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IMPACT OF FRESH GRAPEFRUIT QUALITY ON DEMAND

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Abstract

This study incorporates quality into the Rotterdam demand system based on utility theory. Quality was modeled through its impact on marginal utilities via perceived prices, following theoretical work by Basmann and Barten, among others. Results show that the price elasticity of fresh grapefruit demand is near unitary at the retail level and juice content has had relatively large impacts on fresh grapefruit demand.

Key words: demand, quality, fresh grapefruit, Rotterdam model.

Impact of Fresh Grapefruit Quality on Demand

Introduction

Empirical studies of demand have found quality to be an important demand determinant along with prices and income. The hedonic approach has been used to estimate relationships between product prices and associated quality variables, and results have been used in estimating quality corrected price indices. Household production theory or, alternatively, Fisher and Shell's simple repackaging model has been used to rationalize the hedonic technique (for a review, see Deaton and Muellauer).

In this paper, we examine the relative importance of quality in the fresh grapefruit market. Knowledge of the impacts of demand determinants help in understanding market behavior and can be critical in developing marketing strategies. For example, the Florida Department of Citrus (FDOC) has been considering supply control measures to address low grower prices. The effectiveness of such supply control programs can be expected to depend on not only the price elasticity of demand but also possibly other factors such as the quality of fruit allowed on the market.

For the present study, we use a generalization of Fisher and Shell's approach in developing a model to estimate the impact of quality on demand. Specifically, quality is included in the consumer's utility function which is then maximized subject to a budget constraint, yielding demand equations with prices, income and quality as arguments. When each good under consideration is subject to quality changes, the number of quality-induced demand responses equals the square of the number of goods under consideration, although for empirical analysis the adding-up condition of demand can be used to reduce the number of equality-induced responses by the number of goods. The potentially large number of quality responses to estimate from possibly limited data suggests that parsimonious models be considered for empirical work. In the present study, we consider a simple but theoretically appealing model based on the fundamental matrix equation of demand (Barten, 1977; Philips). In our specification of demand, a change in product quality can be viewed as change in a perceived price for the product in question[1]. A change in a product's perceived price can be decomposed into the actual change in price minus the change in the products's marginal utility as a result of a change in quality; e.g., an increase in quality may increase a product's marginal utility, which in turn would decrease its perceived price, and vice versa.

Model

Effects of Quality on Utility and Demand

Our specification of the impact of quality on demand is based on Barten's (1977) fundamental matrix equation of consumer demand and follows the approach used in modeling advertising by Theil (1980a); Duffy (1987, 1989); and Brown and Lee (1997). Early theoretical work related to this approach was done by Basmann, Tintner, and Ichimura. The approach begins with the traditional consumer problem of choosing that bundle of goods which maximizes utility, subject to a budget constraint. Quality is included in the utility function but not in any restricted

[1] In Fisher and Shell's model, a similar perceived price is defined. Fisher and Shell introduce quality into the consumer's utility function through scaling (Barten, 1964b), resulting in demand specifications where prices are quality adjusted via division of nominal prices by quality parameters. The Fisher and Shell model also implies additional quality impacts directly through the quality parameters, independent of the quality adjusted prices (for a comparison of the scaling and fundamental matrix equation approaches see Brown and Lee, 1993).

fashion as in Fisher and Shell's model[2]. Formally, the utility maximization problem can be written as

(1) maximize $u = u(q, z)$

subject to $p'q = x$,

where u is utility; $p' = (p_1, \ldots, p_n)$ and $q' = (q_1, \ldots, q_n)$ are price and quantity vectors with p_i and q_i being the price and quantity of good i, respectively; $z' = (z_1, \ldots, z_n)$ is a vector of quality levels for the goods under consideration; and x is total expenditure or income.

The first order conditions for problem (1) are

(2a) $\partial u/\partial q = \lambda p$

(2b) $p'q = x$,

where λ is the Lagrange multiplier which is equal to $\partial u/\partial x$.

The solution to (2) is the set of demand equations

(3a) $q = q(p, x, z)$,

and the Lagrange multiplier equation

(3b) $\lambda = \lambda(p, x, z)$.

