A Bayesian Estimation of a Complete Demand System

by

Ann Wilkinson

A BAYESIAN ESTIMATION OF A COMPLETE DEMAND SYSTEM

Ann Wilkinson

INTRODUCTION

At a time when society is placing importance on analyzing the effectiveness of public policy aimed at consumers, farmers, and other intermediaries in the food industry, few analyses of disaggregated food commodities exist. Estimates of demand parameters for food commodities at the retail level generally follow two approaches, ad hoc or system methods. Ad hoc methods specify the demand for a commodity as a function of own price, price of other goods, population, income, and/or any other variables considered appropriate by the researcher. Consequently, parameter estimates vary across specifications. Alternatively, system methods are linked strongly to consumer allocation theory, which appropriates the total income of a consumer over the available set of commodities (Theil). A system approach utilizes consumer utility theory to derive the relationships among the demand parameters. By assuming the demand for food commodities is separable from nonfood commodity groups, it is possible to apply a system wide approach to disaggregated food commodities.

Demand equations derived from utility maximization by individual consumers level have particular properties. They are homogeneous in prices and income, have symmetric compensated cross price elasticities, and exhaust the budget constraint. These properties, homogeneity, symmetry, Engel and Cournot aggregation are generally referred to as Slutsky restrictions.

Household expenditure data at the aggregate level, including food data, has been aggregated across both commodity groups and consumers. Usually, demand system analysis is applied to household commodity groups. The consumption of a particular commodity group is dependent upon the prices of all commodity groups and income. By utilizing the assumption of weak separability, a commodity group, such as food, may be disaggregated from all household commodities. This subset of commodities can then be analyzed within a system framework. Consumption of a commodity group is dependent upon the prices of each of the commodity groups within the subset, total expenditures for the subset, and aggregate expenditures on all other commodities. The prices are generally a weighted average of prices within the commodity groups. Weak separability and weighted prices permit analysis of commodity groups which have been aggregated across individual commodities. Assumptions necessary for aggregation across consumers to be theoretically appropriate, however, are not well defined.

At the market level Slutsky restrictions do not hold except when preferences are homothetic and independent of prices (Eisenberg). Generally preferences, and particularly, non-homothetic preferences, need not satisfy Slutsky restrictions (Sonnenschien 1973a, 1973b). The importance of these results is clear: strong assumptions are needed to justify the use of Slutsky restrictions at the market level.

The author is a graduate research assistant in the Department of Agricultural Economics, University of Missouri-Columbia.

Two different types of demand systems have been defined. Rotterdam type models specify demand systems directly from the data. This model allows the user to impose Slutsky restrictions statistically in the estimation process. Slutsky restrictions can be applied to the Rotterdam model either individually or jointly. The Rotterdam model has been used extensively to test whether or not the results of consumer demand theory can be applied at the market level.

The second category specifies a cost or utility function from which a demand system is derived. Some of these demand functions are algebraic approximations of the demand functions, and are referred to as flexible functional forms. Demand functions derived from specific cost or utility functions may possess certain properties of consumer demand functions. The linear expenditure system, derived by algebraically imposing theoretical restrictions on a particular functional form, satisfies all of the Slutsky restrictions. Some flexible functional forms do not algebraically satisfy all of the restrictions.

The AIDS model inherently satisfies the adding up restrictions derived from the budget constraint. The results from utility maximization, homogeneity and symmetry can be imposed statistically. When a market demand function does not algebraically possess the properties of the consumer demand function, it is possible to test for properties by imposing them statistically.

Problems estimating demand systems at the market level have led to a continued use of Slutsky restrictions. Using Slutsky restrictions in combination with separability assumptions significantly reduces the number of demand parameters to be estimated. This can be important when the number of observations (degrees of freedom) are inadequate, or when it is necessary to compute systems in computers without large core capacity. Market demand systems involving a large number of commodities are often ill behaved due to multicollinearity among the dependent variables (Paulus). Aggregation problems across commodities, the introduction of new products into a commodity group, and changing exogenous factors may also effect parameter estimates. Restrictions can be applied in such cases to improve the properties of the demand system.

