[Note]

Demand System for Fresh Vegetables in the U.S. and Mexico
– An Application of Barten Approach –

Atsushi Oishi*

1. Introduction

U.S. per capita consumption of fresh vegetables increased steadily from 154lb. of 1970 to 199lb. of 2005. The main factors behind these trends are related to U.S. population demographic changes, high income demand elasticities, and changes in consumer preferences. Increased health consciousness of U.S. consumers combined with growing information about the potential cancer - preventing qualities of vegetables have contributed to the surge in fresh vegetable demand (McCracken 1992, Malaga and Williams 1996, Harri and Bianchini 2004). Growing vegetable imports from Mexico and rapid gains in production efficiencies have kept fresh vegetable prices declining in real terms, fostering growth in consumption. Accuracy in the measurement of fresh vegetable demand parameters in both the U.S. and Mexico is key to evaluating the future profitability of the U.S. fresh vegetable industry in the context of a North American free trade area.

---

* Department of Food Economics, Assistant Professor

Key words : 1) Barten model, 2) vegetable demand analysis, 3) Price Elasticity

Although fresh vegetables are mainly consumed in salads, traditional demand estimation, emphasizing tomatoes and onions, has adopted a single demand equation approach, neglecting important interrelationships among demand schedules. However, since the late 1970's, demand system techniques have been developed to simultaneously estimate the parameters of closely related demands, incorporating the constraints of modern demand theory. Additionally, the use of alternative demand system formulations (Rotterdam, AIDS, and others) can provide different elasticity estimates. Mittelhammer (1979) and Scott (1991) applied demand systems to estimate the parameters for U.S. fresh vegetable demand. In both cases, the selection of the demand system was arbitrary with Mittelhammer choosing a mixed statistical estimation method and Scott using an inverse Rotterdam model. Mittelhammer estimated U.S. demand schedules at retail and at the farm level for seven fresh vegetables as a subsystem of a larger structural market. The mixed statistical estimation method utilized to derive the demand parameters incorporated linear probabilistic constraints, including symmetry, homogeneity and negativity. The inverse Rotterdam demand model utilized by Scott included four regional demand systems for tomatoes, cucumbers, bell peppers, and green beans. He found significant own and cross-price elasticities with strong complementary relationships in four big markets.

An important structural characteristic of the fresh vegetable markets in the U.S. and Mexico is the seasonality of production and trade. At least two clearly different U.S. production/marketing seasons exist: (1) fall-winter during which 80 % to 90 % of the fresh vegetables consumed in the U.S. are supplied by Florida and Mexico and (2) spring-summer when California leads the supply and production is more distributed around the country. Given the strong competition between the U.S. and Mexico during the winter season, most of fresh vegetable quantitative analyses have focused on the winter vegetable market.

This paper presents the results of estimating the parameters of seasonal U.S. and Mexican demands for fresh vegetables using a complete demand system methodology that avoids an arbitrary choice of system specification. For this paper, fresh vegetables include tomatoes, onions, cucumbers, squash, and bell peppers. After discussing the characteristics of demand systems including a method developed by Barten (1993) to select among alternative demand systems, the data used in the analysis are presented.

Demand System analysis was introduced to Japan by Sasaki (1993), (1995) and Sawada (1991). This paper tries to introduce the new development of Demand System and apply it to vegetable consumption in U.S. and Mexico.

2. Demand Systems Framework

Complete demand systems are sets of demand equations derived from well-behaved utility functions which describe the allocation of expenditures among alternative commodities. These demand systems are appropriate to deal with interdependence relationships among demands and make a formal attempt to incorporate the restrictions of modern consumer behavior theory. Marshallian demand equations obtained by maximizing the utility function subject to a budget constraint and Hicksian demand derived from the cost minimization principle must satisfy four properties: (1) adding-up, (2) homogeneity, (3) symmetry, and (4) negativity.

The property or restriction of adding-up implies that the sum of expenditures on alternative commodities within a demand system must be equal to the total expenditure on commodities in both Marshallian and Hicksian demands. That is, the following equation must hold:

$$\sum p_i h_i(u,p) = \sum p_i q_i(e,p) = e \tag{1}$$

Where p_i : the priced of i, h_i : the Hicksian demand for i, q_i : the Marshallian demand for i, u : utility, and e: total expenditures. The property of homogeneity of degree 0 in prices and total expenditures for Marshallian demands implies that, for any positive constant $\Theta > 0$, changing prices and expenditures by Θ will not affect the quantities demanded. The property of homogeneity of degree 0 in prices for Hicksian demands implies that for any positive constant $\Theta > 0$, changing all the prices by Θ will not affect the quantities demanded. Expressed in equation form:

$$h_i(u,\Theta p) = h_i(h,p) = q_i(\Theta x,\Theta p) = q_i(e,p) \tag{2}$$

The symmetry property of the cross-price derivatives of the Hicksian demand is implied by Young's theorem. Thus, in a Hicksian constant utility demand system, the effect of the price of commodity j on the demand for commodity i is equal to the effect of the price of commodity i on the demand for commodity j, or :

$$\partial h_i(u,p)/\partial p_j = \partial h_i(u,p)/\partial p_i,\ \forall i \neq j \tag{3}$$

The negativity condition of Hicksian demands implies that the own-price derivatives will be negative because the Slutzky matrix of elements $\partial h_i/\partial p_j = s_{ij}$ is negative semi-definite, a condition derived from the concavity of well-behaved cost functions.

