Demand for Nutrients:
The Household Production Approach

by

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This study tries to measure the household's demand for nutrients in diet. The approach used in this study is based on household production theory (Mincer, 1962; Becker, 1965; Michael and Becker, 1973; Deaton and Muellbauer, 1980). The household production theory is an integration of consumer and firm theories. The household is assumed to produce utility-yielding, nonmarket goods using market goods, time, and human capital as factor inputs. Advantages attributed to the household production approach include the emphasis on the household as the decision-making unit; explicit consideration of the role of time in consumption decisions; and the ability of the theory to explain changes in consumption behavior on the basis of changes in the household production relations and their implicit (shadow) prices rather than the basics of changes in "tastes" as is the case in traditional consumer theory.

In this study, two related optimization problems are considered. First, the household is assumed to minimize the expenditures necessary to achieve given levels of various nutrients and food consumed. Differentiating this expenditure or cost function then allows the calculation of shadow prices of nutrients in food intake. A representation of the household's optimization problem, which explicitly depends on these calculated shadow prices, is then formulated. The solution to this problem provides a system of equations that links the demand for nutrients to the nutrient shadow prices, food expenditure, the number of meals equivalent, and household composition variables.

A Theoretical Model

Assume that the vector **z** = [z_1,..., z_{g+1}] represents g+1 factors consisting of the levels of g nutrients (z_i, $i \leq g$) and the number of meals equivalent consumed (z_{g+1}). According to household production theory, it may be argued that, in order to produce the nonmarket vector **z**, the household must purchase a vector of food inputs (q_is, $i = 1, \ldots, n$; n food items) and labor inputs (l_js, $j = 1, \ldots, r$; r types of labor inputs), **q** = [$q_1, \ldots, q_n, l_1, \ldots, l_r$], at given market prices (p_is) and wages (s_js) vector, **p** = [$p_1, \ldots, p_n, s_1, \ldots, s_r$].

At the first stage the household may be characterized by cost-minimizing behavior, with food inputs assumed to be weakly separable from all other commodity groups (Deaton and Muellbauer, 1980), allowing the expenditure allocation among food groups to be in isolation from other commodities. The household's consumption choices then may be written as:

(1) $$\min C = \mathbf{p}'\,\mathbf{q}$$
$$\text{s. t.}\;\; H(\mathbf{q}, \mathbf{z}; \mathbf{k}) \geq 0,$$

where H(**q**, **z**; **k**) denotes the corresponding transformation function that converts food inputs (q_is), labor inputs (l_rs), and fixed capital stocks (**k**, capital stocks are considered fixed in the short run) into the nonmarket output vector **z**. The solution to equation (1) is the household cost or expenditure function, $C^0 = x(\mathbf{p}, \mathbf{z}; \mathbf{k})$, indicating the minimal short-run cost of obtaining given levels of g nutrients and number of meals equivalent at given prices and wages.

The shadow values of the z_k are defined as (Deaton and Muellbauer, 1980)

(2) $$\pi_k = \partial C/\partial z_k, \qquad k = 1, \ldots, g + 1.$$

The prominent advantage of utilizing the cost function to characterize the household's transformation of market inputs into nonmarket outputs is that it can provide a direct means of imputing values to the nonmarket goods, **z**. Therefore, given the solution of (1), shadow prices for various nutrients and the number of meals equivalent consumed may be obtained by simple differentiation.

With these shadow prices the second-stage optimization problem of determining the levels of various nutrients and the number of meals equivalent can be defined as

(3) $$\max U(\mathbf{z}, \mathbf{HC})$$
$$\text{s. t. } C^0 = x(\mathbf{p}, \mathbf{z}; \mathbf{k}), \quad \text{or} \quad C^0 = g(\boldsymbol{\pi}'\mathbf{z});$$

where U represents a well-defined utility function; **HC** is a vector of household composition variables; $\pi = (\pi_1, \ldots, \pi_{g+1})$ are the shadow prices; and C^0 is the minimized cost of equation (1) for given **p**. Note that this optimization problem is different from the conventional budget-constrained utility maximization problem of demand theory in the sense that the expenditure constraint in this context is a nonlinear function of $\pi'\mathbf{z}$. This nonlinearity of the expenditure of equation (3), $g(\pi'\mathbf{z})$, is associated with the structure of the household's technology. In fact, the linear expenditure constraint corresponds to the assumption of constant return to scale (Deaton and Muellbauer, 1980). In more general cases concerning the household technology, the nonlinear budget constraint is thus more appropriate.