ROTTERDAM MODEL

The Rotterdam model, a directly estimatable demand function, was first introduced by Theil (1965) and Barten (1966). It was originally applied to aggregate household expenditures for the Netherlands and estimated using ordinary least squares. Since then, the model has been used widely for testing the appropriateness of applying Slutsky restrictions to market level data (Barten; Barnett). The model originally estimated by Barten was reestimated using a mixed estimation procedure by Paulus. The Goldberger-Theil mixed estimation procedure was used to combine sample evidence from 41 years of data on 14 household commodities with prior estimates of income elasticities. Keifer has also used the Rotterdam model as a basis for a Bayesian analysis of U.S. household commodity demand and labor supply. He utilized Slutsky restrictions as prior information in the estimation of the demand parameters.

The assumptions of weak separability allows one to estimate subsystems of household expenditures, such as food or clothing. Weak separability implies that the marginal rate of substitution between two food commodities or groups is independent of other nonfood consumption. The Rotterdam model has been used in the estimation of systems of food demand parameters for two reasons. It is linear in its parameters and hence, less expensive and time consuming to estimate when compared to non-linear flexible forms (i.e., Translog and Fourier Flexible Form). In addition, it does not require expenditure share data on disaggregated commodities which is necessary for many dual approximations of consumer demand equations (Huang and Haidacher).

The Rotterdam model may be written in elasticity form:

$$q = E_p p + Nm \tag{1}$$

where q is an (nx1) vector of relative changes in the quantity consumed of the ith commodity. The vector p represents the relative change in the price of the ith commodity. The matrix E_p is an nxn matrix of corresponding own and cross price elasticities, e_{ij}. The relative changes in consumption expenditures is denoted by the scalar m. This corresponds to an (nx1) vector of expenditure elasticities, N. Each element of N denotes the expenditure elasticity, n_i, of the ith commodity. The budget share of the ith commodity is denoted by w_i.[1]

The Slutsky restrictions in this notation are:

a. Engel Aggregation $$\sum_{i=1}^{n} w_i n_i = 1 \tag{2}$$

b. Cournot Aggregation $$\sum_{i=1}^{n} w_i e_{ij} = -w_j \tag{3}$$

c. Homogeneity $$\sum_{j=1}^{n} e_{ij} = -n_i \tag{4}$$

d. Symmetry $$\left(\frac{e_{ji}}{w_i}\right) + n_j = \left(\frac{e_{ij}}{w_j}\right) + n_i \tag{5}$$

The adding up restrictions, Engel and Cournot aggregation, insure that the net of effect of a change in price on expenditures is zero, and that the marginal propensities to consume sum to one. These properties are derived by differentiating the budget constraint with respect to income and prices. Aggregation across consumers results in an aggregate budget constraint still possessing the same properties as an individual budget constraint. When Engel aggregation, homogeneity and symmetry restrictions are imposed fully, Cournot aggregation restrictions are redundant. However, in the absence of a fully restricted model, it would be inconsistent to apply one of the adding up restrictions and not the other. Therefore, Cournot and Engel aggregations are exactly imposed in the model.

Homogeneity and symmetry conditions are derived from the demand curves. Homogeneity conditions are derived by differentiating the demand curve with respect to prices and income. Homogeneity guarantees that proportionate changes in prices and quantities will not affect purchases of a given commodity. Symmetry conditions are derived from the Slutsky equation for a particular demand relationship. This condition guarantees that the compensated cross price elasticities for a pair of goods are equal.

Homogeneity and symmetry conditions may be imposed on the system or tested for. In his 1969 analysis of Dutch household expenditures, Barten found that the homogeneity property did not apply at the market level. Symmetry conditions applied simultaneously with the homogeneity restrictions, also conflicted with consumer theory. Since then, other analyses using different data series have also concluded that the market level homogeneity and symmetry restrictions do not hold when applied to the Rotterdam model (Deaton, 1974a; Barten, 1970a, 1970b).

