A Composite System Demand Analysis for Fresh Fruits and Vegetables in the United States

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Price and expenditure elasticities at retail level for 11 fresh fruits and 10 fresh vegetables were estimated by employing a composite demand system approach and using annual data. Most fresh fruits and vegetables were found to respond significantly to changes in their own prices but insignificantly to changes in total expenditures. The demand for fresh fruit group appeared to have had a clear upward trend since 1973. However, no significant trends were found in the demands for individual fresh fruits or vegetables. The study partially incorporated the interdependent demand relationships between fresh fruits (vegetables) and all other commodities, yet effectively avoided the problem of insufficient degrees of freedom.

Fresh fruit and vegetable consumption in the United States has increased significantly in recent two decades after a downward trend in the 1960's and late 1950's. In the early 1990's, per capita annual consumption of fresh fruits and vegetables (excluding fresh potatoes) reached an average of 114.4 and 103.2 pounds, an increase of 21.3% and 30.42%, respectively, over the comparable averages of 1970-72 (Putnam and Allshouse, 1994). The rise, however, was not uniform among fresh fruits or vegetables. The overall increase in fresh fruit consumption was due entirely to sharp increases in consumption of fresh noncitrus fruits and melons, while the overall gains in fresh vegetable consumption were mainly due to increased consumption of onions, bell peppers, tomatoes, cucumbers, carrots, broccoli and head lettuce (Putnam and Allshouse, 1994).

Among other factors, own price, prices of closely related products and per capita income have often been regarded as major determinants of demand for a commodity. Knowledge of price and income elasticities for fresh fruits and vegetables is thus very useful to both producers and researchers. For instance, price elasticity estimates are sometimes used to derive demand functions for given products. The lack of good estimates for price elasticities for fresh vegetables has caused researchers to make rather strong assumptions about such values (e.g., Epperson and Lei, 1989; and Chien and Epperson, 1990).

In spite of the well-recognized interdependence among food commodities of similar tastes and uses, most early U.S. fresh fruit and vegetable demand studies involved only one or a small number of products, as indicated in two reviews by Nuckton (1978, 1980). Price and Mittelhammer (1979) estimated demand elasticities at the farm level for 14 fresh fruits by mixed two-stage least squares incorporating available prior information, but not within the framework of a complete demand system. Two early works, Brandow (1961) and George and King (1971), involved the estimation of matrices of demand elasticities for a large number of agricultural commodities by using a synthetic method. However, there were only three fresh fruits and six fresh vegetables included in George and King's (1971) study, and Brandow's (1961) matrix had even less detail.

One practical problem in directly estimating a complete large-scale demand system is insufficiency of degrees of freedom. In George and King's (1971) classic study, all foods were classified into 16 separable groups and the demand equation for a single commodity within a group was specified as a function of prices of all commodities within the group, price indexes for other groups, and income. This procedure may not be very effective in overcoming the problem of insufficient degrees of freedom if the number of commodity groups classified is large and individual groups consist of a great number of individual

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commodities. In George and King's (1971) study, some cross-price elasticities within each food group were not estimated directly. In addition, cross-price elasticities showing the effect of individual commodity prices on the commodities outside the group were generated by applying the homogeneity and symmetry conditions. The results of this procedure are affected by the ordering of the food categories in the demand matrix. By carrying out sequential estimations, however, Huang (1985, 1993) estimated the complete demand elasticity matrix directly, and therefore provided a partial, but empirically feasible solution to the above problem.

The purpose of this study is to estimate directly the U.S. demand for fresh fruits and vegetables at the retail level for the period 1960-93. Specifically, this study estimates demand elasticity matrixes for 11 fresh fruits and 10 fresh vegetables, which represents a significant expansion in the availability of demand estimates for individual produce items at the retail level and provides updated demand estimates based on the most recently available data. The empirical estimation procedures, as proposed by Huang (1985, 1993), follow two sequential steps. First, a proposed aggregate demand system consisting of 11 food groups and a nonfood sector was estimated. The price effects of commodity groups other than fresh fruits (vegetables) were then excluded in the estimation of the demand coefficients for individual fresh fruits (vegetables) within respective demand subsystems. Therefore, the possible interdependent demand relationships between fresh fruits (vegetables) and other commodity groups were partially isolated in the estimation, yet without causing the problem of insufficient degrees of freedom.

Methodology and Estimation Procedures

Let the demand system derived from a consumer's utility maximization be:

(1) $q_i = f_i(p,m)$, $i=1,2,\ldots,n$.

Where, n is the number of commodities consumed, q_i the quantity demanded for commodity i, p an n-coordinate vector of the prices, and m the consumer expenditure. By taking the total differential of (1) and then dividing both sides by q_i, one obtains:

(2) $$dq_i/q_i = \sum_{j=1}^{n}\eta_{ij}(dp_j/p_j)+\varepsilon_i(dm/m), \quad i=1,2,\ldots,n.$$

Where $\eta_{ij}=(\partial q_i/\partial p_j)(p_j/q_i)$ is a price elasticity of the ith commodity with respect to a price change of the jth commodity, and $\varepsilon_i=(\partial q_i/\partial m)(m/q_i)$ is the expenditure elasticity of the ith commodity. The demand system (2) can be expressed in the following logarithmic differential form:

(3) $$d\ln q_i = \sum_{j=1}^{n}\eta_{ij}\,d\ln p_j + \varepsilon_i\,d\ln m, \quad i=1,2,\ldots,n.$$

For time-series data, the logarithmic differentials $d\ln q_i$, $d\ln p_j$ and $d\ln m$ are approximated by $\ln(q_{i,t}/q_{i,t-1})$, $\ln(p_{j,t}/p_{j,t-1})$ and $\ln(m_t/m_{t-1})$, respectively.