Unfortunately, even when the demand system approach is selected, theory does not provide much information about the true form of the demand functions. Several approaches have developed specifications that approximate the true form and allow some of the theoretical properties of demand to be imposed or tested. The most used approaches in agricultural economics are: (1) the Almost Ideal Demand System (AIDS) and (2) the Rotterdam model.

(1) The Almost Ideal Demand System (AIDS)

The AIDS model was developed by Deaton and Muelbauer (1980) as an arbitrary first order approximation to any demand system. It satisfies the axioms of choice exactly and aggregates perfectly over consumers up to a market demand function. Its flexible functional form is consistent with known household-budget data and can be used to test the properties of homogeneity and symmetry through linear restrictions on fixed parameters. The AIDS linear approximation suggested by Stone is usually used and can be specified as:

$$w_{it} = \alpha_i + \sum_j \gamma_{ij} \ln p_{jt} + \beta_i \ln\left[Y_t / P_t^*\right] + \varepsilon_{it} \tag{4}$$

Where w_{it} : expenditure share of product i, p_{jt} : nominal price of product j, Y_t : expenditure on the set of products, ε_{it} : disturbance term, α, β and Y : parameters to estimate, p_t^* : $w_{kt} \ln p_{kt}$: Stone's linear approximation.

The classical properties of demand theory can be imposed on the system by the restrictions:

Adding-up: $\sum_i \alpha_i = 1,\ \sum_i \gamma_{ij} = 0,\ \sum_i \beta$ (5)

Homogeneity: $\sum_j \gamma_{ij} = 0$ (6)

Symmetry: $\gamma_{ij} = \gamma_{ji}$ (7)

The Marshallian (uncompensated) and Hicksian (compensated) price elasticities, as well as the expenditure elasticities, can be computed from the AIDS coefficient estimates as follows:

Marshallian Price Elasticity: $-\delta_{ij} + \gamma_{ij} / w_i - \beta_i w_j / w_i$ (8)

Hicksian Price Elasticity: $-\delta_{ij} + w_i + \gamma_{ij} / w_i$ (9)

Expenditure Elasticity: $1 + \beta_j / w_i$ (10)

Where δ_{ij} is the Kronecker delta equal to one if $i = j$ and equal to zero otherwise. The estimation of this system requires one demand equation to be omitted, usually the one with the smallest budget share.

(2) The Rotterdam Model

This directly specified system developed by Barten and Theil (1964) does not assume a particular utility function and allows the classical theoretical demand restrictions to be tested for or imposed. The absolute price version of the Rotterdam model may be written as:

$$\hat{w}_i d\ln(q_i) = \theta_i d\ln(Q) + \sum_i^n \pi_{ij} d\ln(p_i) + \varepsilon_i \quad (11)$$

Where $d\ln(Q) = \sum_i \hat{w}_i d\ln(q_i)$ is the Divisia volume index, q_i : per capita consumption of product i in period t, p_j : price of product j in period t, θ and π: parameters to be estimated, ε: the disturbance term, $\hat{w}_i : (w_{it} + w_{it-1})/2$, w_{it}, : budget share of product i in period t, and $d\ln$ represents log differentials which are replaced by log differences in empirical estimation.

The theoretical classical restrictions are depicted as

Adding-up: $\sum_j \theta_j = 1$ (12)

Homogeneity: $\sum_j \pi_{ij} = 0$ (13)

Symmetry: $\pi_{ij} = \pi_{ji}$ (14)

The set of Marshallian (uncompensated) and Hicksian (compensated) price elasticities and the expenditure elasticity can be calculated from the estimated coefficients as follows:

Marshallian Price Elasticity: $1/\hat{w}_i(\pi_{ij} - \hat{w}_j\theta_j)$ (15)

Hicksian Price Elasticity: $\pi_{ij}/\hat{w}_i$ (16)

Expenditure Elasticity: $\theta_j/\hat{w}_i$ (17)

When estimating any of both demand system models, one equation must be omitted to avoid the singularity of the variance-covariance matrix of disturbances. The parameters associated with the omitted demand equation can be recovered by making use of the classical restrictions.