There are problems in rejecting homogeneity and symmetry based on these results alone. The F-test used to test the restrictions is asymptotically biased. When the sample size is large relative to the number of commodities, restrictions of any sort are more likely to be rejected (Keifer).

The majority of studies which have tested homogeneity and symmetry conditions have used the Rotterdam model as the theoretical framework. Questions still remain whether the homogeneity restriction fails when applied specifically to this model or whether this restriction does not hold in general at the market level. Recent work has centered on the approximation method used to generate the Rotterdam model. It is a local approximation with constancy of the parameters acquired by evaluating the parameters at a "point of approximation" (Barnett, 1984). But, this "point of approximation" is in general unknown and may not even be in the range of the data (Wohlgenant). Thus, there is no assurance that this model will approximate the true demand system.

In view of the weak theoretical link between the property of consumer demand and market demand theory, applying Slutsky restrictions as prior information is intuitively attractive. Conventional estimation methods, with the exception of the Goldberger-Theil technique, require that a system is estimated either totally restricted or unrestricted. The Bayesian procedure offers a method to utilize Slutsky restriction according to how much information is provided by the data. Any information known about the parameters can be summarized in a probability distribution of possible values. This probability represents a degree of belief about the distribution of the parameters instead of a frequency obtained from repeated sampling (Zellner).

A Bayesian procedure has been applied to a system of household expenditure and labor supply data by Keifer. In that analysis, a modal approximation is used to obtain point estimates of demand parameters. Results from Keifer's analysis suggest that this would be an appropriate method to apply to a system of food demand equations. Keifer's notation on the Bayesian estimation procedure was utilized in the following section.

ESTIMATION

An error term is added to equation (1) to yield:

$$y = \underline{\bar{X}}B + u \tag{6}$$

where y is a vector of dimension $nT \times 1$. The number of food groups is n, and T represents the number of years of data. The matrix $\underline{\bar{X}}$ is equal to the Kronecker product of an nxn identity matrix, I_n, and the design matrix X; or I_nxX. The dimensions of X are (n + 2) x T; X contains n vectors of price data plus an expenditure and intercept vector. The elements of the error term, u, are assumed to be normally distributed, with mean zero and constant variance, $\Sigma \otimes I_n$, or Eu = 0 and Euu' = $\Sigma \otimes I_n$. B is an ((n + 2) x n) x 1 vector of parameters to be estimated.

The likelihood function can be written

$$y \sim N(XB, \Sigma \otimes I_n). \tag{7}$$

Restrictions (2) and (3), Engel and Cournot aggregations which are derived from the budget constraint, are assumed to hold exactly. Since individual consumers exhaust their expenditures, aggregation across consumers does not lead to a violation of the budget constraint. However, there is still uncertainty surrounding the results of utility maximization at the aggregate level. Restrictions arising from utility maximization, homogeneity and symmetry, are used as prior information. These restrictions may be written

$$\beta = Qg. \tag{8}$$

The prior density function on B may be written

$$\beta \sim N(Qg, \sigma^2 I_n). \tag{9}$$

The restrictions Qg are assumed to hold locally, or at the mean, and they are stochastic.

In reality, the mean of the distribution of B is unknown, therefore a diffuse prior on σ^2 and Σ are chosen:

$$p(\sigma^2) = 1/\sigma^2$$

$$p(\Sigma) = |\Sigma| \frac{(n+1)}{2} \tag{10}$$

The joint density function over B, Y, g, Σ and σ^2 is formed by combining (7), (9), (10), and a uniform density function for g. From this joint p.d.f. the parameter g is first integrated out. The remaining density is proportional to:

$$|\Sigma| \frac{-(T+n+1)}{2} \exp \{-\tfrac{1}{2}(y-X\beta)^t(\Sigma^{-1}\otimes I)(y-X\beta)\} \tag{11}$$

$$x(\sigma^2)^{-m/2} \exp \{-\tfrac{1}{2} \{\beta-Q(Q^5Q)^{-1}Q^t\beta\}^t \{\beta-Q(Q^tQ)^{-1}Q^t\beta\}$$

Once the parameters σ^2 and Σ are integrated out, the mean of the marginal distribution of β could be used as a point estimate for β. This integration process would have to be carried out in m-space, where m is the number of elements in β.

