumers will have no extra surplus. As supply gets more and more elastic, moving from S1 to S3, quality improvement will result in an increasing quantity consumed at equilibrium and an increasing economic surplus derived. If supply is perfectly elastic, quality improvement will increase consumption but leave price unchanged. The increase in change in economic surplus is then at it's maximum, and it accrues entirely to the consumers; producers will have no surplus but get normal profit on an increased sales volume.

2.4 Parallel and Convergent shift in Demand

Unneverh (1986), in a study of consumer demand for rice grain quality, assumed that rice grain quality improvement caused a parallel rightward shift of a linear demand curve. Factors contributing to a rightward/upward shift of demand curve for a product include the product quality improvement, population growth, income growth, increase in prices of substitutes, and advertising and promotion of the product. Research in marketing processes leading to a reduction in marketing costs (e.g. costs of transport, handling, packaging, processing, storage, distribution services etc.) would cause an upward shift of the derived demand curve (which is the consumer demand curve less the marketing margin). Freebairn, Davis and Edwards (1982) assumed a parallel shift of linear demand curve caused by technological changes in the marketing stage showing that per unit reduction in marketing costs is constant at all quantity or production levels. However, for quality improvement of a product, depending on the type of product, the characteristics to be altered and the extent of improvement, the assumption of a parallel shift of the demand curve may not always be realistic. Quality improvement means enhancement of certain desirable product characteristic(s) or impartation of new characteristic(s). Unlike research inducing cost reductions, quality improvement involving enhancement of product characteristic(s) often leads to a change of product form or appearance, and those involving addition of new characteristic(s) could cause formation of a new and differentiated product. Quality of a washing powder has improved if, for instance, a special substance were added which gives the product a unique power to clean all unwanted stains on clothes. Such a unique attribute may not be present in it's close substitutes and consequently, the product actually deviates from it's own group of substitutes which a consumer can compare, becoming unique and becoming more a product by itself. The elasticity of demand facing a brand is a function of the number and the closeness of substitutes which a consumer can compare. The greater the number of close substitutes facing a product, the more competitive is the market for the product, and an increase in competitiveness makes the demand for a product more price elastic. Quality improvement of a brand in some cases reduces closeness of the brand and it's substitutes, thus causing the brand less competitive relative to other brands. As a result, consumer demand could become less price elastic. More inelastic demand indicates that the slope of the demand curve has increased, that is, a steeper slope is formed (as price elasticity of demand is directly related to the slope of the demand curve). The extent to which a product deviates from it's own group of substitutes depends on the type, the nature, the desirability and the magnitude of characteristic(s) to be improved.

From above discussion, it is proposed that quality improvement could lead to convergent shift of a linear demand curve. In a later section, it is graphically shown that a greater economic surplus can be derived from convergent shift than from a parallel or divergent shift. Convergent shift also means that the demand curves before and after quality improvement
will not intersect. This is because in a competitive market where market information is readily available, consumers always demand more of an improved quality product. Intersection of demand curves before and after quality improvement implies inconsistent consumer behaviour, that is, poorer quality product is preferred to better quality products.

Quality improvement in terms of reduction of DC in beef may cause beef meat to be more desirable relative to other meats and meat products due to an improvement in taste, physical attractiveness and storability. Changes in such attributes may not necessarily reduce competitiveness, thus elasticity changes would be small. Change in elasticity for beef carcasses resulting from quality improvement would even be smaller than those for primal cuts displayed in supermarkets.

Rightward shift of the demand curve can also be induced by advertising and promotion. Advertising and promotion will not alter the product characteristics; it makes a product well-known to the consumers by changing consumer perception of the product. Advertising and promotion are sometimes used as a means to inform consumers of a new brand or new substitute in the market place. When a new brand, say an experience good, is launched and recommended in the market, it has first to be experienced by a consumer in order to test its quality (Nelson, 1970). The product has not been included in the range of products which a consumer can compare. During the experimental or the promotional period, demand is expected to be very inelastic. If the consumer samples at random, that elasticity of demand must be zero (perfectly inelastic). The overall elasticity of demand is a weighted average of the experimental and post-experimental elasticities (Nelson, 1970). Over a period of time after the brand has become popular and that consumers begin to select the new product amongst all other close substitutes, elasticity of demand facing the product increases. Thus, advertising and promotion of a new product brand and quality improvement of a well-known product which reduces market competitiveness tend to have opposite effects on price elasticity of demand.