To ensure theoretical consistency with classical demand theory, the following parametric constraints are imposed on the demand system (3):

(4) Engel aggregation: $\sum_{i=1}^{n} w_i\varepsilon_i = 1$,

(5) Homogeneity: $\sum_{j=1}^{n}\eta_{ij}+\varepsilon_i = 0$, $i=1,2,\ldots,n$

(6) Symmetry:
$$\eta_{ij}/w_j+\varepsilon_i = \eta_{ji}/w_i+\varepsilon_j, \quad i,j=1,2,\ldots,n$$

where w_i (i=1,...,n) is a fixed expenditure weight of the ith commodity at the selected base period. Note that the Engel aggregation and symmetry restrictions are only enforced locally at the point where the selected fixed expenditure weights refer. While there are other demand models such as the Rotterdam and the almost ideal demand system (AIDS), for which global enforcement of the neoclassical restrictions can be accomplished, an advantage of using demand system (3) is that its dependent variables, defined as relative changes of quantities demanded, can be easily quantified by using available time series data expressed as index numbers. In addition, one can directly interpret demand parameters in model (3) as elasticities.

Incorporating restrictions (4)-(6) reduces the total demand parameters to be estimated in the demand system (3) from n(n+2) to [n(n+3)/2-1] (including n constants), which is still intractable if n is large. To overcome the problem of degrees of freedom, George and King (1971) modeled consumer choices in a two-stage maximization process. Suppose that n commodities consumed belong to G separable groups. In the first stage, the total expenditure m is allocated among the G commodity groups such that the utility is maximized. The expenditure for a particular commodity group m_I (I=1,...,G) is defined as a function of the group price indexes and the total expenditure. In the second stage, each group expenditure is split into individual commodity expenditures such that the utility generated from each commodity group is maximized. A demand equation for the jth commodity belonging to group I is then expressed as

$$(7)\quad q_j^I = q_j^I[p_1^I, p_2^I, \ldots, p_{n_I}^I, m_I(P_1, P_2, \ldots, P_G, m)]$$

or simply,

$$(8)\quad \begin{array}{l} q_j^I = q_j^I(p_1^I, p_2^I, \ldots, p_{n_I}^I, P_1, P_2, \ldots, P_G, m), \\ (j = 1, \ldots, n_I;\ I = 1, \ldots, G) \end{array}$$

where p_j^I (j=1,...,n $_I$) represents the price of the jth commodity in the Ith group, P_I (I=1,...,G) stands for the price index of commodity group I, and $n_I+\ldots+n_G=n$. The first difference form of (8) for each commodity, similar to (3), is estimated by single-equation regression. Evidently, George and King's (1971) procedure overcomes the problem of insufficient degrees of freedom in most cases and makes the estimation feasible. However, it is not sufficient in resolving the problem of degrees of freedom if the number of commodity groups (G) and the number of single commodities in an individual group (n_I) are relatively large.

Huang (1985, 1993) conducted a sequential estimation procedure in another manner to overcome the problem of degrees of freedom in the direct estimation of a large-scale demand system. In the first step, all commodities consumed are partitioned into *G-1* food groups and a composite nonfood sector. Thus, the demand system (3) is respecified as:

$$(9)\quad \begin{array}{l} d\ln Q_I = \sum_{J=1}^{G} \mathrm{H}_{IJ}\, d\ln P_J + \mathrm{E}_I\, d\ln m, \\ I = 1,2,\ldots,G \end{array}$$

where Q_I and P_J are, respectively, aggregate quantity and price for commodity groups I and J, which are expressed as the Laspeyres quantity index and the consumer price index. Various parameters H and E represent corresponding direct- and cross-price and expenditure elasticities of the aggregate commodity groups. The aggregate demand system (9) is estimated directly while incorporating the parametric restrictions (4)-(6).

In the second step, the demand parameters within each food group are estimated group by group, using the aggregate parameter estimates obtained from (9) as information to represent approximately the price effects outside the food group under estimation. The demand subsystem for a food group, say group I, is defined as:

$$(10)\quad d\ln \tilde{q}_i = \sum \eta_{ij}\, d\ln p_j + \epsilon_i\, d\ln m,\ i \in I,\ j \in I$$

where $d\ln \tilde{q}_i = d\ln q_i - \sum_{J=1}^{G} H_{IJ}\, d\ln P_J$ for $J \neq I$. The dependent variable $d\,ln\tilde{q}_i$ is the adjusted quantity (in logarithmic differential form) for the ith commodity belonging to group I and is obtained by subtracting the price effects of those food and nonfood prices outside the group from $d\ln q_i$. In estimating the within-group demand subsystem (10), the symmetry condition (6) is imposed.

