DEMAND SYSTEMS AND FRESH VEGETABLES: AN APPLICATION OF THE BARTEN APPROACH

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Abstract: The Barten approach is used to select the demand system specification for U.S. and Mexican fresh vegetable demands. The Rotterdam model was found the most appropriate formulation for U.S. and Mexican demand systems, both in winter and summer. Onion demand was found weakly separable from the other fresh vegetable demands.

Key Words: fresh vegetables, demand systems

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Executive Summary

Growing produce imports from Mexico and rapid gains in production efficiencies have kept U.S. fresh vegetable prices declining in real terms in recent years. 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. Only two serious attempts (Mittelhammer 1978 and Scott 1991) have been made to use demand systems to estimate the parameters for U.S. fresh vegetable demand. In both cases, however, the selection of the demand system was arbitrary.

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. and Mexican production/marketing seasons exist (winter or fall-winter and spring-summer). Nevertheless, given the strong competition between the U.S. and Mexico during the winter season, most fresh vegetable quantitative analyses have focused on the winter vegetable market.

This report presents the results of the first attempt at 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 study, fresh vegetables include tomatoes, onions, cucumbers, squash, and bell peppers.

A demand system approach usually incorporates all the restrictions of modern consumer demand theory into a single model to ensure that consumer behavior in the model is consistent with theory. Unfortunately, even when the demand system approach is used, 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 common of which are the "Almost Ideal Demand System" (AIDS) and the Rotterdam model.

Research has demonstrated, however, that the coefficient and elasticities derived from different demand systems may differ substantially, posing a relevant question about the appropriate choice of demand system specification. Comparisons between alternative specifications can be and have been done by using goodness-of-fit criteria. Such comparisons have been termed "naive" in that the statistical interpretation is not clear (Barten 1990). An alternative approach developed by Barten (1990) allows for a more appropriate method of demand system selection. The Barten technique artificially nests four versions of differential demand systems (Rotterdam, AIDS, NBR, and CBS) 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 1990).

The Barten model for the five selected vegetables (tomatoes, onions, cucumbers, squash, and bell peppers) was applied for both the winter and the summer season models for the U.S. and Mexico. The Barten models for Mexico did not include bell peppers. For the U.S. in both the winter and summer seasons, the Barten model likelihood ratio tests indicated rejection of the Almost Ideal Demand System (AIDS) model but failed to reject the Rotterdam model. In the case of Mexico in both seasons, both AIDS and Rotterdam systems were rejected except for the summer Rotterdam model.

The selected demand system for each country and season was subjected to endogeneity and separability tests and the parameters were re-estimated. A test for separability of onions was run to confirm or reject the hypothesis that onions belong to the "salad" vegetable group. Previous studies have assumed that onions are not considered to be a "salad" vegetable. A test for endogeneity of expenditures was also performed. The three stage least squares (3SLS) systems estimator was used to derive the parameters of the full system because endogenous variables in some equations of the model were used as explanatory variables in other equations.

The study results suggest that the Rotterdam model is the most appropriate demand system for the estimation of fresh vegetable demand parameters for both the winter and summer seasons in both the U.S. and Mexico. Although Hicksian, Marshallian and expenditure elasticities were found to be within expected ranges, they exhibited strong seasonal differences in many cases. For example, cucumber and bell pepper own-price elasticities display substantial seasonal differences even though tomato and squash own-price elasticities are about the same in fall-winter and spring-summer seasons. Except for tomatoes, expenditure elasticities are all above one suggesting that most fresh vegetables might be considered luxury goods. The test for weak separability suggested that onions are separable and, thus, do not belong to the "salad vegetable" demand system. Finally, the likelihood test results implied 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 expenditures and the disturbance terms is not taken into account.

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U.S. per capita consumption of fresh vegetables increased steadily, even dramatically, during the 1980s and 1990s. 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, Málaga and Williams 1996). Growing produce 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.

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, in recent years, demand system techniques have been developed to simultaneously estimate the parameters of closely related demands, incorporating the constraints of modern demand theory (adding up, homogeneity, and symmetry). Unfortunately, the use of alternative demand system formulations (Rotterdam, AIDS, and others) can provide different elasticity estimates.

