FOOD DEMAND ANALYSIS

Implications for Future Consumption

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Global Behavior of Demand Elasticities for Food: Implications for Demand Projections

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A common approach to forecasting demand for food is to choose a particular change in real income for the forecast period and apply a constant income elasticity to this growth rate for some constant set of real commodity prices (see, e.g., George and King, 1971). A problem with this approach is that constant elasticities eventually will lead to violation of the budget constraint unless income elasticities are equal to unity (Deaton and Muellbauer, 1980, Chapter 1). One way to avoid this problem is to allow elasticities to change proportionately with budget shares (as in the Linear Expenditure System or Rotterdam Model), but this method can force a particular relationship between income elasticities and income which may not be compatible with the data (deJanvry, 1976).

From an econometric standpoint, the problem is to choose a model which satisfies the general restrictions of consumer behavior (adding-up, homogeneity, symmetry), but which is flexible enough to closely approximate demand elasticities at particular data points. To meet these requirements, one may consider the class of flexible functional forms among which the translog, generalized Leontief, and Almost Ideal demand systems are leading examples. Appeal is frequently made to Taylor's theorem in justifying these forms. However, as emphasized by White (1980) and by Gallant (1981), no known statistical properties flow from Taylor's theorem. Moreover, even if the approximation is valid for some points in the sample, there is no assurance it will hold at other data points. These considerations naturally lead one to turn to a functional form that has the capability, in principle, to globally approximate demand elasticities. A form with this desirable property is the Fourier flexible form introduced in Gallant (1981, 1984). The ability of this functional form to provide consistent estimates of demand elasticities is discussed in El Badawi et al. (1983).

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This paper applies Gallant's Fourier flexible functional form methodology to estimation of income elasticities for four major food categories: meats, fruits and vegetables, bakery and cereal products, and miscellaneous foods. The empirical specification employed is a logarithmic version of the Fourier form, similar to that used by Gallant (1982). One advantage of this specification is that it includes as a special case Christensen et al's (1975) indirect translog model. The fourier model is useful not only from the standpoint of statistical testing, but also for determining the bias from assuming constant income elasticities in demand projections.

The paper is organized as follows: methodology in estimating global behavior of demand elasticities for food; data and estimation procedure; econometric results; and implications for demand projections.

Methodology

A systems approach is taken to estimating demand elasticities for food. Food commodities are assumed to be weakly separable from nonfood commodities so that demand parameters for food can be estimated in isolation from nonfood. The food demand system estimated relates quantities purchased of four major food categories to total expenditures on food as well as prices within the food group. The commodity aggregates chosen are, with one exception, the same as those used by Manser (1976) and by Blanciforti and Green (1983).

A number of different approaches can be taken to specifying a system of demand functions (see, e.g., Barten, 1977). The approach taken here is to start with a specified indirect utility function and then apply Roy's identity to obtain Marshallian demand equations. This approach has the advantage that the resulting relationships satisfy automatically the general restrictions of consumer behavior. Moreover, any flexible functional form which is non-increasing and quasi-convex in normalized prices (prices divided by total expenditures) is a viable candidate for the indirect utility function.

Let x_i denote the natural logarithm of the normalized price of the ith good, i.e., $x_i = \ln (p_i/y)$, where P_i is price and y is total food expenditures. Then, following Gallant (1982), the indirect logarithmic Fourier flexible form of order K can be specified as

$$g_k(x) = u_o + b'x + 1/2\ x'Cx \qquad (1)$$

$$+ \sum_{\alpha=1}^{A} \{u_{o\alpha} + 2 \sum_{j=1}^{J} [u_{j\alpha}\cos(j\lambda k_\alpha' x) - v_{j\alpha}\sin(j\lambda k_\alpha' x)]\},$$

where x is an N-vector of logarithms of normalized prices and $C = -\Sigma u_{o\alpha}\lambda^2 k_\alpha k_\alpha'$. The sequence $\{k_\alpha\}$ is a sequence of multi-indexes, which indicate the direction of the trigonometric expansion. Rules for determining multi-indexes are provided in Gallant (1981, p.215). The sequence for four commodities (N=4) and a second-order expansion (K=2) are shown in Table 1. The parameter λ is a scale factor used to ensure all variables are between 0 and 2π.