To examine the effects of prices, income and quality on demand, totally differentiate first order conditions (2) and arrange terms to find the fundamental matrix equation of consumer demand theory (Barten, 1977)

(4a) $Udq - pd\lambda = \lambda dp - Vdz$

(4b) $p'dq = -q'dp + dx$,

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[2] In contrast to Fisher and Shell's approach, we do not place restrictions on the utility function but on the resulting differential approximations of demand.

where $U = [\partial^2 u/\partial q_i \partial q_j]$ and $V = [\partial^2 u/\partial q_i \partial z_j]$. U is the Hessian matrix, and V is a matrix indicating how quality effects the marginal utilities.

When (4) is solved for dq and $d\lambda$, one obtains the effects of prices, income and quality on demand—$\partial q/\partial p'$, $\partial q/\partial x$ and $\partial q/\partial z'$, respectively (e.g., Barten, 1977; Philips). Note that (4a) is the same whether $-Vdz = 0$ and $dp = -(1/\lambda)Vdz$, or $-Vdz \neq 0$ and $dp = 0$. This suggests that the changes in quality can be viewed as changes in prices; the only difference is that changes in quality do not generate income effects whereas changes in prices do. Following Barten (1977) the effects of quality on demand can be written as

(5a) $\partial q/\partial z' = -(\partial q/\partial p' \div (\partial q/\partial x)q')\,(1/\lambda)V$,

or,

(5b) $\partial q/\partial z' = -\,(1/\lambda)\,S\,V$,

where $S = (\partial q/\partial p' + (\partial q/\partial x)q')$ is the substitution matrix or Slutsky matrix of compensated price responses. Equation (5) is the basic result underlying our specifications of the effects of quality on demand.

In general, the above results can be extended to other demand determinants (other than income and prices), by redefining variable z as the determinant of interest (Barten, 1977; Phlips). For early formulation of equation (5) with respect to advertising, see Basmann, Tintner and Ichimura.

Quality Effects in the Rotterdam Model

Following Barten (1964a) and Theil (1975, 1976, 1980a,b), an approximation to demand (3a) is the Rotterdam model which can be written as

(6) $w_i\, d(\log q_i) = \theta_i\, d(\log Q) + \sum_j \pi_{ij}\, d(\log p_j) + \sum_j \beta_{ij}\, d(\log z_j)$ $i=1, \ldots, n,$

where $w_i = p_i q_i / x$ is the budget share for good i ; $\theta_i = p_i\ (\partial q_i / \partial x)$ is the marginal propensity to consume; $d(\log Q) = \sum w_i\, d(\log q_i)$ is the Divisia volume index; $\pi_{ij} = (p_i\, p_j / x) * s_{ij}$ is the Slutsky coefficient, with $s_{ij} = (\partial q_i / \partial p_j + q_j\ \partial q_i / \partial x)$ or the element in the i^{th} row and j^{th} column of the substitution matrix S; and $\beta_{ij} = w_i\ (\partial \log q_i / \partial \log z_j)$ are quality coefficients.

The general restrictions on demand are (e.g., Theil, 1975, 1976)

(7a) adding up: $\sum_i \theta_i = 1$; and $\sum_i \pi_{ij} = 0$; $\sum_i \beta_{ij} = 0$;

(7b) homogeneity: $\sum_j \pi_{ij} = 0$;

(7c) symmetry: $\pi_{ij} = \pi_{ji}$.

Quality Restrictions

Based on (5), the quality coefficients can be written as (e.g, Brown and Lee, 1997)

(8) $\beta_{ij} = -\sum_k \pi_{ik}\, \gamma_{kj}$, $i,j = 1, \ldots, n$,

where $\gamma_{kj} = \partial \log (\partial u / \partial q_k) / \partial \log z_j$ for $j, k = 1, \ldots, n$. Note that γ_{kj} is the elasticity of the marginal utility of good k with respect to quality of good j.