(3) The Barten Approach

Since the appearance of the complete demand system concept, its use by agricultural economists has grown. Huang (1985) estimated a complete food demand system for the U.S. using aggregate categories. Capps et al. (1994) used a Rotterdam system to estimate meat demand parameters in the Pacific Rim countries. Scott (1991) used an inverse Rotterdam model to analyze fresh vegetable demands in four selected U.S. terminals. Only a few studies have used complete demand systems to estimate the parameters of Mexican food demands. Heien (1989) used AIDS model to analyze protein-supplying food (tune, salmon like fishes, eggs, cottage cheese, almonds etc.) demand in Mexico. Garcia Vega (1995) compared the AIDS and Rotterdam model estimates of Mexican meat demand parameters. Malaga and Williams (1996) used AIDS model to analyze fresh vegetable demand in U.S. and Mexico.

An alternative approach developed by Barten (1993) allows for a more appropriate method of demand system selection. The Barten technique artificially nests four versions of differential demand systems (Rotterdam, AIDS, NBR (National Bureau of Research) , and CBS (Central Bureau of Statistics)) in a more general model using the Variable Addition Method of McAleer (1983). The method was extended to a combination of vector value functions and applied to a comparison of the demand systems. Given the nature of the dependent variables, the test basically reduces to assessing the extra explanatory power of the vectors of exogenous variables. The Likelihood Ratio Test statistic can be used for this purpose (Barten 1993). The general Barten model specification can be written as:

$$\hat{w}_i d\ln(q_i) = d_i d\ln(Q) + \sum_j e_{ij} d\ln(p_j) + \delta_1\left[\hat{w}_i d\ln(Q)\right] - \delta_2\left\{\hat{w}_i\left[d\ln(p_i) - d\ln(P)\right]\right\} \tag{18}$$

Where: $\hat{w}_i : (w_{it} + w_{it-1})/2$; $d\ln(q_i)$ = ln (P_{it} + $P_{it\text{-}1}$) ; $d\ln(Q) = \sum_i \hat{w}_i d\ln(q_i)$; $d\ln(p)$ = $\sum_i \hat{w}_i d\ln(p_i)$; w_{it} : budget share of product in period t ; δ_1 : coefficient associated with the difference between the Rotterdam and the CBS system ; δ_2 : coefficient associated with the difference between the Rotterdam and the NBR systems.

When the coefficients δ_1 and δ_2 are equal to zero, the Barten general model is equivalent to the Rotterdam model. When δ_1 and δ_2 are equal to one, the Barten model is transformed into an AIDS model. Other combinations are also possible representing the NBR and CBS models. Therefore , determining which is the most appropriate demand system model for a particular set of data reduces to an empirical test of the values of δ_1 and δ_2. The Likelihood Ratio Test can be used for this purpose. In this study case, the Barten approach is used to determine whether Rotterdam or AIDS is the suitable model for the fresh vegetable demand system for the U.S. and Mexico.

(4) Separability and Endogeneity

Demand system studies for U.S. fresh vegetables have not included onions as part of the system. Mittelhammer (1979) did not include onions in his U.S. salad vegetable system because of a lack of adequate data. However, other studies simply assumed that onions "did not belong" to the fresh vegetable system.

Fortunately, the available demand systems methodologies allow for a separability tests. These tests can be used to determine whether a particular commodity, in this case, onion should be included in a demand system. A test based on the assumption of weak separability of the direct utility function will be used. With that assumption, Goldman and Uzawa (1964) showed that:

$$S_{ij} = \phi_{ij}(\partial q_i / \partial e)(\partial q_j / \partial e), i \in I, j \in J \tag{19}$$

Where I refer in these case to the group of fresh vegetables other than onions ; J alludes to the single commodity, in this case onions; S_{ij} represents the Slutzky substitution term; ϕ_{ij} is a substitutability parameter between commodities in groups I and J; and $\partial q_i/\partial e$ are the derivatives of products i and j with respect to total expenditure.

With some algebraic manipulation it can be shown that:

$$\varepsilon^*_{ij} = (\phi_{ij} / e) n_i n_j w_j \tag{20}$$

where, ε^*_{ij} refers to the compensated cross price elasticity between commodities in groups l and J ; n_i and n_j are the expenditure elasticities of products in the two respective groups ; and W_j is the budget share of commodity j. Also for $i, k \in I$ and $j \in J$, equation (20) can be used to demonstrate that:

$$\varepsilon^*_{ij} / \varepsilon^*_{kj} = n_i / n_k \tag{21}$$

In other words, under the assumption of weak separability of the direct utility function, the ratio of Hicksian or compensated cross-price elasticities of two commodities in the same group with respect to a third commodity in another group is equal to the ratio of their respective expenditure elasticities. In the context of the Rotterdam model, (21) implies a nonlinear restriction on the parameters π_{ij}, where the i and $k \in I$, and j

$\in J$. This Rotterdam parameter restriction can be written as:

$$\pi^{*}_{ij} / \pi^{*}_{kj} = \theta_i / \theta_k \tag{22}$$

In this paper, i and $k \in I$ include tomatoes, cucumbers, bell peppers, and squash, and $j \in J$ refers to onions. The separability test becomes a Likelihood Ratio Test of the hypothesis of the separability of onions. In the case of the AIDS model, a similar test can be performed.