Demand functions for the Fourier form can be obtained through application of Roy's identity. In budget share form this formula can be written (Diewert, 1974, p.125)

$$S_i = \frac{\partial g_K(x)/\partial x_i}{\sum_j \partial g_K(x)/\partial x_k}, \tag{2}$$

where $S_i = P_i q_i / Y$ is the budget share of the ith good. Thus all that is required is a specification of the gradient vector of the indirect utility function (1). Because $\partial\cos(x)/\partial x = -\sin(x)$ and $\partial\sin(x)/\partial x = \cos(x)$, the N-vector of partial derivatives of the Fourier indirect utility function can be written

$$\partial g_K(x)/\partial x = b - \lambda \sum_{\alpha=1}^{A} \{u_{o\alpha}\lambda(k_\alpha' x) + 2\sum_{j=1}^{J} [u_{j\alpha}\sin(\lambda k_\alpha' x) + v_{j\alpha}\cos(\lambda k_\alpha' x)]\} k_\alpha.$$

In the empirical application that follows, J will be set equal to 1. Setting J=1 and substituting these partial derivatives into (2) gives

Table 1. The Sequence of Multi-Indexes for N=4 and K=2.

$k_1 = (1,0,0,0)'$,	$k_2 = (0,1,0,0)'$,	$k_3 = (0,0,1,0)'$,	$k_4 = (0,0,0,1)'$
$k_5 = (1,1,0,0)'$,	$k_6 = (1,0,1,0)'$,	$k_7 = (1,0,0,1)'$,	$k_8 = (0,1,1,0)'$
$k_9 = (0,1,0,1)'$,	$k_{10} = (0,0,1,1)'$,	$k_{11} = (1,-1,0,0)'$,	$k_{12} = (1,0,-1,0)'$
$k_{13} = (1,0,0,-1)'$,	$k_{14} = (0,1,-1,0)'$,	$k_{15} = (0,1,0,-1)'$,	$k_{16} = (0,0,1,-1)'$

$$S_i=b_i-\lambda\sum_{a=1}^{A}\{u_{oa}\lambda(k_a'x)+2[u_{1a}\sin(\lambda k_a'x)+v_{1a}\cos(\lambda k_a'x)]\}k_{ia}/D,$$

where (3)

$$D=\sum_j(b_j-\lambda\sum_{a=1}^{A}\{u_{oa}\lambda(k_a'x)+2[u_{1a}\sin(\lambda k_a'x)+v_{1a}\cos(\lambda k_a'x)]\}k_{ja}),$$

and where k_{ia} denotes the ith component of the N-vector k_a.

Price elasticities for this model can be obtained through use of the formula

$$e_{ij} = \partial \ln S_i/\partial x_j - \delta_{ij}, \tag{4}$$

where e_{ij} is the price elasticity of good i with respect to price of good j and δ_{ij}, the Kronecker delta, equals 1 when i=j, but zero otherwise. Income (expenditure) elasticities, e_{iy}, can be obtained through use of the homogeneity constraint

$$e_{iy} = -\sum_j e_{ij}. \tag{5}$$

These elasticities will automatically satisfy the general restrictions of consumer behavior since they are embodied in the indirect utility function (1) and, therefore, in the budget share equations (3). The monotonicity condition is equivalent to requiring budget shares be non-negative. The quasi-convexity condition is equivalent to requiring the NxN matrix of Slutsky price derivatives be negative semi-definite. Neither one of these conditions is imposed directly in estimation. They can be verified by checking the estimated parameters at selected data points.

The logarithmic Fourier demand system (3) has a number of noteworthy characteristics. First, since the x_i's are logarithms of the normalized prices, the indirect translog model is nested within the Fourier model. Thus it is possible to test for the translog model specification using conventional statistical procedures. The translog model is interesting from the standpoint of demand projections because it should give rise to slowly changing demand elasticities over time. This realization is based on an observation by Wohlgenant (1984b, pp. 8-9) that, when Σu_{oa} is close to zero, price elasticities (and therefore income elasticities) will be relatively insensitive to changes in real income. Consequently, testing for the adequacy of the translog model is tantamount to testing for the (relative) constancy of income elasticities.