With the nonlinear budget constraint, the explicit solution to this optimization problem is difficult to obtain. Nevertheless, given the shadow prices of **z**, the implicit form of solution to the second-stage optimization can be written as

(4) $$z_k = z_k(C^0, \pi, \mathbf{HC}), \qquad k = 1, \ldots, g + 1,$$

which states that the demand for various nutrients and the number of meals equivalent is a function of food expenditures C^0, their shadow values π, -- which are determined by the first-stage optimization, and household composition. Therefore, given estimated shadow values π_is and expenditure, the price and expenditure elasticities for the nonmarket output z_is and the impact of individual members of the family on the demand for nutrients can be obtained.

Data and Model

The data used in this study are from the 1987-88 Nationwide Food Consumption Survey (NFCS). This survey covers the period from April 1987 through the first week of August 1988. The 1987-88 NFCS is the most recent of many USDA studies of food consumption. In this survey, nationwide measurements of nutrient contents in each food item are reported and the amount of nutrients in each consumed food item can be obtained. However, this survey has the potential for sampling bias given the low response rate (35 percent) (FASEB, 1991; USDA, 1994; GAO, 1991). However, the bias is believed to be no greater than that of other, comparable household-level data sets (Murphy et al., 1992).

In this study, food items are grouped into five food categories: dairy; meats and other protein food items; vegetables and fruit; grain products; and other (fats and oils, sugar and sweets, and other miscellaneous). Seven nutrients are considered: carbohydrates; fats and oils; proteins; vitamin group I (vitamins measured in milligrams, for example, vitamins C and B-6, thiamin, riboflavin, and niacin); vitamin group II (measured in micrograms, for example, folate and vitamin B-12); digestible fibers; and minerals. In order to correct for the household composition effects on food consumption, the total quantity of food consumption is represented by the number of meals equivalent, which is the total number of meals from household food supplies.

A total of 4,155 observations or households were involved in this study. An average household with 2.81 persons consumed 72.84 pounds of food and 48.37 meals, and spent $62.03 on food per week. The average household consumption of dairy products, meats and other protein source products, vegetables and fruit, grains, and all other foods are 20.64, 13.12, 24.24, 5.17, and 9.67 pounds per week, respectively; the respective budget shares of these food groups are 0.125, 0.339, 0.212, 0.165, and 0.159. The average household consumption of carbohydrates, fats and oils, proteins, vitamin I, vitamin II, fibers, and minerals are 5,234 grams, 2,186 grams, 1,689 grams, 3,136 milligrams, 5,694 micrograms, 313 grams, and 165,686 milligrams, respectively.

Since both wage rates of meal preparers and labor inputs in meal preparation were not reported in the 1987-88 NFCS, the wage and labor variables are deleted from **p** and **z** in equations (1) through (4). Given no a priori knowledge about cost function C^0, a translog cost function is adopted. Formally, this cost function can be written as

$$(5)\qquad \ln C = \alpha_0 + \Sigma_i \alpha_i \ln p_i + \Sigma_k \beta_k \ln z_k + ½ \Sigma_i \Sigma_j \alpha_{ij} \ln p_j \ln p_j + ½ \Sigma_k \Sigma_h \beta_{kh} \ln z_k \ln z_h + ½ \Sigma_i \Sigma_k \theta_{ik} \ln p_i \ln z_k.$$

The number of parameters that needs to be estimated can be reduced by imposing theoretically derived restrictions, such as linear homogeneity in prices ($\Sigma_t \alpha_i = 1$, i = 1,..., n; $\Sigma_j \alpha_{ij} = 0$, i, j = 1,..., n; and $\Sigma_i \theta_{ik} = 0$, k = 1,...,g+1) and symmetry of the cross-price and cross-nutrient derivatives ($\alpha_{ij} = \alpha_{ji}$ and $\beta_{kh} = \beta_{kh}$ (Young's theorem)).

