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ASSESSING THE IMPACT OF RESEARCH TO IMPROVE THE QUALITY OF FOOD COMMODITIES

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ABSTRACT

This paper shows how hedonic price measures can be estimated and used in evaluating the welfare gains from quality improvement in crop varieties. This methodology offers a relatively simple and inexpensive way to rank potential quality improvements and to demonstrate the importance of such improvements to consumers. A simple model of consumer demand for goods characteristics is presented and the estimating equation for hedonic prices is derived. The limitations of assumptions underlying the model are discussed and solutions are suggested for common empirical problems in estimation of hedonic prices. The impact of quality improvements on producer and consumer surplus is demonstrated. The paper concludes with an example of how the methodology has been used to evaluate the returns to quality improvement in modern varieties of rice.

ASSESSING THE IMPACT OF RESEARCH TO IMPROVE THE QUALITY OF FOOD COMMODITIES

Agricultural research has primarily focused on increasing food supply through raising yields. Often initial success in raising yield potential is achieved without encorporating other desirable characteristics in the food crop, such as eating quality. Once new varieties actually increase output and real prices start to fall, consumers can exercise greater choice, and begin to pay higher premiums for eating quality. This induces producers to seek varieties with better eating quality, and places pressure on agricultural research to encorporate better eating characteristics into high yielding varieties.

Efforts to increase quality are sometimes criticized for diverting research resources from the more important task of increasing food supplies. However, food quality is important even to the very poorest consumers, and meeting food preferences can be an important part of fostering better nutrition (Shah). Improving quality does not necessarily mean providing everyone with the best quality. Sometimes very simple changes in food characteristics can greatly increase palatability. Evaluating whether such changes are worthwhile is the subject of this paper.

When agricultural researchers seek to encorporate quality characteristics into new varieties they need to have a way to measure the importance of quality characteristics to consumers. Such measures provide guides to research and demonstrate the potential payoffs to that research. This paper discusses how estimates of hedonic prices for quality characteristics can be used to evaluate the returns to research for quality. The first three sections of the paper present the model for estimating

hedonic prices and discuss the limitations of the underlying assumptions and common estimation problems. The fourth section shows how hedonic price estimates can be used to measure the welfare gains from improved quality under various assumptions. The paper concludes with an example of how this methodology has been used to evaluate the returns to quality improvement in modern varieties of rice.

Model of Demand for Goods Characteristics

Several authors have proposed an alternative view of consumer demand in which consumers derive utility or satisfaction from the characteristics that goods possess, rather than the goods themselves (Lancaster, Griliches, Becker, Ladd and Suvannunt, Rosen).[1] For example, satisfaction is not obtained from food per se, but rather from the nutrients and flavor of the food. This model has been applied to consumer durables in order to estimate a quality constant price index of inflation (see Griliches for examples). In the area of food demand, a few authors have measured the value of food nutrients to consumers (Ladd and Suvannunt, Morgan et.al.). Studies of the value of food characteristics have also been conducted at the international agricultural research centers (Von Oppen and Jambunathan, Unnevehr et.al.)

Hedonic price models all start from a specification of the consumer utility function as a function of the quantity of goods consumed, and the characteristics embodied in those goods. Different assumptions are made, however, concerning the relationship of characteristics yield to quantity consumed and the separability of quantity and characteristic consumption decisions. Ladd and Suvannunt have developed a useful version of the hedonic price model that has assumptions suited to analyzing foods. In their model, the amount of a characteristic obtained from each good is fixed

to the consumer (and variable to the producer) and the consumer determines the quantities of goods consumed. This seems reasonable for foods because the amount of nutrients or flavor characteristics embodied in a food product cannot be determined by the consumer. Furthermore, hedonic prices in Ladd and Suvannunt's model are not constrained to be non-negative as they are in Lancaster's earlier model. It seems reasonable to assume in empirical work that some characteristics detract from quality and have negative utility.

