

Incorporating Nutrients in Food Demand Analysis

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Abstract

Two levels version of the Rotterdam demand systems were developed using utility theory with additional nutrient variables. Income, price, and nutrient demand elasticities were estimated. Results show that some nutrients are important factors in determining the demand for food items.

Key Words: nutrient, demand for food, Rotterdam model.

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Incorporating Nutrients in Food Demand Analysis

Several studies have incorporated nutritional factors into food demand analyses. Some used cholesterol information index as a variable in demand equations (Brown and Schrader; Capps and Schmitz) or considered nutrients as functions of income and sociodemographic variables (Adrian and Daniel; Devaney and Fraker; Basiotis et al.), while other studies (Gould et al.; Pitt; Sahn) added nutrient variables in their demand models without providing a framework about how nutrients can be incorporated in the demand analysis using utility theory.

A recent study by Huang explored the linkage of the determinants for food choice based on consumer nutrient availability using Lancaster's consumer technology approach. In Huang's study, demand elasticities from traditional demand analysis were used to derive the elasticities for changes in the nutritional content of consumer diets using disappearance data compiled by the U.S. Department of Agriculture. As pointed out by Huang, there are limitations of using disappearance data. For example, the nutrition information used in Huang's study are the nutritive values of the edible portion of food items which do not directly related to the disappearance quantities. Therefore, the nutrient elasticities estimated by Huang were under the assumption that the edible portions and disappearance quantities are identical.

The current study is different from Huang's study in two ways. First, the 1987-88 Nationwide Food Consumption Survey data will be used. Since the amount of nutrients in each food item were derived directly from actual food consumed by the reporting households, there is no need to use disappearance data. In addition, instead of using the linear characteristic model (Lancaster), utility theory will be used to derive an extended Rotterdam demand system, which will be used to explain how nutrients affect the demand for food. The two objectives of this study are (1) to investigate whether nutrient contents affect the demand for food and (2) if they do, in what fashion.

Model Specifications

The consumer choice problem, maximization of utility subject to the consumer's budget constraint, for the alternative specifications can be written as

$$(1) \quad \begin{array}{ll} \text{maximize} & u = (q_1, \dots, q_n, a_{11}, \dots, a_{1k}, \dots, a_{n1}, \dots, a_{nk}) \\ \text{subject to} & \sum p_i q_i = x \end{array}$$

where u is utility; q_i , p_i , and a_{ik} are quantity, price, and the k th nutrient level in food i , respectively; and x is total expenditure or income. Problem (1) is the usual consumer choice problem with the addition of nutrients, which are allowed to affect utility and, in turn, the bundle of goods chosen. This specification assumes that the consumer's utility generated from food is not only a function of the quantities consumed but also a function of levels of nutrients embodied in the food items he/she consumed. For example, a factor influencing the consumption of meat may be the product's protein level. In describing the models here, $a_i = (a_{i1}, \dots, a_{ik})$, is treated as a vector of measures of different nutrients in food i . To simplify the notations used in this section, it is assumed here that the number of nutrients in each food group is the same. In reality, due to the richness of different nutrients in each food group, the number of nutrients for each food group in (1) need not be identical.

The demand equations satisfying (1) have the general form

$$(2) \quad q_i = q_i(p_1, \dots, p_n, a_{11}, \dots, a_{1k}, \dots, a_{n1}, \dots, a_{nk}, x)$$

indicating demand for a particular food item by a utility-maximizing consumer depends on the prices for all food items, the nutritional levels in different food items, and total food expenditure.

A basic property of demand systems with factors such as nutrients is that any demand increase(s) for product(s) as a result of a change in the factor must be offset by demand decreases for other products as total consumer expenditures are constant. In the present case, this property can be written as the differentiation of the budget constraint with respect to a_{jk} , nutrient k in food j (Tintner; Ichimura; Barten, 1977; Phlips), i.e.,

$$(3) \quad \sum_i p_i (\partial q_i / \partial a_{jk}) = 0, \text{ or}$$

$$\sum_i w_i (\partial \log q_i / \partial \log a_{jk}) = 0,$$

where $w_i = p_i q_i / x$, the budget share for food item i ; and $\partial \log q_i / \partial \log a_{jk}$ is the elasticity of demand for good i with respect to nutrient k in food item j . The elasticity version of (3) shows that the weighted sum of nutrient elasticities (with respect to nutrient for a specific product) is zero where the weights are the product budget shares.