Differentiating equation (5) with respect to each of the input prices and applying Shephard's lemma, budget (factor) share equations can be derived as

$$(6)\qquad \partial \ln C/\partial \ln p_i = w_i = \alpha_i + \Sigma_j \alpha_{ij} \ln p_j + ½\Sigma_k \theta_{ik} \ln z_k, i, j = 1, . . . , n; k = 1, . . ., g + 1,$$

where $w_i = p_i q_i/C$ is the average propensity of total food expenditure to spend on input group i. The parameters α_{ij}s and θ_{ik}s show the effect of changes in **p** and **z** on factor shares. If θ_{ik} equals zero, for all i and k, the household production technology is homothetic, meaning the factor shares are not affected by the levels of various nutrients and the number of meals equivalent at constant input prices.

The elasticities of substitution (Uzawa, 1962) and Hicksian own-price and cross-price elasticities of demand (Binswanger, 1974) can be obtained given the share equation (6). The elasticities of substitution are

$$(7)\qquad \sigma_{ii} = (\alpha_{ii}/w_i(w_i - 1))/w_i^2,$$
$$\sigma_{ij} = (\alpha_{ij}/w_i w_j) + 1.$$

Note that, if $\sigma_{ij} = 0$, then the elasticity of substitution equals one. The Hicksian own-price and cross-price elasticities of demand are

$$(8) \qquad \eta_{ii} = \sigma_{ii}\, w_i$$
$$\eta_{ij} = \sigma_{ij}\, w_j.$$

In addition, the shadow prices of the elements of **z** can be calculated as

$$(9) \qquad \pi_k = \partial C/\partial z_k = (\partial \ln C/\partial \ln z_k)\,(C/z_k), \qquad k = 1, \ldots, g + 1.$$

Given relationships (9), the demand equations in (4) can be estimated. The approach first requires estimating shadow prices, based on equation (5). The estimation may be accomplished by jointly estimating equation (5) and (n-1) share equations (6). The iterative seemingly unrelated least squares method was used to estimate these parameters.

Results

With five food groups and seven nutrients, the translog cost function has 91 parameters, after imposing the homogeneity and the symmetry conditions. The translog specification (5) appears to fit the data quite successfully -- with 59 of the 91 estimated parameters exceeding twice of their associated standard errors.

The estimated parameters of particular interest are θ_{ik}s. Parameter θ_{i8} indicates the effect of changes in the number of meals equivalent on the *i*th food group budget share, and θ_{ik}, $k \le 7$ indicates the effect of changes in the *k*th nutrient contained in all food groups on the *i*th budget share. The estimated θ_{i8} for the dairy group is positive (θ_{18} = 0.01765), while those for the vegetables and fruit and other groups are negative (θ_{38} = -0.01097 and θ_{58} = -0.00393). This result reflects the fact that budget share for dairy increases as the number of meals consumed by the household increases, while the budget shares of vegetables and fruit and other food groups decrease, assuming constant food prices. The estimates θ_{ik}s, $k \le 7$ show both substitution ($\theta_{ik} < 0$) and complementary ($\theta_{ik} > 0$) relationships.

Elasticities of substitution and of factor demand evaluated at the means of the budget shares based on equations (7) and (8), respectively, are reported in Table 1. All cross-elasticities of substitution are positive, which reveals that all food groups are substitutes. In Table 1, all own-price elasticities of factor demand have the correct sign as expected; that is, relatively, the higher the price for one food group, the less food consumed.

Table 2 shows the mean shadow prices of the nutrient variables z_ks, $k \leq 7$ and of the meals variable, z_8. The shadow prices vary from \$0.02766 per milligram for fibers to \$0.00002 per milligram for minerals. The variation in shadow prices suggests the unit costs of nutrients are different to consumers. The negative price parameter estimate for vitamin II was unexpected. Consequently, the sign for the own-price elasticity of vitamin group II is positive.