Rightward shift of the demand curve can also be induced by income growth and population growth. Unlike quality improvement and promotion and advertising, growth of income and population will not affect a product’s competitiveness vis-a-vis its substitutes. Thus, conceptually, the fact that income and population growth would lead to a parallel shift of consumer demand function seems reasonable.

2.5 The Concepts of Consumer and Producer Surplus

The concepts of consumer and producer surplus and the sum total of these surpluses (social or economic surplus) are frequently adopted in applied welfare analysis to quantify changes in welfare of consumers, producers and the society as a whole resulting from alterations in corresponding shifts of demand and/or supply functions of commodities (see Gunawardana, 1988 for a review). The demand curve shown in Figure 10 can be interpreted as a ‘marginal willingness-to-pay curve’. Consumers are willing to pay a price P for a quantity of commodity Q purchased. Thus, the total area below the demand curve and above the price line P (area Pab in Figure 10) represents the consumer surplus. It is an economic measure of satisfaction which Marshall (1890) defined as ‘the excess of price which a consumer would be willing to pay rather than go without the thing over that which he actually does pay’. It is the extra utility or satisfaction derived from purchase of a commodity.

As in the case of a consumer (buyer), Marshall suggested that a producer (seller) may
also receive a 'surplus' from a transaction, and that this surplus can be measured in a geometrically symmetric manner with the consumer surplus. Producer surplus is interpreted as the extra profit derived from sale of a commodity. It is shown by the area Pbo in Figure 10 which is above the supply curve and below the price line. The producer surplus may be said to be present whenever a seller makes a sale for a sum greater than the least sum for which he would have been willing to make the sale (Boulding, 1945). The measure of a change in producer surplus may be estimated by a change in economic rent or 'quasi-rent' (Mishan, 1968). Similarly, a change in producer surplus involved a change in profit or rent accruing to owners of firms in an industry (Varian, 1978).

Adoption of consumer, producer and social surplus enables one to evaluate ultimate gains or losses to each group resulting from a technical change induced by research and development. The extent to which each surplus varies depends on the magnitude of demand shift, the nature of market demand and supply curves (linear or non-linear), the nature of shift (parallel or non-parallel) and the price elasticity of demand and supply.

Figure 10. THE MARSHALLIAN PRODUCER AND CONSUMER SURPLUS
3 Return to Research for Beef Carcass Quality Improvement in Australia

3.1 Literature Review

There is a lack of scientific and economic research on meat and carcass quality improvement in Australia as well as other parts of the world. Demand shifts resulting from meat/carcass quality improvement have received no previous research attention. Past research was mostly devoted to shifting supply curves by reducing costs and raising yields. There have been no previous estimates of returns to quality improvement research in beef meat and carcasses.

Norton et al. (1987) examined the benefits of agricultural research and extension in an ex-ante consumer-producer surplus framework for several commodities in Peru. The effects of demand shift caused by income and population growth were studied. Edwards and Freebairn (1982) allowed for shift in demand due to increase in income and population. Income or population growth results in parallel shift of consumer demand curve. Their studies showed that substantial returns to public investment can be derived from research and extension.

Unnevehr (1986) attempted a study on consumer demand for rice grain quality and estimated returns to research for rice grain quality improvement in Southeast Asia. The returns to research for rice grain quality improvement were shown to be substantial and there was an indication of underinvestment in this type of research. Unnevehr made a number of simplifying assumptions which enabled him to estimate the gains from research into rice grain quality improvement. First, he assumed a parallel shift of a linear demand function. It has been argued in section 2.4 that changes in product characteristics could impart uniqueness to a product and reduce product competitiveness. Consequently, the demand shift could be convergent in nature, indicating a more inelastic demand. In this paper, we attempt to estimate research benefits occurring as a result of both parallel and non-parallel shifts of linear demand curves.

Second, Unnevehr (1986) assumed an infinitely elastic supply of rice at the retail level. This caused an increase in quantity demanded without any change in price. It is often observed that the supply for most commodities, including rice, is less than perfectly elastic. Improved quality rice (or any commodity) tends to be marketed at a premium price, particularly in the short run. Thus, the assumption of perfectly elastic supply may not be realistic. In this paper, a less-than perfectly elastic supply has been incorporated into our model for assessing research gains from beef carcass quality improvement.

