Estimation of Food Demand and Nutrient Elasticities from Household Survey Data.
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Abstract

A methodology for estimating a demand system from household survey data is developed and applied to the 1987-88 Nationwide Food Consumption Survey data. The empirical results are sets of estimated demand elasticities for households segmented with different income levels. In addition, we apply these demand elasticities to estimate the implied nutrient elasticities for low-income households. The estimation results are useful in evaluating some food policy and program effects related to households of a specific income level.

Keywords: Demand elasticities, household survey data, and food quality effect.

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Summary

Many food programs, like the Food Stamp Program, are concerned about low-income households. To evaluate program effects, one needs demand elasticity estimates pertinent to households of different income levels. Most available demand elasticities, by contrast, are estimated from time-series data based on average consumer behavior and may not represent well the households of concern. In this study, we used data from the 1987-88 Nationwide Food Consumption Survey to estimate demand elasticities for households segmented by income levels.

We developed an approach for estimating a demand system from household survey data in this study. We used the unit values of foods available in household surveys as variables to model a food demand system. Since the unit values of foods reflect market prices and consumer choices of food quality, we adjusted the estimates by excluding the food quality effects and obtained a complete set of demand information including own-, cross-price, and expenditure elasticities. This approach is particularly useful in estimating a demand system when obtaining time series data is difficult or when the estimates of demand elasticities across different population groups are required for food policy decisionmakers.

We classified all households into three income groups and then estimated the demand structures both for the entire sample of households and also for each group of households. Most estimated demand elasticities were statistically significant and acceptable in sign and magnitude. Estimates of food quality effects obtained in this study show that food quality plays a significant role in household budget allocation, and that food quality is an important factor in modeling a food demand system from household survey data. According to the estimates, the demand elasticities among income groups were substantially different. We, therefore, suggest using the demand elasticities of a specific income group (for example, the low-income group) for food policy analysis when that group of households is of interest.

We also used the estimated demand elasticities for low-income households to measure nutrient income elasticities—the percentage change in nutrient availability with respect to changes in household food expenditure. The results indicate that consumption of all 13 food groups increases as food expenditures increase. Consequently, the nutrient elasticities with respect to food expenditure and with respect to food stamp benefits were positive for 25 nutrients studied.

Estimation of Food Demand and Nutrient Elasticities from Household Survey Data

Kuo S. Huang and Biing-Hwan Lin

Introduction

Household food consumption surveys, as conducted in the United States and elsewhere, often collect detailed information on the quantity and expenditure of food consumed and on the economic and sociodemographic characteristics of households. This rich database offers researchers unique opportunities and challenges in analyzing food demands and related policy issues. Many food policies and programs like the Food Stamp Program are targeted at low-income households. For evaluating the program effects, most available demand elasticities may be inadequate, since they are estimated from time-series data based on average consumer behavior rather than on the behavior of the households of interest. Therefore, estimating cross-section demand relationships from household survey data in order to obtain elasticities distinguished by household characteristics, such as income, is of interest.

In this study, we develop a new approach for estimating a demand system from household survey data. We apply this approach to the 1987-88 Nationwide Food Consumption Survey (NFCS) data to analyze food demands for households segmented into three income levels. Since the nutrient status of low-income households is a primary concern of various food programs, we use estimated demand elasticities for low-income households as input information to generate the nutrient elasticities, which are useful in evaluating the effect of the food stamp benefit on nutrient availability.

In this report, we first present a conceptual framework with a focus on the specifications of a demand system and unit value equations and a procedure to measure demand elasticities and nutrient elasticities. We then present empirical results, including data sources, estimates of demand elasticities of all samples and for three income groups, and estimates of nutrient elasticities for low-income households. Finally, we review Deaton's approach for estimating demand elasticities from household survey data in the appendix.

Conceptual Framework

A major problem of using household survey data to estimate a demand system lies in its difficulty in defining price variables. Earlier household budget studies often assumed that prices are constant, and they focused on fitting the Engel curves. In an attempt to retrieve price effects in

household survey data, Theil and Neudecker derived conceptual relationships of substitution and complementarity from the residual variations around the Engel curves. Their methodology, however, is far from practical in developing a working model for empirical application. Recently, Deaton, in a series of articles, developed a procedure by using the residuals of estimated unit value (defined as the ratio of expenditure to quantity) and expenditure share equations to obtain a system of demand equations. By applying a separability assumption, he was able to derive information about price effects from the estimated covariance of residuals. The problem of applying his approach, however, is that there is no guarantee of obtaining accurate estimates of price responses, because many unexplained factors influence covariance of residuals, not price variations alone.

Cox and Wohlgenant proposed an alternative approach, which was then adopted in some cross-sectional demand analyses, such as Park et al., and Gao et al. They assumed that the deviations of unit values from regional or seasonal means reflected the quality effects induced by household characteristics and nonsystematic supply-related factors. By regressing the mean-deviated unit values on household characteristics, they filtered the quality effects out of unit values to obtain the quality-adjusted prices for the subsequent demand system estimation. Specifically, quality-adjusted prices were calculated as the sum of an estimated constant term and residuals from related unit-value equations. A problem with this approach is that the adjusted prices are random, vary from household to household, and are not consistent with the fact that households face quite similar market prices in a short survey period.

Demand Model Specification

In our empirical study, based on the NFCS data, we assumed that food consumption at home was separable from the demands for other goods in the consumer budget. By weak separability, we then focused on a food-demand structure by allocating at-home food expenditures to various food categories. Thus, the demand for each food category was represented as a function of at-home food expenditures and a set of prices for food categories. In addition, only unit values, but not prices of each food category, are available in the household survey data. The unit value of a food category reflects its average market price and consumers' choices of food quality. In fact, the foods purchased by different households are obviously not homogeneous; rather, the foods are a collection of different qualities. Beef as a category, for example, includes meat cuts such as steak and inexpensive ground beef. In this study, we used unit values of food categories as variables in modeling a food demand system, and the rationale of such a specification is given below.

