Market Demand Systems for Food Groups: Linking Theoretical Restrictions with Empirical Applications

by

Jon A. Brandt, S. R. Johnson, Basile Goungetas and Abner Womack

MARKET DEMAND SYSTEMS FOR FOOD GROUPS: LINKING THEORETICAL RESTRICTIONS WITH EMPIRICAL APPLICATIONS

Jon A. Brandt, S.R. Johnson,
Basile Goungetas and Abner W. Womack*

1. Introduction

Most of the operational econometric forecasting and/or policy models for agricultural commodities include specifications for retail demand that are highly specialized. In particular, these specifications typically include as explanatory variables own-price, prices of close substitutes or complements, an income measure, and perhaps some other indicator for tastes and preferences. Elasticities obtained from these specifications tend to be sensitive to the choice of the sample period and minor modifications in the specification including alternative variable combinations and functional forms. These *ad hoc* specifications, together with their sensitivity to selections of sample data and variations in specification, result in models that often produce unsatisfactory forecasts and policy analyses. This problem is even more acute in livestock commodity models where there has been an ongoing discussion regarding changed structure of demand (Chavas; Pope, Green, and Eales). Unfortunately, the specifications utilized in evaluating these structural change

---

*Jon A. Brandt, Basile Goungetas and Abner Womack are, respectively, Visiting Associate Professor, Graduate Research Assistant and Associate Professor, Department of Agricultural Economics, University of Missouri, Columbia. S.R. Johnson is Professor, Department of Economics, Iowa State University.

hypotheses are <u>ad hoc</u>. Thus, the conclusions obtained have had little generality.

The traditional approach of agricultural economists to estimating disaggregated systems of consumer demand equations is suggested by the works of Brandow, George and King and Hassan and Johnson. According to this approach, homogeneity, symmetry, and adding-up conditions are applied along with selected income, own-price and cross-price elasticity estimates to "construct" a matrix of demand parameters. This method has produced operational demand systems at disaggregation levels sufficient to link agricultural commodity policies with consumption and retail prices.

The problem of developing appropriate sets of restrictions for full market demand systems is obviously complicated. In fact, it can be shown that without strong separability assumptions, the Slutsky restrictions from the individual demand theory do not carry over to market demand specifications. This has left demand researchers with a dilemma and perhaps explains the wide variations in specifications used in applied work. Recently, Safyurtlu et al. have shown that Slutsky restrictions can be applied in market demand systems estimation locally and stochastically.

In this analysis, the procedures suggested by Safyurtlu et al. for estimating the market demand system are employed. Comparisons of the results are discussed based on unrestricted ordinary least squares estimations of the demand system, exact restrictions of the Slutsky conditions, and mixed estimation where the restrictions are applied locally and stochastically. Results based on alternative specifications and degree of imposition of theoretical restrictions are reported and evaluated. In order to assess the issue of shifting structural demand for meat, the models are simulated over the historical period based on alternative expenditure budget shares. Conclusions are drawn based on these results.

2. The Theoretical Framework

Individual consumer demand theory has been well developed for some time; however, it is only relatively recently that a comparable understanding of market demand functions has been achieved. Just as consumer demand theory provides a basis for the study of properties common to demand functions generated by the utility maximization for an individual consumer, market demand theory investigates properties of market demand functions. Since market variables are observable and the focus of much of the price and income analysis at both private and governmental levels, it is important to understand the microfoundations of market demand.

When preferences are homothetic and the distribution of income is independent of prices, the market demand function has all of the properties of the individual consumer demand function (Eisenberg). However, with general and in particular, non-homothetic preferences, even if the income distribution is fixed, market demand functions need not satisfy the Slutsky restrictions (Sonnenschein, 1973a, 1973b; Diewert, 1976). The importance of these results for applied demand analysis is clear: strong assumptions are needed to justify use of the Slutsky restrictions in estimating market demand functions.

Empirically, the question of when the Slutsky restrictions carry over to market data has been the subject of extensive investigation (Deaton and Muellbauer). For market data, the Slutsky restrictions are usually rejected (Barten, Byron, Court, Lluch). Of course, these restrictions can be imposed by the utility function for the demand system, but this latter approach and variants that permit testing of the Slutsky restrictions and, in fact, separability assumptions are not feasible for disaggregated demand systems (Berndt et al., Christensen et al.).

The approaches to reconciling the microtheory with market demand have been highly pragmatic in nature. These have ranged from ad hoc constructed systems (Brandow, George and King, Hassan and Johnson) to exact restricted least squares applications imposing the Slutsky conditions (Byron, Court, Huang and Haidacher). More recently, explicit introduction of observable characteristics of consumers in estimating market demand equations has been investigated (Pollak and Wales, 1981). The present method follows this pragmatic bent and imposes the restrictions from the microtheory locally and stochastically.

Linear Demand Systems

For the local, stochastic approximation to the demand system, linearity in the structural parameters is assumed. Let the vectors of T observations on the $i = 1, \ldots, n$ commodity groups be denoted y_i. The concomitant observations on prices and income (or total food expenditure) are denoted by the matrix X_i of dimension $T \times ((n+1) = \ell)$. The demand equation for the ith commodity (or group) is then

$$y_i = X_i\beta_i + u_i \,, \tag{1}$$

where β_i is a conformable parameter vector and u_i is the vector of disturbances distributed with mean 0 and variance covariance matrix Ω_{ii}.

The full system of n demand equations can be expressed as

$$y = X\beta + u \tag{2}$$

where $y' = (y_1', y_2', \ldots, y_n')$, $\beta' = (\beta_1', \beta_2', \ldots, \beta_n')$, $u' = (u_1', u_2', \ldots, u_n')$ and X is a $nTxn\ell$ block diagonal matrix with diagonal submatrices X_i (Zellner).