3.2 Effects of Quality Improvement on the Supply Function

Meat colour improvement in beef carcasses can be achieved by research into reducing DC in beef. This may be accomplished by improved preslaughter management of cattle as well as postslaughter management of meat carcasses. Production and marketing costs may not be affected by improved animal handling techniques but can be affected by improvement of the livestock marketing system (e.g. computer marketing). Theoretically, direct marketing reduces preslaughter stress in cattle resulting in lower incidence of DC. In addition, previous empirical studies showed that direct marketing reduced production costs due to higher operational and pricing efficiencies. In this case, an upward shift of farm demand and a
downward shift of farm supply functions occur simultaneously. A downward shift of supply function resulting from adoption of computer marketing can be divergent in nature due to constant reduction in costs when marketing volume increases. A divergent shift in supply implies that high cost producers would benefit more than low cost producers. In this paper, we assume that quality improvement has no effect on the farm supply function.

3.3 Scope of the Study

Our results represent only a partial analysis of the demand shift resulting from meat quality improvement in beef carcasses due to a reduction in DC. As a result of DC, meat colour in beef carcasses varies from normal bright-red meat to extremely dark coloured meat. Our empirical analysis of the economic benefits from quality improvement relates to those DC carcasses which are at present disposed by abattoir operators or wholesalers at discounted prices. It does not cover those very dark and dull coloured carcasses which are rejected by buyers even with price reductions. At the abattoir, very dark and dull coloured meat in carcasses would be diverted to alternative uses (e.g. production of mince and processed meat). The diversion effect at the wholesale level causes variation in supply of grade 1 meat relative to grade 2 meat. The important aspect of meat diversion due to an emergence of a proportion of unacceptably dark and dull coloured meat in DC carcasses warrant further research.

It is anticipated that a certain proportion of DC meat would be passed on to the consumers due to the absence of sorting and objective measurement of meat colour. This would result in depressed demand for the Australian table quality beef both in the domestic and export markets due to a loss of reputation (i.e. the beef industry is unable to meet the expected quality requirements of consumers). Reduction in DC would cause a smaller proportion of the poorer quality meat to be passed on to consumers giving rise to economic gains to consumers. Our present analysis does not account for benefits and costs that a reduction in DC would cause through reducing the inadvertent flow of undetected DC meat from abattoir to consumers.

There are also additional benefits from quality improvement due to increase in income and population which have not been considered in this paper.

3.4 Analytical framework for assessing returns to research for quality improvement in beef carcasses

An ex-post evaluation of meat colour begins at the abattoir level because data relating to retail beef prices and meat colour variations are not available. The DC phenomena are identified mainly from meat discoloration in beef carcasses. Buyers presume that DC carcasses have dark and dull appearances. In Figure 11, $w$ represents the premium which buyers are willing to pay for normal bright-red, that is, non-DFD carcasses. Various cost factors arising from DC (e.g. meat discoloration, poorer keeping quality and down-grading of carcasses) would be included in our empirical appraisal of DC in beef carcasses. At auction centres, buyers would have taken into consideration consequences and possible costs of purchasing dark carcasses. Such costs are reflected in the discounted price for carcasses.

The benefits of research into meat colour improvement in beef carcasses are quantified using an economic surplus criterion. Illustrative calculations are provided of gains accruing.
Figure 11. PARALLEL AND CONVERGENT SHIFT IN DEMAND DUE TO QUALITY IMPROVEMENT
to producers, consumers and the industry as a whole from reducing dark-cutting. Consumer­ producer surplus has disadvantages as measures of welfare changes due to the error caused partly by ignoring the income effect of price changes. However, income effect is likely to be small because consumers spend only a small percentage of their budget on a particular food product with the result that an increase in its price has only a small impart on their real income.