The following is a slightly simplified summary of the Ladd and Suvannunt model. Let X_{oj} be the total amount of the jth product characteristic provided by consumption of all products, while X_{ij} is the amount of the jth characteristic provided by one unit of product i. Let q_i represent the quantity consumed of product i. Total consumption of each characteristic is a function of the q_i's and the X_{ij}'s (input-output coefficients of the characteristics):

$$X_{oj} = f(q_1, q_2, \ldots q_n, X_{1j}, \ldots X_{nj}) \qquad (1)$$

for $j = 1,m$

The consumer's utility function is expressed as a function of goods characteristics:

$$U = U(X_{o1}, X_{o2}, \ldots X_{om}) \qquad (2)$$

Because each X_{oj} is a function of the q_i's and the X_{ij}'s:

$$U = U(q_1, q_2, \ldots q_n, X_{11}, X_{12}, \ldots X_{21}, \ldots X_{nm}) \qquad (3)$$

Consumers can only vary the q_i's; the X_{ij}'s are given to the consumer.

The consumer maximizes utility (equation 2) subject to the budget constraint:

$$\sum_{i=1}^{n} p_i q_i = E \tag{4}$$

where p_i is the market price for product i and E is total income (equal to total expenditures). The consumer selects values of q_i that maximize the Lagrangian:

$$L = U(X_{o1}, X_{o2}, \ldots X_{om}) - \lambda \left(\sum_{i=1}^{n} p_i q_i - E\right) \tag{5}$$

Because the X_{oj}'s are functions of the q_i's, the constrained maximum of U is:

$$\frac{dL}{dq_i} = 0 = \sum_{j=1}^{m} (dU/dX_{oj})\ (dX_{oj}/dq_i) - \lambda\ p_i \tag{6}$$

The marginal utility of income, λ, is equal to dU/dE. With this substitution and solved for p_i, equation 6 becomes:

$$p_i = \sum_{j=1}^{m} (dX_{oj}/dq_i)\ [(dU/dX_{oj})/(dU/dE)] \tag{7}$$

The marginal yield of the jth product characteristic by the ith product is dX_{oj}/dq_i. The marginal utility of the jth product characteristic is dU/dX_{oj} and dU/dE is the marginal utility of income. Therefore, the ratio in brackets is the marginal rate of substitution between income and the jth product characteristic. Because expenditure is assumed to equal income, the bracketed term is also the marginal implicit price of the jth

characteristic. Equation 7 states that the product price paid by the consumer equals the sum of the marginal values of the product's characteristics. Each value is equal to the quantity of the characteristic obtained from a marginal unit of the product multiplied by the marginal implicit price of the characteristic.

Because yield of most product characteristics is constant for each unit of product, $dX_{oj}/dq_i = X_{ij}$ = constant is assumed. Furthermore, the marginal implicit price is also assumed constant, and represented by P_{ij}. Therefore, equation 7 for a particular product, F, becomes:

$$P_F = \sum_{j=1}^{m} X_{Fj} PF_{fj} \qquad (8)$$

The addition of a random error term to equation 8 provides the familiar equation used to estimate hedonic prices, P_{Fj}, from observations of characteristics, X_{Fj}, and market prices, P_F, of different qualities of good F.[2]

Market Level Assumptions Underlying the Model

Any model is based on simplifying assumptions and the question for empirical applications is whether these assumptions are reasonably realistic. In estimating hedonic prices based on the above model, it is useful to examine whether the market under study conforms to the underlying assumptions of the model.

The model of consumer demand for goods characteristics assumes perfect competition in goods markets, which implies perfect information is available to consumers about the quality characteristics of goods. Most food commodity markets tend to approximate the conditions of perfect competition because there are many buyers and sellers. When food standards are not

regulated by a government agency, quality premiums should reflect consumer's valuation of characteristics. However, consumers may not always be able to perceive quality characteristics when buying a good. Certain eating quality characteristics may only become apparent after food is taken home and cooked. In this case, consumers must either rely on proxy characteristics (such as a brand name) or on an established relationship with a retailer to obtain information about eating quality. For example, rice consumers in Thailand can easily identify physical characteristics of rice but cannot know the chemical characteristics that determine eating quality. For the latter they rely on the location origin of the rice as an indicator. In this way they are indirectly paying for the characteristics they want, and therefore price premiums for chemical characteristics should reflect consumer preferences.