Mixed Estimation

For the consumer optimization problem, there are $(n^2-n)/2$ symmetry restrictions, n homogeneity restrictions, and one Engel aggregation restriction. Moreover, these restrictions are appropriate for the individual consumer only for selected prices, quantities, and income or implicitly, budget proportions unless separability assumptions are imposed.

The market data include effects of heterogeneity of preferences, proxy variables for prices and incomes, and differences in the household production functions to mention a few of the reasons for inaccuracies in the Slutsky conditions. These inaccuracies are the basis for imposing the Slutsky restrictions stochastically.

The full set of stochastic restrictions based on the Slutsky conditions can be written

$$r = R\beta + v \tag{3}$$

where R is a matrix of dimension $Jx((n\ell) = K)$ with $J < K$ and r is a conformably defined vector of constants. The mixed estimation problem (Theil and Goldberger) is completed by assumptions on the distribution of the elements of v assumed distributed with mean 0, $E(v) = 0$, and diagonal variance covariance matrix $V = E(v\ v') = \sigma_v^2 I$.

The mixed estimator is

$$\hat{\beta}* = (X'\Omega^{-1}X + R'V^{-1}R)^{-1}(X'\Omega^{-1}y + R'V^{-1}r) \tag{4}$$

with covariance matrix

$$\text{var}(\hat{\beta}*) = (X'\Omega^{-1}X + R'V^{-1}R)^{-1} . \tag{5}$$

It is easily shown that $\text{var}(\hat{\beta}) - \text{var}(\hat{\beta}*)$, where $\hat{\beta}$ is the least squares estimator, is positive semidefinite (Fomby, Hill, and Johnson). The stochastic prior restrictions can be weighted more or less strongly relative to the sample data by incorporating a factor $1/\omega$. Then the mixed estimator is

$$\hat{\beta}_\omega = (X'\Omega^{-1}X + R'PV^{-1}P'R)^{-1}(X'\Omega^{-1}y + R'PV^{-1}P'r) \tag{6}$$

where P is a diagonal matrix with elements equal to $\omega^{-1/2}$. An <u>ad hoc</u> method of appropriately weighting the restrictions is to evaluate them using demand parameters estimated from the sample data alone. Applying these parameters and the average expenditure proportions, $\bar{r}$ and $\bar{R}$, distributions of the residuals for the Slutsky restrictions can be calculated. It is emphasized that specifying the Slutsky restrictions using $\bar{R}$ and $\bar{r}$ at their mean values implies the restrictions are "more true" for values of prices and quantities near the reference values than for other values of prices and quantities. This is the reason for defining the estimators as local approximations to the market demand system.

3. Data and Sources

Data for the market demand relationships are retail price indexes, per capita food consumption and per capita food expenditures. All prices and expenditures are deflated by a nonfood price index. Food consumption was disaggregated into four specific meat groups--beef, pork, poultry, and fish--and seven other food groups--eggs, dairy, fruits and vegetables, cereal and bakery products, sugar and sweeteners, fats and oils, and non-alcoholic beverages. Price data were obtained from the Bureau of Labor Statistics, food expenditure and consumption levels from the USDA. Expenditure budget shares used in the analysis were derived from selected BLS food surveys of 1960-61, 1972-73, and 1980-81, and the USDA food survey of 1965-66. Annual quantity, price, and expenditure data were obtained for the period 1961-1982.

To the extent possible, data were used which corresponded closely with those used by the Center for National Food and Agricultural Policy (CNFAP), University of Missouri-Columbia (CNFAP is a part of the Food and Agricultural Policy Research Institute (FAPRI) with the other center at Iowa State University). CNFAP maintains and operates a large econometric model of the U.S. agricultural sector. As a continuing part of this research effort, the results of this analysis will serve as input for the four livestock and product retail demand equations for beef, pork, poultry, and eggs. In addition, the indirect effects of demand for cereals and bakery goods, oils, sweeteners, and other commodities can be traced to the crop commodity equations. The time frame of estimation in this analysis coincides with that of the CNFAP agricultural model. Ultimately, the *ad hoc* demand equations currently in the CNFAP model will be replaced by the more theoretically appealing relationships developed in the market demand system approach.

4. Results

The eleven commodity system for food was estimated using double logarithmic functional form. As a result, all reported coefficients are price and expenditure elasticities with respect to the food commodity.[1] The model was estimated using unconstrained ordinary least squares, exactly restricted (Slutsky conditions) least squares, and mixed estimation where the restrictions were imposed locally and stochastically.

Alternative Estimation Procedures

Table 1 reports the elasticity estimates (and standard errors in parentheses) of the ordinary least squares regression. Note that the

---

[1]Deaton and Muellbauer have raised legitimate concerns about the estimation of double logarithmic demand models, particularly with respect to the imposition of theoretical restrictions. These concerns, though noted here, will be more fully explored in subsequent research by the authors.

own price elasticities (diagonal elements) for fish and cereal are of the wrong sign based on theoretical expectations. In addition, four of the other commodity own price elasticities, although correctly signed, are statistically insignificant. In addition, 74 of the 110 cross price elasticities are insignificant.

Table 2 shows the elasticities of the restricted least squares parameters. In this case, homogeneity, Engel, and symmetry conditions are constrained to hold exactly. The own price elasticities for fish, cereal and bakery products, sugar and sweeteners, and beverages are positive, although the fish and cereal coefficients are less positive than in Table 1. Twelve of the cross price elasticities are statistically insignificant. The own price and expenditure elasticities for chicken fell dramatically from those in the unconstrained case (Table 1).