A second noteworthy feature of the Fourier model is that it is semi-nonparametric; this is, the order of the trigonometric expansion generally cannot be determined prior to empirical implementation. Rather, by analogy with time series analysis, one would need to fit different models for different trigonometric expansions to determine which specification is most compatible with the data according to some criterion. As Gallant (1982, pp. 321-322) points out, the choice depends on whether the problem is one of hypothesis testing or estimation. Here the main concern is consistent estimation of income elasticities, meaning primary interest is in the specification that yields smoothed fits to the data (El Badawi et al., 1983). Again by analogy with time series analysis, a parsimonious representation is sought, i.e., a model which gives close approximations with the fewest number of parameters. In practice, this specification can be determined either by the downward or upward selection procedure described in Gallant (1982, pp. 321-322).

Data and Estimation Procedure

There are no official time series on personal consumption expenditures for major food groups. United States Department of Agriculture, Food Consumption, Prices, and Expenditures reports consumer expenditures for domestic farm products bought by civilians in the United States. Published data for fruits and vegetables as well as grain mill products are used directly to obtain per capita expenditures for the food categories of fruits and vegetables and bakery and cereal products. Imports are a negligible component of these categories so they can be safely ignored. Consumer expenditures for meats are constructed from published data by a procedure discussed below. Miscellaneous foods are computed as the difference between personal consumption expenditures for all food, as reported by the U.S. Department of Commerce, and the summation of consumer expenditures for meats, fruit and vegetables, and bakery and cereal products. All expenditures series are converted to per capita amounts by dividing by mid-year civilian population.

Consumer expenditures for meats include beef and veal, pork, poultry, and fish. The USDA's Livestock and Poultry Outlook and Situation periodically reports per capita expenditures for beef and veal, pork, and poultry. For beef and veal and pork these data are available for the years 1955, 1960, 1965, 1970-76, and 1979-82. Values for the other years were obtained through use of the formula:

$$\frac{(CPI_{it}\ Q_{it})E_{io},}{(CPI_{io}\ Q_{io})}$$

where CPI_i is the consumer price index of the ith good, Q_i is the per capita consumption of the ith good, and E_i is per capita expenditures for the ith good. The zero subscript denotes average values for adjoining years in which published data on per capita expenditures were available. (For years prior to 1955, values for 1955 were used). Per capita expenditures for poultry are available for the years 1979-82. Expenditures for earlier years were obtained through application of the above formula, but with base year expenditures for 1979 and the USDA index of per capita consumption for poultry used in place of actual per capita consumption. The same procedure was used to obtain per capita expenditures for fish, where per capita expenditures of $7.11 in 1958 (Christensen and Manser, 1976) were used for the base period. A comparison of the resulting expenditures series with those used by Christensen and Manser indicated a discrepancy of less than one percent for any given year.

Price series for the first three food categories are the Bureau of Labor Statistics' consumer price indexes for meat, poultry, and fish, fruits and vegetables, and bakery and cereal products. A price series for miscellaneous foods is constructed as follows:

$$\ln P_4 = (\ln P_{food} - S_1 \ln P_1 - S_2 \ln P_2 - S_3 \ln P_4)/S_4,$$

where P_i is the consumer price index for the ith good (1 = meats, 2 = fruits and vegetables, 3 = bakery and cereal products, and 4 = miscellaneous foods), P_{food} is the BLS consumer price index for food, and S_i is the consumer budget share for the ith food commodity.

The essential difference between the procedure used here in obtaining commodity expenditures series for food and that used by Manser (1976) and by Blanciforti and Green (1983) is in the definition of miscellaneous foods. Their miscellaneous food category is derived from USDA data while miscellaneous foods here are defined as the difference between personal consumption expenditures for food and consumption expenditures for meats, fruits and vegetables, and bakery and cereal products. The main difference between the two series is that the latter includes imported beverages.