The effect of nutrient can also be related the substitution effects of price changes, i.e.,

$$(4) \quad \partial q_i / \partial a_{jk} = -(1/\lambda) \sum_h s_{ih} v_{hjk},$$

where $\lambda = \partial u / \partial x$, the marginal utility of income;

$$s_{ih} = (\partial q_i / \partial p_h) + q_h (\partial q_i / \partial x),$$

the Slutsky substitution effect or demand price slope with utility held constant; and

$$v_{hjk} = \partial(\partial u / \partial q_h) / \partial a_{jk},$$

the effect of nutrient on marginal utility. Equation (4) can be written as

$$(5) \quad \partial q_i / \partial a_{jk} = -(1/\lambda) \sum_h s_{ih} v_{hjk}, \text{ or}$$

$$(p_i q_i / x) (\partial q_i / \partial a_{jk}) (a_{jk} / q_i) = - \sum_h (p_i p_h / x) s_{ih} [\partial(\partial u / \partial q_h) / \partial a_{jk}] (a_{jk} / (\lambda p_h)), \text{ or}$$

$$w_i (\partial \log q_i / \partial \log a_{jk}) = - \sum_h \pi_{ih} \gamma_{hjk},$$

where

$$\pi_{ih} = (p_i p_h / x) s_{ih},$$

the Slutsky coefficient of the Rotterdam model, and

$$\gamma_{hjk} = \partial[\log(\partial u / \partial q_h)] / \partial \log a_{jk}.$$

Under the block-independence assumption of food group, the unrestricted levels version of the Rotterdam model for the food group associated with (2) can be written as (Barten, 1989; Theil, 1980)

$$(6) \quad w_i \log q_i = \alpha_i + \theta_i \log Q + \sum_j \pi_{ij} \log p_j + \sum_l \sum_k \beta_{ilk} \log a_{lk}$$

$$= \alpha_i + \theta_i \log Q + \sum_j \pi_{ij} (\log p_j - \sum_l \sum_k \gamma_{ilk} \log a_{lk}),$$

where $\theta_i = w_i (\partial \log q_i / \partial x) = p_i (\partial q_i / \partial x)$, the marginal propensity to consume; $\log Q = \sum_j w_j \log q_j$, the Divisia volume index; and $\beta_{ijk} = \sum_j w_i (\partial \log q_i / \partial \log a_{jk}) = - \sum_j \pi_{ij} \gamma_{ijk}$.

As an approximation, the θ_i s, π_{ij} s, and β_{ijk} s (or γ_{ijk} s) are treated as constants to be estimated. The interpretation of β_{ijk} is straightforward. If β_{ijk} is greater than zero, then there is a positive relationship between the demand for q_i and nutrient k from food group j . On the other hand, if β_{ijk} is negative, then there is a negative relationship between the demand for food item i and nutrient k from food group j . If β_{ijk} is zero, then there is no relationship between the demand for food item i and nutrient k from food group j . In addition, β_{ijk}/w_i is the nutrient elasticity of nutrient k from food group j for the demand for food group i .

Following Theil (1980) and Duffy (1987, 1989, 1990) assume $\beta_{ijk} = - \pi_{ij} \gamma_{ijk}$ and let $\gamma_{jk} = \gamma_{ijk}$. For this assumption, the levels version of the Rotterdam model can be written as

$$w_i \log q_i = \alpha_i + \theta_i \log Q + \sum_j \pi_{ij} (\log p_j - \sum_k \gamma_{jk} \log a_{jk}).$$

Note that γ_{jk} represents the elasticity of marginal utility with respect to nutrient k in food j in equation i and is assumed to be constant for all food. The total number of γ_{jk} s needs to be estimated equals $(n \times \kappa)$ instead of $(n \times n \times \kappa)$.

