Analysis of Fruit Consumption in the U.S. with a Quadratic AIDS Model

Dawit Kelemework Mekonnen

Graduate Student
Department of Agricultural & Applied Economics
University of Georgia,
305 Conner Hall
Athens, Georgia, 30602
USA
Email: dawitk@uga.edu

Chung L. Huang

Professor
Department of Agricultural & Applied Economics
University of Georgia
313 Conner Hall
Athens, Georgia, 30602
USA
Email: chuang@uga.edu

Esendugue Greg Fonsah

Associate Professor
Department of Agricultural & Applied Economics
University of Georgia
15 RDC Rd, Room 118
P.O. Box 1209
Tifton, Georgia, 31793
USA
Email: gfonsah@uga.edu

☆Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Birmingham, AL, February 4-7, 2012.

Abstract

The Quadratic AIDS model was estimated to analyze the U.S. fruit consumption using annual per capita consumption data and prices for a demand system consisting of fresh fruit, fruit juice and processed fruit. All Marshallian own price elasticities are found to be negative and the demand system is dominated by complementarity relationships. Both own and cross price Marshallian elasticities are less than one. Fruit juices are found to be expenditure elastic conditional on the total expenditure on fruits while fresh fruits and other processed fruits are found to be expenditure inelastic. However, fresh fruit is close to being unitary expenditure elastic. After allowing for curvature in the Engel function, U.S. fresh fruit demand is found to be more responsive to changes in income than in previous studies.

Keywords: Demand estimation, U.S fruit consumption, Quadratic AIDS

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1. Introduction

A number of studies have estimated demand elasticities for different fruits in the United States. Nzaku, Houston, and Fonsah (2010) estimated a demand system for a selected tropical fresh fruit and vegetable imports in to the U.S. using a Linear Approximate Almost Ideal Demand Systems model. Fonsah and Muhammed (2008) estimated U.S. demand for imported apple juice by exporting country while Mekonnen, Fonsah, and Borgotti (2011) adopted a restricted version of source differentiated almost ideal demand system (RSDAIDS) to analyze the U.S. import demand for fresh apples, apple juice and other processed apples after differentiating each form of apple by import origins. Muhammad, Zahniser, and Fonsah (2011) estimated demand models for U.S. banana imports. With the exception of You, Epperson, and Huang (1998), that estimated composite demand systems for 11 fresh fruits and 10 fresh vegetables at retail level, the other studies focus on import demands for fruits ignoring the interdependence between demand for locally produced fruits and demand for imports. A number of these studies also estimated complete demand systems for a particular fruit, such as apple or banana. However, this would imply that the substitution effect of other types of fruits on the particular fruit under consideration has been ignored. This is because the two stage budgeting that is implicitly assumed in complete demand systems imply that expenditure on other types of fruits affect the demand for the specific type of fruit only through its impact on the amount allocated to that particular fruit. In addition, most of these studies use either the Almost Ideal Demand Systems (AIDS) model or its linear approximation (LA/AIDS model) despite the fact that both models impose a linear Engel function, which might give biased results if the linear Engel function assumption is violated.

In this paper, we didn't make the strong separability assumption between locally produced and imported fruits since we have used USDA domestic consumption data which takes into account local production, imports, left over from last year and carry forward to next year. Moreover, the demand system is defined at a broader commodity grouping - fruit.

The rest of the paper is organized as follows: section two describes the empirical model to be used, section three describes the data, section four presents the findings and section five concludes.

2. Model

The model to be used in this study is based on the concept of utility tree in that it was assumed for consumers to make their decision in two stages. First they allocate their budget among broad categories of expenditure such as food, shelter, and other services. Given the expenditure allotted to food, they decide how much to spend on fruits, vegetables, meat, dairy and so on. Weak separability is assumed among these groups of food expenditure. Thereafter, the demand for the different types of fruits given consumers' total expenditure on fruits were estimated. Hence, expenditure on goods in other non-fruit groups affects the demand for the specific type of fruit only through its impact on the amount to be allocated to the fruit branch. The fruit branch is further divided into fresh fruit, juice and other processed fruits based on the type and availability of data.

