ESTIMATING IMPLICIT MARGINAL PRICES OF QUALITY CHARACTERISTICS OF TOMATOES

Jeffery L. Jordan, R. L. Shewfelt, S. E. Prussia, and W. C. Hurst

Abstract

A hedonic price function is developed for estimating the implicit prices for selected quality characteristics of fresh tomatoes at three points in the marketing season. The estimation of this function, proposed as a method of evaluating changes in the postharvest system, is accomplished using a flexible functional form. Those quality characteristics that most affect the price of tomatoes can help determine the economic feasibility of alternative handling techniques or new technologies.

Key words: hedonic price function, postharvest handling, quality characteristics, Box-Cox, tomatoes.

As the production and distribution of fresh fruits and vegetables have increased, so have concerns about quality maintenance and marketing losses. The magnitude of postharvest losses in fresh fruits and vegetables has been estimated to be 5 to 25 percent of production in developed countries and 20 to 50 percent in developing countries, depending on the commodity (Kader). These losses increase the cost of distribution, reduce quantity, and in some cases, reduce the nutritional quality of foods.

A United States Department of Agriculture study estimated the average annual loss in value of fresh fruit during transit and unloading to be nearly $53 million (USDA). Clayton found that the output of 1 in every 5 acres used to produce perishable foods was lost each year due to spoilage and waste. Hanna and Mohsenin cited several studies showing that nearly all apples on fresh market displays were damaged to some extent, producing losses of over $10 million annually to the apple industry.

Pierson et al. examined the general magnitudes and locations of food losses occurring in the transportation, wholesaling, and retailing stages of the postharvest process in the United States food distribution system. Losses in fresh beef, produce, dairy products, dry grocery, frozen foods, bakery goods, and foods sold through delicatessen departments were estimated. The report suggested that between 9.04 percent and 16.61 percent of the dollar value of United States produce was lost, accounting for a value of $.64 to $1.26 billion. Ceponis and Butterfield estimated tomato losses in eight New York supermarkets from 1974 to 1977 and found losses to be between 4.7 and 7.9 percent.

In this paper, a hedonic price function is developed for estimating the implicit prices for quality attributes of fresh tomatoes at three points in the marketing season. This function assigns a monetary value to quality characteristics at the wholesale level. The estimation of hedonic prices, proposed as a method of evaluation changes in the postharvest system to alleviate some of the system wide losses, is accomplished using a flexible funtional form. Those quality characteristics that most affect the price of tomatoes can help determine the economic feasibility of alternative handling techniques or new technologies.

Postharvest research on tomatoes has included studies on mechanical damage during handling (O'Brien et al.) and transportation (Schueller et al.). Knowing the marginal implicit prices of quality attributes, it is possible to examine the benefit of modifying

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handling techniques. A change in the post-harvest handling of tomatoes that costs less than the implicit price of the affected quality characteristic can be considered as a net benefit.

THEORETICAL MODEL

Most empirical hedonic work has concentrated on creating hedonic price indexes in order to remove quality change from price indexes (Griliches). Research using the hedonic price technique on agricultural commodities includes Ladd and Martin's study which expanded the classical production function for corn to include implicit prices of inputs. Research on malting barley (Wilson) extended that work. Hedonic price functions have also been used in component pricing in milk and in estimating implicit quality prices for cotton. Other agricultural commodities explored by hedonic techniques include asparagus, tomatoes, and cucumbers on the Boston wholesale market (Waugh). Other non-consumer level research noted by Ladd include strawberries, eggs, hard red spring wheat, rough rice, cereals, feeder cattle, boars, and grapes.