Using the procedure outlined above, annual time series data on normalized prices and budget shares for the four food categories were generated for the years 1947 through 1982. All normalized prices are rescaled as: $x_i = \ln(P_i/y) + \ln(486.21095)$. Using the maximum value for all x_i, the scaling factor λ is specified as $\lambda = 6/4.89928$. Since the Fourier form is periodic, this rescaling was necessary in order to avoid Gibb's phenomenon (Gallant, 1984).

With these data preliminaries, the statistical model is given by

$$S_{it} = \frac{f_i(x_t)}{\sum_{j=1}^{4} f_j(x_t)} + \epsilon_{it}, \qquad i = 1,2,3$$

where $f_i(x_t)$ and $\Sigma f_j(x_t)$ are the numerator and denominator of (3), respectively. The last share equation has been discarded due to the adding-up property, which implies a singular contemporaneous variance-covariance matrix (Barten, 1977). These share equations are homogenous of degree zero in the parameters, so the normalization $b_4 = -1$ is chosen.

The estimation procedure employed is the Seemingly Unrelated Nonlinear Regressions method (Gallant, 1975), which is asymptotically equivalent to maximum likelihood. Hypothesis testing is conducted using the likelihood ratio test for the Seemingly Unrelated Regression method (Burguete et al., 1982). All computations are performed with the SYSNLIN procedure of SAS.

Econometric Results

Parameter estimates for the translog and Fourier models are presented in Table 2. The parameter estimates for the Fourier model include the translog parameters plus the parameters corresponding to the sine/cosine terms for the multi-indexes k_1 through k_3 (see Table 1). Motivation for this specification is the belief that the lagest reduction in the residual sum of squares would occur by augmenting the translog model with a Fourier expansion in own normalized prices. (Sine/cosine terms involving k_4 were also included initially, but this specification led to a singular model). This intuition is confirmed by hypothesis testing. The chi-squared value for the null hypothesis that the translog model is correct is 18.94. Comparing this value with the tabled chi-square value with 6 degrees of freedom, the null hypothesis is rejected at a significance level smaller

Table 2. Parameter Estimates, Translog and Fourier Functional Forms

Parameter	Translog Estimate	Translog Standard Error	Fourier Estimate	Fourier Standard Error
b_1	-0.675	0.090	5.095	6.094
b_2	-0.263	0.229	-18.333	42.761
b_3	-0.020	0.307	29.551	22.372
u_{01}	0.136	0.102	0.900	0.878
u_{02}	0.163	0.138	-2.497	6.154
u_{03}	0.015	0.025	4.306	3.218
u_{04}	0.242	0.225	0.153	0.083
u_{05}	-0.031	0.018	-0.027	0.008
u_{06}	0.003	0.016	-0.003	0.007
u_{07}	-0.078	0.041	-0.059	0.013
u_{08}	0.015	0.025	0.007	0.010
u_{09}	-0.077	0.054	-0.057	0.021
u_{10}	-0.022	0.007	-0.023	0.005
u_{11}			-0.370	0.376
u_{12}			1.038	2.501
u_{13}			-1.747	1.300
v_{11}			-0.171	0.220
v_{12}			0.798	1.828
v_{13}			-1.249	0.962

than 0.5 percent. Further estimations indicated the Fourier specification is parsimonious for these data, as no other specification considered led to a significant decrease in the residual sum of squares.

Neoclassical utility theory requires that the indirect utility be non-increasing in normalized prices. This requirement is equivalent to the non-negativity of all predicted budget shares. This monotonicity requirement is satisfied for each functional form at all data points. Neoclassical theory also requires that the indirect utility function be quasi-convex in normalized prices. Convexity fails for each functional form at each observation, although it is not known whether this failure is statistically significant. Gallant and Golub (1984) have developed an alogarithm for imposing quasi-convexity, but the programming task seemed too formidable to impose this restriction.

It is hard to know how to interpret the failure of quasi-convexity. Two possibilities are trend-like shifts in preferences and autocorrelation of residuals. Attempts to take into account these changes, however, proved unfruitful. Therefore, this study proceeds conditionally on the assumption that violation of convexity does not do sufficient damage to the demand models to preclude interest in the implications for elasticities and demand projections.

