Forum

Evaluating Quality Improvement in Nonhomogeneous Agricultural Commodities: The Case of Australian Beef

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This paper develops conceptual and empirical frameworks for assessing the economic benefits from agricultural research which enhances the amount of a desirable characteristic in each unit of a heterogeneous commodity. The commodity is assumed to comprise two or more joint products accruable in fixed proportion. Quality improvement is perceived as an increase in the proportion of a joint product with more of a more-valued characteristic and, as such, is modelled as a shift in the supply curve of a joint product rather than via a shift in commodity demand. A proxy variable is constructed to measure an intertemporal quality change and to estimate the associated size of the supply shift. An application of the framework to the Australian beef industry indicates that the per unit amount of the characteristic 'freshness' in beef has increased over the last two decades. Substantial social benefits can be obtained by research which enhances the quality of Australian beef carcasses. A larger share of the total benefits accrue to beef producers.

1. Introduction

Agricultural research can be broadly classified into cost-reducing and quality-improving research. There has been a large literature on measuring the economic benefits from research which reduces per unit production costs for a commodity (Lloyd and Harris; Edwards and Freebairn; Ruttan; Norton and Davis). However, relatively fewer studies have been devoted to evaluating quality-improving agricultural research (Voon and Edwards 1992; Lemieux and Wohlgenant). Recognising the paucity of studies which evaluate the economic benefits from quality-enhancing agricultural research, and noting a rising consumer demand for better quality products arising from increasing income levels (Steemkamp), it is worthwhile to achieve more progress on the task of evaluating research benefits from commodity quality improvement.

Economic frameworks used in past studies depicted commodity quality improvement as a rightward shift in the demand (or marginal-willingness-to-pay) curve. In those models, agricultural commodities were often assumed to be homogeneous (Voon 1993; Lemieux and Wohlgenant; Unnevehr). In reality, however, there are very few commodities which are considered to be entirely homogeneous (Salayo and Voon). Hence, economic models which assume product heterogeneity appear to be more general in application than those which incorporate product homogeneity (Alston).

In this paper, a partial-equilibrium framework involving a research-caused supply shift is developed for evaluating quality improvement in heterogeneous commodities. Specifically, the hedonic approach to defining quality improvement is adopted in the framework. Using the hedonic approach, quality improvement is perceived as an increase in the per unit amount of one or more characteristics which are positively-valued by consumers (or a decrease of those negatively-valued). Considering one particular characteristic, a heterogeneous commodity is assumed to be composed of two or more joint products with different amounts of the characteristic inherent in each unit of a product class. A change in the relative proportion of these products inherent in each unit of the commodity, denoted by a proxy variable, can give rise to quality improvement of the commodity. In this paper, Australian beef is used as a case study.

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In the next section, a proxy variable which can be used for denoting commodity quality improvement is constructed. Some of the conceptual issues and limitations associated with the evaluation of quality improvement will also be discussed in the next section. Section 3 illustrates how the economic framework developed in section 2 may be used for assessing beef carcass quality improvement. Empirical evidence of Australian beef carcass quality improvement is also presented in section 3 using a simple regression analysis of time-series data. A trading model for measuring the size and distribution of the economic payoffs from beef carcass quality improvement is presented in section 4. The implications arising from the study are discussed in the final section.

2. The Conceptual Framework

2.1 An Approach to Depicting Quality Improvement

Nonhomogeneous agricultural commodities may be perceived as consisting of two or more joint products closely related in production and consumption. For example, wheat may be viewed as a heterogeneous commodity comprising low-protein and high-protein wheat. In this case, the per unit amount of the desirable characteristic 'protein' differs in each of the two joint products. The commodity pork, for instance, may be classified into low-fat and high-fat pork, with the amount of the characteristic 'fatness' as a negatively-valued characteristic differing in each unit of these two joint products. In most cases, quality improvement in a heterogeneous commodity can be represented by an increase in the proportion of the high quality joint product (or grade) and a concomitant decrease in the proportion of the lower quality one. Following Brennan *et al.*, the approach, hence, depicts quality improvement as an increase in supply of the 'higher quality class' (the commodity grade with more of the more-valued characteristic) and a concomitant decrease in supply of the 'lower quality class'. Using this approach, quality improvement can also be seen as a redistribution in supply between two or more joint product classes of a commodity.