Product quality and hedonic price models also pertain to the consumer or retail level and have as their theoretical foundation consumer utility maximization, as developed independently by Houthakker, Theil, and later by Lancaster. Much of the development of hedonic demand analysis applied to agriculture at both the consumer and producer levels has been done by Ladd, Ladd and Martin, Ladd and Suvannunt, and Wilson. Generalizing these approaches, the theory of product characteristics can be applied to the wholesale firm. The hedonic technique assumes that the buyers of a good have a demand, not just for the product, but for the bundle of quality characteristics it possesses. The theoretical development (Ladd and Suvannunt, p. 505) supposes n products where each of the first m product characteristics is provided by several products. Also, each product provides a unique characteristic provided by no other product. Total consumption of each quality characteristic is then expressed as a function of the quantities of products consumed and of consumption input-output coefficients:

$$(1) \quad x_{Oj} = f_j(q_1, q_2, \ldots, q_n, x_{1j}, x_{2j}, \ldots, x_{nj}) \quad \text{for } j = 1, 2, \ldots, m,$$

and

$$x_{Om+i} = f_{m+i}(q_i, x_{im+i}) \text{ for } i = 1, 2, \ldots, n;$$

where x_{Oj} is the total amount of the j^{th} product characteristic provided by all products; x_{ij}, is the quantity of the j^{th} characteristic provided by one unit of product i; and q_i is the quantity of the i^{th} product consumed. The x_{ij}'s are parameters to buyers whose magnitudes are determined by the sellers or producers. The utility function is:

$$(2) \; U = U(x_{O1}, x_{O2}, \ldots, x_{Om}, x_{Om+1}, \ldots, x_{Om+n}).$$

Equation (2) is maximized subject to a budget constraint, $\Sigma \, p_i q_i = I$. Differentiating equation (2), produces the first-order conditions:

$$(3) \quad \sum_j (\partial U/\partial x_{0j})(a x_{0j}/\partial q_i) + (\partial U/\partial x_{Om+i})(\partial x_{Om+i}/\partial q_i) - (\partial U/\partial I)p_i = 0.$$

Solving for p_i yields the hedonic price function where one unit of each product supplies one unit of its unique characteristic:

$$(4) \quad P_i = \sum_j (\partial x_{0j}/\partial q_i)(\partial E/\partial x_{0j}) + \partial E/\partial x_{0m+i},$$

where $\partial x_{0j}/\partial q_i$ is the marginal yield of the j^{th} product characteristic by the i^{th} product, E is the total expenditure on all products, and $\partial E/\partial x_{0j}$ is the marginal rate of substitution between expenditure and the j^{th} product characteristic or the marginal implicit price paid for the j^{th} product characteristic.

As Ladd and Suvannunt state, equation (4) shows that for each product consumed, the price paid by the consumer equals the sum of the marginal monetary values of the product's characteristics. The marginal monetary value of each characteristic equals the quantity of the characteristic obtained from the marginal unit of the product consumed multiplied by the marginal implicit price of the characteristic (p. 504).

Although derived for the consumer level, hedonic theory can apply to the wholesale level when considering the seller-buyer relationship. Since the consumer is willing to pay a price premium for higher quality characteristics, the retailer will pay a price premium to the wholesaler for increased quality attributes. The utility function (equation (2)) that includes quality characteristics has as its counterpart the profit function of the retail firm where profits will increase if tomatoes can be sold at a higher price due to the level of quality attributes supplied by the wholesaler.

The basic characteristics are the same between derived demand and the market demand relationship, the principal difference being the marketing margin. If the marketing margin is an absolute constant, it can be assumed that the slopes of the derived and market demand curves are the same. Thus, hedonic theory will apply as well to the derived demand curve. If, however, the marketing margin is not constant, if it changes by differing percentages throughout the demand curve, the slopes will not be equal, although they should be similar.

In the simplified empirical model used in this study, a good is composed of n attributes, $x_1, ..., x_n$. Since the wholesale price of a good will depend on the quantities of the attributes, the price can be expressed as equation (5):

$$(5) \quad P(X_i) = P(x_{i1}, ..., x_{ij}, u_i),$$

where: $P(X_i)$ = observed wholesale price of commodity i;
x_{ij} = amount of some characteristic j per unit of commodity i; and
u_i = a disturbance term (Lucas).