Demand elasticities are computed using the formulas given in (4) and (5). Given the interest in demand projections, only expenditure elasticities are reported. Price elasticities, however, are available upon request from the author.

The expenditure elasticities reported in Table 3 give the elasticity of demand for each food type with respect to total food expenditures. Overall, the estimates indicate that demands for meats and miscellaneous foods are expenditure elastic and that the demands for fruits and vegetables and bakery and cereal products are expenditure inelastic. These results are consistent with the findings by Manser (1976) for different variants of the translog model and by Blanciforti and Green (1983) for a dynamic Almost Ideal demand system.

In contrast to the translog elasticities, the Fourier elasticities show considerable variation over time. This finding is especially apparent for bakery and cereal products. However, with the exception of this good, both forms have very similar elasticities at the sample means. Thus, on pragmatic grounds, one might prefer the translog model for demand projections, although the statistical tests indicate superiority of the Fourier model.

The expenditure elasticities in Table 3 are with respect to total food expenditures and not total expenditures. Estimates of

Table 3. Estimated Expenditure Elasticities of Food Commodities for Translog and Fourier; Selected Years, 1947-82.

	Translog				Fourier			
Year	Meats	Fruits & Veg.	Bakery & Cereals	Misc.	Meats	Fruits & Veg.	Bakery & Cereals	Misc.
1950	1.17	0.78	0.21	1.24	1.13	0.69	0.54	1.19
1955	1.23	0.76	0.24	1.20	1.35	0.68	0.34	1.12
1960	1.23	0.73	0.25	1.23	1.28	0.88	0.13	1.16
1965	1.22	0.73	0.27	1.23	1.12	0.65	0.70	1.20
1970	1.19	0.78	0.29	1.17	1.15	1.06	-0.93	1.41
1975	1.19	0.76	0.29	1.20	1.05	0.62	0.79	1.22
1980	1.21	0.79	0.29	1.14	0.94	1.30	-0.67	1.35
At Sample Means	1.21	0.76	0.26	1.20	1.23	0.54	0.62	1.18

elasticities of demand with respect to total expenditures can be obtained by multiplying these expenditure elasticities by an estimate of the elasticity of demand for food with respect to total expenditure (Manser, 1976, p. 887). Wohlgenant (1984a, 1984b) reports expenditure elasticity estimates for all food (including alcohol and tobacco) for the Fourier and translog models, estimated with annual data over the period 1948-78. These forms give virtually the same estimates at the sample mean with values of 0.38 and 0.40, respectively. Using the estimate of 0.40, total expenditure elasticities for the translog of 0.48, 0.30, 0.10, and 0.48 for goods (1) through (4) are indicated. For the Fourier, the corresponding total expenditure elasticities are 0.49, 0.22, 0.25, and 0.47. Regardless of the form used, income elasticities for all four food categories are quite inelastic, as one would expect.

Implications for Demand Projections

In this section an attempt is made to determine how sensitive the expenditure elasticities are to changes in real food expenditures. The demand projections problem envisaged here is one in which future (forecasted) food expenditures are allocated among the four food categories. In applications, food expenditures could be predicted from the first stage of an expenditure allocation model between food and nonfood goods (see, e.g., Bieri and deJanvry, 1972).

Here food expenditures are assumed to be exogenously determined so that attention can focus on the sensitivity of food consumption allocation to changes in expenditure elasticities over the forecast period. To make the simulations concrete, a benchmark growth rate in real food expenditures of 13 percent between 1982 and 2000 is assumed. This growth rate is determined by regressing the log of real per capita food expenditures (per capita personal consumption expenditures for food divided by the consumer price index for food) on a linear time trend. In the simulations, relative food prices are assumed fixed at their average values for 1978-82. The normalized prices for the base period are 91.28, 93.50, 90.64, and 96.36 for groups (1) - (4), respectively.