The individual nutrient demand equation may now be estimated. The functional form used for equation (4) is

$$(10) \qquad z_k = \psi_0 + \Sigma_h\, \psi_{kh}\, \pi_h + \psi_{k1}\, C + \psi_{k2}\, C^2 + c_{11}Ag1 + c_{12}Ag2 + c_{13}Ag3 + c_{14}Ag4 + c_{15}Ag5 + c_{16}Ag6 + f_1\, HZ^2, \qquad k, h = 1, \ldots, g + 1,$$

where C is the expenditure variable; Ag1, Ag2, Ag3, Ag4, Ag5, and Ag6 represent the number of household members of ages from zero to six years, seven to 12 years, 13 to 18 years, 19 to 45 years, 46 to 60 years, and over sixty years, respectively; HZ denotes the household size which is the sum of Ag1 through Ag6.

Note that, since all π_ks are themselves functions of the z_k, the estimation of (10) will be biased if the correlations between π_ks and z_ks are not considered. Therefore, a two-stage estimation, using an instrumental variables estimator, provides consistent estimates of π_ks in equation (9), and those consistent estimates are used in the estimation of (10) (Mendelsohn, 1984). In addition to the ability of calculating the price and expenditure elasticities of nutrients, equation (10) also allows us to explore the effects of household composition variables on nutrient demand.

The price and expenditure elasticities for nutrient demand calculated at sample means are reported in Table 3. Results show that the (shadow) price elasticity of demand for each nutrient is inelastic; the expenditure elasticities of carbohydrates, proteins, vitamin II, and fibers are inelastic; and the expenditure elasticities for fats and oils, vitamin I, and minerals are around one. The expenditure elasticity estimates suggest that consumers will demand relatively less carbohydrates, protein, vitamin II, and fiber than fats and oils, vitamin I , and minerals as their incomes increase.

The impacts of the addition of household member by age group on individual nutrient intake are also estimated. Over a half of the estimated household composition parameters are significantly different from zero at $\alpha = 0.05$ level. On average, the addition of a household member of ages between 0 and 18 years would increase the weekly household carbohydrate intakes. The addition of the very young and older member in a household would decrease the consumption of fats and oils. The negative impact estimates of the addition of household member on vitamin I group are unexpected. The addition of members of ages younger than 18 years would likely to increase the consumption of vitamins such as folate and vitamin B-12. The addition of members of ages between 46 and 60 years would increase the consumption fibers. Results also show that the addition of household member of ages between 7 and 18 would increase the consumption of minerals and the addition of older household members between ages 19 and 45 years and those older than 60 years old would decrease the consumption of minerals in the household. The addition of the very young (0-6 years old) and older household members (older than 45 years) would increase at-home meal consumption.

Concluding Remarks

This study tries to model the household's demand for nutrients using the household production theory. In the analysis, this study assumes that the household minimizes its food cost and maximizes its utility at the same time. A translog cost function and seven nutrient demand equations were estimated. Shadow prices for seven nutrients and the number of meals equivalent were calculated using the cost function. The resulting shadow prices were used in the estimation of nutrient demand equations. Price and income elasticities of demand for nutrients were then calculated. Results show that most of these elasticity estimates had the expected signs.

The results obtained in this study demonstrate that the household production theory is promising in analyzing the demand for nutrients. However, due to the complexity of the translog cost function used in this study, the negativity of the Slutsky matrix was not verified. In addition, due to the lack of information of labor inputs in meal preparations, the shadow prices of labor were not estimated.

Table 1. Elasticities of substitution and factor demand calculated at means of data.