An advantage of disaggregating a commodity and using the supply-shifting approach for measuring quality improvement is that it appears to be more general in application. However, unlike the conventional demand-shifting approach, problems arise in measuring welfare changes associated with using a series of supply shifts (Voon 1991; Just, Hueth and Schmitz). For instance, in addition to the substitution on the production side, there is a possibility of substitution in consumption between joint product classes of a commodity due to changes in relative prices. Suppose that a rightward shift in supply of a higher-quality product causes a drop in price of that product. This could result in a fall in demand for the lower-quality product (Thurman). Besides, the approach involving a multiple shift in supply requires estimates of cross-price elasticities of supply and demand between classes of a commody; these estimates are not readily available and also difficult to measure (Alston). The above measurement problem may be overcome by using partial-equilibrium models rather than a cross-product model which involves a series of supply shifts for measuring quality improvement. Using partial-equilibrium models, this paper examines the welfare effects of a supply shift in each of the joint-product markets.

2.2 Using a Proxy Variable As a Measure of Temporal Quality Variation

The quality of a heterogeneous commodity can be represented by a proxy variable, which is constructed as follows. Suppose that a commodity with a production volume Q comprises two joint products, 1 and 2, such that $Q_1+Q_2=Q$ where Q_1 and Q_2 denote the quantity of products 1 and 2. Suppose that joint product 1 has a higher level of a quality characteristic per unit of the product than product 2 has. The proxy variable may be represented as:

$$(1) \qquad R = Q_1/(Q_1+Q_2).$$

R ($0<R<1$) is the proportion of product 1 relative to the aggregate amount of the commodity. For instance, $R=0.6$ means that product 1 constitutes 60 per cent of the heterogeneous commodity. The higher the value of R, the better is the quality of the commodity. Quality improvement over time is represented by a positive increase in R (i.e. $\Delta R_t>0$, where the t subscript denotes the time period and Δ is the time difference operator).

The proxy variable R is derived on the basis that product 1 and 2 are joint products derivable from the commodity in fixed proportion. This being so, it is quite impossible to increase the proportion of product 1 (and decrease the proportion of product 2) deliberately unless the overall quality of the commodity has improved (it is assumed that profit is maximised by maximising R).

The variable ΔR_t can be used to approximate the shift in the supply curve of product 1 and 2. Suppose that research causes the proxy variable R to increase by a value of α per year. Let w be the increase in quantity of product 1 (and an identical decrease in quantity of product 2) as a result of the commodity quality improvement. ΔR_t can be expressed as:

$$(2) \quad \Delta R_t = R_t - R_{t-1} = (Q_{1,t-1}+w)/[(Q_{1,t-1}+w) + (Q_{2,t-1}-w)] - Q_{1,t-1}/(Q_{1,t-1}+Q_{2,t-1})$$

where the subscript t-1 denotes 'the last period'. Equation 2 implies that there has been a quality change without a quantity change: $(Q_{1t}, Q_{2t}) \rightarrow (Q_{1t}+w, Q_{2t}-w)$. This is a shift from product 1 to product 2, keeping the total production level (Q_1+Q_2) unchanged.

Now, by rearranging terms and simplifying,

$$(3) \quad \Delta Rt = w/Q_{t-1} = \alpha$$

where $Q_{t-1} = Q_{1,t-1} + Q_{2,t-1}$ $(Q_{t-1}=Q_t)$, or alternatively,

$$(4) \quad w = \alpha Q_{t-1}.$$

An empirical estimate of the variable α which denotes how the quality of a commodity changes from one time period to another can be derived using the relevant time-series data.

3. An Application

3.1 The Case of Beef Carcass Quality Improvement

Using the hedonic concept, beef carcass quality improvement may be perceived from the viewpoint of one characteristic but not others. For instance, the desirable characteristic 'freshness', *inter alia*, can be used to determine the quality of beef. Suppose that beef carcasses could be cut in fixed proportion into two types of beef, namely, chilled and frozen beef. Chilled beef has a higher per unit amount of the characteristic 'freshness' than frozen beef (Porter and Todd). This is reflected by a higher marginal willingness to pay for chilled than for frozen beef. Hence, if the proportion of chilled beef derivable from each carcass increases and the proportion of frozen beef derivable from each carcass decreases, the amount of the characteristic 'freshness' increases in each unit of a carcass, hence, the commodity beef as a whole improves its quality.