Let the average price of the *i*th food category be p_i, the unit value of the food category paid by an individual household be v_i, and the ratio of unit value to average price be λ_i. Thus λ_i represents a price structure for the quality choices of a food category by a household. If a household's choice of food quality is above average, the ratio λ_i should be greater than one; otherwise, for food quality below average, the ratio λ_i should be less than one. By using the household survey data, the quantity of a food category (say q_i) represents the amount of foods purchased regardless of quality. For example, different households may buy the same number of pounds of beef, which

consist of different cuts. Therefore, the quantity variables that affect consumers' satisfaction in the utility function should be the quantities that are adjusted by quality effect as $\lambda_i q_i$. In other words, for above-average quality of food purchased by a household, the quantity should be augmented by a factor of λ_i. On the other hand, in case of quality of food purchased below average, the quantity should be reduced by a factor of λ_i.

For illustration, let a utility function for a food sector consisting of two food categories be $U = \Sigma_i \alpha_i \log (\lambda_i q_i)$, for i = 1, 2. By maximizing U subject to the food budget constraint $m = \Sigma_i \lambda_i p_i q_i$, we can obtain a demand equation expressed as a function of unit values and income as $q_i = \alpha_i m / [(\alpha_1 + \alpha_2) \lambda_i p_i]$, for i = 1, 2. Moreover, through the duality properties of demand relationships, we can derive a demand equation from a cost function.

Consider the following cost minimization problem. By minimizing $C = \Sigma_i p_i \lambda_i q_i$, for i = 1, 2, subject to a utility function $\log U = \Sigma_i \alpha_i \log (\lambda_i q_i)$, we can derive the conditional factor demands and then the cost function as $C = \Sigma_i p_i \lambda_i q_i^*$, where $q_i^* = (\alpha_i p_j / \alpha_j p_i)^{\alpha j / (\alpha 1 + \alpha 2)} + \lambda_i^{-1} U^{1/(\alpha 1 + \alpha 2)}$, for i = 1, 2, $i \neq j$. This cost function, which can be used to generate a demand system, is obviously a function of unit values and utility level. In general, we may conclude that it is justifiable to substitute unit values for price variables in modeling a food demand system.

In this study, we adopt a cost function as suggested by Deaton and Muellbauer by replacing unit values for prices in the function. By applying Shepard's lemma, we can derive a modified version of an "Almost Ideal Demand System" (AIDS), in which at-home expenditure share of a food category is a function of unit values and the related food expenditures as

(1) $$w_i = \alpha_i + \Sigma_j \delta_{ij} \log v_j + \beta_i \log (m / v^*)$$

where w_i is the at-home food expenditure share, m is per capita at-home food expenditures, and v^* is a unit value index defined by

(2) $$\log v^* = \alpha_0 + \Sigma_j \alpha_j \log v_j + 1/2 \ \Sigma_j \Sigma_k \delta_{jk} \log v_j \log v_k$$

All subscripts of variables and summation throughout this paper refer to a total of n food categories ($i, j, k = 1, 2, .., n$). In practical estimation, $\log v^*$ is approximated by the logarithm of the Stone price index (that is, $\log v^* = \Sigma_j w_j \log v_j$) to allow for linear estimation and for subsequent derivations of demand elasticities. Obviously, this demand system is a first-order approximation to the general unknown relationships among expenditure share, unit values, and expenditure. Theoretical properties of adding up, homogeneity, and symmetry are applied directly to the parameters. They are $\delta_{jk} = \delta_{kj}$, $\Sigma_j \beta_j = \Sigma_j \delta_{jk} = \Sigma_j \delta_{kj} = 0$, and $\Sigma_j \alpha_j = 1$. On empirical application, some sociodemographic variables are also included in the demand system to reflect the nature of household survey data.

In addition, the magnitude of household income and other characteristics such as size and composition may affect the choice of food quality. As we would expect, the better-off households tend to spend more on food and choose more costly, better quality foods. Therefore, a positive relationship between unit values and per capita household food expenditures exists. Also, consumers who spend a larger portion of their food budget away from home can be regarded as valuing taste and convenience more than other consumers may. Because taste and convenience are two important quality attributes in foods, we expect a positive relationship between unit values and the share of food away from home in the food budget. Finally, regional and seasonal dummy variables can be used to capture variations in market prices induced by transportation costs and seasonal supplies. Accordingly, we can explain the variations of unit values by using the following equation:

(3) $$\log v_i = \pi_i \log m + \omega_i f_i + \Sigma_k \gamma_{ik} z_k$$

where f_i is an exogenous variable representing the portion of the total food budget spent on food away from home, z_k is a vector of household sociodemographic variables, and other variables are the same as in equation 1. For given food prices, the parameter $\pi_i = (\partial \log v_i / \partial \log m)$ is defined as the elasticity of unit value with respect to per capita expenditure for food consumed at home. Houthakker and Prais called this the "elasticity of quality," which is an important component that will be used to correct the bias of measuring Engel relationships directly from equation 1 when food quality effects are ignored.

In summary, for our empirical analysis of household food consumption at home, the proposed demand model consists of two sets of equations: one is the modified AIDS equation system and the other is a set of unit value equations. Since the two sets of equations are recursive blocks, it is well known that unbiased estimates of the recursive-form parameters are obtainable by estimating each set of equations separately (Goldberger, p. 383). Therefore, the unit value equations can be estimated by applying ordinary least squares (OLS), while the modified AIDS model can be estimated by applying seemingly unrelated regressions with parameters constrained across equations. After the estimation, we are able to obtain a complete set of demand information including own-, cross-price, and food-expenditure elasticities by excluding the food quality effects from the estimates.

Derivation of Demand Elasticities and Standard Errors

Since the unit value of a food category is a product of average market prices and a quality choices index, we can decompose $\log v_j$ in the AIDS model of equation 1 into the sum of two components: $\log p_j$ and $\log \lambda_j$, and their effects on at-home food expenditure share are implicitly assumed to be the same as showing by an estimate of δ_{ij} . Accordingly, we can derive price and expenditure elasticities by differentiating equations 1 and 2 with respect to prices and expenditure to obtain the following elasticity measures:

(4) Own-price elasticity: $$e_{ii} = (\delta_{ii} - \beta_i w_i) / w_i - 1$$

(5) Cross-price elasticity: $e_{ij} = (\delta_{ij} - \beta_i w_j) / w_i$

(6) Expenditure elasticity: $\eta_i = [\beta_i + \Sigma_j (\delta_{ij} - \beta_i w_j) \pi_j] / w_i + (1 - \pi_i)$

In particular, the quality-adjusted expenditure elasticity measure showing in equation 6 is different from that derived from the conventional AIDS model without considering food quality effect, which is calculated by $(\beta_i / w_i + 1)$. We, therefore, can measure the bias of estimate as $[\Sigma_j (\delta_{ij} - \beta_i w_j) \pi_j / w_i - \pi_i]$, when quality effects are ignored.