The results of the mixed estimation approach are reported in Table 3. Here, the Slutsky restrictions are equally weighted with the sample data. Again, fish, cereal, and beverage own price elasticities are positive. The cereal own price elasticity is also statistically insignificant, as are 27 other cross price elasticity coefficients. The own price elasticity for chicken appears to be low, however, the expenditure elasticity is considerably higher than that in Table 2 (exact restrictions).

Although the results of Tables 1-3 may suggest that the estimates based on the exact restrictions (Table 2) are preferred, historical tracking of the actual versus predicted values of the dependent variables provides contrary evidence. Table 4 illustrates the performance of the three estimation procedures over the fit period 1961-1982. Both root mean squared error and mean absolute error results based on the predictive ability of the equations indicate severe problems for the restricted least squares for nearly all of the commodities. A casual comparison of Tables 1 and 2 will reveal substantial differences in the magnitudes and, occasionally, the signs of the coefficients, particularly for dairy and fruits and vegetables. These are the two worst predicting equations for the restricted least squares model. The mixed estimation results (Table 3) follow more closely those of the ordinary least squares estimates (Table 1).

While the ranking of results in Table 4 is not unexpected (because no constraints are placed on the OLS estimates, better predictive performance would be anticipated), the magnitude of the differences is quite shocking. It lends support to the conclusion reached by Barten, Byron, Court, Lluch, Safyurtlu et al., and others that for market data, the Slutsky restrictions are usually rejected, particularly when imposed exactly. The results obtained in Tables 1 and 2 are similar to those reported by Huang and Haidacher. However, the goodness of fit performance measures differ, particularly with respect to the constrained estimates. Our performance evaluation suggests a substantial decrease in performance as measured by the mean squared error criterion. The proof of the pudding is in the forecasting. The researchers of this analysis plan to compare the results of forecasting with the complete system demand parameters with those obtained based on <u>ad hoc</u> retail demand estimation procedures currently used in the CNFAP model.

Retail Demand for Meat

In recent years, analysts and persons in the meat production and distribution system have hypothesized that a shift in the structural demand for meat may have occurred based on consumers' awareness of health and diet issues, grading changes in the meat industry, and effect of more protein substitutes in the market place. Chavas suggested a method to explore structural shifts in the demand for beef, pork, and poultry. Using a varying parameter over time approach, Chavas reported to have identified structural change to have occurred in the demand for beef and for poultry but not for pork during the 1970s. This conclusion was based on changing price and income elasticities for poultry (both higher) and beef (both lower) and no changes for pork over the period. More recently, Moschini and Meilke obtained results partly in contrast to those obtained by Chavas. In particular, their results did not support any strong conclusions regarding structural change. As noted earlier in this paper, results obtained from these ad hoc specifications tend to be sensitive to the choice of the sample period and modifications in the specification.

As an alternative to the approach used by Chavas, the use of theoretical restrictions based on Slutsky conditions was applied in a mixed estimation specification (locally and stochastically). Different budget shares of consumers' expenditure on the food groups are employed to account for potential changes in food and particularly meat demand. Four sets of budget shares by food group available from cross sectional studies were explored: 1) 1960-61, 2) 1965-66, 3) 1972-73, and 4) 1980-81.

The results of the mixed estimation are presented in Tables 5-8. Of particular concern are the coefficients associated with the first three rows (respectively, beef, pork, and chicken) of each table. Note that with only two exceptions (egg/pork cross price elasticity in Table 5 and fats/beef cross price elasticity in Table 8), the signs of all coefficients are the same and of nearly the same magnitude. In particular, the beef own price elasticity varied from -.26 to -.32, pork -.95 to -.97, and chicken -.07 to -.12 while budget shares changed as much as 4 percent, 2 percent, and 1 percent for beef, pork, and chicken over the period. Furthermore, expenditure elasticities did not change at all (except for a .01 change in chicken in 1980-81). The results in this analysis indicate no evidence of a structural change in the demand for beef, pork, or chicken based on alternative budget shares over the estimated period.

5. Conclusions

An approach imposing prior restrictions from micro theory locally and stochastically was investigated for estimating market demand function and then compared with unrestricted and exact restricted estimation procedures. The mixed estimation approach produced plausible results for the United States. The approach is somewhat limited theoretically due to the heuristic basis for imposing the stochastic restrictions.

The approach offers some promise for both forecasting and policy analysis. By estimating a complete demand system, the potential problems associated with other, more _ad hoc_ approaches are avoided. However, out-of-sample forecasts were not generated using the retail demand equations as part of a larger agricultural economic model; this analysis is the next projected step in the research plan.

Some evidence was generated which suggests that structural shifts in the demand for red meats and chicken have not occurred. Further investigation in this area is also needed, however, the results based on the theoretically more appealing complete demand system approach appear reasonable.

Table 1. Unconstrained or Ordinary Least Squares Estimates of Elasticities and their Standard Errors for Eleven Food Groups in the United States.