Result (8) can be used to specify a simple but appealing parameterization of quality for some products (this parameterization is similar to the brand advertising parameterizations proposed by Theil, 1980a; Duffy, 1987, 1989; and Brown and Lee, 1997). Specifically, we assume that a change in a product's quality only affects the marginal utility of the product in question which results in the restriction

(9) $\beta_{ij} = -\pi_{ij}\gamma_j$,

where $\gamma_{jj} = \gamma_j$, i.e., the elasticity of the marginal utility of good j with respect to quality of good j. Assumption (9) may be not be appropriate for all products, but it may be a reasonable approximation for the some. For example, we do not expect higher quality grapefruit to affect the marginal utility of apples or other fruit, except possibly when the different fruit are used together in particular recipes; however, we doubt the latter possibilities characterize much fresh fruit consumption. With regard to this issue, it is interesting to note that one can make a somewhat weaker assumption which allows a product's quality to affect the marginal utilities of other products, and obtain essentially the same result as (9). Namely, assume that an increase product j's quality affects all other product marginal utilities the same; i.e., $\gamma=\gamma_{kj}$ for all $k \neq j$; also assume $\gamma_{jj} \neq \gamma$. These assumptions are similar to those underlying Theil's (1980b) uniform substitute model. Starting with result (9), we then have $\beta_{ij} = -\sum_k \pi_{ik} \gamma_{kj} = -\pi_{ij} \gamma_{jj} - \gamma \sum_{k \neq j} \pi_{ik} = -\pi_{ij}(\gamma_{jj} - \gamma)$, since $\sum_{k \neq j} \pi_{ik} = -\pi_{ij}$, by homogeneity restriction (7b). Hence, restriction (9) is appropriate for the weaker assumption that the fresh fruit under consideration are like uniform substitutes with respect to quality.

Restrictions (9) can be substituted into demand specification (6) to obtain

(10) $\quad w_i \, d(\log q_i) = \theta_i \, d(\log Q) + \sum_j \pi_{ij} \, [d(\log p_j) - \gamma_j \, d(\log z_j)] , \quad i = 1, \ldots, n .$

In addition to reducing the parameter space, a possible benefit of model (10) is that it may yield more precise Slutsky coefficient estimates when price variation is limited (Theil, 1980a), as both price and quality variation contribute to the estimation of the these coefficients.

Finally, note that the bracketed terms following the Slutsky coefficients in equation (10) can be viewed as log changes in perceived or quality-adjusted prices. That is, demand equation (10) can be written as

(11) $w_i\, d(\log q_i) = \theta_i\, d(\log Q) + \sum_j \pi_{ij}\, d(\log p^*_j)$,

where $d \log p^*_j = d(\log p_j) - \gamma_j\, d(\log z_j)$ is the log change in the perceived price $p^*_j = p_j / z_j^{\gamma_j}$.

Data

Demand model (10) was applied to annual data on per capita fresh fruit consumption and retail prices, reported in the *Fruit and Tree Nuts, Situation and Outlook Yearbook, October 1997,* published by the United States Department of Agriculture (USDA). The period from 1980 through 1997 was studied; prices for the period before 1980 were not reported. Retail price data were only reported for grapefruit, oranges, apples, pears, bananas, grapes and lemons. Reported orange prices were for the Navel and Valencia varieties; these two price series were used to construct a weighted average orange price with the weights based on fresh utilization levels for Navels and Valencias reported by the Florida Agricultural Statistics Service in various issues of *Citrus Summary*. Fresh lemons are not normally used as complements or substitutes for the other fresh mentioned above and were not included in the model (fresh lemons are largely used as a flavor additive in meals). Apples and pears were grouped together based on similarity of fruit. The number of fresh fruit categories studies then was five—grapefruit, oranges, apples/pears, bananas and grapes. Mean budget shares for these categories are shown in Table 1.