Furthermore, the standard errors of demand elasticities are obtainable by following a method for computing an asymptotic variance for a function of random variables (Goldberger, p. 124). Let Φ be the estimated covariance matrix of a vector of parameter estimates α's, β's, and δ's in the AIDS system, and $Var(\pi_i)$ be the variance of estimate π_i. We can measure the variances of estimated demand elasticities in terms of Φ and $Var(\pi_i)$, as follows:

(7) $Var(e_{ii}) = J_a' \Phi J_a$

(8) $Var(e_{ij}) = J_b' \Phi J_b$

(9) $Var(\eta_i) = J_c' \Phi J_c + \Sigma_j (\partial\eta_i / \partial\pi_j)^2 Var(\pi_j)$

where J_a is a vector with entries: $\partial e_{ii} / \partial\delta_{ii} = 1 / w_i$, and $\partial e_{ii} / \partial\beta_i = -1$;

J_b is a vector with entries: $\partial e_{ij} / \partial\delta_{ij} = -1/ w_i$, and $\partial e_{ij} / \partial\beta_i = - w_j / w_i$, for $i \neq j$;

J_c is a vector with entries: $\partial\eta_i / \partial\delta_{ij} = \pi_j / w_i$, $\partial\eta_i / \partial\beta_i = 1 / w_i - (\Sigma_j w_j \pi_j) / w_i$; and

$\partial\eta_i / \partial\pi_i = (\delta_{ii} / w_i) - \beta_i - 1$, and $\partial\eta_i / \partial\pi_j = (\delta_{ij} / w_i) - \beta_i (w_j / w_i)$, for $i \neq j$.

Measuring Nutrient Demand Elasticities

Given the estimated demand elasticities, we can translate them into changes in the total level of nutrients available for consumption by following the same approach developed in Huang (1996). To explore the linkage of the demand model to nutrient availability, let a_{ki} be the quantity of the *k*th nutrient in a total of k nutrients obtained from a unit of the *i*th food. The total quantity of that nutrient, say φ_k, obtained from various foods may be expressed as:

(10) $\varphi_k = \Sigma_i a_{ki} q_i$

Lancaster (1966) called this equation the "consumption technology" of consumer behavior. This equation, including all foods consumed, plays a central role in the transformation of food demand into nutrient availability.

Suppose a household consumes n foods with a predetermined total food expenditure, m, the demand for ith food quantity q_i can be expressed as:

(11) $$q_i = f(p_1, ..., p_n, m)$$

Furthermore, the demand system may be expressed by applying the first-order differential approximation of the conceptual demand relationships as:

(12) $$dq_i / q_i = \Sigma_j e_{ij} (dp_j / p_j) + \eta_i (dm / m)$$

where e_{ij} is a price elasticity of the ith commodity, with respect to a price change of the jth commodity, and η_i is expenditure (or income) elasticity showing the effect of the ith quantity in response to a change in per capita expenditure. This demand model is a general approximation of conceptual demand relationships relating to some small change from any given point on the n-commodity demand surface.

By differentiating φ_k of equation 10 with respect to price and expenditure and then by incorporating equation 12, as shown in Huang (1996, p. 22), relative changes in nutrient consumption can be expressed as a function of relative changes in prices and expenditure:

(13) $$d\varphi_k / \varphi_k = \Sigma_j (\Sigma_i e_{ij} a_{ki} q_i / \varphi_k) (dp_j / p_j) + (\Sigma_i \eta_i a_{ki} q_i / \varphi_k) (dm / m)$$

$$= \Sigma_j \pi_{kj} (dp_j / p_j) + \rho_k (dm / m)$$

where $\pi_{kj} = \Sigma_i e_{ij} a_{ki} q_i / \varphi_k$ is a price elasticity measure relating the effect of a change in the jth food price on the availability of the kth nutrient, and $\rho_k = \Sigma_i \eta_i a_{ki} q_i / \varphi_k$ is an income elasticity measure relating the effect of a change in income on the availability of that nutrient. In other words, the measurement of π_{kj} represents the weighted average of all own- and cross-price elasticities (e_{ij}'s) in response to a change in the jth price, with each weight expressed as the share of each food's contribution to the kth nutrient ($a_{ki} q_i / \varphi_k$'s). Similarly, the measurement of ρ_k represents the weighted average of all income elasticities (η_i's), with each weight again expressed as the share of each food's contribution to the kth nutrient.

In measuring the effect of food stamp benefits (as part of total food expenditure) on nutrient consumption, we need information on the relationship between food stamp benefits and food expenditure. Letting variable s be the food stamp benefits, the elasticity of food expenditure with respect to food stamp benefits can be expressed as $(dm/m)/(ds/s)$. Thus, the nutrient elasticity with respect to food stamp benefits can then be derived as:

(14) $$(d\varphi_k / \varphi_k) / (ds / s) = [(d\varphi_k / \varphi_k) / (dm / m)] [(dm / m) / (ds / s)]$$

$$= \rho_k [(dm / m) / (ds / s)]$$

Empirical Application

Data Source

Since the 1930's, USDA has conducted seven household food consumption surveys on a national scale: 1936, 1942, 1948 (urban households only), 1955, 1965-66, 1977-78, and 1987-88. The data have been used to describe food-consumption behavior patterns and to assess the nutritional content of diets for policy implications related to food production and marketing, food safety, food assistance, and nutrition education.