We have allowed curvature in the Engle curve by using a Quadratic Almost Ideal Demand System (QAIDS) model as follows:

$$w_i = \alpha_i + \sum_j \gamma_{ij} ln(P_j) + \beta_i ln[\frac{E}{a(P)}] + \frac{\theta_i}{b(P)} ln[\frac{E}{a(P)}]^2 \quad (1)$$

where

$$lna(P) = \alpha_0 + \sum_i \alpha_i ln(P_i) + 1/2 \sum_i \sum_j \gamma_{ij} ln(P_i) ln(P_j) \quad (2)$$

and

$$b(P) = \prod_i P_i^{(\theta_i)} \tag{3}$$

where w_i refers to the budget share of fruit group i in the U.S. resulting in three budget share equations for fresh fruit, fruit juice and other processed fruit; P_j is price of fruit group j, E is total consumption expenditure of the U.S. on fruits; while $\alpha_o, \alpha_i, \beta_i, \theta_i$ and γ_{ij} are parameters to be estimated.

Economic theory suggests the following restrictions on the parameters of the budget share equations.

Adding up: $\sum_i \alpha_i = 1; \sum_i \gamma_{ij} = 0; \sum_i \beta_i = 0;$

Homogeneity:

$\sum_j \gamma_{ij} = 0;$

$\sum_j \theta_i = 0;$

and

Slutsky Symmetry:

$\gamma_{ij} = \gamma_{ji}$

After differentiating the budget share equations above with respect to ln E and lnp_j to obtain

$$\mu_i \equiv \frac{\partial w_i}{\partial lnE} = \beta_i + \frac{2\theta_i}{b(P)}\{ln[\frac{E}{a(P)}]\} \tag{4}$$

$$\mu_{ij} \equiv \frac{\partial w_i}{\partial lnp_j} = \gamma_{ij} - \mu_i(\alpha_j + \sum_k \gamma_{jk} ln(P_k) - \frac{\theta_i \beta_j}{b(P)}\{ln[\frac{E}{a(P)}]\}^2 \tag{5}$$

we computed the demand elasticities for the QAIDS model as follows as suggested by Banks, Blundell, and Lewbel (1997).

The expenditure elasticity is:

$$\eta_i = \frac{\mu_i}{w_i} + 1$$

Marshallian Price Elasticity:

$$\xi_{ij} = \frac{\mu_{ij}}{w_i} - \delta_{ij}$$

where δ_{ij} is the Kronecker delta, that is, $\delta_{ij} = 1$ if $i = j$ and $\delta_{ij} = 0$ otherwise.

From the Slutsky equation, the Hicksian Price Elasticity is computed as:

$$\zeta_{ij} = \xi_{ij} + \eta_i w_j$$

After imposing the theoretical restrictions, the resulting system of equations was initially estimated using Seemingly Unrelated Regression (SUR) technique for analyzing a system of multiple equations with cross equation parameter restrictions and correlated error terms. However, the SUR estimation of the model results in almost all of the coefficients to be statistically insignificant while most of them were depicting unexpected signs. We believe this was due to the particularly high collinearity between the price of juice and other processed fruit that had a correlation coefficient of more than 0.9 and possible measurement error in these variables. As a result, we adopted the Non-linear Three Stage Least Squares (NL3SLS) by instrumenting the price indexes of juice and other processed fruits with the consumer price index of all fruits and vegetables, producer price index of juices, primary weight equivalent of per capita juice and other processed fruit consumption as well as the import shares of fruit juice, dried, canned and frozen fruits in the U.S consumption of the respective sub-groups.

The budget share equation for processed fruit was dropped to avoid singularity of the system and its parameters were estimated from the coefficients of the other two equations using the adding up restrictions but the number of iterations to be performed on the parameters of the covariance matrix of the residuals were treated in such a way that the results of the NL3SLS estimation will be invariant to which budget share equation is dropped from the estimation. The same set of instruments were used in the budget share equations of fresh fruit and fruit juices.