	Price											
Quantity	Beef	Pork	Chicken	Fish	Eggs	Dairy	Fruits & Vegetables	Cereal & Bakery	Sugar & Sweeteners	Fats & Oils	Beverages	Food Expenditure
Beef	-.82 (.14)	.39 (.12)	-.08 (.18)	.31 (.16)	-.20 (.14)	1.1 (.28)	.55 (.28)	-1.8 (.48)	.57 (.18)	-.07 (.26)	-.33 (.08)	.75 (.01)
Pork	.29 (.07)	-1.1 (.06)	.12 (.10)	-.09 (.09)	.09 (.08)	.42 (.15)	-.21 (.15)	.83 (.26)	-.38 (.10)	-.16 (.14)	.04 (.05)	.69 (.01)
Chicken	.45 (.16)	.42 (.14)	-.79 (.21)	.09 (.19)	-.08 (.17)	-.08 (.33)	.28 (.34)	-.40 (.57)	.23 (.22)	-.36 (.31)	.01 (.10)	.56 (.00)
Fish	-.01 (.09)	-.04 (.08)	.02 (.12)	.51 (.10)	.14 (.10)	-.32 (.19)	-.07 (.19)	-.72 (.32)	.15 (.12)	.13 (.17)	-.12 (.06)	.38 (.01)
Eggs	.01 (.09)	-.27 (.08)	.28 (.12)	-.42 (.11)	-.11 (.10)	.19 (.19)	-.22 (.19)	.31 (.33)	-.30 (.12)	.13 (.18)	.05 (.06)	.53 (.01)
Dairy	-.23 (.15)	-.47 (.13)	.49 (.19)	-.27 (.17)	.09 (.16)	-.50 (.30)	-.39 (.31)	.61 (.52)	-.38 (.20)	.26 (.28)	.01 (.09)	.95 (.01)
Fruits & Vegetables	-.05 (.12)	-.43 (.10)	.29 (.15)	-.13 (.13)	.11 (.12)	-.57 (.24)	-.64 (.24)	.98 (.41)	-.34 (.16)	.05 (.22)	.07 (.07)	.94 (.01)
Cereal & Bakery	.05 (.11)	-.40 (.10)	.28 (.15)	-.06 (.13)	.08 (.12)	-.40 (.23)	-.47 (.24)	.99 (.40)	-.24 (.15)	-.12 (.21)	.05 (.07)	.80 (.01)
Sugar & Sweeteners	-.07 (.04)	-.20 (.03)	.03 (.05)	.15 (.04)	-.02 (.04)	-.24 (.08)	.13 (.08)	.17 (.14)	-.09 (.05)	-.19 (.07)	-.05 (.02)	.78 (.01)
Fats & Oils	.07 (.08)	.13 (.07)	-.24 (.10)	-.10 (.09)	-.07 (.08)	.02 (.16)	.17 (.16)	-.12 (.27)	.16 (.10)	-.35 (.15)	-.12 (.05)	.62 (.01)
Beverages	.08 (.07)	-.16 (.06)	.13 (.09)	.10 (.08)	-.17 (.07)	-.02 (.14)	.08 (.14)	.78 (.25)	-.04 (.09)	-.57 (.13)	-.06 (.04)	.68 (.01)
Budget Share	.181	.106	.046	.030	.029	.153	.179	.135	.036	.030	.076	

Table 2. Exact Restricted Least Squares Estimates of Elasticities and their Standard Errors for Eleven Food Groups in the United States.

	Price											
Quantity	Beef	Pork	Chicken	Fish	Eggs	Dairy	Fruits & Vegetables	Cereal & Bakery	Sugar & Sweeteners	Fats & Oils	Beverages	Food Expenditure
Beef	-.28 (.06)	.21 (.01)	.10 (.01)	.01 (.01)	-.02 (.01)	-.26 (.02)	-.27 (.04)	-.19 (.03)	-.03 (.01)	-.00 (.01)	.02 (.01)	.74 (.01)
Pork	.32 (.02)	-1.01 (.01)	-.02 (.01)	-.05 (.01)	.01 (.00)	-.06 (.01)	.03 (.02)	.17 (.02)	-.13 (.00)	-.03 (.01)	-.17 (.01)	.93 (.01)
Chicken	.51 (.05)	.06 (.02)	-.08 (.04)	.17 (.02)	.05 (.01)	-.37 (.04)	-.49 (.07)	-.29 (.25)	.25 (.01)	.05 (.02)	.10 (.02)	.04 (.00)
Fish	.04 (.03)	-.15 (.02)	.24 (.03)	.32 (.02)	-.31 (.01)	-.35 (.03)	.35 (.06)	-1.03 (.05)	.28 (.02)	.22 (.01)	-.18 (.01)	.56 (.00)
Eggs	-.16 (.02)	.03 (.01)	.04 (.01)	-.32 (.01)	-.34 (.01)	.11 (.01)	.25 (.02)	-.28 (.02)	-.09 (.01)	-.02 (.01)	-.19 (.01)	.91 (.00)
Dairy	-.46 (.02)	-.11 (.01)	-.18 (.01)	-.10 (.01)	.00 (.00)	-.27 (.02)	.06 (.03)	-.06 (.02)	-.19 (.01)	-.05 (.01)	-.21 (.01)	1.56 (.00)
Fruits & Vegetables	-.37 (.04)	-.02 (.02)	-.18 (.02)	.04 (.01)	.03 (.00)	.10 (.02)	-.41 (.06)	-.31 (.03)	.05 (.01)	-.07 (.01)	-.13 (.01)	1.27 (.00)
Cereal & Bakery	-.33 (.03)	.12 (.01)	-.15 (.02)	-.24 (.01)	-.07 (.01)	-.00 (.02)	-.39 (.04)	.15 (.04)	-.13 (.01)	.12 (.01)	.03 (.01)	1.13 (.01)
Sugar &	-.18 (.02)	-.37 (.01)	.29 (.01)	.23 (.01)	-.07 (.01)	-.69 (.02)	.36 (.04)	-.43 (.04)	.02 (.02)	.27 (.02)	-.20 (.01)	.77 (.00)
Fats & Oils	.03 (.03)	-.05 (.02)	.06 (.02)	.22 (.02)	.04 (.01)	-.07 (.03)	-.28 (.05)	-.43 (.04)	.33 (.02)	-.14 (.02)	-.13 (.01)	.43 (.00)
Beverages	.02 (.02)	-.22 (.01)	.02 (.01)	-.08 (.01)	-.07 (.00)	-.31 (.01)	-.22 (.03)	.09 (.02)	-.10 (.00)	-.06 (.01)	.09 (.01)	.84 (.00)
Budget Share	.181	.106	.046	.030	.029	.153	.179	.135	.036	.030	.076	

Table 3. Mixed Estimates of Elasticities and their Standard Errors for Eleven Food Groups in the United States (Average of Four Budget Shares).