Most household surveys before 1965-66 were conducted during the spring. Since 1965-66, all surveys have been conducted in all four seasons. The 1987-88 Nationwide Food Consumption Survey (NFCS) included two components: (1) household food used during a 7-day period, and (2) individual food intakes by household members for a 3-day period. While the household-food-used component has not been conducted since 1987-88, the individual food-intakes component was implemented during 1989-91 and 1994-96.

The NFCS 1987-88 provides the most recent data on quantities used and expenditures for foods by households in the United States. Additionally, the data set contains a wealth of information about the economic and sociodemographic characteristics of American households. Therefore, the NFCS 1987-88 data are well suited for analyzing household food-consumption behavior.

The NFCS 1987-88 sample was designed as a self-weighting, multistage, stratified, area probability sample, representative of households in the 48 contiguous States. The stratification plan took into account geographic location, degree of urbanization, and socioeconomic considerations. In total, 13,733 housing units were selected, of which 12,181 (89 percent) were occupied housing units. After screening, 4,589 households participated in the survey and 4,495 households completed household food-use questionnaires. The response rate for NFCS 1987-88 is lower than the response rates for earlier surveys.

Among those completing the household food use questionnaire, 4,273 households had at least one member having 10 or more meals from the household food supply, and these households are called "housekeeping households." Only housekeeping households should be used for analytical studies, because these households provide more comprehensive information about home food practices. Since household income is an important determinant for food use, we included only those households (4,245) with a positive income, reported or imputed.

In the NFCS 1987-88 data, more than 3,000 food items were defined in accordance with the similar frequency of use, comparability of products, and nutritional contents. In this study, we focus on foods consumed at home because households did not report expenditures on each food item consumed away from home; rather, they reported total expenditures spent on all foods away from home. We aggregated foods consumed at home into 13 composite food categories, with the first three digits of food codes listed in parentheses, as follows: beef (441), pork (442), poultry

(451), other meat (443-447), fish (452), dairy products (400-409), cereal (420-429), bread (430-439), fats and oils (410-419), eggs (461-462), vegetables (480-495, 511, 521, 541), fruits (501-503, 512, 522, 542), and juice (530-539).

In computing a unit value for a food category, we first calculated the unit values of individual items in the category and then aggregated them into the expenditure-weighted average. Some households did not consume certain food categories; the unit value for nonconsuming households is treated as "missing" in the analysis of quality choice. Table 1 shows the mean unit values, percent of households consuming a food category, and the distribution of at-home food expenditures among the 13 food categories.

Arrays of sociodemographic factors that may influence consumers' food choices are included in the analysis. They are per capita household income, per capita at-home food expenditure, away-from-home share of the food budget, education level (household head attended college or not), race (White, Black, Hispanic, and other), urbanization (city, suburb, and rural), region (Northeast, Midwest, West, and South), household size measured in 21-meal equivalence, and household composition. The household composition is characterized by 10 groups: children for age groups 2-5 and 6-11, and male and female separately for age groups 12-17, 18-34, 35-64, and above 64. Table 1 contains descriptive statistics of the above variables.

In our analysis, we segment the entire sample into three subsamples according to household income, measured as a percent of the Federal poverty guideline. The poverty guideline developed by the U.S. Department of Health and Human Services used to implement Federal food programs varies by household size; it ranged from $5,360 for a household of one person to $18,520 for a household of eight persons, and an additional $1,800 for each additional person in a household with more than eight persons, in 1987-88. Some Federal food assistance programs, such as the Food Stamp Program, have used 130 percent of the poverty level to determine eligibility for participants. In this study, we classify three income groups: low-income, below 130 percent of the poverty income guidelines; high-income, above 300 percent of the poverty income guidelines; and the medium-income group falling in between. Accordingly, the household income groups are distributed as 23.2 percent for low-income, 35.4 percent for medium-income, and 41.4 percent for high-income.

Estimates of Demand Elasticities for All Samples

In our empirical study, we assumed that food consumption at home was separable from the demands for other goods in the consumer budget. By weak separability, the demand for each food category can be represented as a function of total food consumption expenditure at home and a vector of prices for various food categories. The focus of analysis on allocating food consumption expenditure at home is proper, mainly because the survey data permit us to separate the consumption expenditure at home into different food categories.

The AIDS model of equation 1 is estimated as a system of linear equations, using the systems linear regression (SYSLIN) procedure in SAS computer programs. The parametric constraints of homogeneity and symmetry conditions across the equations are imposed. To avoid singularity in the variance-covariance matrix, the "fish equation" is deleted from direct estimation because almost half of Americans do not eat fish weekly. Also, the survey data show that a high proportion (47 percent) of U.S. households did not consume fish over a 1-week period. The parameter estimates of the fish equation were derived using the homogeneity, symmetry, and adding-up conditions.

In the process of estimation, we found that some households reported zero consumption of certain foods in household food consumption surveys, because of its cost or personal preferences, or because that food was not purchased during the short survey period. Consequently, it is possible that consuming and nonconsuming households may react differently to changes in market conditions, making traditional regression methods inappropriate.

The econometric treatment of zero consumption has received considerable attention in household demand analyses, and Gould summarized the proliferating literature. A popular procedure in dealing with zero consumption in estimating demand systems is to use a Heckman-type sample selection correction factor (Heien and Wessell). This approach is attractive because of the ease in model estimation, but it does not capture cross-commodity censoring impacts (Gould). In this study, while our focus is on the treatment of unit value and its relationship with demand elasticity, we sidestep the zero consumption issue. When a household did not report consuming a food, the unit value of the food is missing for the household. Mean unit values are used to replace missing unit values in AIDS estimation. Future research in integrating our approach in dealing with quality issues and recent developments in treating zero consumption, such as in Dong et al., and Shonkwiler and Yen, should be encouraged.

Partial estimation results of the AIDS model, including the parameter estimates of price and expenditure coefficients (δ_{ij}'s and β_i's), are reported in table 2. The budget share (dependent) variables of food categories are listed across the top of the table, and the unit value and expenditure (independent) variables are listed on the left. Presented are the estimated parameters of a share of particular food category in response to the changes in unit values with estimated standard errors in parentheses. The empirical results show that most unit values of each food category have positive effects on the budget shares within that category, and the estimates are statistically significant at the 1-percent level. The only negative effect is for juice, but its estimate is not statistically significant. The budget share of each food category is also affected by changes in per capita food expenditure. According to estimates, the budget shares of beef, other meat, egg, cereal, and bread decrease as total food expenditures increase, while the budget shares of poultry, fruits, vegetables, and juice increase with an increase in expenditures. These estimates of price and expenditure effects will be used as basic input information to derive demand elasticities.