Keifer utilized a modal approximation of the marginal distribution of β as point estimates for β. This procedure involved setting the derivatives of (11) with respect to Σ and σ^2 equal to zero and solving for the modal estimators $\Sigma*$ and σ^2. Once these were found, they could be inserted into the mean of the posterior distribution of β to obtain mean values for β.

Fortunately, it has recently been shown that the mean of the Bayes estimator is identical to the estimates derived from the Goldberger-Theil estimation procedure (Deiderich). Because of the algebraic complexity of configuring the matrix Q, this latter method was used to derive the actual estimates.

For comparison purposes (6) was estimated using ordinary least squares with the adding up restrictions and again with all of the restrictions holding exactly.

DATA

Twelve food commodity groups are used in this analysis. The five meat groups are: beef, pork, poultry, fish, and other meats. Both beef and veal consumption are included in the beef category. The poultry category is composed of both turkey and chicken. The fish quantities include fresh, frozen, canned, and cured products. Other meats are comprised of the edible offals. This category includes processed meats and lamb. The seven other groups are eggs, fruits and vegetables, cereals and bakery products, sugars and sweeteners, fats and oils, dairy products and beverages. The data consist of annual U.S. per capita observations for the years 1951-1983. Price indexes, food expenditures, and consumption levels have been obtained from the USDA bulletins Food Consumption, Prices, and Expenditures (FCPE), 1951-63, and the FCPE for 1963-83. The price data were originally in base 1957-59 and base 1967 periods. They were converted into base 1972 for consistency. In most cases the price data corresponds well to the consumption data. However, the price index for fish is simply based on canned prices. The consumption data is in per capita form. Mid-year U.S. resident civilian population was used as a divisor.

Budget share weights necessary for much of the computations have been derived from value aggregates, found in FCDE, for food items for the periods 1957-1959 and 1965-1968. Simple average of the two series were used.

RESULTS

The results of the estimation of the three systems of food demand equations are presented in Tables 1, 2 and 3. Both of the systems are in double log form, hence the coefficients represent uncompensated demand elasticities. An intercept term was added to the systems to account for changing taste over time.

The estimates calculated using prior information are reported in Table 1. The adding up restriction were fully imposed while simultaneously using the restriction from utility maximization as prior information. These restrictions are calculated using budget shares and local prices and quantities.

With the exception of the fish coefficient, all of the own price elasticities are negative. The own price elasticities for dairy and other meats, although negative, were insignificant. In comparison to the OLS estimates from Table 2, a substantially greater number of price elasticity estimates, 86 of the 144, were statistically significant at the 5 percent level. The income elasticity of the dairy group was the only negative and only insignificant income coefficient.

The coefficients in Table 2 are Ordinary Least Squares Estimates which satisfy the budget constraint. These estimates were obtained by applying the adding up restriction to the model.

It is necessary to use food budget shares in the restriction calculations. These budget shares are listed beneath the matrix of demand coefficients. The adding up restrictions may be verified by multiplying the vector of budget shares by the first (n + 1) columns of the demand matrix. The first n products will be the negatives of the budget shares (Cournot Aggregation) and the (n + 1) the product will be one (Engel Aggregation).

Ten of the twelve own price elasticities in Table 2 have the correct sign. The fish and sugar elasticities had the wrong sign. However, the sugar coefficient was insignificant.

Approximately 50 of the 144 price elasticities and eleven of the twelve income elasticities are significant. The beef, pork, and other meat categories had the greatest income elasticities.