	Price											
Quantity	Beef	Pork	Chicken	Fish	Eggs	Dairy	Fruits & Vegetables	Cereal & Bakery	Sugar & Sweeteners	Fats & Oils	Beverages	Food Expenditure
Beef	-.28 (.06)	.22 (.01)	.07 (.01)	.00 (.01)	-.01 (.00)	-.19 (.02)	-.17 (.04)	-.17 (.03)	-.02 (.00)	.00 (.01)	.02 (.01)	.75 (.00)
Pork	.39 (.02)	-.97 (.01)	-.02 (.01)	-.03 (.01)	.02 (.00)	.11 (.01)	.05 (.03)	.17 (.02)	-.11 (.00)	-.03 (.01)	-.12 (.01)	.68 (.00)
Chicken	.29 (.05)	-.05 (.02)	-.09 (.04)	.17 (.02)	.00 (.00)	-.17 (.04)	-.65 (.07)	-.29 (.04)	.16 (.01)	-.07 (.02)	.11 (.02)	.57 (.00)
Fish	.08 (.04)	-.07 (.02)	.27 (.03)	.35 (.03)	-.28 (.01)	-.34 (.03)	.22 (.06)	-.99 (.05)	.27 (.02)	.25 (.02)	-.14 (.01)	.38 (.00)
Eggs	.03 (.02)	.11 (.01)	.01 (.01)	-.29 (.01)	-.22 (.01)	.01 (.02)	.19 (.03)	-.49 (.03)	-.01 (.01)	.18 (.01)	-.17 (.01)	.52 (.00)
Dairy	-.25 (.02)	.05 (.01)	-.07 (.01)	-.08 (.01)	-.01 (.00)	-.37 (.02)	.01 (.03)	.02 (.02)	-.14 (.01)	-.01 (.01)	-.17 (.01)	.94 (.00)
Fruits & Vegetables	-.21 (.04)	.00 (.01)	-.18 (.02)	.02 (.01)	.02 (.00)	.01 (.02)	-.12 (.06)	-.05 (.03)	.03 (.01)	-.09 (.01)	-.14 (.01)	.94 (.00)
Cereal & Bakery	-.23 (.03)	.11 (.01)	-.11 (.02)	-.23 (.01)	-.11 (.01)	.04 (.02)	-.04 (.04)	.00 (.03)	-.05 (.01)	.00 (.01)	-.00 (.01)	.81 (.00)
Sugar & Sweeteners	-.13 (.02)	-.33 (.01)	.20 (.01)	.22 (.02)	-.01 (.01)	-.56 (.03)	.19 (.04)	-.17 (.04)	-.04 (.02)	.10 (.02)	-.12 (.01)	.78 (.00)
Fats & Oils	.03 (.03)	-.09 (.02)	-.11 (.02)	.24 (.02)	.18 (.01)	-.01 (.03)	-.50 (.06)	.04 (.04)	.12 (.02)	-.37 (.03)	-.04 (.01)	.62 (.00)
Beverages	.05 (.02)	-.16 (.01)	.06 (.01)	-.06 (.01)	-.07 (.00)	-.30 (.01)	-.27 (.03)	.02 (.02)	-.05 (.00)	-.02 (.01)	.11 (.01)	.68 (.00)
Budget Share	.181	.106	.046	.030	.029	.153	.179	.135	.036	.030	.076	

Table 4. Performance Measures of Three Alternative Estimation Procedures of a Complete Food Demand System.

Commodity	Ordinary Least Squares		Exact Restricted Least Squares		Mixed Estimation	
	RMSE[a]	MAE[B]	RMSE	MAE	RMSE	MAE
Beef	3.1	1.5	14.8	8.4	9.1	5.5
Pork	1.1	.6	1201.4	261.3	6.2	3.5
Poultry	1.3	.8	52.9	35.9	4.9	2.6
Fish	.3	.1	35.7	24.4	.9	.5
Eggs	.4	.3	1057.1	236.6	2.7	1.5
Dairy	10.7	6.3	22195.1	15276.0	50.9	27.8
Fruits & Vegetables	8.8	5.0	3376.6	2323.0	33.1	18.6
Cereal & Bakery	3.6	2.0	1380.0	950.6	10.9	5.7
Sugar & Sweeteners	1.1	.6	10.4	6.7	2.7	1.5
Fats & Oils	.8	.4	50.5	34.7	3.0	1.7
Beverages	1.1	.6	175.5	120.6	3.9	2.1

[a]Root Mean Squared Error.

[b]Mean Absolute Error.

Table 5. Mixed Estimates of Elasticities and their Standard Errors for Eleven Food Groups in the United States (Budget Shares for 1960-61).