The parameter estimates of sociodemographic variables are not reported in the table, but they are available upon request. The results indicate that larger households allocate more of their food expenditure to beef and pork, and less to bread and juice. Households headed by those who attended college allocate more of their food budgets to poultry, fruits, and vegetables, and less for beef, pork, other meat, and eggs. In terms of differences by race, Black households allocated more of their food budgets for pork, poultry, other meat, fish, eggs, and juice than White households, but less for dairy, bread, and fruits. City and suburban households allocated less of their food budgets for pork and fats, and more for fruits and juice than rural households. We also found significant regional and seasonal differences in food budget allocation. For example, households in the West devoted a greater proportion of their food budget to dairy products and fruits than other households and less to pork and other meat. Family composition influences food budget allocation; households with more children ages 2-5 tended to spend more of their food budgets on dairy products.

The unit value equation 3, which is specified as a function of per capita food expenditure and some sociodemographic variables, was estimated by OLS (see table 3). The overall goodness-of-fit for the equations appears to be satisfactory in the standard of analyzing household survey data, with R^2 values in a range of 6 to 15 percent. For all 13 food categories, per capita food expenditure had a positive effect on the unit values of each category, with estimates statistically significant at the 1-percent level. Because both the unit value and food expenditure are expressed in logarithmic terms, the parameter estimate (π_i) represents the elasticity of quality, the percentage change in unit value in response to a change in food expenditure. The elasticity of quality varied greatly among food categories, from 0.06 for eggs to 0.34 for dairy products. In particular, the estimates of quality elasticities for dairy products, beef, poultry, fish, fats, bread, fruits, and vegetables exceed 0.15, signifying the importance of food quality effects in consumers' food choices.

Other estimates showed that the share of food expenditure consumed away from home has a positive effect on the unit values of all food categories. A household having a larger share of food expenditure away from home can be regarded as having a higher preference for taste or convenience, or both, in foods, and hence the household tends to purchase value-added foods that cost more. Household size, measured in 21-meal equivalence, has a negative effect on the unit value, a result consistent with economies of scale, because a large family may enjoy discounts for buying bulk foods. Households with college-educated heads paid a significantly higher unit value for all foods, except for eggs, than other households. Non-Hispanic white households tended to pay more for poultry, other meat, bread, and juice than other households. Unit values varied significantly across some regions and seasons, reflecting regional and seasonal variations in market prices.

On the basis of equations 4 to 9, we can generate demand elasticities and their standard errors, as shown in table 4. Most own-price elasticities, except for eggs, were significant at the 1-percent level. The demands for dairy, fruits, and vegetables were relatively more price elastic than those for other food categories, with elasticities ranging from -0.72 to -1.01, while the estimated own-price elasticities for meat categories were -0.35 for beef, -0.69 for pork, -0.64 for poultry,

and -0.39 for fish. The own-price elasticities were substantially larger than those obtained from time-series data such as in Huang (1993), in which the estimates of price elasticities were less than -0.4 in absolute value for most food categories.

The estimates of expenditure elasticities with and without adjustments of food quality effects are listed in the last two columns of table 4. The results show that the measurement of elasticities by ignoring the quality adjustment would yield upward bias comparable to the adjusted elasticities in a range from14 to 44 percent. The adjusted expenditure elasticities of fruits, vegetables, and juice were 1.16, 1.04, and .98 greater than those of other foods, while the estimates for bread, eggs, other meats, dairy, and cereals were less elastic, with elasticity estimates ranging from 0.58 to 0.68. The food expenditure elasticities could be larger than income elasticities because the elasticities of food expenditure with respect to changes in income are in general less than 1, as found in Park et al.

Estimates of Demand Elasticities Segmented by Income

By following the same estimation procedure outlined for all samples, we can estimate the demand structure for each group—low-, medium-, and high-income, separately. As mentioned earlier, we classified three income groups based on the poverty income guideline. The low-income households are below 130 percent, and the high-income households are above 300 percent of the poverty income guidelines, while the medium-income households fall between the two. The demand elasticities are reported in table 5 for high-income households, table 6 for medium-income households, and table 7 for low-income households. The estimates for low-income households will be used as input information to generate nutrient elasticities in the next section of this report. For purposes of comparison, we report the own-price, expenditure, and quality elasticities of the three household income groups in table 8.

A comparison of own-price elasticities among different income groups shows that the estimates did not vary systematically across income groups. For example, the price elasticity of beef for the low-income group was 0.29, compared with 0.41 for the high-income group. But the price elasticity of pork for the low-income group was 0.72, relatively higher than that of 0.67 for the high-income group. Similarly, the estimated expenditure elasticities did not vary systematically across income groups. On the other hand, the estimated quality elasticities of the low-income group were in general lower than those of the medium- and high-income groups, as expected, because high-income households likely choose higher quality foods and value taste and convenience more than low-income households.

To provide an indicator of the amount of difference in the estimated demand elasticities among the three income groups, we calculated the coefficient of variation (CV) for these elasticity estimates. The CV is calculated as the percentage of standard deviation to its mean in absolute

value. The differences in the own-price elasticities for pork, poultry, dairy, cereal, vegetables, fruit, and juice were relatively small among income groups, with the CV estimates being less than 10 percent. An exceptionally high CV estimate for eggs was a result of insignificant elasticities for the medium- and high-income groups.

The differences in the expenditure elasticities among income groups, except for other meat, eggs, and juice, were also relatively small, with CV estimates less than 10 percent. The difference in food quality elasticities among income groups, however, was relatively large. For example, the CV estimates of meat and fish categories are in a range from 24 to 37 percent. In general, higher income households appeared to have higher food quality elasticities, especially for beef, pork, poultry, and fish. Nevertheless, the empirical results suggest that low-income households also devoted substantial food expenditures toward improving food quality, with the quality elasticities ranging from a high of 28 percent for dairy products to a low of 4 percent for eggs.