Implicit in the assumption of competitive markets is the assumption that quality premiums are transmitted through the marketing chain. Many (if not most) food crops undergo some kind of processing between farm and consumer. The characteristics of the unprocessed commodity that produce preferred characteristics in the processed good must be known and measurable. Otherwise consumer preferences will not be transmitted back through the marketing chain and reflected in price premiums at the farm gate.[3]

Perhaps the most serious restriction of the model of consumer demand for goods characteristics is that it only models one side of the market. Prices observed in a marketplace reflect both the forces of supply and demand. Rosen has demonstrated that any estimated hedonic price represents both the marginal cost of producing a quality characteristic and the marginal utility of that characteristic to consumers. For example, a fancy

variety of a food commodity costs more both because it tastes better and because it has higher costs of production than ordinary varieties. Rosen has suggested that this identification problem disappears when all consumers are identical but producers have different costs of production. Then estimates from equation 8 identify consumer demand for quality.

Whether consumers have identical preferences for quality must be decided from prior information about the consumer population. Is it reasonable to assume that all consumers define quality in the same way? In other words, as incomes rise, will all consumers demand more of the same characteristics? If not, it may be desirable to estimate the hedonic price function separately for different segments of the population. This could be accomplished by collecting samples in markets frequented by particular income classes, or, if resources are available, by household surveys of the purchases of particular income groups.[4]

Common Problems in Estimating Hedonic Prices

The first task for a researcher who wishes to estimate equation 8 is to choose the X_{Fj}. The obvious starting point would be measures of quality that are already used in agricultural research for evaluating breeding material. However, a more rigorous approach would be to first conduct consumer taste panels and interviews about taste preferences. Such panels would ensure that all the relevant variables will be included in estimation. In this approach it is necessary to establish some correlation between consumer statements about quality and laboratory measures of quality. For example, if consumers prefer a sticky rice, are they choosing rice that has a low amylose content? If so, then amylose content is a good measure of quality in texture (Del Mundo and Juliano).

Not all the variables that determine quality are related to the genetic base of a food crop. Quality is determined by variety, growing environment, post-harvest handling, and the interactions among these three. Identifying the role of genetics and other factors in food quality is an important step in the definition and interpretation of quality characteristic measures. For example, the percent brokens in milled rice is an important quality characteristic that would appear to be a function of post-harvest processing. However, potential head rice recovery in milling is an inherited trait and thus genetics also has an influence on this quality factor.

Frequently quality characteristics are highly correlated in a particular sample. Values of different characteristics tend to bunch together, because higher (lower) quality varieties tend to have all the more (less) desirable quality characteristics at once.[5] The resulting multicollinearity among variables inflates the standard errors of the P_{Fj}. Therefore, it is difficult to estimate the individual contribution of each quality characteristic to total value. Although there are econometric techniques that will improve the estimates' reliability, it is better to eliminate the multicollinearity problem if possible. Collection of more data could provide greater variation in combinations of characteristic values. It may also be the case that quality is actually viewed by consumers as a function of groups of characteristics, and individual characteristics have no value by themselves. If so, then it is more useful to define variables as combinations of characteristics.

The simplification of the above model to obtain equation 8 for estimation includes an assumption of constant marginal utility for each characteristic. This assumption may be unrealistic, particularly when there

is wide variation in the observed range of values for a characteristic. In this case an non-linear approximation, for example by adding the squared value of a variable, may provide better estimates of hedonic prices.

Market prices vary for reasons other than quality. The whole schedule of price variation due to quality can shift up or down with changes in location or time of the year. In collection of market samples of different qualities of a food commodity, care should be taken to ensure that price variations are primarily due to quality. Usually this means limiting sampling to a particular time and location. However, if this is not possible, dummy variables can be added to the estimating equation to account for variation in prices across locations and sampling periods.

Measurement of the Welfare Gains from Improved Quality

Agricultural research can alter the amounts of different characteristics available to consumers in each unit of a food commodity. For example, plant breeders can alter the chemical characteristics of rice varieties, and thereby change the cooked texture of milled rice. When research alters the X_{Fj}'s in a food commodity, the demand for that commodity will shift because the utility gained from consumption increases. This demand shift will increase consumer surplus. Whether the price of the commodity and producer surplus also change will depend on the cost of production of the new higher quality variety. This section outlines the theory behind measurement of changes in producer and consumer surplus following a change in a good's characteristics.