Measures of fruit quality were limited. In this study, we focus our attention on an important dimension of fresh grapefruit's quality, juice content. This dimension of quality was measured by average grapefruit pound solids per 85 pound box of fruit and was constructed from USDA data reported in *Fruit and Tree Nuts, Situation and Outlook Yearbook*. A large percentage of grapefruit pound solids are sugars and hence this measure of quality reflects sweetness. Fresh grapefruit pound solids were measured indirectly by data reported for processing. USDA data on total grapefruit juice production in single strength equivalent gallons were divided by short ton utilization. The juice data were transformed to pound solids per 85 pound box, following industry convention of reporting yields (a single strength gallon was defined as having a quarter of the pound solids (.981 ps) in a 40 degree Brix gallon (3.924 ps)). There are other measures of grapefruit quality including various flavor attributes and measures of external appearance but consistent data on these factors were not available. Much of the fresh grapefruit in the U.S. market comes from Florida and most of the grapefruit juice is produced in Florida so that using pound solids reported at the processing level seems to be a reasonable approximation of this measure of U.S. fresh grapefruit quality. On the other hand, a similar measure of quality for oranges was not used as Florida produces most of the orange juice but California supplies the largest share of the fresh oranges (processed juice yields in Florida are not representative of juice content in California). Quality measures for the remaining fresh fruit studied were not available.

Although our data is not complete across all fruit varieties and across other dimensions of quality, we believe it is complete enough to gain insight on the demand for fresh grapefruit, the major interest of this study.

Application

Model (10) was applied to the five fresh fruit categories discussed above, treating these fresh fruit as separable from other goods. Hence, the system is conditional on expenditure allocated to the fresh fruit studied. Based on the theory of rational random behavior, the conditional real income variable (Divisia volume index) was treated as independent of the error terms in each fresh fruit demand equation (Theil, 1975, 1976, 1980b; Brown et al, 1994). Iterated seemingly unrelated regression was used to estimate the model. As the data add up by construction, the error covariance matrix was singular and an arbitrary equation was excluded (Barten, 1969); the parameters for the excluded equation can be obtained using conditions (7) or by re-estimating the model omitting a different equation. The primary interest of our study is estimation of demand responses and we treat model (10) as our maintained hypothesis. Given the present data and model limitations, testing the various propositions of consumer demand theory would be problematic (Keuzenkamp and Barten).

Estimates of (10) are shown in Table 2. All (conditional) own-Slutsky coefficient estimates were negative and statistically different from zero at the α=.10 level of significance, as expected based on demand theory. The cross-Slutsky coefficient estimates were largely positive, indicating substitution relationships. However, half of these estimates were insignificant. Four cross-Slutsky coefficient estimates were positive and significant; one estimate, that for the relationship between grapefruit and oranges, was unexpectedly negative and significant, suggesting a complementary relationship. Perhaps consumers tend to eat oranges and grapefruit at different meals/occasions limiting the possibilities of substitution and/or increased consumption of one specific variety of citrus heightens awareness for citrus in general.

The coefficient estimate for grapefruit quality (the elasticity of the marginal utility of grapefruit with respect to quality) was positive and significant at 2.2. This estimate suggests that increased sweetness may reduce consumers' perceived price for grapefruit resulting in increased fresh grapefruit consumption and offsetting demand changes for the other fresh fruit varieties through the cross price relationships.

Demand elasticities estimated at sample mean budget shares[3] are shown in Table 3. The price elasticities are uncompensated. Elasticity formulas are provided in Duffy (1987), and Brown and Lee, 1993. The (conditional) income elasticities indicated that oranges, apples/pears and grapes were relatively sensitive to changes in conditional fresh fruit expenditures while grapefruit and bananas were not. The income elasticities ranged from near zero for grapefruit to 1.4 for oranges and apples/pears. The income elasticities for bananas and grapes were .2 and 1.2, respectively.

The (conditional) own-price elasticities ranged from -.2 for bananas to -1.1 for grapefruit. Grapefruit was the only fruit with an elastic own-price response and its elasticity was not significantly different than unity. The cross-price elasticities were mixed in sign, ranging from -.5 to .7 with a number near zero. The grapefruit quality elasticity was 2.3 for grapefruit. For the other fruit, the elasticities of demand with respect to grapefruit quality were much smaller (in absolute value, the largest of these elasticities was less than one fifth the size of that for grapefruit) and negative, except for oranges, following the cross-price relationships estimated.