3.2 Evidence of Beef Quality Improvement Through Time

This section investigates whether or not beef carcass quality or 'freshness' (R) has improved in the last 20 years or so using time series data. This is accomplished by regressing the proxy variable (R) for chilled beef against the time trend (T).

The relevant linear time-trend regression function is:

$$(5) \quad R_t = \alpha_0 + \alpha_1 T_t + E_t$$

where T is the time trend, α_1 denotes the extent to which carcass quality improves through time, and E_t is the error term.

Data on the annual production of chilled and frozen beef covering 1973/74 to 1993/94 were obtained from the Australian Bureau of Statistics (ABS) and the variable R was estimated. The regression results were as follows.

$$R_t = -0.169 + \underset{(12.036)^*}{0.00536Tt}$$

R^2=0.895 DW=0.372 F = 144.863

Note: Number in parenthesis is t-value and * denotes significant at 1 per cent level.

The coefficient on the time trend has the expected sign, indicating that Australian beef carcass quality of freshness has improved through time. The coefficient is significant at one per cent level, hence, the hypothesis that $\alpha_1>0$ is therefore not rejected.[1] Using the linear relationship, Rt increased, on average, by a value of 0.00536 per annum. This indicates that Australian chilled beef as a proportion of the aggregate beef pro-

1 The low DW statistics indicate significant autocorrelation. This could imply the existence of a nonlinear rather than a linear relationship. If the anticipated non-linear curve represents an increasing function, ΔR rises over time. In this case, the use of a linear specification would result in an underestimation of ΔR in recent years. Conversely, if the expected curve represents a decreasing function, ΔR declines over time. In this case, a linear specification would give rise to an overestimation of ΔR. Hence, it may be said that ΔR might be under or over-estimated in more recent years depending on the exact nature of the functional form. However, the use of linear specification provides a good approximation if one calculates the average value (a large change in R) taken over the entire 20 years period (covering past and recent years) rather than the annual value (which is likely to be a small change in R).

duction increased by an average of 0.54 per cent per year over the last 20 years.

There are several factors causing R for chilled beef to increase over the last two decades in Australia. One possible reason is the research-caused reduction in the incidence of dark-cutting (DC) beef in Australia. DC beef is unacceptable for chilling and export purposes because it has an unacceptably dark colour and a sticky surface texture which, collectively, create an unhealthy impression for consumers (Voon 1992). Besides, DC beef has a lower shelf-life than normal beef, and is, therefore, commonly diverted to frozen beef production (Brownlie). Research on minimising the stress level in cattle during transport and handling effectively decreased the mean incidence of DC beef in Australia (Shorthose; Warner *et al.*).

The following section evaluates the welfare changes associated with an increase in the quantity of chilled beef (designated w) as a result of a rise in the proportion of chilled beef per unit of the carcass. "w" is used to estimate the proportionate change in the quantity of chilled beef (designated h where $h=w/Q_c$) as a result of carcass quality improvement. A one per cent increase in output per unit of input is equivalent to approximately 0.91 per cent decrease in the input (and hence production cost) per unit of the output.[2] The absolute per unit cost reduction, v, associated with h per cent increase in output per unit of input is $0.91hP_c$, where P_c is the per unit cost of chilled beef.

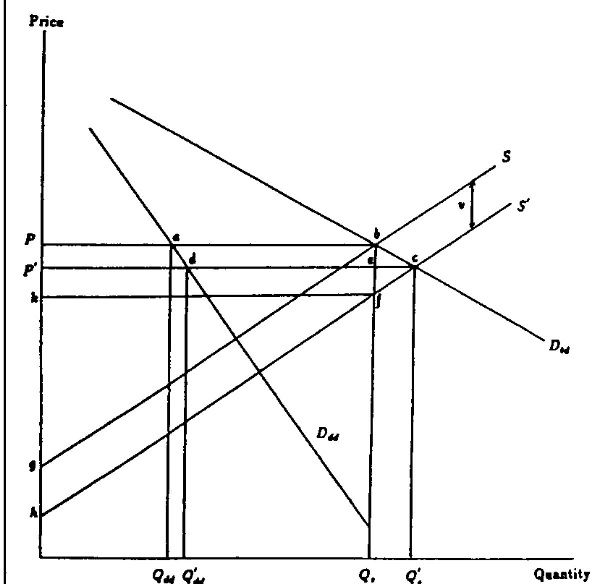
4. Welfare Changes from Beef Carcass Quality Improvement

4.1 The Model

The standard partial-equilibrium trading model for assessing producer, consumer and social gains from beef carcass quality improvement is shown in Figure 1 (from Voon 1992). The model allows for effects on world prices via an excess demand curve. Linear supply and demand curves for chilled beef and competitive pricing behaviour are assumed.