The own price elasticity for fish had the wrong sign in both sets of estimates. This problem could be due to the price data used. As noted earlier, the price index for fish is based on the price of canned fish. The proportion of canned fish consumed relative to other fish products is less than half.

The exactly restricted least squares estimates are reported in Table 3. Homogeneity, Engel and Cournot aggregation and symmetry conditions hold exactly using the unrounded estimates. With the exception of fish and dairy, all of the own price elasticities have the expected negative sign, and only one of these is statistically insignificant. Many more, 96 of the 122, cross price elasticities were significant when compared to the adding up of restricted OLS estimates.

The performance of the three estimation procedures over the fit period 1951-1983 is illustrated in Table 4. There is little difference between the percentage root mean squared error (PRMSE) and mean absolute percentage error (MAPE) based on predictive ability of the equations for the three sets of estimates.

This implies that insignificant predictive power was lost by utilizing homogeniety and symmetry as prior information. Yet the behavioral difference between the systems, as judged by the number of significant coefficients and expected signs, is much different. The Bayes estimates had a slightly higher proportion of expected signs.

Surprisingly there is not much difference between the PRMSE for the adding up restricted estimates and the fully restricted estimates. The imposition of homogeneity and symmetry restrictions, in the presence of adding up restrictions, does not change the predictive power of the estimates substantially.

CONCLUSION

This paper introduces an intuitively appealing method to apply the results from economic theory to a system of demand equations. Adding up properties, which hold at the consumer level as well as the aggregate level, are displayed in the Bayes estimates. The properties derived from utility maximization, homogeneity and symmetry, are used as "prior information" in the derivation of the estimate. The results indicate that there is no difference in the statistical errors of the Bayes estimates compared with the adding up or exactly restricted estimates. The Bayes estimates, however, have more intuitively appealing coefficients.

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 stop in the research plan.

TABLE 1 BAYES ESTIMATES OF ELASTICITIES CALCULATED USING HOMOGENEITY AND SYMMETRY CONDITIONS AS PRIOR INFORMATION AND THEIR STANDARD ERRORS FOR TWELVE FOOD GROUPS IN THE UNITED STATES, 1951-1983

	Beef	Pork	Poultry	Fish	Other Meats	Eggs	Dairy	Fruits and Vegetables	Cereals	Sugars and Sweeteners	Fats and Oils	Beverages	Expenditures	Constant
Beef	-1.05	.04	-.09	-.02	-.11	-.07	-.42	.00	-.29	-.11	-.07	-.31	2.95	-13.81
	.07	.05	.03	.02	.05	.03	.11	.13	.08	.04	.03	.03	.11	.70
Pork	.12	-.90	.04	.06	-.07	-.07	-.30	-.54	-.17	-.17	-.01	-.10	2.14	-9.12
	.04	.04	.03	.02	.04	.02	.09	.08	.07	.04	.03	.02	.08	.49
Poultry	.24	.04	-.07	-.09	.06	-.02	-.26	-.01	-.07	-.04	-.01	.03	1.03	-2.58
	.05	.04	.03	.03	.05	.02	.09	.08	.07	.04	.03	.02	.08	.49
Fish	.09	.24	-.11	.39	-.34	-.20	-.64	-.22	-.61	-.01	-.08	-.09	1.49	-6.80
	.08	.05	.03	.06	.09	.03	.10	.08	.10	.05	.04	.03	.10	.59
Other Meats	-.37	-.25	-.11	-.25	-.23	-.09	-.34	-.49	.29	-.49	-.06	-.15	2.42	-12.25
	.13	.07	.04	.05	.16	.03	.13	.11	.12	.06	.05	.03	.11	.70
Eggs	-.02	-.04	.09	-.22	.04	-.14	.33	-.34	-.39	-.09	.08	.03	.36	1.50
	.04	.03	.02	.02	.04	.02	.06	.05	.05	.02	.02	.01	.05	.31
Dairy	-.05	.01	.05	-.06	-.02	.03	-.01	-.07	.04	-.10	-.03	.03	-.03	6.02
	.03	.03	.02	.02	.04	.02	.07	.06	.06	.03	.02	.01	.05	.34
Fruits and Vegetables	.07	.00	-.02	.03	.02	.00	-.11	-.46	.01	.07	-.03	.10	.09	5.56
	.04	.03	.02	.02	.03	.02	.07	.08	.06	.03	.02	.02	.07	.41
Cereals	-.01	-.02	.00	-.05	.13	-.01	.19	-.22	-.24	.18	.02	.06	.02	4.84
	.05	.03	.02	.02	.05	.02	.07	.07	.07	.03	.02	.02	.07	.41
Sugars and Sweeteners	.14	-.09	.02	.00	-.27	-.07	-.32	.26	.02	-.10	.05	-.08	.84	-.36
	.06	.05	.03	.03	.05	.03	.11	.11	.08	.05	.03	.03	.10	.61
Fats and Oils	-.06	-.01	-.08	-.05	-.06	-.08	-.49	-.23	-.03	.07	-.29	-.08	1.70	-6.65
	.06	.04	.03	.03	.07	.02	.09	.08	.08	.04	.04	.02	.08	.49
Beverages	-.28	-.20	-.07	-.07	-.02	-.11	-.38	-.16	-.14	-.22	-.04	-.40	1.84	-8.60
	.06	.06	.03	.03	.04	.03	.12	.13	.09	.04	.03	.03	.12	.75
Budget Shares	.141	.089	.042	.024	.038	.038	.170	.221	.102	.054	.030	.052		