Estimates of Nutrient Elasticities for Low-Income Households

The Food Stamp Program (FSP) is the largest domestic food-assistance program, costing the Federal Government nearly $19 billion each year and serving an average of 20.8 million persons per month in 1998 (USDA). An objective of the FSP is to improve the diets of low-income people by providing food stamps to eligible households to increase their food expenditure. In this section, we measure how food stamps influence the nutrient content of diets in low-income households.

The FSP had its origins as a coupon-based food program during the Great Depression era, but it was relatively short-lived. A coupon-based food program was resurrected in the early 1960's, but only on a limited pilot basis. The program became available in all States and counties starting in 1975. The existence of hunger in the United States and the rapid growth of the FSP spurred empirical studies of its effectiveness. The literature on the effect of FSP on food consumption has proliferated since the release of NFCS 1977-78 data, and this rich literature was reviewed by Fraker in 1990.

The literature has shown that the food stamp benefits increase food expenditure and nutrient availability, but that literature has some drawbacks. First, most studies are quite dated, analyzing data collected before 1980. Before 1979, food stamps were purchased at a discount. This purchase requirement was eliminated in 1979. Second, attention has focused increasingly on overconsumption of fat, saturated fat, cholesterol, and sodium rather than underconsumption of other nutrients. Third, previous studies employed ad hoc econometric models in which nutrient availability was regressed on food stamp participation/benefit and sociodemographic variables, excluding prices. In our study, food expenditures were allocated among food groups according to prices and sociodemographic variables. Given demand elasticities, the nutrient elasticities can be derived to estimate the effect of food expenditure on nutrient availability.

Using the mean values of the nutrient share of each food in the consumption of the 13 food groups by low-income households (table 9), we can transform low-income household expenditure elasticities (table 7) into nutrient elasticities with respect to food expenditures based on equation 13. These nutrient expenditure elasticities, adjusted and unadjusted for food quality effect, are reported in table 10. To derive the nutrient elasticities with respect to food stamp benefits, we need the information pertaining to the effect of food stamps on food expenditure.
Many researchers have estimated the relationship between food expenditures and food stamp benefits. Fraker's review indicates that each additional dollar of food stamps would stimulate roughly 20-45 cents of at-home food expenditure, while each additional dollar of regular income would result in 5-10 cents of at-home food expenditure. These figures are estimated using much earlier survey data, with NFCS 1977-78 being the latest. Recently, Levedahl used USDA's San Diego Cash-Out Demonstration data in 1990-91 and found a marginal propensity to spend 26 cents for each dollar of food stamps and an elasticity of 0.054.

By using Levedahl's estimate of elasticity, we can estimate the nutrient elasticities with respect to food stamp benefits according to equation 14. Because each percent of food stamp benefit would result in only a 0.054 percent change in food expenditure, the nutrient elasticity with respect to food stamps as shown in table 10 is quite small compared with the nutrient elasticity with respect to food expenditure. The results in the table indicate that consumption of all 13 food groups rises when total food expenditure increases. Consequently, the nutrient elasticities with respect to either food expenditure or food stamp benefit are positive for all 25 nutrients reported in NFCS 1987-88.

Conclusion

Many food programs like the Food Stamp Program are concerned about low-income households. To evaluate program effects, we need to know the demand elasticity estimates for the targeted households. In this study, we developed a new approach for estimating a demand system from household survey data. To overcome the difficulty of obtaining price data, we used the unit value of each food category as variables in modeling a modified Almost Ideal Demand System. Since the unit values reflect both market prices and consumers' choices of food quality, we further calculated the quality-adjusted own-price, cross-price, and expenditure elasticities.

The developed methodology was successfully applied to the 1987-88 Nationwide Food Consumption Survey data. The empirical results are sets of estimated demand elasticities for households segmented at three different income levels. These demand elasticities were further applied to estimate the implied nutrient elasticities for low-income households. The significant estimates of food quality effects obtained in this study show that food quality plays a significant role in household budget allocation, and is an important factor in modeling a food demand system from household survey data. The estimation results are useful in evaluating some food policy and program effects that are related to households of a specific income level.

For various reasons, a household may report no consumption of a particular food in the survey. The treatment of zero consumption in cross-section demand estimation has received increasing attention in the literature. In this study, we focused on the treatment of unit value and its relationship with demand elasticity and sidestepped the zero-consumption issue. Future research in integrating our approach in dealing with quality issues and recent developments in treating zero consumption would be useful.

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Appendix: Review of Deaton's Approach

Deaton, in his series of articles starting in 1987, developed a methodology to estimate a complete demand system including own- and cross-price elasticities from cross-section data.
The unique feature of his approach was its ability to estimate a set of unit value and expenditure share equations and then recover the price effect from the estimated covariance matrices of residuals. Since his study represents a major contribution in demand system research, our review may provide a better understanding of his approach.

In household survey data, for household *i* in cluster *c*, there are two equations for good *g;* one is the budget share equation and the other is the unit value equation as in the following:

(15) $$w_{gic} = \alpha_g + \beta_g \ln x_{ic} + \gamma_g z_{ic} + \Sigma_h \theta_{gh} \ln p_{hc} + f_{gc} + u_{gic}$$

(16) $$\ln v_{gic} = \alpha^*_g + \beta^*_g \ln x_{ic} + \gamma^*_g z_{ic} + \Sigma_h \phi_{gh} \ln p_{hc} + u^*_{gic}$$

where w_{gic} is the budget share of good *g* in *i*th household's budget, x_{ic} is total expenditure on all goods and services, z_{ic} is a vector of household characteristics, p_{hc} is the price of good *h* in a total of the *n* goods, v_{gic} is the unit value of good *g* defined as the expenditure on the good divided by the quantity bought, f_{gc} is a cluster-fixed effect for good *g*, and u_{gic} and u^*_{gic} are random disturbances.

The expenditure share equation is assumed to be a linear function of the logarithm of total expenditure, of the prices, and of a vector of household characteristics. Each household in a cluster is assumed to face the same prices for market goods. The logarithm of the unit value, which is the logarithm of quality plus the logarithm of price, is a function of the same variables that appear in the share equation, with the exception of the cluster-fixed effect.