3. Data

Data on per capita consumption and price per pound on fresh fruits, fruit juices and processed fruits were obtained from the USDA Economic Research Service. The annual data covers the period 1980 to 2007. The per capita consumption data were adjusted for losses at the farm and retail levels from the aggregate food availability data. Processed fruit subgroup included dried, canned and other prepared fruits while the fruit juice group also included the consumption of frozen fruit. The data on fresh fruit refers to apples, apricots, avocados, bananas, cherries, cantaloup, cranberries, grapes, grapefruit, honeydew, kiwifruit, lemons, limes, mangoes, nectarines, oranges, papayas, peaches, pears, pineapples, plums, prunes, strawberries, tangelos, tangerines, temples, and watermelon. The fruit juice group was composed of orange, grape fruit, lemon, apple, pineapple, cranberry and prune. The other processed fruit group included frozen, dried and canned fruits from different types of berries, apples, apricots, cherries, peaches, plums, olives, figs, pears and raisins.

The price data on the different fruit forms were consumer price indexes with 1982-84 as the base year. To be consistent, the per capita consumption data were converted into quantity indexes with the same base year.

Fresh fruit accounts for about 37 % of U.S. expenditure on fruit while juice accounts for close to 30 %. Other types of processed fruits such as canned, dried and frozen fruits accounted for the remaining one third of the U.S. expenditure on fruits (Table 1).

Table 1: Descriptive Statistics of the variables

	Mean	Std Dev
Fresh fruit budget share	0.37	0.07
Fruit juice budget share	0.30	0.03
Other processed fruit budget share	0.34	0.06
Price of fresh fruit	116.84	63.89
Price of fruit juice	94.39	36.97
Price of other processed fruit	93.55	34.70
Total expenditure on fruit	31515.83	14828.87

Source: Authors' computation using USDA data

4. Empirical Results

The results of the estimation of the QAIDS model are presented in the form of price and expenditure elasticities. The expenditure share of fresh fruit responds positively to increases in its own price and negatively to changes in the price of fruit juices and other processed fruits (Table 2). On the other hand, the expenditure share of fruit juices respond negatively to own price changes but positively to price changes in the fresh and other processed fruits. The response of the expenditure share of other processed fruits to changes in its own prices is similar to that of fruit juice both in direction and magnitude.

Table 2: Parameter Estimates from the QAIDS Model

	Fresh	Juice	Processed	β	θ	Intercept
Fresh	0.266	-0.118	-0.148	0.008	0.001	0.328
	[.008]	[.063]	[.061]	[.025]	[0.004]	[.085]
Juice		-0.720	0.838	0.199	-0.002	-3.366
		[.715]	[.712]	[.088]	[0.012]	[2.927]
Processed			-0.691	-0.207	0.000	4.038
			[.714]	[.098]	[0.009]	[2.869]

Standard errors are in bracket under the estimated coefficients
Fresh, Juice and Processed refer to the log of prices of the respective fruit forms

The Marshallian and expenditure elasticities revealed that all own-price elasticities were negative, thus consistent with economic theory (Table 3). All the three forms of fruits have own-price inelastic demand. Fresh fruit is found to be a gross complement to both fruit juice and other processed fruits and the relationship is about the same in strength with the two goods. Similarly, fruit juice is found to be gross complement to both fresh fruit and other prepared fruit though the response is much stronger to changes in fresh fruit prices. Processed fruit has a complementary relationship with fresh fruit and though statistically insignificant, it has the only substitutability relationship with fruit juices. All the statistically significant cross price elasticities were found to be less than one in absolute value.

Conditional on the amount of money spent on fruit, juice is found to be expenditure elastic with elasticity of about 1.73. Fresh fruits are expenditure inelastic but close to being unitary elastic with elasticity level of 0.985. Other processed fruit is also expenditure inelastic with the lowest level of expenditure elasticity among the three forms of fruits. As expenditure on

Table 3: Average Marshallian and Expenditure Elasticities

	Fresh	Juice	Processed	Expenditure
Fresh	-0.222	-0.328	-0.334	0.985
	[0.139]	[0.153]	[0.202]	[0.035]
Juice	-0.699	-0.796	-0.120	1.732
	[0.073]	[0.519]	[0.632]	[0.121]
Processed	-0.185	3.481	-0.529	0.352
	[0.065]	[4.266]	[0.585]	[0.092]

Standard errors are in brackets under the estimated elasticities

fruits increases, more and more of it goes to juice than to fresh fruits and other forms of processed fruits such as frozen, dried and canned fruits.