Only two serious attempts (Mittelhammer 1978 and Scott 1991) have been made to use 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 "salad" vegetables as a subsystem. The fresh vegetables included tomatoes, cucumbers, bell peppers, lettuce, carrots, celery, and cabbage. The selection of these vegetables was based on a national consumer survey regarding the most used vegetables in salads. The mixed statistical estimation method utilized to derive the demand parameters incorporated linear probabilistic constraints, including symmetry, homogeneity and negativity. As hypothesized, he found significant complementary and substitution relationships.

The inverse Rotterdam demand model utilized by Scott included four regional demand systems for tomatoes, cucumbers, bell peppers, and green beans. Monthly data over a ten year period was used for the terminal markets of New York, Los Angeles, Chicago, and Atlanta. He found significant own and cross-price elasticities with strong complementary relationships in all four 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) winter or 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. A similar structure is observed in Mexico where Sinaloa is the major supplier during the winter season. 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 report presents the results of the first attempt at 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 study, fresh vegetables include tomatoes, onions, cucumbers, squash, and bell peppers. After discussing the characteristics of demand systems including a method developed by Barten (1990) to select among alternative demand systems, the data used in the analysis are presented. The demand system parameter estimation results are then presented which is followed by a discussion of conclusions.

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 that system in both Marshallian and Hicksian demands. That is, the following equation must hold:

$$(1) \qquad \Sigma p_i h_i (u,p) = \Sigma p_i q_i (e,p) = e,$$

where p_i = the price of i, h_i = the Hicksian demand for i, q_i = the Marshallian demand for i, u = utility, and e = total expenditures. The Engel aggregation condition is derived from the adding-up property.

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:

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

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:

(3) $\partial h_i(u,p)/\partial p_j = \partial h_j(u,p)/\partial p_i, \ \forall i \neq j$.

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.

A demand system approach usually incorporates these restrictions into one model to ensure that consumer behavior in the model is consistent with theory. Additionally, imposing the classical restrictions allows economies of parameterization, always important when dealing with time series data. Moreover, these restrictions when appropriately imposed, are useful in an econometric sense, permitting gains in efficiency of estimation and likely reducing multicollinearity. These advantages are encouraging agricultural economists to use complete demand systems instead of the more conventional "ad-hoc" single demand equation approach for investigating the statistical characteristics of consumer behavior.

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" or "AIDS" and (2) the Rotterdam model.

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 (LA/AIDS) and can be specified as:

(4) $w_{it} = \alpha_i + \Sigma_j \gamma_{ij} \, ln p_{jt} + \beta_i \, ln[Y_t/P_t^*] + \epsilon_{it}$

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 γ = 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:

(5) Adding-up: $\Sigma_i \alpha_i = 1$, $\Sigma_i \gamma_{ij} = 0$, and $\Sigma_i \beta_i = 0$;
(6) Homogeneity: $\Sigma_i \gamma_{ij} = 0$;
(7) Symmetry: $\gamma_{ij} = \gamma_{ji}$.

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

(8) Marshallian Price Elasticity: $-\delta_{ij} + \gamma_{ij}/w_i - \beta_i w_j/w_i$
(9) Hicksian Price Elasticity: $-\delta_{ij} + w_j + \gamma_{ij}/w_i$
(10) Expenduture Elasticity: $1 + \beta_j/w_i$

where δ 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.

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:

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

where $d\ln(Q) = \Sigma_i \hat{w}_i \, d\ln(q_i)$ 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:

(12) Adding-up: $\Sigma_j \theta_j = 1$;
(13) Homogeneity: $\Sigma_j \pi_{ij} = 0$;
(14) Symmetry: $\pi_{ij} = \pi ji$.

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

(15) Marshallian Price Elasticity: $1/\hat{w}_i (\pi_{ij} - \hat{w}_j \theta_j)$;
(16) Hicksian Price Elasticity: $\pi_{ij} / \hat{w}_i$;
(17) Expenduture Elasticity: $\theta_j / \hat{w}_i$.

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.

The Barten Approach

Since the appearance of the complete demand systems concept, its use by agricultural economists has grown. Huang estimated a complete food demand system for the U.S. using aggregate categories (1985). Wahl (1989) and Tsai (1994) used AIDS models to analyze the meat demand in Japan and Taiwan, respectively. Capps *et al.*(1994) used a Rotterdam system to estimate meat demand parameters in the Pacific Rim countries. Mittelhammer (1978) used a system approach to estimate the parameters of the U.S. “salad” vegetable demand. 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 a LA/AIDS model to analyze protein-supplying food demand in Mexico. Minert (1994) used also a AIDS model to study meat demand in Mexico. García Vega (1995) compared the LA/AIDS and Rotterdam model estimates of Mexican meat demand parameters. No demand system study has been performed for Mexican vegetable demand.