The model for assessing research gains from quality improvement in beef carcasses has been developed (see Figure 11). This is a market clearing model involving partial equilibrium analysis of meat colour in beef carcasses. The demand and supply curves relate just to the demand for and supply of Australian table quality beef. The manufacturing quality beef produced mainly for export is not included in our analysis. The implicit price values for meat colour as represented by \( w \) in Figure 11 were obtained from regression estimates of cross-sectional data collected in two carcass auction centres in Perth metropolitan areas (see Porter and Todd, 1985). The farm demand function before quality improvement is given by the line \( D_0D \). Quality improvement causes an upward shift of the farm demand curve. A parallel shift is shown by the line \( D_1D_3 \) and a convergent shift by \( D_2D \). The industry supply curve is \( SS \). The initial equilibrium price \( (P_0) \) and quantity \( (Q_0) \) are point \( E \). The equilibrium price after quality improvement \( (P_1) \) and quantity \( (Q_1) \) are point \( E' \). The implicit price (i.e. the price premium resulting from meat colour improvement in beef carcasses) is shown by the line \( E'E \). The final equilibrium price for a parallel shift is the same as that for non-parallel shift. Both types of shift have identical \( w \) since the price premiums paid for improved colour in carcasses and final equilibrium price at carcass auction are the same regardless of the nature of \( t \) shift. Thus, for parallel and convergent shift, the shift is defined to be equal at the new equilibrium, not at the initial equilibrium.

In this section, diagram and algebra are used to evaluate research gains from meat colour improvement in beef carcasses. Several formulae have been developed to measure the areas in Figure 11 that represent consumer, producer, and total net economic surpluses. Differences are caused by alternative specifications of the supply and demand curves (e.g. linear versus constant elasticity), the nature of demand shift (convergent versus parallel), and whether the demand shift is measured horizontally as a consumption increase or vertically as a price premium (i.e. the extra price which buyers are willing to pay for an improved quality product). Formulae for parallel and convergent shift of farm demand are presented below. The derivation of formulae is presented in the appendix.

For parallel shift (case 1), the change in producer benefits from the demand shift is represented by the area \( P_1E'E P_0 \) and the change in consumer surplus is represented by the area \( D_1E'H'D_0 \) less area \( P_1H'E P_0 \). The net economic benefits to producers and consumers equal the sum of the changes in producer and consumer surplus.

\[
P_1E'E P_0 + D_1E'H'D_0 - P_1H'E P_0 - D_1E'E D_0
\]

For convergent shift (case 2), the change in producer benefits is given by the area \( P_1E'E P_0 \) and the change in consumer surplus is area \( D_2E'H'D_0 \) less area \( H'E P_0 \). The net economic surplus is represented by

\[
P_1E'E P_0 + D_2E'H'D_0 - P_1H'E P_0 - D_2E'E D_0
\]

Let \( CTS \) be change in total net economic surplus, \( CPS \) be change in producer surplus, \( CCS \) be change in consumer surplus, \( k \) be the proportionate vertical shift \( (w \cdot P_0) \) in the
demand curve, due to quality improvement, $P_0$ and $Q_0$ be equilibrium price and quantity without a demand shift, $P_1$ and $Q_1$ be the equilibrium price and quantity with a demand shift, $e$ be the supply elasticity at initial equilibrium point $P_0Q_0$, $n$ be the demand elasticity at initial equilibrium point $P_0Q_0$, $n_F$ be the demand elasticity at point $F$ ($P_1Q_1$), and $Z = kn/(e + n)$. The changes in economic surplus in the case of a parallel shift are calculated as

$$CTS = 1/2kP_0Q_0(2 + eZ),$$

$$CPS = 1/2P_0Q_0(2Z + eZ^2),$$

$$CCS = CTS - CPS.$$  \hspace{1cm} (3)

In the case of non-parallel convergent shift, changes in economic surplus are calculated as

$$CTS = 1/2kP_0Q_0\left(\frac{1 + 2n - eZ}{n - eZ}\right)(1 + eZ) - (eZ),$$

$$CPS = 1/2P_0Q_0(2Z + eZ^2),$$

$$CCS = CTS - CPS.$$  \hspace{1cm} (6)

Once the changes in consumer, producer, and total net economic surplus are calculated, the present values of the benefits and the marginal internal rates of return to agricultural research (IRR) for beef quality improvement can be calculated.

### 3.5 Data Collection

Values of key price and quantity variables required to apply the formulae are listed in Table 1. They refer to average 1988 conditions. Both the price and quantity variables refer to the wholesale level. $P_0$ is the average whole carcass price for the top quality yearling beef at $2.47/kg and a lower grade beef (i.e., very lean beef with less desirable muscle conformation) at $2.34/kg. $Q_0$ is equivalent to the total beef and veal table quality carcass production (i.e., the total production less export quality manufacturing beef).