Differentiating $P(X_i)$ with respect to its j^{th} argument, the wholesale price function that is implicit in $P(X_i)$ can be derived, $p(x_i)$. The usual hedonic method is to estimate $p(x_i)$ by regressing observed differentiated product prices, $P(X_i)$, on all their characteristics, using the best fitting functional form.

The model developed here is concerned only with the demand function. As noted by Wilson, it is often necessary to estimate the demand and supply functions simultaneously to avoid simultaneous equations bias. Cross-sectional data were gathered for this study in a 24-hour period. Thus, the supply of a characteristic is assumed to be perfectly inelastic with respect to its marginal implicit price. When estimating time-series hedonic functions, however, the supply response of quality characteristics should be determined (Rosen).

Economic theory provides no guidance to correct specification of the functional form for hedonic equations. A hedonic price equation is a reduced-form equation reflecting both supply and demand influences. Consequently, the appropriate functional form cannot be specified on theoretical grounds (Halvorsen and Pollakowski; Rosen; Bender et al.). To determine the correct functional form, Box and Cox introduced the concept of a power transformation of the form:

$$(6) \quad y^{(\lambda)} = \begin{cases} (y^{\lambda}-1)/\lambda & \lambda \neq 0 \\ \ln y & \lambda = 0 \end{cases}$$

which can be generalized for equation (5) to a function of the form:

$$(7) \quad p^{(\lambda)} = \beta_1 + \beta_2 X_2^{(\mu)} + ... + \beta_k X_k^{(\mu)} + E.$$

The estimation of the parameters λ and μ is equivalent to choosing the functional form which best fits the data using the Box-Cox transformation.[1] Although Box-Cox transformations of hedonic models have been used recently (Edwards and Anderson; Milon et al.), none of the studies is in the context of agricultural commodities.

DATA AND EMPIRICAL MODEL

Cross-sectional observations on product attributes of 1,694 "vine-ripened" tomatoes harvested in Florida, Georgia, and North Carolina during April, early August, and late September 1984, respectively, and corresponding prices were obtained at each packinghouse facility.[2] The observed prices were

[1]As noted in equation (7), different transformation parameters are used for the dependent and independent variables. Although most of the examples cited for Box-Cox transformations on hedonic functions do not use different transformations, their use here provides greater flexibility for testing functional forms. As noted by Boyes and Gerking (and demonstrated by Welland and Spitzer, 1976), when the more general specification was used, it was found to be superior to restricted specifications in that this specification had a higher concentrated likelihood value. Also, as noted by Huang (p. 17), a different transformation parameter can be assigned to each variable, rather than just λ and μ. However, this may increase the degree of multicollinearity and the matrix may become singular. In addition, the computer and programming time to generalize the model with different transformation parameters would be expensive in relation to improve statistical and economic estimates. The total number of iterated regressions required if different parameters with the same range and intervals were applied to each variable would be X , where X is the number of times that each transformation parameter will vary and n is number of parameters.

[2]In April, 394 tomatoes harvested in Florida were sampled at the Atlanta Terminal Market. In August, 413 Georgia tomatoes were sampled at the packinghouse in Murphy, North Carolina, and in September, 884 tomatoes from North Carolina were sampled. To measure firmness, the tomato must be punctured and cannot be used for other quality measurements. Thus, the number of tomatoes used for each regression is less than the total sampled.

those market clearing prices that the packinghouses sold the tomatoes for on the sampling day. Samples were taken at a single packing shift in each time period. Sampling of boxes was done on a random basis by pallet. Each tomato was weighed and evaluated for color using an 8-point circumferential measurement with a Gardner colorimeter. All tomatoes with decay, serious or other scorable damage based on USDA standards of identity were recorded. Laboratory measurements of quality included firmness, vitamin C, moisture, pH, soluble solids, and acidity. The rate of deterioration was calculated after the samples had been stored for 7 days at 68° Fahrenheit.