García Vega (1995) demonstrated that the coefficient and elasticities derived from different demand systems may differ substantially, posing a relevant question about the appropriate choice of demand system specification. Comparisons between alternative specifications can be and have been done by using goodness-of-fit criteria. Such comparisons have been termed “naive” in that the statistical interpretation is not clear (Barten 1990). Because the dependant variables are not the same for the various systems, the R^2 as a measure of goodness-of-fit is not a particularly useful measure of relative performance of demand systems. Moreover, a comparison between full demand systems rather than between individual equations is most appropriate. Statistical test procedures must take into account that the models being compared are not nested within each other.

An alternative approach developed by Barten (1990) allows for a more appropriate method of demand system selection. The Barten technique artificially nests four versions of differential demand systems (Rotterdam, AIDS, NBR, and CBS) 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 1990). The general Barten model specification can be written as:

$$(18) \qquad \hat{w}_i \, d\mathit{ln}\,(q_i) = d_i \, d\mathit{ln}\,(Q) + \Sigma_j \, e_{ij} \, d\mathit{ln}\,(p_j) + \delta_1 \, [\hat{w}_i \, d\mathit{ln}\,(Q)] \; - \; \delta_2 \, \{\hat{w}_i \, [d\mathit{ln}\,(p_i) - d\mathit{ln}\,(P)]\}$$

where: $\hat{w}_i = (w_{it} + w_{it-1})/2$; $d\mathit{ln}\,(q_i) = \mathit{ln}\,(q_{it} + q_{it-1})$; $d\mathit{ln}\,(p_i) = \mathit{ln}\,(p_{it} + p_{it-1})$; $d\mathit{ln}\,(Q) = \Sigma_i \hat{w}_i \, d\mathit{ln}\,(q_i)$,;

$dln(P) = \Sigma_i \hat{w}_i \, dln(p_i)$; w_{it} = budget share of product i in period t; δ_1 = coefficient associated with the difference between the Rotterdam and the CBS system (Rotterdam and AIDS expenditure coefficients); δ_1 = coefficient associated with the difference between the Rotterdam and the NBR systems (Rotterdam and AIDS price coefficients).

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 in the U.S. and Mexico.

Separability and Endogeneity

Demand system studies for U.S. fresh vegetables have not included onions as part of the system. Mittelhammer (1978) did not include onions in his U.S. salad vegetable system because of a lack of adequate data. However, he refers to a U.S. Department of Agriculture (USDA) nationwide survey which concludes that consumers consider white onions to be a "salad" vegetable. 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 onions, 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:

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

where I refers 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 $\partial q_i / \partial e$ and $\partial q_j / \partial e$ are the derivatives of products i and j with respect to total expenditure.

With some algebraic manipulation it can be shown that:

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

where, ϵ^*_{ij} refers to the compensated cross price elasticity between commodities in groups I 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:

$$(21) \qquad \epsilon^{*}_{ij}/\epsilon^{*}_{kj} = n_{i}/n_{k}.$$

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:

$$(22) \qquad \pi_{ij}/\pi_{kj} = \theta_{i}/\theta_{k}.$$

In this study, 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 *et al.* (1994) applied a technique developed by Attfield (1985) and by Hausman (1977). For the case of the Rotterdam model, this procedure requires the estimation of an n-equation system of the following form:

$$\begin{aligned}(23) \qquad & \hat{w}_{i}\, d\mathit{ln}\,(q_{i}) = \theta_{i}\,[\,\alpha_{0} + \Sigma_{k}^{m}\,\alpha_{k} Z_{k}\,] + \Sigma_{j}^{n}\,\pi_{ij}\, d\mathit{ln}\,(p_{j}) + \varepsilon_{i}, \qquad i = 1,...n-1 \\ & d\mathit{ln}\,(Q) = \alpha_{0} + \Sigma_{k}^{m}\,\alpha_{k} Z_{k} + \mu,\end{aligned}$$

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 have been biased and inconsistent. In other words, total expenditures are not endogenous and its correlation with the disturbance term needs to be taken into account. This is done by keeping the extra equation as part of the demand system for estimation.

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 in each constitutes an independent system with no relevant linkages between them. Consequently, in attempting to model the fresh vegetable markets in each country, 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 1971 through 1993.