Another relevant issue when dealing with food demand systems is the assumption of endogeneity of total expenditures. Since by definition total expenditures are the sum of expenditures on each commodity, total expenditures are generally expected to be endogenously determined. However, if the total expenditures variable is correlated with the equation error, the parameter estimates could be biased and inconsistent.

To deal with this problem, Capps al. (1994) applied a technique developed by Hausman (1977). For the case of the Rotterdam model, this procedure requires the estimation of an n-equation system of the following form:

$$\begin{aligned} &\hat{w}_i d\ln(q_i) = \theta_i \left[\alpha_0 + \sum_k^m \alpha_k Z_k \right] + \sum_k^m \pi_{ij} d\ln(p_j) + \varepsilon_i \\ &\qquad\qquad\qquad\qquad\qquad\qquad i = 1,\ldots,n-1 \\ &d\ln(Q) = \alpha_0 + \sum_k^m \alpha_k Z_k + \mu \end{aligned} \tag{23}$$

Where θ_i, π_{ij}, α_0 and α_k are structural parameters; and Z_k corresponds to a set of predetermined variables including $d\ln(p_j)$.

Therefore, this procedure includes an additional equation in the demand system which is a regression of the total expenditure variable $d\ln(Q)$ on a set of exogenous variables (which, in this study, include the log differences of the prices of tomatoes, onions, cucumbers, bell peppers, and squash, and the log difference of real per capita income). The hypothesis that the parameters α_k are jointly equal to zero can then be tested. If the hypothesis is rejected, the estimates of both the price and expenditure coefficients in the demand system would be biased and inconsistent. In other words, total expenditures are not endogenous and its correlation with the disturbance term needs to be taken into account.

３. Data

As discussed previously, important production, marketing, and trade patterns clearly differentiate the two main fresh vegetable seasons in the U.S. and in Mexico. Except for onions, where some degree of storage exists in the U.S., the perishable nature of these vegetables does not allow for inventory carry over from one season to another. Preliminary research determined that each productive season constitutes an independent system with no relevant linkages between them. Consequently, in attempting to model the fresh vegetable markets in both countries, each season must be accounted for separately. According to U.S. and Mexican production data, the winter season covers vegetable production and consumption corresponding to the months of December through May in both countries while the summer season covers the months of June through November. Monthly data were converted into seasonal data using these seasonal definitions. Because of data limitations, only five fresh vegetables were included in the analysis: (1) tomatoes, (2) onions, (3) cucumbers, (4) squash, and (5) bell peppers. These vegetables are the most traded between both countries and, except for lettuce, account for most of fresh vegetable consumption. The available data allowed for a period of analysis of 1980 through 2005.

U.S. monthly shipment data from the USDA Agricultural Marketing Service (AMS) were used to calculate seasonal weights for the production of each vegetable. The annual production figures of the USDA National Agricultural Statistics Service (NASS) and the seasonal shipment structures were used to determine the U.S. seasonal production following the method used by the Economic Research Service (ERS) to estimate monthly production levels. U.S. imports from Mexico were provided by AMS. Imports from other countries, U.S. exports, and border prices were obtained from the U.S. Bureau of the Census (USBC) and the U.S. Department of Commerce (USDC). Retail prices were obtained from the Bureau of Labor Statistics, U.S. Department of Labor.

During 1982 through 1991 when USDA discontinued publication of national level data for cucumbers, national production was calculated as production-weighted averages of the corresponding data obtained from the Agricultural Statistical Services of the major producing states (Florida, California, Texas, Georgia, New Jersey, New York, Virginia, Arizona, Michigan, and North Carolina). Because squash production statistics were available only for Florida, those data were used to represent national data. Seasonal consumption per capita was computed from the production, trade, and population figures.

Mexican seasonal production data were obtained primarily from "Anuario Estadistico de la Produccion Agricola de los Estados Unidos Mexicanos" published by the Secretaria de Agricultura, Ganaderia y Desarrollo Rural (SAGAR). Retail prices in Mexico were calculated using the monthly retail price indices for tomatoes, onions, cucumbers, and squash published by the Banco de Mexico in the Cuaderno Mensual Indice de Precios. Mexican monthly consumer price indices were taken from the International Financial Statistics (IMF). Retail prices in both countries were deflated by the respective CPI index.