In using time series data, there is the possibility of structural change in commodity demands. Over the decades, consumers have been advised to eat less eggs, fats and red meats and to have more fruits, vegetables and cereal products for health purposes. One way to examine the existence of structural change is to test for significant time trends in the demand equations. As equations (9) and (10) are expressed in differential forms, their intercepts imply trends in quantities consumed. A positive (negative) and statistically significant intercept implies an increase (a decrease) in consumption of a commodity over time, independent of changes in its own price, prices of related commodities and income. By the same token, an insignificant intercept can be interpreted as evidence that there is no taste change in the commodity demand. A dummy variable can further be introduced to allow the trend effects to enter after a certain point of the observed period.

Structural change may affect the values of slope parameters in the demand equations as well, which can be captured partially by dummy variables. However, given the parametric restrictions (4)-(6), introducing slope dummy variables to capture structural change would, in general, double the number of the explanatory variables included in the demand system, which could result in the problem of insufficient degrees of freedom and multicollinearity. Besides, slope parameters in equations (9) and (10) are directly interpreted as elasticities. Differences in price and income elasticities do not necessarily imply structural change and vice versa (Choi and Sosin, 1990). For simplicity, our discussions on the existence of structural change will focus on testing for significance of the intercepts (time trends).

Data Sources

The basic data used in this study were the time series data of quantities and retail prices of individual fresh fruits and vegetables, quantity and price indexes for food groups and the nonfood sector, and per capita total expenditure. Annual data covering 1960-93 for 11 food categories, 1 nonfood sector, 11 fresh fruits and 10 fresh vegetables were obtained. George and King used proportionality factors, developed by deJanvry (1966, p.112), to group food commodities. However, in order to calculate proportionality factors, one needs information on income elasticities and budget shares for all individual food commodities. For simplicity, the breakdown of food groups in this study was based on data availability. The 11 food categories used corresponded to the major food groups published in various issues of *Food Consumption, Prices, and Expenditures* (Hiemstra; Prescott; and Putnam and Allshouse, 1993) and were very similar to the classifications in Huang (1993) and Huang and Haidacher: (1) red meats, poultry and fish, (2) eggs, (3) dairy products, (4) fats and oils, (5) caloric sweeteners, (6) flour and cereal products, (7) fresh fruits (including melons), (8) fresh vegetables (including fresh potatoes), (9) processed fruits, (10) processed vegetables, (11) other foods.

The food category and nonfood price indexes were obtained from the *CPI Detailed Report* by the U.S. Department of Labor. The quantity indexes for each food group were collected from various issues of *Food Consumption, Prices, and Expenditures* (Hiemstra; Prescott; and Putnam and Allshouse, 1993). Per capita total expenditure was calculated by dividing the personal consumption expenditures (obtained from the U.S. Department of Commerce) by the midyear U.S. civilian population. The quantity index for the nonfood composite sector was derived by dividing the current value of per capita expenditure on nonfood by the CPI of all items less food.

The fresh fruit subsystem estimated consisted of apples, bananas, cherries, grapefruits, grapes, lemons, oranges, peaches, pears, strawberries and watermelon. The fresh vegetable subsystem included asparagus, cabbage, carrots, celery, cucumbers, lettuce, onions, peppers, potatoes and tomatoes. The data on per capita consumption and retail prices (or price indexes) for individual fresh fruits and vegetables were collected from various issues of *Food Consumption, Prices, and Expenditures* (Hiemstra; Prescott; and Putnam and Allshouse, 1994), *U.S. Fresh Market Vegetable Statistics, 1949-80* (Pearrow and Davis), *Fruits and Tree Nuts* (USDA), and *Vegetables and Specialties* (USDA). No retail prices (or price indexes) were reported for cabbage, carrots, celery and onions in 1979, for grapes, grapefruits, lemons and strawberries in 1978-79, and for cucumber and peppers in 1960-62 and 1979. For asparagus, cherries, watermelon, and pears and peaches, the data on retail prices were only available in years 1963-78, 80-91, 53-77, and 80-93, respectively. The missing data were estimated from a set of price linkage equations between retail price and grower price and the CPI of food, which generated quite reasonable predictions (see appendix). The quantity data used for estimating the demand systems were defined as the retail-weight equivalents of civilian food disappearance. As all food is not sold through retail foodstores, it should be pointed out that the price and quantity data series might not correspond exactly. However, it was the best one could achieve, given the limited availability of data sources.

The remaining data needed were the fixed expenditure weights for each of the 12 commodity groups and for those individual fresh fruits and vegetables used to impose parametric constraints. The expenditure weights between food and nonfood groups were calculated from the personal consumption expenditures reported by the U.S. Department of Commerce, and the averages over the period of 1960-1993 were used. As in Huang (1993), the expenditure weight for total food was then allocated proportionally to each food group in accordance with its value in 1967-69, as reported in Table 3 of the 1979 issue of *Food Consumption, Prices, and Expenditures* (Johnson). Although shares of expenditures on some food groups have changed differently over time, the expenditure weights of 1967-69 are the only available complete data. Finally, the average expenditure share of each fresh fruit (vegetable) as a percentage of the considered fresh fruit (vegetable) group over the period of 1960-1993 was calculated by using the available quantity and price data as described above. The expenditure weight obtained for the fresh fruit (vegetable) group with respect to the total per capita expenditure in the second step was then further allocated proportionally to each single fresh fruit (vegetable) in accordance with the estimated average expenditure shares.