Moreover, consider the budget allocation of a representative consumer; that is, the subscripts of household *i* in cluster *c* are temporarily disregarded, and the equations of cluster means may be represented as in the following:

(17) $$w_{gc} = \alpha_g + \beta_g \ln x_c + \gamma_g z_c + \Sigma_h \theta_{gh} \ln p_{hc} + f_{gc} + u_{gc}$$

(18) $$\ln v_{gc} = \alpha^*_g + \beta^*_g \ln x_c + \gamma^*_g z_c + \Sigma_h \phi_{gh} \ln p_{hc} + u^*_{gc}$$

Since the price variables p_{hc} in the model are not observable, it is not possible to estimate the price coefficients in the equations directly. Deaton developed a two-stage procedure to link the price effects to the estimated residuals, which are estimated from a model excluding price variables.

In the first stage of estimation, both equations are estimated separately by OLS with cluster means subtracted from all data. The subtraction of cluster means removes not only the fixed effects but also the cluster invariant prices in both equations as in the following:

(19) $(w_{gic} - w_{gc}) = \beta_g (\ln x_{ic} - \ln x_c) + \gamma_g (z_{ic} - z_c) + (u_{gic} - u_{gc})$

(20) $(\ln v_{gic} - \ln v_{gc}) = \beta^*_g (\ln x_{ic} - \ln x_c) + \gamma^*_g (z_{ic} - z_c) + (u^*_{gic} - u^*_{gc})$

Based on the estimates of β_g, γ_g, β^*_g and γ^*_g, the residuals associated with each equation can be generated. Using these estimated residuals, we can estimate the matrices of covariance in each equation and across equations as $\Omega = \text{Cov}(u^*_{gic} - u^*_{gc})$, and $\Gamma = \text{Cov}[(u_{gic} - u_{gc}), (u^*_{gic} - u^*_{gc})]$, respectively.

In the second stage of estimation, the first-stage estimates are used to calculate the parts of mean cluster shares and unit values that are not accounted for by the first-stage variables. To obtain the covariance matrices, comprised of price components and residuals, we may define ε_{gc} and ε^*_{gc} as follows:

(21) $\varepsilon_{gc} = w_{gc} - \beta_g \ln x_c - \gamma_g z_c = \alpha_g + \Sigma_h \theta_{gh} \ln p_{hc} + f_{gc} + u_{gc}$

(22) $\varepsilon^*_{gc} = \ln v_{gc} - \beta^*_g \ln x_c - \gamma^*_g z_c = \alpha^*_g + \Sigma_h \phi_{gh} \ln p_{hc} + u^*_{gc}$

We then calculate the matrices of covariance associated with ε_{gc} and ε^*_{gc} as follows:

(23) $S = \text{Cov}(\varepsilon^*_{gc}, \varepsilon^*_{gc}) = \Psi M \Psi' + (1/n)\Omega$

(24) $R = \text{Cov}(\varepsilon_{gc}, \varepsilon^*_{gc}) = \Psi M \Theta' + (1/n)\Gamma$

where M is the covariance matrix of the unobservable price vector, Θ is a matrix of θ_{gh}, Ψ is a matrix of ϕ_{gh}, and n is the number of households in the cluster.

For given information of S, R, Ω, and Γ, Deaton is able to obtain a matrix B, which is defined by $B = [S - (1/n)\Omega]^{-1} [R - (1/n)\Gamma]$. Furthermore, he is able to obtain the relationships of Θ and Ψ by using available information B as a linkage, while the unknown matrix M can be ignored:

(25) $B = [S - (1/n)\Omega]^{-1} [R - (1/n)\Gamma]$

$= (\Psi M \Psi')^{-1} \Psi M \Theta'$

$= (\Psi')^{-1} \Theta'$

By applying a separability assumption, in which the demand for individual commodities depends on the associated group expenditures and on the prices of the individual commodities in that group, Deaton is able to derive information on the price effects from the estimated covariance of residuals as follows:

(26) $E = [D^{-1}(w_g) B' - I] [I - D(\xi_g) B' + D(\xi_g) D(w_g)]^{-1}$

where E is a matrix of all own- and cross-price elasticities, I is an identity matrix, $D^{-1}(w_g)$ is a diagonal matrix with $(1/w_g)$'s as entries, and $D(\xi_g)$ is a diagonal matrix with $(1/\xi_g)$ as entries, in which ξ_g is defined as $\beta^*_g / [(1 - \beta^*_g) w_g + \beta_g]$.

In addition to complicated matrix multiplication, the main problem of applying Deaton's approach is that there is no guarantee of obtaining accurate estimates of price responses, because the covariance matrices of residuals S, R, Ω, and Γ are influenced by many unexplained factors, but not by price variations alone. In fact, we applied Deaton's approach to fit the NFCS 1987-88 data, and the results were deemed unsatisfactory.

Table 1—Descriptive statistics of variables in the 1987-88 Nationwide Food Consumption Survey