TABLE 2 ORDINARY LEAST SQUARES ESTIMATES OF ELASTICITIES AND THEIR STANDARD ERRORS FOR TWELVE FOOD GROUPS IN THE UNITED STATES, 1951-1983

	Beef	Pork	Poultry	Fish	Other Meats	Eggs	Dairy	Fruits and Vegetables	Cereals	Sugars and Sweeteners	Fats and Oils	Beverages	Expenditures	Constant
Beef	-.66	.30	-.25	-.05	-.67	-.13	.07	.34	-.22	-.20	-.10	-.30	2.57	-11.43
	.33	.16	.10	.14.	41	.09	.29	.23	.41	.16	.15	.07	.24	1.49
Pork	-.28	-1.06	.08	.10	.39	-.11	-.20	-.50	-.35	-.13	.07	-.16	2.17	-9.28
	.16	.08	.05	.07	.20	.04	.14	.11	.20	.08	.07	.04	.12	.72
Poultry	-.36	-.12	-.60	-.04	.86	-.07	-.20	-.06	-.02	-.02	-.04	-.03	.98	-2.26
	.14	.07	.04	.06	.18	.04	.12	.10	.18	.07	.07	.03	.10	.64
Fish	-.39	.05	-.19	.47	.24	-.06	-.64	-.21	-1.02	.16	.00	-.15	1.52	-6.94
	.14	.07	.04	.06	.17	.04	.12	.10	.17	.07	.06	.03	.10	.63
Other Meats	.10	-.01	-.26	-.29	-.83	-.08	-.02	-.41	.53	-.59	-.16	-.09	2.18	-10.77
	.23	.11	.07	.10	.29	.06	.20	.16	.29	.11	.11	.05	.17	1.05
Eggs	.12	-.04	.12	-.38	-.16	-.15	.16	-.34	-.35	-.11	.17	.05	.63	-.14
	.11	.05	.03	.04	.13	.03	.09	.07	.13	.05	.05	.02	.08	.47
Dairy	.24	.11	.05	-.24	-.36	.01	-.14	-.04	.07	-.13	.04	.07	.15	4.91
	.11	.05	.03	.04	.13	.03	.09	.07	.13	.05	.05	.02	.08	.47
Fruits and Vegetables	.09	-.09	.04	.04	-.01	.08	-.45	-.65	.23	.03	-.06	.11	.36	3.87
	.16	.08	.05	.07	.20	.04	.14	.11	.20	.08	.07	.04	.12	.73
Cereals	-.02	-.03	.07	.08	.13	.00	.07	-.33	-.23	.20	-.07	.05	-.01	5.06
	.16	.08	.05	.07	.20	.04	.14	.11	.20	.08	.07	.03	.12	.71
Sugars and Sweeteners	-.39	-.17	-.01	.29	.41	-.07	.06	.28	-.46	.11	-.07	-.14	.37	2.53
	.23	.11	.07	.10	.28	.06	.20	.16	.29	.11	.11	.05	.17	1.04
Fats and Oils	-.32	-.12	.00	.02	.24	-.15	-.39	-.18	-.02	.06	-.28	-.13	1.65	-6.30
	.14	.07	.04	.06	.17	.04	.12	.10	.17	.07	.06	.03	.10	.63
Beverages	-.71	-.27	-.09	-.10	.73	-.16	-.37	-.27	-.69	-.06	.10	-.40	1.68	-7.59
	.33	.16	.10	.14	.41	.09	.29	.13	.41	.16	.15	.07	.24	1.50
Budget Shares	.141	.089	.042	.024	.038	.038	.170	.221	.102	.054	.030	.052		