Results and Implications

The demand systems of (9) and (10) were estimated in two sequential steps. In the first step, the aggregate demand system (9) was estimated incorporating the Engel aggregation, homogeneity and symmetry conditions. The likelihood ratio test (LR=44 as compared to the 1% critical value of 26.22 for 12 degrees of freedom) rejected the restriction of zero intercepts, implying that there were significant trends in food demands. Next, an intercept dummy variable was introduced in each equation of the demand system and the log-likelihood function was maximized at the observation representing year 1973. The intercept dummy variables were supported by the likelihood ratio test (LR=46.02 as compared to a critical value of 26.22), indicating that there was a shift in trends in food demands. The year observing structural change (year 1973) accorded well with the movement of nutritional education for the public.

Table 1 reports the estimates of the demand elasticities and trends for the food groups and the nonfood sector. All direct-price elasticities except for the flour and cereal products group were negative as expected. Seven of 12 coefficients were different from zero at a significance level of 5% or better. The positive estimate of the direct-price elasticity for the flour and cereal products group was not statistically significant. The expenditure elasticities for all food groups were less than 1. Six of 12 coefficients differed from zero at a significance level of 5% or better. Per capita consumptions of fresh fruits and flour were found to increase since 1973, while consumptions of meats and eggs as groups were found to exhibit downward trends since then.

Adding the intercept dummy variables had improved the performance of the demand system. For instance, without introducing the intercept dummies, the estimate of the time trend for fresh fruit group was statistically insignificant and its estimated expenditure elasticity had negative sign, as were obtained in the studies by Huang (1993) and Huang and Haidacher (1983). The results from estimating the aggregate demand system suggested that income was not an important factor in determining the overall consumption level of fresh fruits or vegetables as the estimates of their expenditure elasticities were statistically insignificant. Cross-price parameter estimates indicated that both fresh and processed vegetables were substitutes to fresh fruits, while fresh fruits and all the other food groups were neutral. Per capita consumption of fresh fruits appeared to have increased at a yearly rate of 1.84% since 1973 after a clear decline in the 1960's. Although demand for fresh vegetables was not found to have a significant upward trend after 1973, the estimate of the intercept dummy variable in the fresh vegetable equation was positive and significant (t=1.70) and the downward trend observed in 1960's had disappeared in the recent two decades due probably to health concerns.

In estimating the fresh fruit or vegetable demand subsystem (10), the aggregate parameter estimates obtained in the first step were used. The quantity variables in the fresh fruit (vegetable) demand subsystem were adjusted by subtracting the price effects of all commodity groups other than the fresh fruit (vegetable) group. These price effects were represented approximately by the cross-price parameters of the aggregate demand equation for the fresh fruit (vegetable) group. The

Table 1. Demand Elasticities and Time Trends for Food Groups and Nonfood.