Initially, the supply curve for chilled beef is represented by S, domestic demand by D_{dd} and total demand by D_{td} (with D_{td}-D_{dd} being export demand). Quality improvement causes a rightward shift in the supply curve for chilled beef from S to S'. The supply shift is assumed to be parallel. The absolute vertical shift in supply (i.e. per unit cost reduction) is denoted v.

Figure 1: Effect of a Downward Shift in Supply



With the supply shift, chilled beef price decreases from P to P', domestic consumption increases from Q_{dd} to Q_{dd}' and the quantity exported increases from (Q_s-Q_{dd}) to (Q_s'-Q_{dd}'). The domestic consumer surplus increases by area PadP' and domestic producers gain area P'cfk. With some algebraic manipulation, the consumer, producer and aggregate welfare changes can be expressed, respectively, as:

(7) $G_c = PQ_{dd}Z(1+0.5\eta_{dd}Z)$

(8) $G_p = 0.5PQ_s(k-Z)(2+\eta_{td}Z)$

(9) $G_t = G_c + G_p$

where $Z=k\varepsilon/(\varepsilon+\eta_{ed})$, $k=v/P$, η_{dd} is domestic demand price elasticity and η_{td} is total (domestic plus export) demand elasticity, and ε is the supply elasticity.

2 Suppose initially that one requires one unit of input to produce 10 units of output. Suppose that one can now produce 11 units of output with the same one unit of input. This represents a 10 per cent rise in output per unit input (or productivity gain). Alternatively, however, we can now use less than one (or approximately 10/11) unit of input in order to produce the original 10 units of output, assuming a constant return to scale. This represents a 0.91 per cent decrease in input per unit of the output. Hence, a 10 per cent increase in output per unit of input is equivalent to about 9.1 per cent reduction in the use of input (hence the costs of input) in order to maintain the initial amount of output.

Table 1: Values of Variables for Measuring the Economic Benefits from Beef Carcass Quality Improvement in Australia

Variable	Value	Description
Q_s	777.95kt	Production of chilled or fresh beef
Q_{dd}	639kt	Domestic consumption of chilled or fresh beef
Q_{ed}	138.95kt	Quantity of chilled beef exported
Q_f	657.05kt	Production of frozen beef
P	\$5.68/kg	Average retail price forAustralian chilled beef
η_{dd}	-0.05, -0.5	Domestic demand elasticity for chilled beef
η_{td}	-1, -4	Aggregate demand elasticity for chilled beef
ε	0.16, 1.34	Supply elasticity
w	4.17kt	Increase in quantity of chilled beef due to a rise in R
v	2.77cents/kg	Absolute vertical shift in chilled beef supply

4.2 Parameters and Data

The values of key variables for applying equations 7 through 9 are listed in Table 1. Prices and quantities were taken from the Commodity Statistical Bulletin and the Australian Bureau of Statistics. They correspond to 1993/94 conditions. Supply price elasticity values were obtained from Hall and Menz. The domestic demand price elasticities were taken from Murray.[3] The export demand for beef was estimated to be very price elastic ($|\eta_{ed}| > 4$) (Scobie and Johnson). However, an export demand elasticity of -1 is used for sensitivity analysis on the basis that Australia is considered to be a reasonably large exporter of vacuum-packaged chilled beef.

The increase in the supply for chilled beef (w) can be derived from the value of α, using equation 4. The mean historical value for in Australia is taken to be 0.00536 per year, following the results of the time-trend analysis. Research is assumed to raise the value ofα by a similar amount, for the purpose of an *ex-ante* evaluation. Using α=0.00536, w is calculated to be 4.17 kilo tonnes (kt), fixing Q_t=Q_{t-1}. The derived value of w is considered to be the expected value since production in the next period may be larger or smaller than that in the last period.

4.3 Results and Implications

Table 2 shows the values of the level and distribution of benefits from beef carcass quality improvement calculated for the various combinations of supply and demand price elasticities. Research which causes an average 0.54 per cent increase in R per year provides a gross annual research benefit (GARB) of about A\$21 millions. This gain is not very sensitive to changes in demand and supply elasticities.