A separate equation was estimated for each of the 3 months.[3] Of the quality characteristics measured, vitamin C, moisture, pH, soluble solids, acidity, and deterioration cannot be judged by the wholesaler or retailer prior to sale. Consequently, pricing decisions are not based explicitly on such quality measures. Of the quality characteristics measured, only those variables that appeared to be used by the marketing agents to determine price at the packinghouse level were incorporated into the hedonic model. Considering this, the empirical model was specified as:

$$(8)\quad P_i^* = \beta_0 + \beta_1 SIZE_i^* + \beta_2 DAM_i^* + \beta_3 COL_i^* + \beta_4 FIRM_i^* + \varepsilon_i$$

where:

P_i = the price of the i^{th} sample of tomatoes on a cents per box basis;

$SIZE_i$ = weight in grams, i^{th} sample;

DAM_i = damage: percent of tomatoes in box i with scorable defects as described in USDA grade standards;

COL_i = color indicator as measured by the ΔE value, i^{th} sample;[4]

$FIRM_i$ = measure of the firmness of the i^{th} sample using a puncture test;[5]

and the $*$ indicates the λ and μ are transformation parameters to be determined.

For equation (8), the expected sign for size is positive. The expected sign for damage is negative since high damage levels result in lower prices. The expected sign for firmness is positive since more firm tomatoes have a longer potential shelf-life. The expected sign for color is negative since a decreasing ΔE value indicates the tomato is turning color (maturing) from green to pink; that is, as ΔE declines, price should increase. The parameters of the equations were estimated using an iterative OLS procedure (Huang; Zarembka).

RESULTS

Estimated results for equation (8) for each of the months are shown in Table 1.[6] The maximum likelihood function was first maximized using a grid search for λ and μ set between −2 and 2, with increments of .5. The initial estimates of λ and μ were used to narrow the range where λ and μ are maximized. A refined grid search using an interval

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[3]The data were first combined into a single equation over the entire sample and run with OLS. A Chow-Fisher error test to determine whether the slope estimates were equivalent and intercept estimates were also equivalent across months was employed. The test showed they were not. For the overall sample, no significant difference in variability from month-to-month was found. Thus, the variability in the April data sample was equal to the variability in the August and September samples. However, when testing the interaction of the class variable (month) and the independent (quality) variables, there was a significant difference in slopes for firmness and size across the months. Thus, for two of the four variables, different equations were appropriate. It was then decided to use three regressions rather than one overall regression. Also, the Box-Cox transformation procedure used does not transform dummy variables. Thus, slope shifters cannot be used in the Box-Cox program.

[4]Color is expressed as ΔE or the total color difference of the sample from a reference standard pink tile in the Hunter L, a, b color system. The value of ΔE decreases as the tomato changes from green to pink and then increases as the pink tomato becomes more dark and red.

[5]Firmness is measured as the force (kilogram) required to puncture the tomato to a depth of 7 centimeters using a Universal Fruit Testing Machine. As the tomato ripens, it softens and requires less force for puncture.

[6]The estimated coefficients in the Box-Cox procedure do not directly indicate the marginal implicit prices of the variables. To estimate the marginal implicit prices (MIP), the following transformation is performed:

$$b\left(\frac{\bar{x}^{\mu-1}}{\bar{y}^{\lambda-1}}\right) = MIP$$

where b = the estimated coefficients shown in Table 1, $\bar{x}$ and $\bar{y}$ are the mean values of the variables and μ and λ are the transformation parameters.

It has been demonstrated (Spitzer, 1984; Blackley et al.) that the use of an iterative OLS procedure to find the maximum likelihood estimates will generally underestimate the covariance matrix and thus overestimate the t-value. Thus, a t-value near the critical value may indicate insignificance.