	Price												Exp	Trends	
Commodities	Meats	Eggs	Dairy	Fats	Sweeten	Flour	F.fruit	F.veg	P.fruit	P.veg	O.food	Nonfood		Before 73	73 & After
Meats	-.4405	.0137	.0030	.0129	-.0133	.0371	.0085	-.0294	.0020	-.0201	-.0142	.0157	.4245	.0037	-.0094
	(7.03)	(1.49)	(0.09)	(1.19)	(0.98)	(1.28)	(0.44)	(1.38)	(0.15)	(1.69)	(0.56)	(0.13)	(3.02)	(0.58)	(2.18)
Eggs	.1431	-.1213	-.0405	-.0136	-.0566	-.1155	-.0566	.0497	.0224	.1306	.0024	.1777	-.1217	-.0089	-.0107
	(1.94)	(3.80)	(0.48)	(0.43)	(1.69)	(1.36)	(1.28)	(1.00)	(0.75)	(3.85)	(0.06)	(1.20)	(0.80)	(1.39)	(2.42)
Dairy	.0047	-.0154	-.1886	-.0354	.0378	.0067	-.0407	-.0193	-.0424	.0107	-.0225	-.1459	.4503	-.0200	-.0033
	(0.07)	(0.70)	(1.65)	(1.05)	(1.10)	(0.07)	(1.01)	(0.42)	(1.50)	(0.26)	(0.59)	(0.94)	(2.95)	(3.12)	(0.72)
Fats	.1137	-.0196	-.1470	-.1428	.1534	-.2526	-.0114	-.1641	-.0423	.0502	-.0614	.1055	.4183	-.0053	.0035
	(1.16)	(0.55)	(1.04)	(1.57)	(2.49)	(1.24)	(0.18)	(2.39)	(0.96)	(0.70)	(1.09)	(0.51)	(2.02)	(0.61)	(0.56)
Sweeten	-.0278	-.0288	.0798	.0689	-.1608	-.1502	.0425	.0698	.0221	.0102	.0011	-.0008	.0740	.0071	.0077
	(0.53)	(1.76)	(1.27)	(2.56)	(4.29)	(1.76)	(1.38)	(2.12)	(1.01)	(0.34)	(0.04)	(0.01)	(0.60)	(1.36)	(2.15)
Flour	.1598	-.0498	.0278	-.0939	-.1313	.1872	-.0463	.0038	.0840	.0242	-.0031	-.0603	-.1020	-.0013	.0203
	(1.56)	(1.37)	(0.19)	(1.20)	(1.74)	(0.70)	(0.71)	(0.06)	(1.85)	(0.30)	(0.06)	(0.28)	(0.49)	(0.15)	(3.10)
F.fruit	-.0831	-.0547	-.1325	-.0073	.0819	-.1047	-.4005	.1696	.0674	.1285	-.0250	.0863	.1088	-.0223	.0184
	(0.58)	(1.33)	(0.94)	(0.14)	(1.40)	(0.74)	(3.78)	(1.90)	(1.22)	(2.24)	(0.32)	(0.29)	(0.34)	(1.67)	(2.02)
F.veg	-.1709	.0349	-.0510	-.1130	.1081	-.0007	.1383	-.0335	-.1089	.0328	-.1049	-.0262	.2949	-.0204	.0005
	(1.29)	(0.92)	(0.39)	(2.40)	(2.10)	(0.01)	(1.88)	(0.29)	(2.16)	(0.67)	(1.42)	(0.09)	(0.97)	(1.64)	(0.06)
P.fruit	.0266	.0266	-.2124	-.0510	.0578	.2564	.0958	-.1918	-.3451	-.2171	.1100	.1065	.3377	-.0054	-.0083
	(0.18)	(0.65)	(1.47)	(0.95)	(0.96)	(1.81)	(1.19)	(2.14)	(4.43)	(3.80)	(1.30)	(0.31)	(0.94)	(0.36)	(0.81)
P.veg	-.1164	.1006	.0374	.0370	.0135	.0377	.1079	.0340	-.1270	-.1364	-.0376	-.2254	.2746	.0212	.0014
	(1.52)	(3.74)	(0.31)	(0.72)	(0.28)	(0.25)	(2.20)	(0.66)	(3.78)	(1.70)	(0.96)	(1.42)	(1.82)	(3.39)	(0.31)
O.food	-.0733	-.0057	-.0494	-.0291	-.0098	-.0191	-.0183	-.0707	.0373	-.0276	-.3570	-.0948	.7174	-.0179	-.0112
	(0.73)	(0.31)	(0.72)	(1.19)	(0.34)	(0.31)	(0.45)	(1.53)	(1.25)	(1.17)	(4.66)	(0.39)	(2.63)	(1.51)	(1.41)
Nonfoods	-.0466	-.0087	-.0276	-.0045	-.0186	-.0255	-.0083	-.0096	-.0042	-.0120	-.0095	-.9936	1.1686	-.0008	.0006
	(7.32)	(7.82)	(6.22)	(3.12)	(10.65)	(6.49)	(3.65)	(3.59)	(2.43)	(7.70)	(2.89)	(60.4)	(68.0)	(0.62)	(0.64)
Weights	.06431	.00814	.03060	.00733	.01693	.01894	.00872	.01056	.00601	.01024	.01672	.8015			

Note: 1) Numbers in parentheses are t-ratios; 2) Some notations are meats (red meat, poultry, fish and eggs), fats (fats & oils), sweeten (caloric sweeteners), flour (flour and cereal products), f.fruit (fresh fruits), f.veg (fresh vegetables), p.fruit (processed fruits), p.veg (processed vegetables), o.food (other foods), Exp (total expenditures), weights (expenditure weights).

symmetry condition was imposed in the estimation of the parameters of the fresh fruit (vegetable) demand subsystem.

The likelihood ratio test rejected the null hypothesis that the intercepts in the fresh fruit demand subsystem were zero (*LR*=23.73 as compared to the 2.5% critical value of 21.92 for 11 degrees of freedom) and supported the inclusion of the intercept dummy variables (*LR*=24.03 as compared to the critical value of 21.92), implying the existence of trends in fresh fruit demands and a shift in the trends. The point identifying the shift in trends happened to be in year 1973 again when the log-likelihood function was maximized. Ten of 11 estimated own-price elasticities for fresh fruits were negative (an exception was pears), and among them 7 coefficients were significant statistically at a level of 5% or better (Table 2). Most estimated expenditure elasticities for fresh fruits were positive with the exceptions of apples, cherries, peaches, and strawberries, but none of them were statistically significant.

A few points could be made from the empirical results. First, total income seemed to have little effects on the demands for individual fresh fruits and therefore their consumption levels would not have significant increases along with expected income rises in the future. This was consistent with the results obtained from estimating the aggregate demand system and paralleled to Huang's (1993) findings. Secondly, of the 11 fresh fruits studied, demands for grapefruit, grapes, oranges and peaches were found to have relatively larger responses to the changes in their own prices, with the estimated own-price elasticities around -1. Demands for the other 7 fresh fruits appeared to respond inelastically to the changes in their own-prices. The obtained own-price elasticities (in absolute value) for apples and bananas were smaller than the estimates from George and King's (1971) study (-0.72 for apples, and -0.61 for bananas), while that for oranges was larger than what they got (-0.66). In general, the estimated own-price elasticities were similar to those available estimates in Huang (1993) except for grapefruits, whose own-price elasticity was -0.45 in that study. Finally, in spite of the fact that, based on the *t*-tests, no significant upward trends were found in the demands for individual fresh produces, per capita consumption of most fresh fruits did appear to have regained some in the recent two decades after a clear decline in the 1960's. This was partially supported by the evidence that more positive intercepts, which represented time trends, were obtained for the period after 1973 than for the period before 1973. The cross-price effects among fresh fruits could have resulted in the difference in the outcomes of the likelihood ratio test and the *t*-test. Therefore, reducing retail price seemed to be the key for the industry of a specific type of fruit to gain its market share of retailing fresh fruits.