TABLE 3 EXACTLY RESTRICTED LEAST SQUARES ESTIMATES OF ELASTICITIES AND THEIR STANDARD ERRORS FOR TWELVE FOOD GROUPS IN THE UNITED STATES, 1951-1983

	Beef	Pork	Poultry	Fish	Other Meats	Eggs	Dairy	Fruits and Vegetables	Cereals	Sugars and Sweeteners	Fats and Oils	Beverages	Expenditures	Constant
Beef	-.98 .05	.02 .02	-.02 .01	.01 .01	-.10 .04	-.07 .01	-.61 .03	-.53 .05	-.41 .03	-.07 .02	-.05 .01	-.25 .02	3.07 .06	-14.52 .36
Pork	.18 .03	-.89 .03	.03 .01	.07 .01	-.12 .02	-.09 .01	-.32 .03	-.42 .04	-.21 .02	-.09 .02	.00 .01	-.14 .01	1.99 .04	-8.16 .25
Poultry	.23 .04	.16 .03	-.77 .03	-.03 .02	.06 .03	.05 .01	-.24 .06	-.27 .06	-.13 .03	.08 .02	-.05 .02	-.01 .02	.91 .07	-1.86 .41
Fish	.27 .07	.33 .04	-.07 .03	.33 .05	-.56 .08	-.33 .02	-.53 .09	-.18 .08	-.51 .07	-.10 .04	-.02 .03	-.07 .02	1.44 .08	-6.46 .50
Other Meats	-.31 .13	-.34 .06	-.01 .04	-.38 .05	-.18 .16	-.17 .03	-.39 .11	-.65 .09	.44 .09	-.56 .05	-.07 .05	-.07 .03	2.67 .09	-13.81 .57
Eggs	.11 .03	-.05 .02	.08 .01	-.18 .01	-.08 .03	-.11 .01	.36 .03	-.19 .03	-.14 .03	-.19 .02	.00 .01	.06 .01	.33 .03	1.65 .21
Dairy	-.06 .02	.01 .02	-.02 .01	-.04 .01	.02 .02	.10 .01	.13 .04	-.06 .04	.09 .02	-.13 .02	-.06 .01	.07 .01	-.03 .04	6.03 .22
Fruits and Vegetables	.08 .03	.00 .02	-.02 .01	.01 .01	-.01 .02	-.02 .01	-.06 .03	-.10 .04	-.08 .02	.04 .01	-.01 .01	.08 .01	.08 .04	5.64 .23
Cereals	-.12 .04	.00 .02	-.01 .01	-.08 .02	.27 .04	-.04 .01	.15 .04	-.14 .04	-.17 .04	.16 .02	.01 .02	.03 .01	-.07 .04	5.43 .26
Sugars and Sweeteners	.15 .04	-.04 .03	.07 .02	-.03 .02	-.32 .03	-.15 .01	-.55 .05	.02 .06	.23 .04	-.14 .03	.12 .02	-.11 .02	.76 .06	.13 .37
Fats and Oils	-.04 .05	.03 .03	-.10 .02	-.01 .03	-.04 .06	-.05 .02	-.61 .07	-.37 .06	-.10 .05	.17 .03	-.30 .04	-.11 .02	1.55 .06	-5.74 .40
Beverages	-.55 .04	-.25 .02	-.06 .01	-.05 .01	-.03 .02	-.02 .01	-.16 .04	-.12 .05	-.16 .02	-.19 .02	-.08 .01	-.49 .03	2.16 .07	-10.58 .40
Budget Shares	.141	.089	.042	.024	.038	.038	.170	.221	.102	.054	.030	.052		