Simulations of expenditure elasticities for alternative growth rates in real food expenditures are presented in Table 4. Not surprisingly, elasticities for the translog model show little change from the sample period. On the other hand, the Fourier specification suggests marked changes in all elasticities. The projected elasticities, however, seem highly implausible for both fruits and vegetables and bakery and cereal products. In fact, if projections are made far enough into the future, the Fourier model would imply that the budget share for bakery and cereal products would go to zero, with fruits and vegetables taking up most of the slack. Therefore, one should exercise caution in using the Fourier model directly to forecast outside the sample.

The main reason for exercising caution in using the Fourier model to forecast outside the sample is the bias-instability tradeoff in approximating elasticities (see, e.g., Chalfant). By adding

Table 4. Projected Expenditure Elasticities for Alternative Food Expenditure Growth Rates, 1978-82 Constant Relative Prices

Food Expend. Growth Rate	Translog				Fourier			
	Meats	Fruits & Veg.	Bakery & Cereals	Misc.	Meats	Fruits & Veg.	Bakery & Cereals	Misc.
5%	1.20	0.79	0.30	1.15	0.92	1.56	-2.04	1.54
10%	1.19	0.79	0.32	1.14	0.85	2.19	-4.92	1.71
13%	1.18	0.80	0.32	1.14	0.80	2.60	-8.12	1.81
15%	1.18	0.80	0.33	1.13	0.77	2.88	-11.68	1.88
20%	1.17	0.81	0.34	1.13	0.69	3.55	-47.67	2.08

additional terms in the Fourier expansion one can approximate demand elasticities as closely as possible at all data points in the sample (El Badawi et al.). However, this expansion comes at the price of increased variability in the estimates. On the other hand, one can reduce the variability in these estimates by deleting terms in the expansion. But this reduction in variability comes at the price of higher levels of bias. The analyst is, therefore, forced to weigh the relative costs of bias and instability.

Given this dilemma, one solution might be to use the Fourier model to estimate elasticities, say at the sample means, and then employ a Taylor's series expansion at this point to extrapolate outside the sample (A.R. Gallant, pers. comm.). This method would provide both unbiased estimation of elasticities at some data point, but stable elasticities for projection purposes.

To illustrate this approach, a second-order Taylor's series expansion is applied at the sample means of normalized prices of the estimated gradient of the Fourier indirect utility function. The expansion is made on the gradient, rather than on the elasticities so that the predicted elasticities would automatically satisfy the general restrictions of consumer behavior. A second-order Taylor's expansion seemed to be adequate in this case; in other applications higher order expansions may be required.

Simulated expenditure elasticities from the approximated Fourier model are presented in Table 5. These elasticities show the same direction of change from the sample as those calculated directly from the Fourier model (Table 4). However, the changes are less dramatic

Table 5. Projected Expenditure Elasticities Based on a Taylor's Series Expansion of the Estimated Fourier Specification, 1978-82, Constant Relative Prices

	Commodity			
Food Expenditure Growth Rate	Meats	Fruits & Veg.	Bakery & Cereals	Misc.
5%	1.10	0.60	0.10	1.35
10%	1.08	0.60	-0.11	1.39
13%	1.07	0.59	-0.25	1.42
15%	1.07	0.59	-0.34	1.44
20%	1.05	0.57	-0.60	1.47

and the elasticities seem more plausible than those in Table 4. Overall these simulations indicate that, relative to the sample means, demand for meats will become less expenditure-elastic while fruits and vegetables and miscellaneous foods will become more expenditure elastic. The model indicates bakery and cereals will become an inferior good, although these estimates may not be significantly different from zero or are perhaps confounded with other trends in demand not accounted for by the model. It is interesting to note that, although the translog and Fourier models give similar elasticities at the sample means, only the Fourier suggests marked changes from the sample means.

In summary, these simulation results support the notion that one needs a different set of elasticities when projecting future demand for food. The methodology utilized here provides a consistent approach to this problem. A systems approach to demand is taken to ensure that the expenditure elasticities satisfy the general restrictions of consumer behavior in the forecast period as well as within the sample. Gallant's Fourier methodology produces consistent demand elasticities in the context of the systems approach. By approximating the estimated Fourier model by smoothed polynomial functions, one is able to obtain elasticities for the forecast period which take into account the effect of changes in income on values for income elasticities.

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