Table 3 presents the estimated demand elasticities and trends in the demands for fresh vegetables. The null hypothesis that the intercepts were zero was again rejected by the likelihood ratio test (*LR*=28.19 as compared to the 1% critical value of 23.21 for 10 degrees of freedom). The likelihood ratio test further supported the adding of the intercept dummies in the fresh vegetable demand subsystem (*LR*=23.42 as compared to the critical value of 23.21). All estimated own-price elasticities for fresh vegetables were negative except cabbage. Seven of 10 estimated own-price elasticities were significant at a level of 5% or better. The expenditure elasticities obtained from this study were all positive, but only those estimates for celery and tomatoes were statistically significant at a level of 10% or better.

For most of the fresh vegetables studied, total income was not an important factor in determining their demand levels, which was consistent with the outcomes obtained from the aggregate demand system. It is expected, however, that conditional expenditure elasticities for most fresh vegetables would be significant. Demands for cabbage, celery, and lettuce were found to respond insignificantly to changes in their own prices. For all the other 7 fresh vegetables, demand responses to changes in their own prices appeared to be inelastic though significant. The obtained own-price elasticities were close to the available estimates from George and King (1971) as well as those from Huang (1993). However, compared with either study, about twice the number of fresh produce items were included in this estimation. The demand for celery was found to exhibit a downward trend in the entire sample, while a clear declining trend in the demand for tomatoes in the 1960's seemed to have disappeared since 1973. Although the demands for asparagus, carrots, cucumbers, onions,

Table 2. Demand Elasticities and Time Trends for Selected Fresh Fruits.

	Price											Exp	Trends	
Fruits	Apples	Bananas	Cherries	Gfruit	Grapes	Lemons	Oranges	Peaches	Pears	Sberries	Wmelon		Before 73	73 & After
Apples	-.1649	.0821	-.0285	-.0341	.1365	-.0171	.0340	.0865	-.0414	.0846	.0129	-.1918	-.0253	-.0037
	(1.05)	(1.01)	(1.27)	(0.59)	(1.81)	(0.52)	(0.43)	(1.52)	(0.88)	(2.41)	(0.25)	(0.24)	(0.48)	(0.06)
Bananas	.1175	-.4236	.0233	.0582	-.0510	-.1370	-.0311	.1635	-.0092	-.1385	-.1496	.6324	-.0479	.0200
	(1.00)	(2.35)	(0.89)	(0.67)	(0.49)	(2.14)	(0.38)	(1.94)	(0.11)	(2.12)	(1.75)	(1.12)	(1.32)	(0.49)
Cherries	-.6101	.3496	-.0323	-.2155	-.0527	-.2289	.0703	.3814	-.1930	-.2741	.3943	-1.797	.1525	.1297
	(1.26)	(0.89)	(0.23)	(0.78)	(0.15)	(1.41)	(0.21)	(1.34)	(0.80)	(1.58)	(1.53)	(0.64)	(0.83)	(0.61)
Grapefruit	-.1272	.1483	-.0371	-1.022	.2048	-.0210	.2504	.0592	.0428	.0353	-.1425	.6007	-.0274	-.0501
	(0.59)	(0.67)	(0.79)	(4.99)	(1.13)	(0.22)	(1.60)	(0.42)	(0.31)	(0.35)	(1.01)	(0.52)	(0.37)	(0.59)
Grapes	.3438	-.0891	-.0064	.1404	-.9075	-.0436	-.2799	.2204	-.0932	.0118	.2090	.6608	-.0499	.0019
	(1.80)	(0.49)	(0.15)	(1.13)	(4.14)	(0.55)	(2.02)	(1.85)	(0.82)	(0.14)	(1.72)	(0.67)	(0.76)	(0.03)
Lemons	-.1036	-.5669	-.0639	-.0340	-.1033	-.3016	.0793	.3937	-.1464	-.2566	.3436	.4443	-.0610	-.0058
	(0.52)	(2.13)	(1.42)	(0.22)	(0.55)	(1.27)	(0.49)	(2.48)	(0.80)	(1.92)	(2.06)	(0.51)	(1.06)	(0.09)
Oranges	.0634	-.0416	-.0060	.1301	-.2124	.0253	-1.135	.1477	.0141	.0973	.0467	.8938	-.0680	-.0395
	(0.42)	(0.38)	(0.20)	(1.60)	(2.02)	(0.49)	(8.35)	(1.91)	(0.21)	(1.97)	(0.65)	(0.91)	(1.07)	(0.54)
Peaches	.3067	.4015	.0627	.0572	.3097	.2332	.2741	-.9624	.0366	.0944	-.3375	-.0779	-.0760	.0008
	(1.52)	(1.94)	(1.34)	(0.43)	(1.85)	(2.48)	(1.92)	(5.24)	(0.27)	(0.98)	(2.56)	(0.07)	(1.07)	(0.01)
Pears	-.2555	-.0391	-.0551	.0708	-.2257	-.1496	.0449	.0627	.2897	-.3988	.3135	.9298	-.0515	-.0486
	(0.88)	(0.11)	(0.80)	(0.31)	(0.82)	(0.78)	(0.21)	(0.26)	(0.82)	(2.21)	(1.32)	(0.69)	(0.59)	(0.49)
Strawberries	.4456	-.5017	-.0671	.0508	.0254	-.2248	.2680	.1402	-.3422	-.2753	.1629	-.4738	.0285	.0634
	(2.41)	(2.11)	(1.58)	(0.35)	(0.15)	(1.91)	(1.98)	(0.99)	(2.21)	(1.78)	(1.10)	(0.57)	(0.53)	(1.04)
Watermelon	.0336	-.2783	.0492	-.1041	.2229	.1546	.0660	-.2566	.1382	.0832	-.6000	0.4146	-.0510	-.0105
	(0.24)	(1.74)	(1.53)	(1.00)	(1.72)	(2.06)	(0.65)	(2.57)	(1.32)	(1.09)	(4.11)	(0.64)	(1.21)	(0.22)
Weights	.00175	.00121	.00008	.00047	.00069	.00029	.00091	.00049	.00029	.00033	.00065			