	Price											
Quantity	Beef	Pork	Chicken	Fish	Eggs	Dairy	Fruits & Vegetables	Cereal & Bakery	Sugar & Sweeteners	Fats & Oils	Beverages	Food Expenditure
Beef	-.26 (.06)	.28 (.01)	.07 (.01)	.00 (.01)	-.01 (.00)	-.21 (.02)	-.19 (.05)	-.19 (.03)	-.03 (.01)	.01 (.01)	.02 (.01)	.75 (.00)
Pork	.42 (.02)	-.95 (.01)	-.03 (.01)	-.02 (.01)	-.02 (.00)	.11 (.01)	.00 (.03)	.16 (.02)	-.11 (.00)	-.03 (.00)	-.08 (.01)	.68 (.00)
Chicken	.28 (.05)	-.05 (.03)	-.10 (.04)	.17 (.02)	.03 (.01)	-.13 (.04)	-.63 (.08)	-.28 (.05)	.18 (.02)	-.11 (.02)	.07 (.02)	.57 (.00)
Fish	.06 (.04)	-.06 (.03)	.28 (.03)	.35 (.02)	-.32 (.01)	-.23 (.04)	.26 (.06)	-1.23 (.05)	.36 (.02)	.28 (.02)	-.15 (.01)	.38 (.00)
Eggs	-.01 (.02)	.09 (.01)	.04 (.01)	-.23 (.01)	-.21 (.01)	-.04 (.02)	.16 (.03)	-.51 (.02)	.00 (.01)	.18 (.01)	-.15 (.01)	.52 (.00)
Dairy	-.23 (.02)	.04 (.01)	-.05 (.01)	-.05 (.01)	-.03 (.00)	-.42 (.02)	-.01 (.03)	-.00 (.02)	-.14 (.01)	-.01 (.01)	-.11 (.01)	.93 (.00)
Fruits & Vegetables	-.20 (.04)	-.03 (.02)	-.16 (.02)	.02 (.01)	.02 (.01)	-.01 (.02)	-.14 (.06)	-.02 (.03)	.03 (.01)	-.11 (.01)	-.10 (.01)	.94 (.00)
Cereal & Bakery	-.22 (.03)	.11 (.02)	-.10 (.02)	-.24 (.01)	-.14 (.01)	.02 (.02)	-.01 (.04)	-.02 (.04)	-.03 (.01)	.02 (.01)	.01 (.01)	.80 (.00)
Sugar & Sweeteners	-.13 (.02)	-.34 (.01)	.20 (.02)	.25 (.01)	-.00 (.01)	-.58 (.03)	.18 (.04)	-.11 (.04)	-.05 (.02)	.07 (.02)	-.13 (.01)	.78 (.00)
Fats & Oils	.05 (.03)	-.08 (.02)	-.14 (.02)	.22 (.02)	.19 (.01)	-.01 (.03)	-.50 (.06)	.09 (.05)	.09 (.02)	-.37 (.03)	-.03 (.01)	.62 (.00)
Beverages	.07 (.02)	-.13 (.01)	.04 (.01)	-.08 (.01)	-.10 (.00)	-.29 (.02)	-.25 (.03)	.06 (.02)	-.08 (.01)	-.02 (.01)	.12 (.01)	.68 (.00)
Budget Share	.160	.109	.043	.027	.038	.168	.182	.143	.038	.034	.058	

Table 6. Mixed Estimates of Elasticities and their Standard Errors for Eleven Food Groups in the United States (Budget Shares for 1965-66).

	Price											
Quantity	Beef	Pork	Chicken	Fish	Eggs	Dairy	Fruits & Vegetables	Cereal & Bakery	Sugar & Sweeteners	Fats & Oils	Beverages	Food Expenditure
Beef	-.27 (.06)	.23 (.01)	.06 (.01)	.00 (.01)	-.01 (.00)	-.18 (.02)	-.20 (.05)	-.15 (.03)	-.02 (.00)	.00 (.00)	.01 (.01)	.75 (.00)
Pork	.40 (.02)	-.96 (.01)	-.02 (.01)	-.02 (.01)	.03 (.00)	.10 (.01)	.02 (.03)	.17 (.02)	-.10 (.00)	-.03 (.00)	-.10 (.01)	.68 (.00)
Chicken	.30 (.05)	-.05 (.03)	-.12 (.04)	.18 (.02)	.02 (.01)	-.13 (.04)	-.66 (.08)	-.28 (.05)	.17 (.01)	-.11 (.02)	.09 (.02)	.57 (.00)
Fish	.08 (.04)	-.06 (.03)	.28 (.03)	.34 (.01)	-.31 (.01)	-.29 (.04)	.22 (.06)	-1.08 (.05)	.31 (.02)	.27 (.02)	-.14 (.01)	.38 (.00)
Eggs	-.03 (.02)	.10 (.01)	.03 (.01)	-.26 (.01)	-.22 (.01)	-.01 (.02)	.12 (.03)	-.48 (.02)	-.00 (.01)	.19 (.01)	-.16 (.01)	.52 (.00)
Dairy	-.25 (.02)	.05 (.01)	-.05 (.01)	-.07 (.01)	-.02 (.00)	-.39 (.02)	-.03 (.03)	-.03 (.02)	-.13 (.01)	-.01 (.01)	-.14 (.01)	.94 (.00)
Fruits & Vegetables	-.21 (.04)	-.02 (.02)	-.15 (.02)	.01 (.01)	.01 (.00)	-.02 (.02)	-.10 (.06)	-.06 (.03)	.02 (.01)	-.07 (.01)	-.11 (.02)	.94 (.00)
Cereal & Bakery	-.23 (.04)	.13 (.02)	-.10 (.02)	-.24 (.01)	-.13 (.01)	.05 (.02)	-.08 (.05)	.00 (.04)	-.04 (.01)	.01 (.01)	.01 (.01)	.81 (.00)
Sugar & Sweeteners	-.13 (.02)	-.34 (.01)	.20 (.02)	.24 (.01)	-.01 (.02)	-.56 (.02)	.15 (.04)	-.13 (.04)	-.04 (.02)	.09 (.01)	-.13 (.01)	.78 (.00)
Fats & Oils	.04 (.03)	-.11 (.02)	-.16 (.02)	.26 (.02)	.22 (.01)	-.02 (.03)	-.48 (.06)	.05 (.05)	.12 (.02)	-.39 (.03)	-.05 (.01)	.62 (.00)
Beverages	.07 (.02)	-.16 (.01)	.05 (.01)	-.06 (.01)	-.08 (.00)	-.27 (.01)	-.27 (.04)	.03 (.01)	-.06 (.00)	-.02 (.01)	.11 (.01)	.68 (.00)
Budget Share	.182	.108	.041	.027	.033	.148	.204	.128	.034	.027	.068	