4. Estimation Results

(1) The Barten Model

The Barten model for the five selected vegetables (tomatoes, onions, cucumbers, squash, and bell peppers) was used for both season models for the U.S. and Mexico. The Barten models for Mexico did not include bell peppers, because of the loss of data. For the U.S. in the both seasons, the Barten model likelihood ratio tests indicated rejection of the AIDS model but failed to reject the Rotterdam model (Table 1). In the case of Mexico in Both seasons, both AIDS and Rotterdam systems were rejected except for the summer Rotterdam model.

(2) Separability Test

A test for weak separability of onion demand, as described above, was performed using the Rotterdam model for the United States. Mittelhammer (1978) argues that onions have multiple food uses and might not be a typical salad vegetable except for white onions. The test failed to reject the null hypothesis of weak separability of onions at the 0.05 significance level of the χ^2 distribution (Table 2). This outcome suggests that onion demand can be separated from the other fresh vegetable demands for analytical purposes. Subsequent demand system analyses will include, therefore, only

Table 1 Barten Model Test Results (Including Onions)

Season/Model	Log Likelihood (Restricted)	Log Likelihood (Unrestricted)	Log Likelihood Ratio	Hypothesis Test χ^2 at 0.05 level
U.S. Winter				
AIDS	284.355	292.797	16.875	Reject
Rotterdam	290.970	292.797	3.654	Fail to Reject
U.S. Summer				
AIDS	271.663	275.206	7.078	Reject
Rotterdam	265.983	275.206	1.295	Fail to Reject
Mexico Winter				
AIDS	114.078	117.740	7.323	Reject
Rotterdam	113.413	117.740	8.653	Reject
Mexico Summer				
AIDS	150.215	154.430	8.429	Reject
Rotterdam	153.126	154.430	2.607	Fail to Reject

Critical value for χ^2 at 0.05 level and two degrees of freedom: 5.991

Table 2 U.S. Rotterdam Model Onion Separability Test Results

Season	Log Likelihood (Restricted)	Log Likelihood (Unrestricted)	Log Likelihood Ratio	Hypothesis Test χ^2 at 0.05 level
Winter	281.354	288.121	8.070	Fail to Reject
Summer	269.092	278.991	4.827	Fail to Reject

Critical value for χ^2 at 0.05 level and four degrees of freedom: 9.488

Table 3 Barten Model Test Results (Onions Excluded)

Season/Model	Log Likelihood (Restricted)	Log Likelihood (Unrestricted)	Log Likelihood Ratio	Hypothesis Test χ^2 at 0.05 level
U.S. Winter				
AIDS	196.605	207.306	20.691	Reject
Rotterdam	205.641	207.306	3.330	Fail to Reject
U.S. Summer				
AIDS	199.079	202.071	6.049	Reject
Rotterdam	201.280	202.071	1.581	Fail to Reject
Mexico Winter				
AIDS	82.685	91.506	17.660	Reject
Rotterdam	80.119	91.506	22.774	Reject
Mexico Summer				
AIDS	103.729	107.218	6.960	Reject
Rotterdam	105.914	107.218	2.608	Fail to Reject

Critical value for χ^2 at 0.05 level and two degrees of freedom: 5.991

tomatoes, cucumbers, squash, and bell peppers. Onion demand will be modeled separately.

A Barten model, without onions, was then estimated to confirm the appropriateness of the Rotterdam specification for the fresh vegetable demand system of both countries. The AIDS model was again rejected in all cases while the Rotterdam model was not rejected except for the winter season vegetable demand in Mexico (Table 3).

Table 4 U.S. Rotterdam Model - Endogenditures Test Results

Season	Log Likelihood (Restricted)	Log Likelihood (Unrestricted)	Log Likelihood Ratio	Hypothesis Test χ^2 at 0.05 level
Winter	197.811	237.960	80.298	Reject
Summer	207.810	241.344	67.059	Reject

Critical value for χ^2 at 0.05 level and four degrees of freedom: 11.070

(3) Endogeneity Test

Another concern in the analysis of demand systems is the endogeneity of total expenditures. Because fresh vegetable consumption likely increases with the level of education and income, total consumer expenditures for fresh vegetables might not be exogenous to the demand system as the original Rotterdam model assumes leading to biased and inconsistent parameter estimates (Capps, et al.1994). To get around this problem, the technique developed by Hausman (1977) can be used which involves extending the demand system with a regression of the total expenditure variable (Q) on a set of exogenous variables including the log differences of the prices of each one of the included fresh vegetables and the log difference of real per capita income.

The structural parameters of the augmented demand system are then estimated using the nonlinear maximum likelihood algorithm in the SHAZAM econometrics package. The hypothesis that the parameters of the augmented equation are jointly equal to zero can be tested. This hypothesis was rejected for the U.S. fresh vegetable model in both seasons using the likelihood ratio test at 0.05 significance (Table 4). This result implies that exogeneity of total expenditures cannot be assumed and that the parameters of the Rotterdam model would be biased and inconsistent if the correlation of total expenditure and the disturbance terms was not taken into account.