[3] Ideally, more recent supply and demand elasticity estimates should be chosen since the price and quantity data used correspond to the 1994 conditions. However, in the the absence of the recent data, a sensitivity analysis covering a range of elasticity values was performed.

Table 2: The Size and Distribution of Research Benefits from Beef Carcass Quality Improvement in Australia (Values in millions of dollars per year).

η_{ed}	-1				-4			
ε	0.16	0.16	1.34	1.34	0.16	0.16	1.34	1.34
η_{dd}	-0.05	-0.5	-0.05	-0.5	-0.05	-0.5	-0.05	-0.5
G_p	18.706	19.479	9.481	11.401	20.736	20.816	16.243	16.647
G_c	2.341	1.706	9.925	8.356	0.673	0.608	4.404	4.063
G_t	21.047	21.185	19.406	19.757	21.409	21.449	20.647	20.710
G_p/G_c	0.889	0.919	0.489	0.577	0.969	0.970	0.787	0.804

An implication of the analysis is for investment in research which raises the per unit amount of a characteristic valued by consumers. Suppose that the GARB is accruable for the next 20 years. Assuming a social rate of time preference of 10 per cent, the present value of the GARBs (expressed in terms of annuities) is estimated to be A$179 million. Hence, if the costs of the research (in present value term) intended to raise the value of R by 0.54 per cent a year are smaller than the calculated present value of the benefits, the project would be worthwhile, since the net present value (NPV) is positive. However, for this project to be chosen, its NPV must be greater than that of other projects.

Table 2 also shows that the bulk of the economic benefits from beef carcass quality improvement is likely to accrue to beef producers, depending on specifications of demand and supply price elasticities. With a very price elastic export demand for beef ($|\eta_{td}|$=-4, assuming a small country assumption), more than 79 per cent of the benefits accrue to beef producers. This implies that beef producers, on equity grounds, would have to bear a larger burden of the research expenditure than domestic consumers. It is of interest that the distribution of quality-improving research benefits is less sensitive to specifications of domestic demand and supply price elasticities where the export demand is very price elastic than where the export demand is price inelastic.

5. Summary and Concluding Comments

In this paper, the concept of quality improvement in a heterogeneous commodity is elucidated using the hedonic approach. Using this approach, quality improvement is perceived as an increase in per unit amount of a desirable characteristic inherent in the commodity. The commodity is assumed to be comprised of two joint products accruable in fixed proportion. One joint product has a greater per unit amount of the characteristic than the other. Research may be undertaken to increase the proportion of one joint product and concomitantly decrease the proportion of another. This causes the total amount of the desirable characteristic inherent in each unit of the commodity to increase. Hence, the quality of the commodity improves.

A simple dynamic framework involving a proxy variable R (which depicts a joint product as a proportion of the commodity) is developed for quantifying commodity quality improvement. A rise in R is an indication of commodity quality improvement. Given the same production level, a rise in R implies that the quantity supplied of one joint product increases and the quantity of the other decreases. Commodity quality improvement is therefore represented by a shift in supply of a joint product. The size of the shift in supply and hence the economic benefits from a shifting supply can be derived from an assumed R value using the dynamic framework.

In an application of this conceptual and quantitative framework, Australian beef is used as an example. Heterogeneous beef carcasses were categorised into two joint products, namely chilled and frozen beef, each with a different per unit amount of the characteristic 'freshness' inherent in the product. It was reported that a substantial economic benefit could be achieved from a research-caused increase in supply or an equivalent reduction in marginal cost of chilled beef arising from beef carcass quality improvement. Australian beef producers are likely to reap a larger share of the total research benefits than the consumers. Other hedonic differences in product quality could be investigated by this method.

Using a similar partial-equilibrium analysis but applying it to the frozen beef market, the welfare loss in that market is roughly half the welfare gain in the chilled beef market. This is mainly because the value of frozen beef is approximately half the value of chilled beef and Q_f is only slightly smaller than Q_c. In general, welfare losses in the low-quality segment of the market are always lower than welfare gains in the high-quality segment of the market if $Q_1 \geq Q_2$. The difference in social welfare gains between the two markets is bigger if the value of the production in the low-quality market is a smaller fraction of that in the high-quality market.

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