Food Groups	Dairy	Meats & Protein Products	Vegetables & Fruit	Grains	Others
			Elasticity of Substitution		
Dairy	-3.52182*	0.37757*	0.68621*	0.20326*	0.82478*
	(0.12861)	(0.04587)	(0.06210)	(0.06412)	(0.06554)
Meats & Protein Products		-0.67290*	0.14348*	0.13918*	0.80146*
		(0.02610)	(0.02847)	(0.02945)	(0.02981)
Vegetables & Fruit			-1.50977*	0.25952*	0.90240*
			(0.05677)	(0.04342)	(0.04314)
Grains				-1.55902*	0.80848*
				(0.06174)	(0.04587)
Others					-6.16010*
					(0.07250)
			Elasticity of Factor Demand		
Dairy	-0.43870*	0.12803*	0.14575*	0.03344*	0.13148*
	(0.01602)	(0.01555)	(0.01319)	(0.01055)	(0.01045)
Meats & Protein Products	0.04703*	-0.22817*	0.03048*	0.02290*	0.12776*
	(0.00571)	(0.00885)	(0.00605)	(0.00485)	(0.00475)
Vegetables & Fruit	0.08548*	0.04865*	-0.32068*	0.04270*	0.14385*
	(0.00774)	(0.00965)	(0.01206)	(0.00714)	(0.00688)
Grains	0.02532*	0.04719*	0.05512*	-0.25652*	0.12888*
	(0.00799)	(0.00999)	(0.00922)	(0.01016)	(0.00731)
Others	0.10274*	0.27176*	0.19168*	0.13303*	-0.98198*
	(0.00816)	(0.01011)	(0.00916)	(0.00755)	(0.01156)

*denotes the estimate is significantly different from zero at = 0.05 level. The values in parentheses are the corresponding standard errors.

Table 2. Mean shadow prices.

Nutrients	Mean	Standard Deviation
Carbohydrates	0.00139	0.00125
Fats and oils	0.00372	0.00208
Proteins	0.02289	0.00982
Vitamin I	0.00309	0.00177
Vitamin II	-0.00021	0.00043
Fibers	0.02766	0.02334
Minerals	0.00002	0.00006
Number of meals equivalent	0.00846	0.06135

Table 3. Price and expenditure elasticity estimates, and the estimated impacts of household composition on nutrient demand

Nutrients	Elasticity		Household Composition					
	Own-price	Expenditure	0-6 yrs	7-12 yrs	13-18 yrs	19-45 yrs	46-60 yrs	> 60 yrs
Carbohydrates	-0.11095*	0.87900*	357.55*	442.36*	513.27*	82.94	82.73	88.23
	(0.00636)	(0.01521)	(50.27)	(54.75)	(54.60)	(46.20)	(52.82)	(64.52)
Fats and Oils	-0.09953*	1.04113*	-75.22*	2.09	6.46	-3.69	-55.77*	-100.75*
	(0.01114)	(0.01575)	(21.74)	(23.68)	(23.61)	(19.98)	(22.84)	(27.91)
Proteins	-0.47252*	0.93405*	32.04*	51.22*	66.41*	35.16*	55.56*	31.70
	(0.00997)	(0.00971)	(10.36)	(11.29)	(11.25)	(9.52)	(10.89)	(13.30)
Vitamin I	-0.39605*	1.00011*	-148.24*	-59.37	8.51	-138.30*	-50.09	-90.06*
	(0.01311)	(0.01768)	(35.02)	(38.15)	(38.04)	(32.18)	(36.80)	(44.95)
Vitamin II	0.06057*	0.87098*	189.77*	334.04*	431.03*	- 42.69	172.53*	141.89
	(0.00389)	(0.01801)	(64.79)	(70.56)	(70.36)	(59.54)	(68.07)	(83.15)
Fibers	-0.25859*	0.89948*	4.17	3.76	5.39	-2.93	8.01*	7.08
	(0.00715)	(0.01744)	(3.45)	(3.76)	(3.75)	(3.17)	(3.62)	(4.43)
Minerals	-0.03746*	0.96268*	578.61	3799.17*	5039.05*	-3186.63*	-2046.20	-4194.78*
	(0.00109)	(0.00999)	(1045.48)	(1138.69)	(1135.49)	(960.74)	(1098.40)	(1341.83)
# of Meals Equivalent	0.00843*	0.18553*	16.47*	13.39*	12.05*	12.70*	14.04*	15.17*
	(0.00048)	(0.00806)	(0.25)	(0.27)	(0.27)	(0.23)	(0.26)	(0.32)
				12.05*	14.04*			
				(0.27)	(0.26)			

*denotes the corresponding estimate is significantly different from zero at   = 0.05 level. The values in parentheses are the corresponding standard errors.

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