Table 7. Mixed Estimates of Elasticities and their Standard Errors for Eleven Food Groups in the United States (Budget Shares for 1972-73).

Quantity	Price											
	Beef	Pork	Chicken	Fish	Eggs	Dairy	Fruits & Vegetables	Cereal & Bakery	Sugar & Sweeteners	Fats & Oils	Beverages	Food Expenditure
Beef	-.32 (.06)	.19 (.01)	.07 (.01)	.01 (.01)	-.01 (.00)	-.18 (.02)	-.13 (.03)	-.14 (.03)	-.02 (.00)	.00 (.00)	.02 (.01)	.75 (.00)
Pork	.36 (.02)	-.97 (.01)	-.02 (.01)	-.04 (.01)	.02 (.00)	.11 (.01)	.06 (.02)	.16 (.02)	-.09 (.00)	-.02 (.01)	-.12 (.01)	.68 (.00)
Chicken	.30 (.06)	-.03 (.03)	-.08 (.04)	.16 (.02)	-.01 (.01)	-.23 (.04)	-.61 (.07)	-.29 (.04)	.12 (.01)	-.05 (.02)	.13 (.02)	.57 (.00)
Fish	.12 (.04)	-.10 (.02)	.26 (.03)	.34 (.03)	-.25 (.01)	-.40 (.03)	.17 (.05)	-.85 (.04)	.22 (.02)	.22 (.02)	-.11 (.01)	.38 (.00)
Eggs	-.06 (.02)	.11 (.01)	-.03 (.01)	-.31 (.01)	-.21 (.01)	.05 (.02)	.24 (.03)	-.50 (.03)	.02 (.01)	.17 (.01)	-.18 (.01)	.52 (.00)
Dairy	-.28 (.03)	.05 (.01)	-.10 (.01)	-.10 (.01)	-.00 (.00)	-.34 (.02)	.04 (.03)	.03 (.02)	-.12 (.01)	-.01 (.01)	-.19 (.01)	.94 (.00)
Fruits & Vegetables	-.20 (.05)	.02 (.02)	-.21 (.02)	.02 (.01)	.03 (.00)	.03 (.03)	-.14 (.06)	-.04 (.03)	.04 (.01)	-.10 (.01)	-.15 (.01)	.94 (.00)
Cereal & Bakery	-.24 (.04)	.12 (.02)	-.13 (.02)	-.23 (.01)	-.11 (.01)	.05 (.02)	-.02 (.04)	.02 (.04)	-.06 (.01)	-.00 (.01)	-.02 (.01)	.81 (.00)
Sugar & Sweeteners	-.15 (.02)	-.35 (.01)	.23 (.02)	.23 (.02)	.01 (.01)	-.56 (.03)	.22 (.04)	-.25 (.04)	.00 (.02)	.10 (.02)	-.13 (.02)	.78 (.00)
Fats & Oils	.03 (.03)	-.09 (.02)	-.08 (.03)	.24 (.02)	.15 (.01)	-.03 (.03)	-.48 (.05)	.02 (.04)	.11 (.02)	-.34 (.03)	-.03 (.01)	.62 (.00)
Beverages	.06 (.02)	-.17 (.01)	.08 (.01)	-.05 (.01)	.07 (.00)	-.31 (.02)	-.26 (.03)	-.01 (.02)	-.05 (.00)	-.01 (.01)	.10 (.01)	.68 (.00)
Budget Share	.205	.113	.051	.032	.026	.148	.159	.128	.030	.029	.079	

Table 8. Mixed Estimates of Elasticities and their Standard Errors for Eleven Food Groups in the United States (Budget Shares for 1980-81).