(4) Endogeneity-Corrected Parameter Estimates

Based on the results of the endogeneity test, the augmented equation was kept in the Rotterdam model of the U.S. fresh vegetable demand system. The Rotterdam model for Mexican vegetable demand yielded parameters of low statistical significance with some elasticity levels outside reasonable ranges and the results are not provided in this paper.

The parameters of all but one of the demand equations in the endogeneity-corrected Rotterdam model for the United States in the winter and summer seasons were

Table 5 U.S. Winter Fresh Vegetable Rotterdam Model Parameter Estimates (Corrected for Endogeneity)

Variable	Tomatoes	Cucumbers	Squash	B. Peppers	Q
Price of Tomatoes	−0.0089	0.0087	0.0209	−0.00243	−0.0666
	(−0.28)	(0.58)	(1.75)	(−0.84)	(−0.52)
Price of Cucumbers	0.0076	−0.0432	0.0004	0.0288	−0.0141
	(0.58)	(−2.01)	(0.03)	(2.22)	(−0.11)
Price of Squash	0.0190	0.0033	−0.0211	−0.0089	−0.1911
	(1.55)	(0.47)	(−0.93)	(−0.77)	(−3.12)
Price of Bell Peppers	−0.019	0.0308	−0.0008	−0.0009	−0.1339
	(−0.77)	(2.03)	(−0.77)	(−0.09)	(−1.73)
Q	0.5545	0.2058	0.0998	0.287	−
	(8.45)	(6.13)	(3.5)	(3.45)	
DLINC	−	−	−	−	1.225
					(3.88)
R-Square	0.87	0.64	0.41	*	0.65
D-W Statistic	1.93	1.99	1.70	*	1.49

t-values are in parentheses

Table 6 U.S. Summer Fresh Vegetable Rotterdam Model Parameter Estimates (Corrected for Endogeneity)

Variable	Tomatoes	Cucumbers	Squash	B.Peppers	Q
Price of Tomatoes	−0.0895	0.00111	−0.0045	0.0724	−0.0817
	(−1.71)	(0.49)	(−0.75)	(2.00)	(−0.25)
Price of Cucumbers	0.0101	−0.0011	0.0022	−0.0145	0.3160
	(0.44)	(−0.04)	(0.11)	(−0.14)	(2.51)
Price of Squash	−0.0002	0.0027	−0.0050	−0.0009	−0.0099
	(−0.33)	(0.70)	(−0.34)	(0.05)	(−0.12)
Price of Bell Peppers	0.0755	−0.0099	0.0022	−0.0665	0.0008
	(1.98)	(−0.88)	(0.23)	(−0.92)	(0.09)
Q	0.5288	0.1609	0.0145	0.3357	−
	(5.17)	(3.98)	(1.35)	(3.01)	
DLINC	−	−	−	−	−0.3445
					(−1.50)
R-Square	0.82	0.21	0.19	*	0.22
D-W Statistic	1.39	2.29	3.23	*	1.88

t-values are in parentheses

estimated directly because the adding-up constraint implies that only three of the four demand equations are independent (Tables 5 and 6). The bell pepper demand equation was omitted from estimation but its parameters were recovered using the classical restrictions from demand theory.

The R^2 statistics are somewhat low across the board with the highest for the tomato demand equations in the winter and summer seasons (0.87 and 0.82, respectively). Serial correlation, as measured by the Durbin-Watson (DW) coefficient, was not evident in any of the equations in either season, except perhaps for the summer tomato demand equation. The t-values corresponding to the estimated coefficients indicate that only

Table 7 U.S. Winter Fresh Vegetable Elasticities, Rotterdam Model

	Marshallian Elasticities			
	Tomatoes	Cucumbers	Squash	B. Peppers
Tomatoes	−0.519	−0.099	−0.023	−0.179
	(−5.99)	(−3.44)	(−1.22)	(−4.55)
Cucumbers	−0.767	−0.559	−0.077	−0.044
	(−3.64)	(−4.99)	(−1.08)	(−0.09)
Squash	−0.469	−0.098	−0.358	−0.336
	(−1.78)	(−1.07)	(−3.31)	(−2.55)
B. Peppers	−0.774	0.044	−0.112	−0.290
	(−2.97)	(0.33)	(−2.12)	(−1.50)
	Hicksian Elasticities			
	Tomatoes	Cucumbers	Squash	B. Peppers
Tomatoes	−0.022	0.012	0.008	−0.009
	(−0.31)	(0.33)	(1.65)	(−0.55)
Cucumbers	0.098	−0.389	0.014	0.222
	(0.49)	(−2.14)	(0.49)	(2.36)
Squash	0.313	0.061	−0.121	−0.321
	(1.54)	(0.49)	(−0.77)	(−0.32)
B. Peppers	−0.101	0.165	−0.066	−0.000
	(−0.45)	(2.30)	(−0.18)	(−0.04)
	Expenditure Elasticities			
	Tomatoes	Cucumbers	Squash	B. Peppers
	0.952	1.455	1.212	0.980
	(9.05)	(6.88)	(2.89)	(2.41)

t-values are in parentheses

four winter parameters estimates and three summer estimates are significant at 0.05 significance level (Tables 5 and 6).