Item	Whole sample Mean	Whole sample SD	Low income Mean	Low income SD	Medium income Mean	Medium income SD	High income Mean	High income SD
Price: dollars per pound								
Beef	1.73	1.18	1.45	0.94	1.67	1.06	1.94	1.34
Pork	1.51	1.24	1.33	1.14	1.53	1.16	1.60	1.35
Poultry	1.09	1.15	0.88	0.94	1.05	1.16	1.26	1.23
Other meats	1.53	1.33	1.42	1.18	1.51	1.23	1.62	1.49
Fish	1.62	2.07	1.20	1.59	1.52	1.94	1.94	2.35
Dairy	1.26	0.92	1.10	0.82	1.17	0.73	1.42	1.09
Eggs	0.49	0.36	0.49	0.26	0.49	0.33	0.49	0.42
Fats	1.13	0.63	0.98	0.57	1.08	0.61	1.26	0.65
Cereals	1.62	0.86	1.42	0.84	1.64	0.82	1.71	0.88
Bread	1.56	0.77	1.36	0.73	1.50	0.68	1.74	0.83
Vegetables	0.95	0.56	0.83	0.53	0.93	0.47	1.03	0.62
Fruits	0.63	0.49	0.53	0.43	0.61	0.45	0.71	0.54
Juice	0.53	0.46	0.46	0.45	0.53	0.46	0.56	0.46
Budget share: percent								
Beef	12.75	10.60	12.99	11.15	12.77	10.27	12.60	10.56
Pork	7.25	8.04	7.91	9.11	7.52	7.95	6.64	7.40
Poultry	6.55	7.05	6.53	7.13	6.29	6.86	6.78	7.15
Other meats	4.66	5.73	5.24	5.97	4.83	5.76	4.19	5.52
Fish	5.10	8.26	4.52	7.97	4.62	7.48	5.84	8.98
Dairy	15.36	8.87	15.60	9.90	15.49	8.80	15.12	8.30
Eggs	1.49	1.59	1.80	1.60	1.60	1.83	1.22	1.29
Fats	3.39	2.78	3.55	3.14	3.39	2.67	3.30	2.64
Cereals	6.87	5.41	7.28	6.25	7.22	5.39	6.35	4.86
Bread	11.10	7.27	10.12	7.47	11.19	7.07	11.58	7.27
Vegetables	13.62	7.12	13.49	7.78	13.52	6.69	13.78	7.09
Fruits	7.72	7.17	6.88	7.08	7.44	6.77	8.42	7.49
Juice	4.14	4.62	4.09	4.74	4.11	4.44	4.19	4.71
Consuming household: percent								
Beef	84.66	36.04	83.06	37.53	86.01	34.70	84.41	36.28
Pork	70.08	45.80	67.44	46.88	73.48	44.16	68.66	46.40
Poultry	73.22	44.29	73.73	44.03	71.95	44.94	74.00	43.87
Other meats	68.98	46.26	71.30	45.26	71.35	45.23	65.64	47.50
Fish	52.72	49.93	47.26	49.95	52.50	49.95	55.97	49.66
Dairy	98.96	10.13	97.67	15.10	99.47	7.28	99.26	8.57
Eggs	85.82	34.89	88.03	32.47	87.81	32.73	82.88	37.68
Fats	92.93	25.63	90.26	29.66	93.87	23.99	93.63	24.43
Cereals	92.70	26.02	90.97	28.67	93.60	24.48	92.89	25.71
Bread	98.68	11.41	97.77	14.78	98.93	10.27	98.98	10.07
Vegetables	97.79	14.72	96.45	18.51	98.20	13.30	98.18	13.37
Fruits	84.62	36.08	77.79	41.59	84.94	35.77	88.17	32.31
Juice	72.91	44.45	66.33	47.28	73.42	44.19	76.17	42.62

Continued—

Table 1—Descriptive statistics of variables in the 1987-88 Nationwide Food Consumption Survey—Continued

Item	Whole sample Mean	Whole sample SD	Low income Mean	Low income SD	Medium income Mean	Medium income SD	High income Mean	High income SD
Household income:								
Percent of poverty level	316	269	81	33	211	48	538	287
Food expenditure at home:								
Dollars per person	18.55	9.99	16.73	9.03	17.81	8.76	20.21	11.17
Away-from-home share of total food budget	26.63	22.64	16.13	20.24	24.89	21.37	34.01	22.36
Household size	2.43	1.34	2.47	1.55	2.59	1.40	2.26	1.13
Education:								
Less than college	64.83	47.76	87.53	33.06	73.62	44.09	44.60	49.72
College	35.17	47.76	12.47	33.06	26.38	44.09	55.40	49.72
Race:								
White	83.02	37.55	64.60	47.84	84.41	36.29	92.15	26.90
Black	11.57	31.99	26.17	43.98	10.39	30.53	4.38	20.47
Other	5.42	22.64	9.23	28.96	5.20	22.20	3.47	18.31
Urbanization:								
City	23.35	42.31	30.43	46.03	20.92	40.69	21.44	41.06
Suburb	47.28	49.93	30.43	46.03	45.57	49.82	58.19	49.34
Nonmetro	29.38	45.55	39.15	48.83	33.51	47.22	20.36	40.28
Region:								
Northeast	20.52	40.39	16.23	36.89	20.79	40.59	22.70	41.90
Midwest	26.20	43.98	22.52	41.79	27.51	44.67	27.13	44.48
South	34.42	47.52	45.03	49.78	33.31	47.15	29.41	45.58
West	18.87	39.13	16.23	36.89	18.39	38.75	20.76	40.57
Percent of household members								
Age 0-5	7.12	15.21	9.90	18.23	7.93	15.58	4.86	12.45
Age 6-11	6.71	14.34	7.96	15.62	8.12	15.69	4.80	12.00
Male 12-17	3.26	9.78	3.33	10.37	3.49	10.18	3.01	9.08
Male 18-34	11.30	20.76	8.92	19.11	11.22	19.84	12.69	22.26
Male 35-64	15.88	22.27	8.11	18.10	12.11	19.54	23.46	24.18
Male 65 +	7.32	19.57	7.47	21.02	9.03	21.15	5.77	17.05
Male 65 +	7.32	19.57	7.47	21.02	9.03	21.15	5.77	17.05
Female 12-17	3.21	9.85	3.96	10.95	3.49	10.28	2.55	8.72
Female 18-34	13.10	21.20	12.80	20.49	13.07	20.80	13.29	21.92
Female 35-64	19.44	25.13	15.06	26.22	17.73	24.41	23.35	24.56
Female 65 +	12.68	29.14	22.48	38.67	13.79	29.57	6.23	19.23
Season:								
Spring 1987	13.76	34.45	14.71	35.43	13.72	34.42	13.25	33.92
Summer 1987	12.06	32.57	14.50	35.23	11.93	32.42	10.81	31.06
Fall 1987	15.92	36.59	14.40	35.13	15.46	36.16	17.18	37.73
Winter 1987	28.69	45.24	27.99	44.92	29.11	45.44	28.73	45.26
Spring 1988	26.57	44.18	24.95	43.29	27.18	44.50	26.96	44.39
Summer 1998	2.99	17.04	3.45	18.26	2.60	15.91	3.07	17.26

SD = standard deviation.

Source: Nationwide Food Consumption Survey 1987-88, USDA.