	Price											
Quantity	Beef	Pork	Chicken	Fish	Eggs	Dairy	Fruits & Vegetables	Cereal & Bakery	Sugar & Sweeteners	Fats & Oils	Beverages	Food Expenditure
Beef	-.28 (.06)	.20 (.01)	.06 (.01)	.00 (.01)	-.00 (.00)	-.17 (.02)	-.15 (.04)	-.18 (.03)	-.02 (.00)	-.01 (.01)	.01 (.01)	.75 (.00)
Pork	.38 (.02)	-.97 (.01)	-.02 (.01)	-.04 (.01)	.02 (.02)	.12 (.02)	.07 (.03)	.19 (.02)	-.13 (.01)	-.03 (.01)	-.16 (.01)	.68 (.00)
Chicken	.25 (.05)	-.04 (.02)	-.07 (.04)	.16 (.02)	-.01 (.01)	-.22 (.04)	-.65 (.07)	-.32 (.05)	.16 (.01)	-.02 (.02)	.18 (.02)	.56 (.00)
Fish	.08 (.04)	-.09 (.02)	.25 (.03)	.39 (.03)	-.23 (.01)	-.42 (.03)	.21 (.06)	-.84 (.05)	.19 (.02)	.24 (.02)	-.16 (.02)	.38 (.00)
Eggs	.00 (.02)	.13 (.01)	-.03 (.01)	-.36 (.01)	-.24 (.01)	.07 (.02)	.23 (.03)	-.44 (.03)	-.05 (.01)	.18 (.01)	-.19 (.01)	.53 (.00)
Dairy	-.24 (.02)	.05 (.01)	-.09 (.01)	-.11 (.01)	.00 (.00)	-.33 (.02)	.05 (.03)	.03 (.02)	-.16 (.01)	-.00 (.01)	-.24 (.01)	.94 (.00)
Fruits & Vegetables	-.19 (.04)	.01 (.02)	-.20 (.02)	.02 (.01)	.02 (.00)	.04 (.02)	-.10 (.06)	-.05 (.03)	.04 (.01)	-.10 (.01)	-.19 (.01)	.94 (.00)
Cereal & Bakery	-.24 (.04)	.11 (.01)	-.12 (.02)	-.21 (.01)	-.07 (.00)	.05 (.02)	-.04 (.04)	-.00 (.04)	-.04 (.01)	-.01 (.01)	-.03 (.01)	.81 (.00)
Sugar & Sweeteners	-.11 (.02)	-.31 (.01)	.19 (.02)	.15 (.02)	-.03 (.01)	-.55 (.02)	.19 (.04)	-.15 (.04)	-.07 (.02)	.12 (.01)	-.08 (.01)	.78 (.00)
Fats & Oils	-.01 (.03)	-.09 (.02)	-.02 (.03)	.24 (.02)	.12 (.01)	.02 (.03)	-.50 (.06)	-.02 (.05)	.17 (.02)	-.37 (.02)	-.02 (.01)	.62 (.00)
Beverages	.02 (.02)	-.15 (.01)	.02 (.01)	-.06 (.01)	-.04 (.00)	-.32 (.01)	-.29 (.02)	-.02 (.02)	-.03 (.00)	-.01 (.06)	.10 (.01)	.68 (.00)
Budget Share	.177	.094	.049	.033	.021	.046	.171	.140	.040	.031	.098	

REFERENCES

Barten, A.P. "Maximum likelihood estimation of a complete system of demand equations," European Economic Review 45 (1969):23-51.

Berndt, E.R.; Darrough, M.N.; and Diewert, W.E. "Flexible functional forms and expenditure distributions: An application to Canadian consumer demand functions," International Economic Review 18 (1977):651-675.

Brandow, G.E. Interrelationships Among Demands for Farm Products and Implications for Control of Market Supply, Pennsylvania Agricultural Experiment Station Bulletin 680, University Park, 1961.

Byron, R.P. "The restricted Aitken estimation of sets of demand relations," Econometrica 38 (1970):816-830.

Chavas, J.P. "Structural change in the demand for meat," American Journal of Agricultural Economics 65 (1983):148-153.

Christensen, L.R.; Jorgenson, D.W.; and Lau, L.J. "Transcendental logarithmic utility functions," American Economic Review 65 (1975):367-383.

Court, R.H. "Utility maximization and the demand for New Zealand meats," Econometrica, 35 (1967):424-446.

Deaton, A.S., and Muellbauer, J. Economics and Consumer Behavior, Cambridge University Press, New York, 1980.

Diewert, W.E. "Generalized Slutsky conditions for aggregate consumer demand functions," Discussion paper 76-05, University of British Columbia, 1976.

Eisenberg, B. "Aggregation of utility functions," Management Science 7 (1961):337-350.

Fomby, T.B.; Hill, R.C.; and Johnson, S.R. Advanced Econometric Methods, Springer-Verlag, New York, 1984.

George, P.S., and King, G.A. Consumer Demand for Food Commodities in the United States with Projections for 1980, Giannini Foundation Monograph 26, University of California, Davis, 1971.

Hassan, Z.A., and Johnson, S.R. Consumer Demand for Major Foods in Canada, Agriculture Canada, Economics Branch No. 76/2, April 1976.

Huang, K.S., and Haidacher, R.C. "Estimation of a composite food demand system for the United States," Journal of Business and Economic Statistics 1 (1983):285-291.

Lluch, C. "Consumer demand functions, Spain, 1958-64," European Economic Review 2 (1971):277-302.

Moschini, G., and K.D. Meilke. "Parameter stability and the U.S. demand for beef," Western Journal of Agricultural Economics 9 (1984):271-282.

Pollak, R.A., and Wales, T.J. "Demographic variables in demand analysis," Econometrica 49 (1981):1533-1551.

Pope, R.; Green, R.; and Eales, J. "Testing for homogeneity and habit formation in a flexible demand specification of U.S. meat consumption," American Journal of Agricultural Economics 62 (1980):778-784.

Safyurtlu, A.N.; Johnson, S.R.; and Hassan, Z.A. "A market demand system for food with stochastic, local slutsky restrictions." University of Missouri-Columbia, Department of Agricultural Economics, Working Paper, 1985.

Sonnenschein, H. "Do Walras' identity and continuity characterize the class of community excess demand functions?," Journal of Economic Theory 6 (1973a):345-354.

________. "The utility hypothesis and market demand theory," Western Economic Journal 11 (1973b):404-410.

Theil, H., and Goldberger, A.S. "On pure and mixed statistical estimation in economics," International Economic Review II (1961):65-78.

Zellner, A. "An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias," Journal of American Statistical Association 57 (1962):348-368.