The Hicksian (income-compensated) and Marshallian (income-uncompensated) elasticities derived from the Rotterdam model were derived at the sample means of the data (Tables 7 and 8 for the winter and summer seasons, respectively). Marshallian elasticities for the winter season are generally in the expected range according to previous studies (Table 7). All own-price Marshallian elasticities for the winter season are negative and all but one is significant at 0.05 level. Own - price elasticities range from -0.290 for bell peppers to -0.559 for cucumbers. Except for the bell pepper-cucumber case, all Marshallian cross-price elasticities for the winter season are negative, implying gross complementarily of the respective commodities in consumption. Only half Hicksian cross-price elasticities for the winter season are negative implying that some gross complements are net substitutes. Expenditure elasticities for the summer season are relatively high, ranging from 0.952 for tomatoes to 1.455 for cucumbers.

Marshallian own-price elasticities for the summer season are also negative in all cases

Table 8 U.S. Summer Fresh Vegetable Elasticities, Rotterdam Model

	Marshallian Elasticities			
	Tomatoes	Cucumbers	Squash	B. Peppers
Tomatoes	−0.698	−0.656	−0.015	−0.033
	(−4.89)	(−1.44)	(−1.44)	(−0.66)
Cucumbers	−1.014	−0.099	0.012	−0.498
	(−2.91)	(−0.49)	(0.56)	(−2.37)
Squash	−1.120	0.058	−0.289	0.059
	(−1.09)	(0.28)	(−1.33)	(0.55)
B. Peppers	−0.799	−0.155	0.002	−0.788
	(−1.65)	(−2.87)	(0.01)	(−3.79)
	Hicksian Elasticities			
	Tomatoes	Cucumbers	Squash	B. Peppers
Tomatoes	−0.113	0.013	−0.004	0.085
	(−0.91)	(0.36)	(−1.88)	(1.89)
Cucumbers	0.087	−0.022	0.005	−0.143
	(0.39)	(−0.14)	(0.66)	(−0.77)
Squash	−0.179	0.199	−0.213	0.209
	(−0.87)	(0.79)	(−0.88)	(0.66)
B. Peppers	0.421	−0.009	0.002	−0.343
	(2.01)	(−0.92)	(0.81)	(−1.07)
	Expenditure Elasticities			
	Tomatoes	Cucumbers	Squash	B. Peppers
	0.656	1.414	1.139	1.103
	(4.05)	(3.87)	(0.82)	(3.40)

t-values are in parentheses

(Table 8), from -0.099 for cucumbers to -0.788 for bell peppers. As is the case for the winter demand equations, most cross-price elasticities are negative. Only four demand elasticities for the summer season indicate substitution in consumption (squash-cucumbers and bell pepper-squash). Only three Marshallian cross-price elasticities for the summer season are significant at 0.05 level Summer expenditure elasticities range from 0.74 for tomatoes to 1.7 for bell peppers.

The Marshallian own-price elasticities for winter and summer tomato and squash demand are similar in magnitude. The cucumber own-price elasticity is higher in the summer season and that of bell peppers is higher in the winter season. The magnitudes and signs of Marshallian cross-price relationships also change with the season. For example, squash and cucumbers are gross complements in winter but gross substitutes in summer. Similarly, squash is a gross substitute of bell peppers in winter but a gross complement in summer. In general, though, complementary relationships are more common in the winter season which may be related to seasonal differences in consumption habits and products availabilities. Expenditure elasticities are in the same range in both seasons, except for bell peppers (clearly higher in summer). In both seasons, all cross-price elasticities with respect to tomatoes are positive and high in magnitude, suggesting that tomatoes are the primary salad vegetable.

The magnitudes of the Marshallian own-price elasticities are in general consistent with the results of previous studies. Tomato own-price elasticities for winter demand (-0.519) and summer demand (-0.698) are very close to the annual elasticity reported by Huang 1985 (-0.56), Simmons in 1987 (-0.50), and somewhat above the magnitudes found by Salcedo Bacain 1990 (-0.31), Mittelhammer in 1978 (-0.42), and Gutierrez (1983) for the winter season in 1988 (-0.44). Shonkwiler and Emerson (1980) report a winter tomato own-price elasticity of -0.79.

The winter cucumber uncompensated own-price elasticity of -0.559 corresponds closely to the elasticity reported by Mittelhanmer in 1978 (-0.54) and that reported by Castro and Simmons in 1974 (-0.57). Similarly, the winter bell pepper elasticity of -0.290 is close to that found by Mittelhammer (-0.23). However, the estimated own-price elasticities for summer cucumber and bell pepper demand are quite different from their respective annual elasticities reported in previous studies.