Ladd and Suvannunt have shown that the relationship of quantity demanded of good u to changes in characteristic v are:

$$dq_u/dX_{uv} = [(-1/dU/dE)(dU/dX_{uv})](dq_u/dP_u)^* \qquad (9)$$

where $(dq_u/dP_u)^*$ is the income compensated own-price substitution effect from the Slutsky equation. It is assumed that the change in X_{uv} does not alter any of the other characteristics' marginal utilities. From equations 7 and 8, the term in brackets is equal to $-P_{uv}$. As the income compensated own-price substitution term is always negative, an increase in a positively valued characteristic will increase the quantity demanded of the good.

The change in quantity demanded is represented by a rightward shift in the demand curve (Figure 1). This increase in quantity demanded is equivalent to an increase in consumer utility obtained from each unit of of the good. From equation 8, this increase is equal to

$$G = (X^*_{uv} - X_{uv})P_{uv} \qquad (10)$$

where G is the consumer surplus gain per unit of good u consumed, P_{uv} is the hedonic price of characteristic v, X^*_{uv} is the new value of characteristic v obtained from one unit of u, and X_{uv} is the old value of characteristic u obtained from v.[6] It is assumed that P_{uv} does not vary with the change in X_{uv}. The new quantity demanded, q^*_u, is given by the following:[7]

$$q^*_u = q_u \, [1 - (G/P_u)\epsilon_d]$$

where ϵ_d is the income compensated own-price elasticity of demand. In order to estimate q^*_u it is necessary to have some estimate of the income compensated own-price elasticity of demand for the food commodity in question. Fortunately, in most countries existing consumer demand studies can provide such estimates for the major food crops.

The size of the total change in consumer surplus depends on whether the price of good u, P_u, changes following the change in quality. This in turn will depend on the cost of production of the new higher quality variety and the elasticity of supply. In the simplest case, the new higher quality variety would have the same cost of production as the most common older

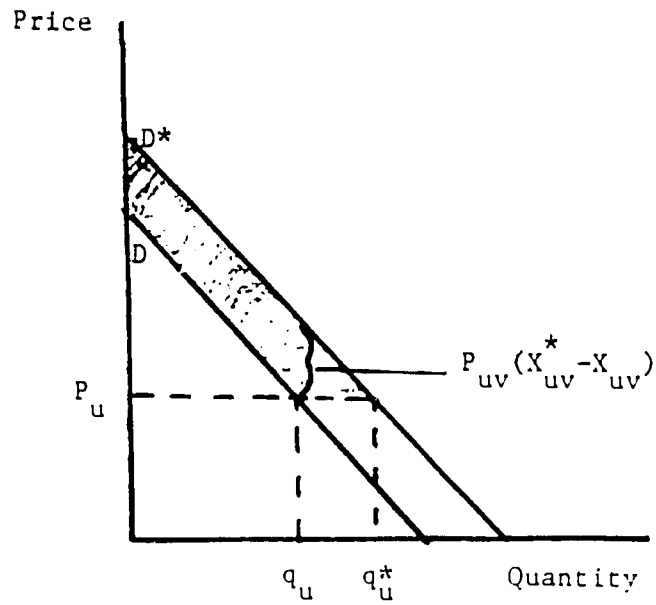

Figure 1. Consumer Surplus Gains From Quality Improvement with Infinitely Elastic Supply.

varieties, and supply would be infinitely elastic over the range of the increase in quantity demanded. This latter assumption would not be unrealistic for fairly small shifts in quantity demanded. Under these assumptions, P_u would remain unchanged, there is no change in producer surplus, and the consumer surplus gain is the shaded area in Figure 1. This area is estimated by the following:

$$CS = q_u G + 1/2\ [(q^*_u - q_u)G] \qquad (12)$$

Even if the new higher quality variety has the same costs of production as existing ordinary varieties, the increase in quantity demanded may be large enough that increased supply can only be provided at higher cost. In this case supply is not infinitely elastic over the range of the increase in quantity demanded, and the price of good u will increase after the quality change. This situation is illustrated in Figure 2. Consumers gain the area ebfg, producers gain the area abcd, of which afcd is a transfer from consumers, and society's net gain is ebcg.