TABLE 1. RESULTS OF THE HEDONIC PRICE ESTIMATION FOR TOMATOES, NORTH GEORGIA PACKINGHOUSES, 1984

Variable and statistic	Estimated coefficient			Marginal implicit price		
	April	August	September	April	August	September
Size	.1647 (13.66)[a]	−.0004 (−.454)	−.00002 (−1.30)	.03	−.002	−.003
Damage	−.1271 (−10.59)	−.0081 (−12.54)	−.0010 (−15.78)	−.06	−.10	−.06
Color	−.7861 (−4.45)	−.0014 (−.308)	−.0020 (−5.99)	−.23	−.01	−.16
Firmness	.3344 (5.46)	.0052 (.914)	.0257 (7.10)	.36	.17	.78
F value	91.682	45.353	72.729			
$\bar{R}^2$	.486	.564	.393			
$L_{MAX}(\lambda,\mu)$	−271.269	−69.282	−280.657			
λ	.70	−1.1	−.50			
μ	.50	.50	1.40			
N	385	138	445			

[a]Values in parenthesis are the calculated t-statistics.

of .1 was then employed to obtain a more precise combination of λ and μ. The values of λ and μ at which the likelihood function was maximized are shown in Table 1 for each month. For all 3 months, the likelihood ratio test, using the Chi-square distribution to test a significant difference between the Box-Cox estimator and standard functional forms, indicated that at the .01 level, there was a significant difference between the functional form of equation (8) and all other tested functions.[7] The parameter estimates for April were of the correct *a priori* sign and all coefficients were significantly different from zero at the 95 percent level. The F-value indicated that the overall regressions of all 3 months were significant.

For August tomatoes, the parameter estimate for damage had the correct *a priori* sign and was significant. The coefficients for size, firmness, and color were insignificant at any reasonable level. For September tomatoes, the parameter estimates for damage, firmness, and color were of the correct *a priori* sign and significant, while the coefficient for size was negative but insignificant.

For April and September tomatoes, the results indicated that a 1 percent reduction in defects will increase price about 6 cents per box. For August tomatoes, a 1 percent reduction in defects will increase price 10 cents per box. A unit change in color (toward pink) will increase price 23 cents per box for April tomatoes and 16 cents per box for September tomatoes. Increasing the weight by 1 gram per tomato increases price 3 cents per box for April. A one unit increase in firmness (correlated with shelf-life) will increase the price of a box of tomatoes in April by 36 cents and by 78 cents in September. With the exception of the August data, firmness appears to be the most important quality attribute, followed by color, damage, and size. For April and September, the marginal prices for color and damage are relatively consistent. Firmness was of higher value in September since it is corelated with shelf-life which is more important late in the marketing season. The marginal implicit price for damage in August is also near that for April and September.

SUMMARY AND IMPLICATIONS

Marginal implicit prices for selected quality attributes that affected the wholesale price of tomatoes during 1984 were estimated. Equations were specified and parameters were estimated to derive market determined implicit prices for size, damage, color, and firmness.

The costs of changes in handling techniques or new technologies in the tomato system are usually known. What is more difficult to estimate is the benefit to be derived from implementation. In determining the benefits and costs of a new investment, the information derived from the hedonic estimation procedure can be used. When $MC_I < MIP_i$, where MC_I is the marginal cost of the investment and MIP_i is the marginal implicit

[7]Using a likelihood ratio test, the null hypothesis of a significant difference between the Box-Cox estimation and various functional forms was tested (including semi-log, log-inverse, double-log, inverse, and linear functions). Under general conditions, -2 ln L is distributed approximately as the Chi-square distribution, χ^2 (f), where L is the ratio of the two likelihood functions and f is the degrees of freedom equal to the number of transformation parameters.