TABLE 4 PERFORMANCE MEASURES OF TWO ALTERNATIVE ESTIMATION PROCEDURES OF A COMPLETE FOOD DEMAND SYSTEM[a]

Commodity	Bayes Estimates		Ordinary Adding Up Restricted Least Squares		Exact Restricted Least Squares	
	PRMSE	MAPE	PRMSE	MAPE	PRMSE	MAPE
Beef	5.52	.28	5.49	.34	5.67	.20
Pork	6.17	.42	6.16	.43	6.19	.42
Poultry	.61	.04	.45	.01	.75	.03
Fish	10.36	.50	10.34	.58	10.40	.53
Other Meats	14.93	.70	14.93	.76	14.97	.65
Eggs	3.69	.18	3.67	.16	3.73	.19
Dairy	1.04	.05	1.01	.04	1.07	.05
Fruits and Vegetables	1.14	.04	1.11	.05	1.19	.04
Cereals and Bakery	.61	.01	.61	.01	.81	.01
Sugars and Sweeteners	1.09	.06	.98	.07	1.25	.04
Fats and Oils	2.51	.06	2.50	.06	2.54	.05
Beverages	14.30	.30	14.28	.35	14.35	.33

[a]PRMSE is percentage root mean squared error, MAPE is mean absolute percentage error.

REFERENCES

Barnett, W.A. "On the Flexibility of the Rotterdam Model." European Economic Review 24(1984): 285-89.

Barten, A.P. "Evidence on the Slutsky Conditions for Demand Equations." The Review of Economics and Statistics 49(1967): 77-84.

________. "Maximum Likelihood Estimation of a Complete System of Demand Equations." European Economics Review 45(1969): 7-73.

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

Deiderich, G.T. "The Kalman Filter from the Perspective of Goldberger-Theil." The American Statistician 39(1985): 193-98.

Eisenberg, B. "Aggregation of Utility Functions." Management Science 7(1961): 337-50.

Huang, K.S. and R.C. Haidacher. "Estimation of a Composite Food Demand System for the United States." Journal of Business and Economic Statistics 1(1983): 285-91.

Keifer, N.M. "A Bayesian Analysis of Commodity Demand and Labor Supply." International Economics Review 18(1977): 209-18.

Paulus, J.D. "Mixed Estimation of a Complete System of Consumer Demand Equations." Annals of Economic and Social Measurement 4(1975): 117-31.

Sonnenschein, H. "Do Walras' Identify and Continuity Characterize the Class of Community Excess Demand Functions?" Journal of Economic Theory 6(1973a): 345-54.

________. "The Utility Hypothesis and Market Demand Theory." Western Economic Journal 11(1973b): 404-10.

Theil, Henri. The System-Wide Approach to Microeconomics, The University of Chicago Press, Chicago, 1980.

Wohlgenant, Michael K. "Conceptual and Functional Form Issues in Estimating Demand Elasticities for Food." American Journal of Agricultural Economics 66(1984): 211-15.