Our finding of -0.222 own price elasticity for fresh fruit is close to the -0.27 elasticity that You, Epperson, and Huang (1998) found in their demand estimation for fruits and vegetables in the U.S. However, they found -0.29 own price elasticity for processed fruit against -0.53 in this study. The biggest difference in our results with that of You, Epperson, and Huang (1998) is on expenditure elasticity of fresh fruits. They found expenditure for fresh fruit to be 0.13 while after allowing for curvature in the Engel function, we found it to be 0.985. That is, U.S. fresh fruit demand is apparently more responsive to changes in income than found to be in previous studies. The -0.35 expenditure elasticity for processed fruits, however, is more or less similar with that of You, Epperson, and Huang (1998)'s -0.29. The other demand estimation studies mentioned in the introduction section don't directly lend themselves to such type of comparison either because they focus on a particular fruit and/or on imports alone. The studies that focus on imported fruits report relatively higher own-price and expenditure elasticities. Nzaku, Houston, and Fonsah (2010) found uncompensated own price elasticities of -0.54 for fresh banana, -0.61 for fresh Mango/Guava, and -0.88 for imported fresh avocado. Mekonnen, Fonsah, and Borgotti (2011) found uncompensated own price elasticities for fresh apple between -0.76 and -1.18 depending on the source of origin for the imported apple. These high elasticities may have resulted from practical violations of the strong separability assumption between domestic and imported fruits as the two are more likely to be strong substitutes or complements.

The fact that we have allowed curvature in Engel curve has also resulted in economically sound results as shown in Figure 1. As expenditure per capita on fresh fruit increases, its expenditure elasticity decreases, with the correlation coefficient between the two being -0.93. The same trend can be seen for other processed fruit as well with the correlation coefficient between the level of expenditure and the expenditure elasticity of other processed fruit being -0.79. However, the expenditure elasticity of fruit juice doesn't decrease along with expenditure with a small correlation (0.14) between the two.

On the average, all the Hicksian price elasticities, were found to be statistically insignificant (Table 4). Nevertheless, most of the complementarity relationships from the Marshallian elasticities among the three forms of fruits is still maintained here.

Table 4: Average Hicksian Elasticities

	Fresh	Juice	Processed
Fresh	0.138	-0.035	-0.001
	[0.140]	[0.154]	[0.198]
Juice	-0.062	-0.283	0.461
	[0.058]	[0.543]	[0.600]
Processed	-0.066	3.587	-0.402
	[0.055]	[4.253]	[0.570]

Standard errors are in brackets

5. Conclusion

The Quadratic AIDS model was estimated to analyze the U.S. fruit consumption using annual per capita consumption data and prices for a demand system consisting of fresh fruit, fruit juice and processed fruit. The demand restrictions of adding up, homogeneity and Slutsky symmetry were imposed on the model. All Marshallian own price elasticities are found to be negative and the demand system is dominated by complementarity relationships. Both own and cross price Marshallian elasticities are less than one.

Fruit juices are found to be expenditure elastic conditional on the total expenditure on fruits while fresh fruits and other processed fruits are found to be expenditure inelastic albeit to a different degree. Fresh fruit is close to being unitary expenditure elastic. Moreover, the Hicksian price elasticities are found to be statistically insignificant. This could partly be due to small sample size or for not addressing the time series nature of the data. Future research directions may focus on finding longer series or quarterly or monthly consumption and price data as well as addressing the time series nature of the data. The welfare implications of the elasticity estimates due to some policy changes such as changes in indirect taxes on fruits could also be analyzed.

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Figure 1: Expenditure Elasticity Vs Expenditure Level