In order to estimate the changes in consumer and producer surplus, it is necessary to first estimate the new equilibrium P^*_u and q^*_u. In this case some estimate of the elasticity of supply is needed. Then the new equilibrium can be calculated from the following:[9]

$$q^*_u = q_u + [G\ (q_u/P_u)]/(1/\epsilon_s - 1/\epsilon_d) \qquad (13)$$

$$P^*_u = P_u(1-1/\epsilon_s) + P_u/\epsilon_s + (G/\epsilon_s)/(1/\epsilon_s - 1/\epsilon_d) \qquad (14)$$

where ϵ_s is the elasticity of supply. The net social gain is given by:

$$NS = q_u G + 1/2\ [G(q^*_u - q_u)] \qquad (15)$$

Although this contains the same terms as equation 12, the net social gain in this case will be smaller because q^*_u is smaller.

It may be of interest to calculate the gains to consumers and producers separately, in order to see the income distribution effects of the change

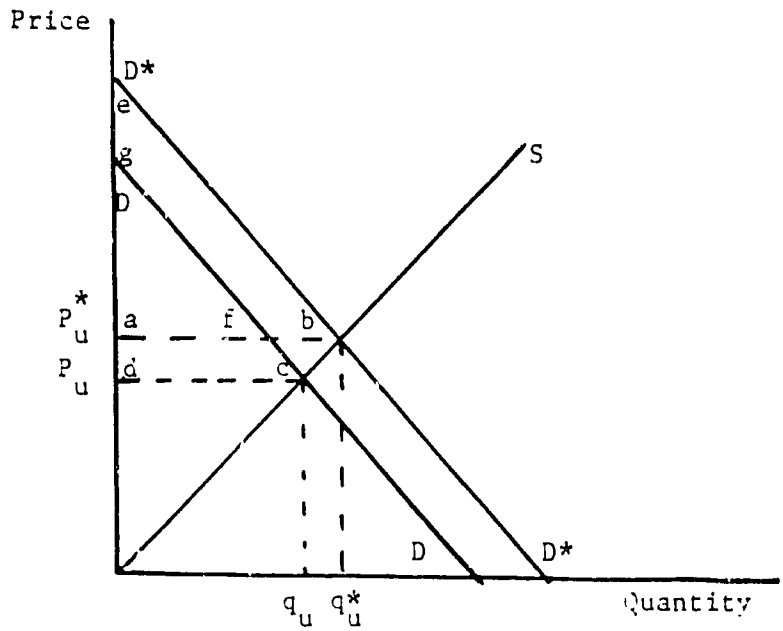

Figure 2. Changes in Producer and Consumer Surplus After Quality Improvement with Less Than Infinitely Elastic Supply.

(Bale). The following equations give the changes in consumer and producer surplus:

$$CS = q_u G \tag{16}$$

$$PS = q_u(P^*_u - P_u) + 1/2[(q^*_u - q_u)(P^*_u - P_u)] \tag{17}$$

If producers are in general poorer than consumers, then the transfer from consumers to producers will improve the distribution of income. If purchasing consumers are poorer than producers, then a quality change that results in a price increase will cause a deterioration in the distribution of income.

The net social gain can be estimated on the basis of production in one year, and presumably this gain will reoccur for several years in the future. The present value of the net social gain in future years can be compared with the present value of research costs to develop the new variety in order to estimate the returns to research on quality improvement.

The methodology presented in this section relies on some simplifying assumptions. First, supply and demand curves are assumed to be linear over the portions relevant to the demand shift. Hertford and Schmitz have argued that the difference in surplus estimates between linear and nonlinear models is small for the percentage changes usually considered in ret· ns to research studies, so this simplification seems reasonable.