The implicit price data were obtained from recent estimates by Porter and Todd (1985) based on 1981 conditions. These prices were converted into percent gains, losses of total carcass value (‘pink’ meat has an economic gain equivalent to 3.11% of total carcass value whereas ‘mature red’ and ‘dark red’ meat are 7.06% and 10.29% of total carcass value respectively) and were converted back to relevant premium and discounts using current beef carcass price data based on 1988 conditions. Meat colour improvement in carcasses is seen in two different angles: a change from mature red and dark red colour to bright red colour of normal meat (bright red colour as control), and from bright-red colour to pink colour. Pink colour has been reported to be the most desirable and a premium of $w_1$ is added to each kg of such carcass produced (Porter and Todd, 1985). However, both mature red and dark red meat are discounted by $w_2$ and $w_3$ respectively with reference to the normal bright-red
Table 1: Values of Variables for Estimation of Research gains in Australia

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w_1 )</td>
<td>$0.075/kg</td>
<td>Implicit price estimate (price premium) for 'pink' meat&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>( w_2 )</td>
<td>$0.170/kg</td>
<td>Implicit price estimate (discounted price) for 'mature red' meat&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>( w_3 )</td>
<td>$0.248/kg</td>
<td>Implicit price estimate (discounted price) for 'dark' meat&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>( P_0 )</td>
<td>$2.41/kg</td>
<td>Average wholesale price of table quality beef carcasses&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>( Q_0 )</td>
<td>835.14 kt</td>
<td>Domestic table quality beef production (carcass weight)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>( \eta_1 )</td>
<td>0.05</td>
<td>Lowest value of demand elasticity for beef carcasses&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>( \eta_2 )</td>
<td>0.50</td>
<td>Highest value of demand elasticity for beef carcasses&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>( e_1 )</td>
<td>0.67</td>
<td>Short-run supply elasticity of beef carcasses&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>( e_2 )</td>
<td>1.34</td>
<td>Long-run supply elasticity of beef carcasses&lt;sup&gt;g&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Implicit prices for meat colour from regression estimates by Porter and Todd (1985).
<sup>b</sup> From The Victorian Meatwork Association.
<sup>c</sup> From Australian Bureau of Statistics, quarterly publications.
<sup>d</sup> From Papadopalous (1973).
<sup>e</sup> From Marceau (1967).
<sup>f</sup> From Wicks and Dillon (1978).
<sup>g</sup> From Hall and Menz (1985).

The dark red meat is presumed to be meat from DC carcasses but the mature red meat is presumed to be meat from older animals. Beef carcasses are adjudged to be DC in relation to the meat colour alone since a more objective measurement of pHu in meat (which is a better description of DC in beef) was not made at the time of data collection. It must be clarified here that, apart from the dark red colour of DC meat (which has been the main focus of this paper), the other two classes of meat (pink and mature red) are included in our empirical analysis mainly for the purpose of interest and comparisons.

The elasticity of demand and supply data were available from various authors. The lowest and highest values of demand elasticity were chosen because demand elasticity varies from one state to another in Australia. Both the short run and long run supply elasticity values were selected for comparison.

3.6 Results and Discussion

Some estimates of the size and distribution of the economic benefits from meat quality improvement are reported in Table 2. The values in Table 2 are expressed in terms of 100% carcasses. In reality, we merely expect improvement up to a maximum of 9.6% of the total carcasses (which is the incidence of DC in Australia). Estimates of present values for quality improvement are listed in Table 3.

Results from parallel shift of demand showed that, on a national basis, if half the incidence of DC (4.8%) in beef were avoided as a result of research, a gross annual saving of $10 million could be derived, of which 20% accrue to producers sellers and 80% to consumers/buyers. Reduction in the incidence of DC is reflected by the improvement of meat colour in beef carcasses from dark to normal bright red colour.

Our empirical results show that there is an incentive for research into production of pink coloured meat in beef carcasses. Assuming current incidence of pink carcasses to be 12%
(based on data in Porter and Todd, 1985), it is estimated that a gross annual benefit of $55 million has been forgone due to the industry's failure to produce pink meat in 100% carcasses in Australia. Results in this paper also reveal that substantial benefit may be derived from reducing incidence of mature red meat in carcasses, for instance, by marketing the livestock at an earlier age.