Focusing on fresh grapefruit demand, beta coefficients or standardized regression coefficients (Goldberger) were estimated to measure the importance of the different demand determinants. A beta coefficient is the estimated coefficient times ratio of the standard deviation of the dependent variable to the standard deviation of the independent variable. The beta coefficients are reported in Table 4 and show that quality, own-price and the price of oranges were the most important factors

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[3] The Rotterdam coefficient for general explanatory variable y is $w_i\,(\partial \log q_i / \partial \log y_j)$; hence, the elasticity formulas are based on division of the Rotterdam coefficients by the budget shares.

underlying fresh grapefruit demand---in absolute value, quality had the largest beta coefficient, followed closely by the beta coefficients for the two prices.

Relative importance of the determinants of fresh grapefruit demand was also estimated by decomposing the impacts of the different determinants over the sample period as in Duffy (1989). The results for this decomposition are shown in Table 5. The decomposition shows log changes in demand over time due to the different determinants and suggests that quality moved fresh grapefruit demand by as much as 20 % in the early 1990's. On average, quality was estimated to shift fresh grapefruit demand by about 8.5%. The price of grapefruit was also a relatively important demand determinant, along with the price of oranges; income had very little impact.

Concluding Comments

The results of this study suggest that fresh grapefruit quality as measured by pound solids is an important determinant of fresh grapefruit demand. The elasticity of fresh grapefruit demand with respect to quality was estimated at 2.3 at the sample mean, and, on average, quality shifted fresh grapefruit demand by an estimated 8.5% per year over the last two decades. Price was similarly important, with the own-price elasticity of fresh grapefruit estimated at near unity and price changing quantity demanded by an average 8.3% per year over the sample.

The own-price elasticity estimate indicates that supply controls by themselves would leave revenue roughly unchanged at the retail level but not necessarily at the grower sales. At the grower level, the price elasticity could be much different; e.g., under a constant grower-retail price margin, the grower demand would be expected to be inelastic, in which case a supply control program would result in increased grower revenue. Findings on the impact of fresh grapefruit quality on demand support industry quality standards and suggest that there may be further benefits to gain through quality control. Although quality may be the most important demand shifter, unfortunately, due to vagaries of weather, the quality of fresh grapefruit can not always be well controlled.

Lastly, our results suggest how quality may affect the consumer choice process. A change in grapefruit quality was viewed as resulting in a change in the perceived price for grapefruit—perceived price changes were decomposed into the actual grapefruit price changes minus quality-induced changes in the marginal utility for grapefruit. The elasticity of the marginal utility of grapefruit with respect to quality was estimated at roughly two, which along with variation in quality over the sample, indicated quality induced relatively large perceived price changes. This result along with the price coefficient estimates support conjectures on the consumer choice process put forth by Barten, 1977, Basmann, Tintner, and Ichimura, among others. As more information becomes available on fresh fruit demand, the appropriateness of this modeling approach might be better ascertained.

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Table 1. Mean Budget Shares

Item	Fruit Subscript (i)	Average Budget Share
Oranges	1	0.179
Grapefruit	2	0.067
Apples/Pears	3	0.353
Bananas	4	0.223
Grapes	5	0.178

Table 2. Iterated Nonlinear Seemingly Unrealted Regression Estimates of Model (1).

Fresh Fruit	Quality	MPC	Slusky Coefficient Oranges	Grapefruit	Apples/ Pears	Bananas	Grapes
Oranges		0.242	-0.076	-0.022	0.055	-0.002	0.045
		(2.932)	(-4.720)	(-3.330)	(3.331)	(-0.217)	(3.678)
Grapefruit	2.169	0.006	-0.022	-0.072	0.049	0.012	0.033
	(5.448)	(0.185)	(-3.330)	(-6.259)	(3.713)	(1.037)	(3.539)
Apples/Pears		0.481	0.055	0.049	-0.118	0.029	-0.015
		(5.647)	(3.331)	(3.713)	(-3.054)	(1.594)	(-0.602)
Bananas		0.054	-0.002	0.012	0.029	-0.043	0.005
		(0.996)	(-0.217)	(1.037)	(1.594)	(-2.256)	(0.311)
Grapes		0.217	0.045	0.033	-0.015	0.005	-0.067
		(3.290)	(3.678)	(3.539)	(-0.602)	(0.311)	(-3.170)

Note: t satistics in parentheses.