Note: 1) Numbers in parentheses are t-ratios; 2) Some notations are Exp (total expenditures), Weights (expenditure weights).

Table 3. Demand Elasticities and Time Trends for Selected Fresh Vegetables.

	Price										Exp	Trends	
Vegetables	Aspara	Cabbage	Carrots	Celery	Cucumb	Lettuce	Onions	Peppers	Potatoes	Tomatoes		Before 73	73 & after
Asparagus	-.5762	-.2436	.2601	.6339	-.0219	.0893	.1668	-.4810	.4301	-.1493	.1167	-.0327	.0107
	(2.08)	(1.90)	(0.78)	(2.51)	(0.09)	(0.40)	(1.00)	(1.89)	(2.24)	(0.36)	(0.09)	(0.38)	(0.11)
Cabbage	-.0531	.0267	-.0160	.0517	-.0655	.0861	.0415	-.0690	-.0302	.1381	.3132	-.0295	-.0174
	(1.90)	(0.68)	(0.23)	(1.14)	(1.55)	(1.57)	(1.06)	(1.47)	(0.62)	(1.58)	(0.90)	(1.32)	(0.67)
Carrots	.0532	-.0149	-.4258	-.2042	.0681	-.0586	.0646	-.0113	.1026	.1454	.0834	.0044	.0226
	(0.78)	(0.23)	(1.92)	(1.93)	(0.67)	(0.46)	(0.72)	(0.10)	(0.88)	(0.69)	(0.10)	(0.08)	(0.37)
Celery	.1148	.0427	-.1815	-.0501	.1422	-.0454	-.0668	-.1254	.0753	.0678	1.212	-.0678	-.0874
	(2.51)	(1.13)	(1.94)	(0.52)	(2.13)	(0.69)	(1.36)	(1.87)	(1.29)	(0.56)	(2.94)	(2.61)	(2.90)
Cucumbers	-.0058	-.0802	.0887	.2095	-.2976	.0220	-.1230	.0551	-.0013	.0729	.3192	-.0014	.0161
	(0.09)	(1.55)	(0.67)	(2.14)	(2.45)	(0.22)	(1.78)	(0.55)	(0.01)	(0.44)	(0.51)	(0.03)	(0.35)
Lettuce	.0035	.0157	-.0117	-.0098	.0032	-.0139	-.0081	-.0084	-.0471	.0584	.6377	-.0149	-.0296
	(0.40)	(1.56)	(0.46)	(0.67)	(0.21)	(0.15)	(0.40)	(0.47)	(0.84)	(1.76)	(1.09)	(0.39)	(0.67)
Onions	.0223	.0254	.0421	-.0490	-.0618	-.0267	-.1832	-.0297	-.0733	-.0222	.5725	-.0221	.0038
	(1.00)	(1.05)	(0.72)	(1.34)	(1.78)	(0.39)	(3.38)	(0.71)	(1.19)	(0.29)	(1.26)	(0.75)	(0.11)
Peppers	-.0955	-.0629	-.0111	-.1369	.0410	-.0412	-.0439	-.2472	-.0181	.0115	.3925	.0112	.0527
	(1.89)	(1.47)	(0.10)	(1.86)	(0.55)	(0.46)	(0.71)	(2.36)	(0.23)	(0.08)	(0.68)	(0.31)	(1.24)
Potatoes	.0193	-.0062	.0225	.0191	-.0002	-.0521	-.0245	-.0041	-.1751	.0183	.2870	-.0353	-.0043
	(2.24)	(0.62)	(0.88)	(1.32)	(0.01)	(0.83)	(1.19)	(0.23)	(2.30)	(0.53)	(0.50)	(0.95)	(1.00)
Tomatoes	-.0082	.0343	.0384	.0205	.0147	.0790	-.0092	.0030	.0212	-.4050	.7978	-.0363	-.0255
	(0.36)	(1.57)	(0.68)	(0.57)	(0.44)	(1.76)	(0.30)	(0.08)	(0.51)	(4.19)	(2.69)	(1.92)	(1.17)
Weights	.00009	.00039	.00042	.00047	.00032	.00213	.00064	.00043	.00190	.00157			

Note: 1) Numbers in parentheses are t-ratios; 2) Some notations are Exp (total expenditure), Weights (expenditure weights).

and peppers had shown increasing signs since 1973, no significant trends were found according to the *t*-tests. Retail prices again turned out to be the major determinants of fresh vegetable demands.