The tomato expenditure elasticities of 0.952 for winter demand and 0.656 for summer demand found in this study are above those estimated for the entire year by Huang (0.49) and Mittelhammer (0.29) and below the income elasticities for tomatoes reported by Shonkwiler and Emerson in 1982 (2.09) , Gutierrez in 1988 (1.47) , and Salcedo Baca in 1990 (2.60). Expenditure elasticities reported here for winter and summer cucumbers (1.455 and 1.414, respectively) and for winter and summer bell peppers (0.980 and 1.103, respectively) are much higher than the expenditure elasticities reported by Mittelhammer in 1978 (0.23 for cucumbers and 0.43 for bell peppers).

The differences found between the seasonal own and cross-price elasticities for some vegetables supports the general hypothesis that there are important structural differences in the nature of the seasonal demands for vegetables, probably related to salad consumption habits. Moreover, the different signs of some cross-price elasticities between seasons reinforce the appropriateness of the seasonal separation of fresh vegetable demand for analytical purposes.

5. Conclusions

The results of this study indicate that the Rotterdam model is the most appropriate demand system for the estimation of fresh vegetables demand parameters for both the winter and summer seasons in both the U.S. and Mexico. Hicksian, Marshallian and expenditure elasticities are calculated separately for each Season. Own- and cross-price elasticities display seasonal differences. A weak separability test suggests that onions are separable or that they do not belong to the "salad vegetable" demand system. Finally, likelihood test results imply that exogeneity of total expenditures cannot be assumed and that the parameters of the Rotterdam model would be inconsistent.

As a result, the Rotterdam model appears to be the appropriate demand system for estimating the parameters of the demand for fresh vegetables in both the U.S. and Mexico. Onion demand equations apparently do not belong to the fresh vegetable demand group. Marhsallian and expenditure elasticities are found to be within expected ranges. While tomato and squash own-price elasticities are about the same in fall-winter and spring-summer seasons, cucumber and bell pepper own-price elasticities display substantial seasonal differences. Except for tomatoes, expenditure elasticities are all above one suggesting that most fresh vegetables could be considered superior goods.

References

〔1〕 Barten, A. P. (1993) "Consumer Allocation Models: Choice of Function Form" *Empirical Economics* 18

〔2〕 Capps, Jr. O., R.Tsai, and G. Williams (1994) "A Comparison of Demands for Meat Products in the Pacific Rim Region" *Journal of Agriculture and Resource Economics* 1

〔3〕 Deaton, A. and J. Muellbauer (1980) "*Economics and Consumer Behavior*" Cambridge University Press

〔4〕 Garcia Vega, J. (1995) "The Mexican Livestock, Meat, and Feed grain Industries: A Dynamic Analysis of U.S. - Mexico Economic Integration" *Ph. D. Dissertation*, Texas A&M University

〔5〕 Goldman, S. M. and H. Uzawa (1964) "A Note on Separability in Demand Analysis" *Econometrica* 32

〔6〕 Hausman, J. A. (1997) "Errors in Variables in Simultaneous Equation Models" *Journal of Econometrics* 5

〔7〕 Heien, D., L. S. Jarvis and F. Perali (1989) "Food Consumption in Mexico" *Food Policy* 14

〔8〕 Huang, K. (1985) "U.S. Demand for Food : A Complete System of Price and Income Effect"

Technical Bulletin #1795 U.S. Department of Agriculture, Economic Research Service

[9] Malaga, J. and G. W. Williams (1996) "U.S. and Mexican Fresh Vegetable Markets: A Descriptive Analysis" Texas Agricultural Market Research Center *International Market Research Report* IM 5-96,

[10] McAleer, M. (1983) "Exact Tests of a Model Against Non-Nested Alternatives" *Biometrika* 70

[11] McCracken, V. A. (1992) "The U.S. Demand for Vegetables" *Vegetable Market in the Western Hemisphere* Iowa State University Press

[12] Mittelhammer, R. C. (1979) "The Estimation of Domestic Demand for Salad Vegetables Using A Priori Information" *Ph.D. Dissertation*, Washington State University

[13] Sasaki,K. (1993) "The Structure of Food Demand in Japan : An Application of the Rotterdam System" *Agribusiness*, Vol.9, No.5.

[14] Sasaki, K. (1995) "Consumption Behavior of Japanese Agricultural Households : Analysis of an Almost Ideal Demand System" *Journal of Rural Economics*, Vol.67, No.3

[15] Sawada, M. (1991) "A Nonparametric Demand Analysis of the Structure of Consumer Preferences" *Journal of Rural Economics*, Vol.63, No.1

[16] Vainio, H. and F. Bianchini (2004) "*Fruits and Vegetables*" IARC Handbook of Cancer Prevention, World Health Organization