price of the affected attribute, a net benefit is produced. If $MC_I > MIP_i$, the resulting price benefit may not cover costs. The hedonic benefit-cost approach can aid in the evaluation of different handling systems and materials. For example, a USDA study (Mongelli), compared the variable costs of handling fresh tomatoes from wholesaler to retailer using a handstacked versus palletized system. Results showed that the total cost of handling tomatoes by pallets is more than for handstacking, \$.7030 versus \$.6249 per box, respectively. However, the palletized system produces less damage because there is a lower probability that a box will be dropped, resulting in bruising. The results of the hedonic estimation indicated that a 1-percent reduction in damage would increase the price of a box of tomatoes between \$.06 and \$.10. Since the difference in the cost of the two handling systems is nearly \$.08 per box, the feasibility of the investment in the palletized system will depend on the difference in damage that occurs. If the palletized system does not reduce damage by more than 1 percent, the investment would not likely be feasible. If, on the other hand, the palletized system reduces damage by 2 percent, the price of tomatoes would be expected to increase between \$.12 and \$.20 per box making the \$.08 per box difference in cost a feasible investment. It is in this way that the estimation of hedonic prices can aid the economic evaluation of the postharvest system.

To further explore the potential use of marginal implicit prices as an investment criterion, a more sophisticated financial analysis is necessary. Ideally, a net present value analysis would be conducted using the information on quality characteristics obtained in this study. To do this, more information is required on the palletized system that is within the scope of this study. However, to briefly illustrate the use of hedonic price information as an investment criterion, a payback period analysis can be accomplished.

At the firm level, a packinghouse operator could use this information to estimate the payback period to recover the cost of the investment in pallets. To handload and unload 900 boxes of tomatoes, Mongelli estimated the labor cost to be \$22.43 per truck. Labor cost when pallets were used was estimated at \$11.75, a cost saving of \$10.68 per 900 box truck. All other variable costs were assumed equal between the two systems. Costs were estimated for shipments from central Florida to Washington, D.C. using 1980 prices.

While the firm would save \$10.68 in labor costs, the palletized system requires an investment of \$81 for 18, 48 by 40-inch wooden pallets at \$4.50 each for each truckload of tomatoes. Thus, the payback period for the investment would be nearly 8 trips (\$81 ÷ \$10.68) if the price effects of quality improvement are not taken into account. If the impact on the price of tomatoes due to reduced damage is known, the payback period can be calculated as shown in Table 2.

If the price of tomatoes increased by \$.06 per box and the palletized system results in a .05 percent reduction in damage, the payback period would be just over two trips. If the marginal implicit price of damage is \$.10 per box, the payback period would drop to under 1.5 trips at .05 percent reduction. The payback period declines to less than one trip if the damage reduction is 1.5 percent or greater and the marginal implicit price is \$.06 per box. If the marginal implicit price is \$.08 or \$.10 per box, the damage reduction needs to be just 1 percent for the payback period to be less than one trip. Thus, in most cases purchasing and using pallets just once is financially feasible. At the firm level then, the approach to postharvest technologies suggested in this paper could be used to make investment decisions.

A price-size/quality relationship can aid tomato handlers in making decisions concerning the size and color of the fruit at harvest. Growers, harvesters, and transporters have the best opportunity for increased prices by providing packinghouses with large, undamaged tomatoes at early stages of color change. Firmness is an additional quality characteristic that packinghouse operators should consider. Since most operations are done by hand, proper training and supervision are keys to improvement. Careful selec-

TABLE 2. PAYBACK PERIODS (NUMBER OF TRIPS) OF PALLETIZED SYSTEM BASED ON THE MARGINAL IMPLICIT PRICE OF DAMAGE AND QUALITY IMPROVEMENT

Damage reduction	Marginal implicit price		
	\$.06	\$.08	\$.10
	Payback period (trips)		
0.5 percent	2.15	1.74	1.45
1 percent	1.25	.98	.80
1.5 percent	.88	.68	.56
2 percent	.68	.52	.42

Source: Based on variable cost data from Mongelli.

tion of fruit for harvest increases average value and enables unharvested fruit to increase in size and reach optimum color. Other possibilities worth considering include early sizing, special handling of large tomatoes, use of cushioned shipping containers to minimize bruising, and procedures for ripening based on weight and color.

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