The second simplification is that international trade is not explicitly incorporated in the model of supply and demand. In an open economy, exports or imports will adjust so that price will not vary following the shift in the demand curve. Domestic consumers then gain from the increase in quality of domestically produced food. Equation 12 would provide estimates of the consumer surplus gain from consumption of domestic production. It is likely that welfare gains will be limited to the domestic market because the value

and even the definition of quality frequently differ between domestic and world markets. On the other hand, if the quality improvements are valued on the world market and the commodity is exported, consumers outside the country will benefit. Domestic producers of the commodity will benefit only if the increase in quality allows them to capture a greater share of the world market.

Finally, this discussion does not include the impact of a quality improvement embodied in a variety with higher costs of production than current ordinary varieties. This type of improvement would provide benefits to a limited group of producers who could grow the variety and to better-off consumers who could afford to buy it. Such improvements would not serve the primary goal of agricultural research, which is to increase food supplies and the welfare of low income consumers and producers. Therefore this case is not considered.

An Example of Returns to Quality Improvement in Rice

Hedonic prices of rice characteristics were estimated for samples of rice from three Southeast Asian countries at the International Rice Research Institute.[10] One of the striking findings was the universal and strongly significant preference for better milling quality, i.e. fewer broken grains of rice and better polish. An increase of one percent in the proportion of broken grains in rice reduced the price of rice by .12 cents/kg in the Philippines and .18 cents/kg in Indonesia.

Potential head rice recovery in milling is an inherited trait. The earliest modern varieties (MVs) of rice, IR5 and IR8, had potential head rice recovery of only 36 to 40 percent of paddy. By 1970, these early MVs had been adopted on 50 and 25 percent of Philippine and Indonesian rice

area, respectively (Herdt and Capule, Salmon). IR20, a new MV with potential head rice recovery of more than 60 percent, was introduced in 1970, and rapidly replaced the earlier MVs in farmer's fields.

The increase of 38 percent in potential head rice recovery with the introduction of IR20 had a value to consumers of 4.56 cents per kg in the Philippines and 6.84 cents per kg in Indonesia (Table 1). If the own price-elasticity of rice is 1.16 in Indonesia (Timmer and Alderman) and 0.67 in the Philippines (Bouis), then this quality improvement should have led to an 8 and 14 percent increase in consumption in the Philippines and Indonesia, respectively. This increase in demand could be supplied by an increase in adoption of higher-yielding MVs, which in fact occured after the introduction of IR20. Therefore, supply was assumed to be infinitely elastic over the range of the projected demand increase. The total annual consumer surplus gain was $73 million in the Philippines and $224 million in Indonesia (Table 1).

The cost of developing better head rice recovery is taken to be 15 percent of IRRI's budget from 1962, when the Institute opened, to 1969, when IR20 was released. IRRI plant breeders estimate that 15 percent of the program effort was devoted to quality, and as other programs support plant breeding, 15 percent of the total budget is taken as a conservative estimate of costs.

The future value of the consumer surplus gain was compared to the past value of research costs. The improvement in head rice recovery had a benefit cost ratio of 49 (using a 12 percent discount rate) and an internal rate of return of 61 percent.[11] This return is substantial, although not as large as past returns of 84 to 87 percent to improvements in rice yields (Evenson and Flores, Scobie and Posada). These large returns to quality

Table 1. Welfare Gains From Introduction of Modern Rice Varieties with Better Head Rice Recovery

	Philippines	Indonesia
$P_{uv}[X^*_{uv}-X_{uv}]$(¢/kg)[a]	4.56	6.84
q_u(000 MT rice)[b]	1532	3059
q^*_u(000 MT rice)[c]	1655	3487
CS (million $)[d]	73	224

[a] Head rice recovery assumed to improve 38%. Each reduction of 1% in broken grains increases the price by .12 and .18¢/kg in the Philippines and Indonesia, respectively.

[b] Consumption from MVs is 50% and 25% of average rice production 1967-71 in Philippines and Indonesia, respectively.

[c] Estimated from equation 11 with own-price elasticity of rice assumed to be in 1.16 in Indonesia (Timmer and Alderman) and 0.67 in the Philippines (Bouis).

[d] This is estimated from equation 12.

improvement suggest that there is underinvestment in research to improve the quality of agricultural commodities, in addition to the widespread underinvestment in research to increase yields suggested by Akino and Hayami.