The distribution of benefits between carcass buyers and sellers is given in Table 2. Distributional variations are caused by differences in demand and supply elasticity and the nature of demand shift. Where price elasticity of demand is high, producers' share of benefit is relatively greater. On the contrary, when price elasticity of supply is high (in a longer run), producers' share of benefit is depressed relative to consumers' share.

In contrast to a parallel shift, exceptionally large aggregate values were obtained from a convergent shift, particularly with very inelastic demand. Theoretically, a smaller additional benefit would be derived from a convergent shift when the base demand is relatively elastic. Unlike many consumer products, including those retail primal beef cuts displayed at supermarkets, beef carcasses face a very small number of close substitutes and consequently demand is very price inelastic. For some consumer products facing a large number of close substitutes and whose demand are relatively price elastic, alteration of certain product characteristics could make them uniquely differentiated from their substitutes resulting in a decline in demand elasticity. For beef carcasses, however, this may not be so since carcasses are not competitive by nature and quality improvement, for instance, an improvement of meat colour characteristic in a small proportion of total beef carcass production, would not make the product uniquely different from other animal carcasses (e.g. sheep carcasses and pig carcasses). Thus, assumption of parallel shift seemed to be more realistic in assessment of farm demand for carcasses. Consequently, we accept only the analytical results from parallel shift presented in this paper.

The present values given in Table 3 are calculated in terms of 100% carcasses. The actual values are thus the stated values multiplied by the improved incidences. Note that the assumption of parallel and convergent shift give enormously different results.
Table 2: Estimated Annual Returns From Beef Meat Colour Improvement ($ million)

<table>
<thead>
<tr>
<th>Demand Shift</th>
<th>Quality Improvement</th>
<th>Elasticity</th>
<th>Recipients of benefits*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Farmer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_1$</td>
<td>4.353</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_2$</td>
<td>2.255</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_3$</td>
<td>26.887</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_4$</td>
<td>17.117</td>
</tr>
<tr>
<td>Parallel</td>
<td>$w_1$</td>
<td>$\eta_1$</td>
<td>9.881</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_2$</td>
<td>5.119</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_3$</td>
<td>61.322</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_4$</td>
<td>39.099</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_5$</td>
<td>14.417</td>
</tr>
<tr>
<td></td>
<td>$w_2$</td>
<td>$\eta_1$</td>
<td>7.467</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_2$</td>
<td>89.815</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_3$</td>
<td>57.336</td>
</tr>
<tr>
<td></td>
<td>$w_3$</td>
<td>$\eta_1$</td>
<td>4.353</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_2$</td>
<td>2.255</td>
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<td></td>
<td>$\eta_3$</td>
<td>26.887</td>
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<tr>
<td></td>
<td></td>
<td>$\eta_4$</td>
<td>17.117</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_5$</td>
<td>9.881</td>
</tr>
<tr>
<td>Convergent</td>
<td>$w_1$</td>
<td>$\eta_1$</td>
<td>5.119</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_2$</td>
<td>61.322</td>
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<tr>
<td></td>
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<td>$\eta_3$</td>
<td>39.099</td>
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<td></td>
<td></td>
<td>$\eta_4$</td>
<td>14.417</td>
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<td></td>
<td>$w_2$</td>
<td>$\eta_1$</td>
<td>7.467</td>
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<td></td>
<td></td>
<td>$\eta_2$</td>
<td>89.815</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\eta_3$</td>
<td>57.336</td>
</tr>
</tbody>
</table>

* Estimation based on formulas 5.4 to 5.9 in text.