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 structure 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 and bell peppers, 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 per capita apparent consumption was computed from the production, trade, and population figures.

Mexican seasonal production data were obtained primarily from *Anuario Estadístico de la Producción Agrícola de los Estados Unidos Mexicanos* published by the Secretaría de Agricultura, Ganadería y Desarrollo Rural (SAGAR). For the years 1986-1988 when SAGAR data were discontinued, state level data from major producing states were collected from *Delegaciones Estatales de la SAGAR* and unpublished SAGAR data provided by the Center for Economic, Social, and Technology Research on World Agriculture and Agribusiness (CIESTAAM) at the Autonomous University of Chapingo in Mexico (Gómez Cruz, Rindermann, and Merino 1991 and Universidad Autónoma de Chapingo 1992). Apparent Mexican consumption was calculated using Mexican seasonal production and trade.

Retail prices in Mexico were calculated using the monthly retail price indices for tomatoes, onions, cucumbers, and squash published by the Banco de Mexico (1993) in the *Cuaderno Mensual Indice* *de Precios*. Those indices were transformed into a series of absolute prices using the Banco de Mexico actual prices for January 1989 which were then converted into seasonal averages. Because consistent official monthly data for Mexican exports do not exist, U.S. statistics of monthly imports from Mexico were assumed to correspond to Mexican exports. 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.

Estimation Results

To determine the appropriate demand system model for fresh vegetable demand in each country, the Barten approach described earlier was used. The selected demand system was subjected to endogeneity and separability tests and the parameters re-estimated. Because previous studies have assumed that onions are not considered to be a "salad" vegetable, a test for separability of onions was conducted to confirm or reject the hypothesis that onions belong to the "salad" vegetable group. A test for endogeneity of expenditures was also performed. The three stage least squares (3SLS) systems estimator was used to derive the parameters of the system because endogenous variables in some equations of the model were used as explanatory variables in other equations (system simultaneity).

The Barten Model

The Barten model for the five selected vegetables (tomatoes, onions, cucumbers, squash, and bell peppers) was used for both the winter and the summer season models for the U.S. and Mexico. The Barten models for Mexico did not include bell peppers. For the U.S. in both the winter and summer seasons, the Barten model likelihood ratio tests indicated rejection of the Almost Ideal Demand System (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.

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

A new 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).

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 Attfield (1985) and 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.

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 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 (0.88 and 0.83, 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 four winter parameter 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). Winter Marshallian elasticities are generally within the expected range according to previous studies (Table 7). All own-price winter Marshallian elasticities are negative and all but one are significant at 0.05 level. Own-price elasticities range from -0.21 for bell peppers to -0.53 for tomatoes. Except for the bell pepper-cucumber case, all winter cross-price Marshallian elasticities are negative, implying gross complementarity of the respective commodities in consumption. Only half the winter Hicksian cross-price elasticities are negative implying that some gross complements are net substitutes. Winter expenditure elasticities are relatively high, ranging from 0.85 for tomatoes to 1.35 for cucumbers.

Summer Marshallian own-price elasticities are also negative in all cases (Table 8), from -0.17 for cucumbers to -0.63 for tomatoes. As is the case for the winter demand equations, most cross-price elasticities are negative. Only four summer demand elasticities indicate substitution in consumption (squash-cucumbers and bell pepper-squash). Only three summer Marshallian cross-price elasticities 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 produce 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 agreement with the results of previous studies. Tomato own-price elasticities for winter demand (-0.53) and summer demand (-0.63) are very close to the annual elasticity reported by Huang in 1985 (-0.56), Simmons in 1987 (-0.50), and somewhat above the magnitudes found by Salcedo Baca in 1990 (-0.31), Mittelhammer in 1978 (-0.42), and Gutiérrez (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 -0.51 corresponds closely to the elasticity reported by Mittelhammer in 1978 (-0.54) and that reported by Castro and Simmons in 1974 (-0.57). Similarly, the winter bell pepper elasticity of -0.21 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. Unfortunately, there have been no previous studies of squash demand to allow a comparison with the winter squash own-price elasticity of -0.32 found in this study.

The tomato expenditure elasticities of 0.85 for winter demand and 0.74 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 (1.3 and 1.5, respectively) and for winter and summer bell peppers (1.1 and 1.7, respectively) are much higher than the expenditure elasticities reported by Mittelhammer in 1978 (0.23 for cucumbers and 0.43 for bell peppers). No previous study reports expenditure or income elasticities for squash.