Concluding Comments

This paper has outlined a methodology for measuring the returns to research to improve the quality of food commodities. While agricultural research focuses on raising yield potential, many programs already evaluate the quality characteristics of breeding material. The methodology outlined here would enable these programs to test the importance of quality measures and to estimate the potential returns to improving quality with few additional research resources. The hedonic or implicit prices of quality characteristics are relatively easy to estimate from market samples. If the laboratory equipment is in place to screen breeding lines for quality, then it is easy to also measure the quality characteristics of market samples. These characteristic measures can then be regressed on observations of market prices with a microcomputer statistical package.

Interpreting the estimates of hedonic prices requires knowledge of the commodity market and consumer preferences, which must be provided by the economists, cereal chemists, and other scientists in the quality program. If the estimates are reasonable and significant, then they provide a measure of the value of different quality characteristics to consumers. These values yield estimates of the returns to research for improving quality, and can be used to rank the importance of potential quality improvements in setting research priorities.

More importantly, the returns to quality improvements can be used to demonstrate the usefulness of research to improve quality. Most agricultural research seeks to increase the food supply in order to benefit consumers, and producers who retain their crop for home consumption. If, in addition to increasing food supply, agricultural research can also provide better quality varieties that have the same or lower production costs as current varieties, then all consumers' welfare in enhanced.

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FOOTNOTES

1. Becker proposed a more comprehensive model in which goods are inputs into a household production function that produces the characteristics (i.e. a cooked meal with flavor and nutrients) that yield utility. In practice it is difficult to apply this model because observations on household capital and labor inputs are rarely available.

2. Note that this equation is linear. Lucas observed that the estimation equation derived from Lancaster's model is also linear, yet researchers frequently estimate hedonic price equations in a log-linear form. The log-linear functional form cannot be justified from theory, but may be justified empirically by aggregation over consumers with different tastes, incomes or non-homothetic indifference maps.

There is also the issue of how to interpret the constant term. In Ladd and Suvannunt's original model they define a unique characteristic for each good that is only found in that good. The price of this unique characteristic should be found in the constant. Alternatively, the constant can be interpreted as the value of the unspecified characteristics.

3. An alternative, related model for measuring the value of characteristics in a good that is an industrial input is found in Ladd and Martin.

4. Sometimes preferences vary across different regions of a country. A national research program must then allocate scarce research resources to make quality improvements that will be valued by the largest possible portion of the population.

5. Ironically this bunching can occur even when there is no relationhsip among characteristics across different breeding lines. That is, it is technically possible to breed a variety with any combination of characteristics, yet in practice only a few combinations are common in varieties planted by farmers.

6. If more than one characteristic changes, then G is equal to the sum of the changes in characteristics times their implicit values.

7. The demand function can be written as:

$$P_d = P_u(1 - 1/\epsilon_d) + (P_u/q_u\epsilon_d)q_d \qquad (11a)$$

The new demand function after the quality change is:

$$P^*_d = P_u(1 - 1/\epsilon_d) + G + (P_u/q_u\epsilon_d)q^*_u \qquad (11b)$$

Solving equation 11b for the new equilibrium quantity yields equation 11 in the text.

8. The income compensated own-price elasticity of demand can be calculated from estimates of the own-price elasticity, the income elasticity, and the budget share, using the Slutsky equation.

9. The supply functions can be written as:

$$P_s = P_u(1 - 1/\epsilon_s) + (P_u/q_u\epsilon_s)q_s \qquad (13a)$$

The new demand function after the quality change is still equation 11b. Setting equation 11b equal to 13a and solving for the new equilibrium quantity yields equation 13 in the text. Substituting the right hand side of equation 13 for q_s in equation 13a yields equation 14 in the text. See Norton and Davis for a review of equations used to calculate consumer and producer surplus changes.

10. See Unnevehr et.al. and Unnevehr for details of the study.

11. Full adoption of IR20 (or later varieties with equivalent milling quality) was assumed to be complete 5 years after introduction. Hence, consumer benefits start 5 years after the improvement, and last for 50 years.