Table 3: Returns to Research for Quality Improvement ($ million)

<table>
<thead>
<tr>
<th>Demand Shift</th>
<th>Quality Improvement</th>
<th>Present Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel</td>
<td>$w_1$</td>
<td>506</td>
</tr>
<tr>
<td></td>
<td>$w_2$</td>
<td>1152</td>
</tr>
<tr>
<td></td>
<td>$w_3$</td>
<td>1684</td>
</tr>
<tr>
<td>Convergent</td>
<td>$w_1$</td>
<td>3374</td>
</tr>
<tr>
<td></td>
<td>$w_2$</td>
<td>7952</td>
</tr>
<tr>
<td></td>
<td>$w_3$</td>
<td>11972</td>
</tr>
</tbody>
</table>

* The estimates on returns to research were based on average own-price elasticity of demand and supply where $\eta = 0.275$ and $e = 1.01$.

b Present values summed over 30 years and discount rate of 12% used to obtain present values. It is assumed that domestic production (and consumption) would be constant over the 30 years period.
REFERENCES


APPENDIX

DERIVATION OF NEW EQUILIBRIUM PRICE AND QUANTITY FOLLOWING AN UPWARD SHIFT IN THE DEMAND CURVE

From figure 9, the relative change in equilibrium price, \( dP \), and equilibrium quantity, \( dQ \), depends on the extent of demand shift, \( w \), the demand elasticity, \( n \), and supply elasticity, \( e \). To simplify calculation, price elasticity of demand is treated as positive. The price elasticity of supply is given by the formula

\[
e = \frac{dQ}{dP}(P_0/Q_0)
\]

and by arrangement,

\[
dP = \frac{dQ}{e}(P_0/Q_0).
\]

The price elasticity of demand is given by the formula

\[
n = \frac{dQ}{dP_1}(P_0/Q_0)
\]

and by arrangement,

\[
dP_1 = \frac{dQ}{n}(P_0/Q_0).
\]

Given that \( dP + dP_1 = w \) and by substitution,

\[
w = \frac{P_0}{Q_0}(dQ)(1/e + 1/n).
\]

Therefore,

\[
dQ = wQ_0/P_0\left(\frac{en}{e + n}\right).
\]

\( Q_1 = Q_0 + dQ \), and if \( k = w/P_0 \), after some algebra,

\[
Q_1 = Q_0(1 + \frac{kn}{e + n}).
\]

Let \( Z = (\frac{kn}{e + n}) \), then

\[
Q_1 = Q_0(1 + eZ). \tag{7}
\]

From supply elasticity equation,

\[
dP_1 = \frac{dQ}{e}(P_0/Q_0)
\]

\[
= \frac{P_0kQ_0}{P_0}\left(\frac{en}{e + n}\right)P_0/eQ_0
\]

\[
= kP_0/\left(\frac{e + n}{e + n}\right).
\]

But \( P_1 = P_0 + dP \) and after some algebra,

\[
P_1 = P_0\left(1 + \frac{kn}{e + n}\right).
\]
Substituting $\frac{ke}{e+n}$ into $Z$, we have

$$P_1 = P_0(1 + Z).$$

From demand elasticity equation,

$$dP_1 = \frac{dQ}{n}(\frac{P_0}{Q_0}) = \frac{P_0}{P_0}(\frac{en}{e+n})P_0/nQ_0$$

$$= P_0\left(\frac{ke}{e+n}\right).$$

But $P_2 = P_0 - dP_1$ and after some algebra,

$$P_2 = P_0(1 - \frac{ke}{e+n}).$$

Let $Y = \frac{ke}{e+n}$, then

$$P_2 = P_0(1 - Y).$$

DERIVATION OF DEMAND ELASTICITY AT POINT F AND THE LINE $D_2D_0$

By definition, the demand elasticity function $D_0D$ at the initial equilibrium point $E$ (moving from point $E$ to point $E'$), is given by

$$n = (Q_0Q_1/P_0P_1)(OP_0/OQ_0).$$

For simplicity, the value of $n$ is treated as positive. The two triangles $\triangle EFG$ and $\triangle FDQ_1$ are similar because both of them are right triangles sharing the same angle $\angle Q_0ED$, therefore the third angles are necessarily equal. In geometry, the corresponding sides of similar triangles are proportional. Hence,

$$\frac{GF}{EG} = \frac{Q_0D}{EQ_0} = \frac{Q_0Q_1}{P_0P_2} = \frac{Q_0D}{OP_0}.$$