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.

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 biased and inconsistent if the correlation of total expenditures and the disturbance terms is not taken into account.

Consequently, 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 luxury goods.

Table 1. Barten Model Test Results (Including Onions).

Season/Model	Log Likelihood (Restricted)	Log Likelihood (Unrestricted)	Likelihood Ratio	Hypothesis Test χ^2 at 0.05 level [1]
U.S. Winter				
AIDS	315.95	325.33	18.75	Reject Ho
Rotterdam	323.30	325.33	4.06	Fail to Reject Ho
U.S. Summer				
AIDS	316.66	320.79	8.25	Reject Ho
Rotterdam	310.04	320.79	1.51	Fail to Reject Ho
Mexico Winter				
AIDS	138.95	143.41	8.92	Reject Ho
Rotterdam	138.14	143.41	10.54	Reject Ho
Mexico Summer				
AIDS	172.86	177.71	9.70	Reject Ho
Rotterdam	176.21	177.71	3.00	Fail to Reject Ho

[1] Critical value for χ^2 at 0.05 level and two degrees of freedom: 5.99

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

Season	Log Likelihood (Restricted)	Log Likelihood (Unrestricted)	Likelihood Ratio	Hypothesis Test χ^2 at 0.05 level [1]
Winter	314.82	319.42	8.39	Fail to Reject Ho
Summer	312.45	314.86	4.86	Fail to Reject Ho

[1] Critical value for χ^2 at 0.05 level and four degrees of freedom: 9.49

Table 3. Barten Model Test Results (Onions Excluded).

Season/Model	Log Likelihood (Restricted)	Log Likelihood (Unrestricted)	Likelihood Ratio	Hypothesis Test χ^2 at 0.05 level [1]
U.S. Winter				
AIDS	218.45	230.34	22.99	Reject Ho
Rotterdam	228.49	230.34	3.70	Fail to Reject Ho
U.S. Summer				
AIDS	234.21	237.73	7.05	Reject Ho
Rotterdam	236.80	237.73	1.86	Fail to Reject Ho
Mexico Winter				
AIDS	92.80	102.70	19.82	Reject Ho
Rotterdam	89.92	102.70	25.56	Reject Ho
Mexico Summer				
AIDS	122.51	126.63	8.22	Reject Ho
Rotterdam	125.09	126.63	3.08	Fail to Reject Ho

[1] Critical value for χ^2 at 0.05 level and two degrees of freedom: 5.99

Table 4. U.S. Rotterdam Model - Endogeneity of Expenditures Test Results.

Season	Log Likelihood (Restricted)	Log Likelihood (Unrestricted)	Likelihood Ratio	Hypothesis Test χ^2 at 0.05 level [1]
Winter	219.79	264.4	89.22	Reject Ho
Summer	230.90	268.16	74.51	Reject Ho

[1] Critical value for χ^2 at 0.05 level and five degrees of freedom: 11.07

Table 5. U.S. Winter Fresh Vegetable Rotterdam Model Parameter Estimates (3SLS) (Corrected for Endogeneity).

Variable	Tomatoes	Cucumbers	Squash	B. Peppers	Q
Price of Tomatoes	-0.0098 (-0.29)	0.0089 (0.59)	0.0210 (1.73)	-0.0201 (-0.74)	-0.0731 (-0.75)
Price of Cucumbers	0.0089 (0.59)	-0.0446 (-2.01)	0.0044 (0.59)	0.0313 (2.20)	-0.0149 (-0.21)
Price of Squash	0.0210 (1.73)	0.0044 (0.59)	-0.0156 (-0.87)	-0.0097 (-0.89)	-0.1881 (-3.08)
Price of Bell Peppers	-0.0201 (-0.74)	0.0313 (2.20)	-0.0097 (-0.89)	-0.0015 (-0.05)	-0.1385 (-1.73)
Q	0.5132 (8.06)	0.1836 (5.12)	0.1030 (3.40)	0.2002 (2.53)	-
DLINC	-	-	-	-	1.1711 (3.37)
R-Square	0.88	0.57	0.40	*	0.56
D-W Statistic	1.91	2.01	1.70	*	1.36

* Bell Pepper equation was omitted as discussed in the text. Parameters for this equation were recovered using the classical restrictions of Demand Theory.