Table 3. Estimated Unconditional Elasticities at Sample Means.

Fresh Fruit	Quality	Income	Price				
			Oranges	Grapefruit	Apples/ Pears	Bananas	Grapes
Oranges	0.261	1.351	-0.668	-0.212	-0.165	-0.314	0.008
	(2.927)	(2.932)	(-7.729)	(-5.037)	(-0.798)	(-2.339)	(0.074)
Grapefruit	2.323	0.088	-0.335	-1.077	0.691	0.155	0.479
	(6.587)	(0.185)	(-3.953)	(-6.636)	(2.315)	(0.692)	(2.953)
Apples/Pears	-0.300	1.368	-0.087	0.046	-0.815	-0.223	-0.289
	(-3.670)	(5.647)	(-1.979)	(1.232)	(-5.091)	(-2.806)	(-3.668)
Bananas	-0.114	0.244	-0.054	0.036	0.044	-0.247	-0.023
	(-1.039)	(0.996)	(-1.194)	(0.738)	(0.338)	(-2.234)	(-0.278)
Grapes	-0.404	1.213	0.033	0.105	-0.512	-0.245	-0.594
	(-3.328)	(3.290)	(0.482)	(1.942)	(-2.425)	(-1.925)	(-4.376)

Note: t satistics in parentheses.

Table 4. Fresh Grapefruit Beta Coefficients.

	Quality	Income	Price				
			Oranges	Grapefruit	Apples/ Pears	Bananas	Grapes
Est. Coefficient (a)	0.157	0.006	-0.022	-0.072	0.049	0.012	0.033
Std. Dev. x (b)	0.045	0.049	0.270	0.091	0.080	0.056	0.083
Std. Dev. y (c)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Beta Coefficient (d)	0.702	0.029	-0.585	-0.662	0.392	0.066	0.279

(a) For income and prices, MPC and Slutsky coefficients estimates from Table 1; for quality, minus the own-Slutsky coefficient times quality coefficient.
(b) Standard deviation of dependent variable.
(c) Standard deviation of independent variable.
(d) (a)*(b)/(c).

Table 5. Decompostion of Log Changes in Grapefruit Per Capita Consumption.

Season	Qualilty	Income	Prices				
			Oranges	Grapefru	Pears	Bananas	Grapes
1981	0.144	-0.005	-0.024	-0.104	-0.062	0.009	0.031
1982	0.065	0.006	-0.091	0.106	0.071	-0.004	-0.053
1983	-0.109	0.004	0.102	-0.028	-0.041	0.013	0.023
1984	-0.030	-0.004	-0.167	-0.092	0.056	-0.013	0.013
1985	0.113	-0.000	0.065	-0.195	0.052	0.004	-0.081
1986	0.090	0.007	0.050	-0.087	0.088	0.009	0.097
1987	0.121	0.004	-0.067	-0.018	-0.038	-0.009	0.013
1988	0.012	0.001	-0.004	0.002	-0.014	0.022	-0.004
1989	0.034	0.001	-0.007	-0.016	-0.021	0.012	0.017
1990	-0.204	-0.005	0.024	-0.252	0.034	0.006	0.022
1991	0.234	-0.007	-0.175	0.071	0.148	0.007	0.058
1992	-0.085	0.009	0.165	0.020	0.005	-0.009	-0.042
1993	0.005	0.001	-0.054	0.160	-0.043	-0.008	0.050
1994	-0.011	0.001	0.041	0.040	-0.035	0.011	0.037
1995	-0.059	-0.002	-0.034	-0.077	0.018	0.011	0.016
1996	0.040	-0.000	-0.033	-0.062	0.111	0.000	0.052
Avg. (a)	0.085	0.003	0.069	0.083	0.052	0.009	0.038
Range	0.438	0.016	0.339	0.412	0.211	0.035	0.178
Min.	-0.204	-0.007	-0.175	-0.252	-0.062	-0.013	-0.081
Max.	0.234	0.009	0.165	0.160	0.148	0.022	0.097

(a) Average of absolute values.