Substituting this equality into the right side of the expression for elasticity, we have

$$n = (Q_0D/OP_0)(OP_0/OQ_0).$$

Therefore, by simplifying the above term, we have

$$n = (Q_0D/OP_0).$$

Given also in geometry that parallel lines cut any straight lines into proportional segments. Since $D_0O\parallel EQ_0$, therefore

$$\frac{Q_0D}{OP_0} = \frac{ED}{OQ_0}.$$

By substitution, we have

$$n = \frac{ED}{OQ_0}$$

Similarly, using identical principle, elasticity of demand at point $F$ on the same demand function $D_0D$, is given by

$$n_F = \frac{\overline{FD}}{\overline{FQ_0}}$$
To calculate the numerical value of demand elasticity at point $F$, the following method is adopted:

$$n_F = \frac{dQ}{dP}(P_2/Q_1).$$

The slope of the demand curve $dQ/dP = nQ_0/P_0$, and previously it was deduced that $P_2 = P_0(1-Y)$ and $Q_1 = Q_0(1+nY)$ where,

$$Y = \frac{k_2}{e+n}.$$  

Therefore, by substitution

$$n_F = n\frac{1-Y}{1+nY} = \frac{n-nY}{1+nY} = \frac{n-eZ}{1+eZ}.$$

From Figure 14, it can be seen that triangles $\triangle F E'D$ and $\triangle D_2D_0E'$ are similar sharing the same angle $\angle E'DF$ and since $D_2D_0||E'F$, the other two angles are necessarily equal. In geometry, the corresponding sides of similar triangles are proportional, so

$$\frac{E'E}{FD} = \frac{(D_2D_0/\overline{D_0F} + \overline{FD})}{\overline{D_0F}}.$$

By arrangement,

$$D_2D_0 = \frac{(D_0F + FD)}{FD} \overline{D_0F}.$$

Previously it was shown that $n_F = \overline{FD}/\overline{D_0F}$, hence $1/n_F = \overline{D_0F}/\overline{FD}$ and

$$D_2D_0 = w(1 + 1/n_F) \text{ (12)}$$

and by arrangement,

$$D_2D_0 = w\left(\frac{n_F + 1}{n_F}\right).$$

**DERIVATION OF EQUATIONS**

**Case 1: Parallel shift**

$$CTS = \text{Area}(D_1E'FD_0) - \text{Area}(EE'F)$$

$$= kP_0Q_1 - 1/2kP_0(Q_1 - Q_0)$$

$$= kP_0Q_0(1 + eZ) - 1/2kP_0(Q_0eZ)$$

$$= 1/2kP_0Q_0(2 + eZ)$$
\[ C_{PS} = \text{Area}(P_1E'E'EP_0) \]
\[ = \frac{1}{2}(Q_0 + Q_1)(P_1 - P_0) \]
\[ = \frac{1}{2}(Q_0 + Q_0 + Q_0eZ)(P_0Z) \]
\[ = \frac{1}{2}P_0Q_0Z(2 + eZ) \]
\[ = \frac{1}{2}P_0Q_0(2Z + eZ^2) \]

Case 2: Convergent shift

\[ CTS = \text{Area}(D_2E'F'D_0) - \text{Area}(EE'F) \]
\[ = \frac{1}{2}[kP_0 + (\frac{n_F + 1}{n_F})kP_0]Q_1 - \frac{1}{2}kP_0(Q_1 - Q_0) \]
\[ = \frac{1}{2}kP_0[(1 + \frac{n_F + 1}{n_F})Q_0(1 + eZ) - \frac{1}{2}kP_0(Q_0eZ) \]
\[ = \frac{1}{2}kP_0Q_0[(\frac{2n_F + 1}{n_F})Q_0(1 + eZ) - eZ] \]
\[ = \frac{1}{2}kP_0Q_0[(\frac{2n - 2eZ}{1 + eZ}) + (\frac{1 + eZ}{1 + eZ})\frac{1}{n - eZ}(1 + eZ) - (eZ) \]
\[ = \frac{1}{2}kP_0Q_0[(\frac{1 + 2n - eZ}{1 + eZ})\frac{1 + eZ}{n - eZ}(1 + eZ) - (eZ)] \]
\[ = \frac{1}{2}kP_0Q_0[(\frac{1 + 2n - eZ}{n - eZ})(1 + eZ) - eZ] \]

where \( n_F = \frac{n - eZ}{1 + eZ} \)

\[ C_{PS} = \text{Area}(P_1E'E'EP_0) \]
\[ = \frac{1}{2}P_0Q_0(2Z + eZ^2) \]