** t-values are in parentheses.

Table 6. U.S. Summer Fresh Vegetable Rotterdam Model Parameter Estimates (3SLS) (Corrected for Endogeneity).

Variable	Tomatoes	Cucumbers	Squash	B. Peppers	Q
Price of Tomatoes	-0.0795 (-1.81)	0.0109 (0.50)	-0.0045 (-0.63)	0.0731 (1.99)	-0.0781 (-0.72)
Price of Cucumbers	0.0109 (0.50)	-0.0015 (-0.05)	0.0043 (0.71)	-0.0136 (-0.85)	0.3190 (2.28)
Price of Squash	-0.0045 (-0.63)	0.0043 (0.71)	-0.0049 (-0.46)	0.0051 (0.91)	-0.0043 (-0.11)
Price of Bell Peppers	0.0731 (1.99)	-0.0136 (-0.85)	0.0051 (0.91)	-0.0646 (-1.60)	0.0115 (0.13)
Q	0.5178 (3.90)	0.1502 (2.64)	0.0178 (0.95)	0.3142 (2.16)	-
DLINC	-	-	-	-	-0.4553 (-1.43)
R-Square	0.83	0.25	0.3	*	0.16
D-W Statistic	1.47	2.36	3.19	*	1.71

* Bell Pepper equation was omitted as discussed in the text. Parameters for this equation were recovered using the classical restrictions of Demand Theory.

** t-values are in parentheses.

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

Marshallian Elasticities

	Tomatoes	Cucumbers	Squash	Bell Peppers
Tomatoes	-0.529	-0.101	-0.032	-0.189
	(-5.61)	(-3.27)	(-1.36)	(-4.38)
Cucumbers	-0.747	-0.512	-0.073	-0.017
	(-3.58)	(-4.64)	(-1.19)	(-0.12)
Squash	-0.523	-0.122	-0.304	-0.364
	(-1.71)	(1.03)	(-2.78)	(-2.66)
Bell Peppers	-0.768	0.022	-0.138	-0.209
	(-2.81)	(0.27)	(-2.05)	(-1.42)

Hicksian Elasticities

	Tomatoes	Cucumbers	Squash	Bell Peppers
Tomatoes	-0.017	0.015	0.035	-0.033
	(-0.29)	(0.59)	(1.73)	(-0.75)
Cucumbers	0.065	-0.328	0.032	0.229
	(0.59)	(-2.01)	(0.59)	(2.20)
Squash	0.268	0.056	-0.201	-0.123
	(1.73)	(0.59)	(-0.87)	(-0.89)
Bell Peppers	-0.109	0.171	-0.053	-0.008
	(-0.74)	(2.20)	(-0.89)	(-0.05)

Expenditure Elasticities

	Tomatoes	Cucumbers	Squash	Bell Peppers
	0.852	1.349	1.313	1.093
	(8.06)	(5.12)	(3.40)	(2.53)

* t values are in parentheses

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

Marshallian Elasticities

	Tomatoes	Cucumbers	Squash	Bell Peppers
Tomatoes	-0.632 (-4.38)	-0.607 (-1.43)	-0.018 (-1.64)	-0.032 (-0.46)
Cucumbers	-0.912 (-2.28)	-0.165 (-0.70)	0.018 (0.31)	-0.402 (-2.25)
Squash	-1.056 (-1.23)	0.153 (0.37)	-0.327 (-1.60)	0.115 (0.31)
Bell Peppers	-0.792 (-1.75)	-0.183 (-2.19)	0.001 (0.04)	-0.664 (-3.24)

Hicksian Elasticities

	Tomatoes	Cucumbers	Squash	Bell Peppers
Tomatoes	-0.114 (-1.81)	0.016 (0.50)	-0.006 (-0.63)	0.105 (1.99)
Cucumbers	0.106 (0.50)	-0.015 (-0.05)	0.004 (0.71)	-0.132 (-0.85)
Squash	-0.279 (-0.63)	0.268 (0.71)	-0.309 (-0.46)	0.320 (0.91)
Bell Peppers	0.396 (1.99)	-0.074 (-0.85)	0.027 (0.91)	-0.350 (-1.60)

Expenditure Elasticities

	Tomatoes	Cucumbers	Squash	Bell Peppers
	0.743 (3.90)	1.461 (2.64)	1.114 (0.95)	1.705 (2.16)

*t values are in parentheses

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