Finally, to determine if the employed sequential estimation procedure performed better than the approach proposed by George and King (1971), model (8) expressed in the logarithmic differential form was used to estimate the fresh fruit (vegetable) demand system. Since 12 price indexes of the commodity groups were included in (8), the numbers of the explanatory variables in each equation of the fresh fruit and vegetable systems were now 23 and 22, respectively. Consequently, the degrees of freedom of the two demand systems dropped dramatically. The fresh fruit (vegetable) demand system was then estimated while imposing the symmetry restriction on the cross-price coefficients for individual fresh fruits (vegetables). The estimated parameters were much less significant than those obtained from the sequential estimation procedure. This might result from possible multicollinearity among fresh fruit (vegetable) prices and the price indexes of the commodity groups included.

Conclusions

Demand responses for 11 fresh fruits and 10 fresh vegetables to changes in prices and income (expenditures) were modeled using a composite demand system approach. The estimation followed two sequential steps. First, an aggregate demand system consisting of 11 food groups and a nonfood sector was estimated. The parameter estimates obtained in this fashion were then used in the estimation of fresh fruit and vegetable demand subsystems to exclude the price effects of other food groups and the nonfood sector. The analysis of fresh fruit and vegetable demand, thus, partially incorporated the interdependent demand relationships among all commodities. Since the price and expenditure elasticities were obtained directly from estimating the demand systems specified, their statistical inferences were straightforward.

Most fresh fruits and vegetables as well as aggregate commodity groups were found to respond significantly to changes in their own prices and in the directions as expected. All own-price elasticities obtained (except for grapefruit and oranges) were less than unity. The demands for all fresh vegetables and most fresh fruits was found to increase when per capita total expenditures rose. However, few estimates of expenditure elasticities were statistically significant. The demand for fresh fruit group appeared to have had a significant upward trend since 1973, and an increasing sign was also found in the demand for the fresh vegetable group in the recent two decades. However, no significant trends were found in the demands for individual fresh fruits or vegetables. The industry of a specific type of fresh produce seemed to have to rely primarily on reducing the retail price to gain its market share.

The composite demand system approach, as conducted in two sequential steps, overcomes the problem of insufficient degrees of freedom and appears to be a promising approach in estimating a large scale demand system. However, the cross-price parameters of commodity groups represent only approximately the effects of other prices outside a particular commodity group under estimation; and, therefore, sufficient care should be given in grouping commodities in order to achieve a high degree of isolation of the price effects of all other commodity groups in the estimation of a demand subsystem.

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Appendix Table. Price Linkage Equations Used for Generating Missing Data:

Commodity	Coefficient Estimates α_0	α_1	α_2	R^2	Sample (years)
Asparagus	-.0692 (1.93)	1.263 (4.15)	.00660 (2.71)	0.9833	63-78
Cabbage	.03495 (5.73)	2.144 (9.50)	.00034 (1.08)	0.9803	60-78
Carrots	.04122 (7.74)	1.603 (11.8)	.00126 (9.99)	0.9918	60-78 & 80-93
Celery	.00515 (0.93)	1.988 (13.0)	.00210 (15.1)	0.9941	60-78 & 80-93
Cucumber	.03875 (1.56)	1.208 (1.27)	.00367 (2.56)	0.9247	63-78
Onions	.02480 (2.10)	.8664 (3.22)	.00219 (8.06)	0.9444	60-78 & 80-93
Peppers	.00065 (0.01)	2.550 (2.61)	.00282 (1.09)	0.9159	63-78
Cherries	-.4527 (0.86)	2.106 (1.74)	.01118 (2.19)	0.6089	80-91
Grapes	.23606 (2.22)	1.243 (3.73)	.00551 (6.02)	0.8783	80-93
Grapefruits	-.0808 (1.04)	.8539 (1.71)	.00426 (5.11)	0.8461	80-93
Lemons	.07466 (0.62)	.8945 (2.06)	.00599 (4.07)	0.8985	80-93
Peaches	-.1118 (0.65)	2.645 (1.56)	.00364 (4.30)	0.9024	80-91
Pears	.13012 (1.26)	.0269 (0.03)	.00499 (3.64)	0.7425	80-91
Strawberries	-.3728 (1.80)	.5150 (1.12)	.01161 (11.3)	0.9510	80-93
Watermelon	-.0056 (2.24)	1.361 (5.82)	.00126 (7.43)	0.9868	53-77

Note: For peaches, the CPI for fresh fruits is used in place of the CPI for food for purpose of goodness of fit.

Model: $P_i^r = \alpha_0 + \alpha_1 P_i^g + \alpha_2 CPI_{food}$,

P_i^r, P_i^g --- retail and grower prices for commodity i: \$/lb;

CPI_{food} --- CPI for food: 82-84=100.