Intuitively, γ_{ijk} should be non-negative if nutrients increase utility. In addition, the last term in model (7), $\log p_j^* = \log p_j - \sum_k \gamma_{jk} \log a_{jk}$ can also be considered as the modified (by nutrients found in food j) or the perceived price for food item j . The impact of a change in a_{jk} on p_j^* can be expressed as $\partial \log p_j^* / \partial \log a_{jk} = - \gamma_{jk}$. If γ_{jk} is positive, then an increase in nutrient k in food group j decreases the price perceived by the consumer for food item j . In other words, for a given market price, a nutrient may decrease the "perceived" price and increase the demand for the food item. An alternative possibility would be for nutrients to have an quantity-diminishing change. In this case, γ_{jk} is negative, and an increase in the nutrient increases the "perceived" price and decreases the demand for the food item.

When all β_{ijk} s or γ_{jks} are zeros, model (7) degenerate to the basic Rotterdam model, an indication that nutrients have no impact on consumer's utility. Note that, the basic Rotterdam model is nested in model (7); therefore, a likelihood ratio test can be constructed to test whether nutrients have impacts on utility using these models.

Note that the Divisia quantity index, $\log Q$, in the levels version of the Rotterdam model is not invariant to changes in the units of measurement of quantities (Moschini). To solve this problem, the sample means of w_{is} were used in (7).

Nutrients and Food Groups

In general, foods can be classified into five groups: dairy products, meats and other protein foods, fruits, vegetables, and grain. The dairy group provides calcium; meats and other protein food group provide iron; fruits and vegetables groups provide vitamin A and C; while the grain group provides fiber. The U.S. Department of Agriculture recommends that a daily balanced diet should include 2-3 servings of dairy products; 2-3 servings of meats and other protein products; 3-5 servings of vegetables; 2-4 servings of fruits, 6-11 servings of grain products, and use sparingly of fats, oils, and sweets (U.S. Department of Agriculture and U. S. Department of Health and Human Services).

Proteins come mostly from meats and beans; carbohydrates come from all varieties of foods; fats and oils come from dairy products, meats, nuts, deserts, and sweets; fibers are found only in plant foods such as whole-grain breads and cereals, beans and peas, and other vegetables and fruits; while vitamins and minerals mostly come from fruits and vegetables (U.S. Department of Agriculture and U. S. Department of Health and Human Services).

A recent study (USDA) found that: less than one-third of the people in the survey consumed the recommended servings of milk and meat and fewer than one-fifth of the people consumed the recommended servings of grains, vegetables, and fruits; less than 20 percent of the people in the survey achieved the recommended total fat and saturated fat

intakes; only 35 percent of the people met the recommendation for sodium. In addition, less than one-third of the people achieved the recommended amount of variety in dietary patterns. The findings paint a picture that average Americans were not eating healthily.

Data and Results

The 1987-88 Nationwide Food Consumption Survey (NFCS) data were used in this study. The use of household food consumption data would avoid the limitations mentioned in Huang's study about disappearance data, i.e., the amount of nutrients in food items can not be measured accurately. In the 1987-88 NFCS data, measurements of nutrient contents in each food item are reported and the amount of nutrients in each consumed food item can be obtained.

Food items were grouped into five categories: dairy; meats (beef, pork, lamb, poultry, fish, and other protein foods); vegetables and fruits; grain products; and other (fats and oils, sugar and sweets, and miscellaneous). Six nutrients were included in this study: carbohydrates (grams), fats (grams), vitamins, minerals (calcium, phosphorus, magnesium, iron, zinc, copper, sodium, and potassium; measured in milligrams), digestible fibers (grams), and proteins (grams). As discussed above, dairy and meat groups are rich in proteins, fats, and minerals; vegetables, fruits, and cereals are rich in carbohydrates, digestible fibers, vitamins and minerals; and the other food group is rich in fats, carbohydrates, and minerals; therefore, these nutrients are included in the analysis. As different measurements were used to quantify the contents of vitamins, two variables were created for vitamins. The first group of vitamins includes vitamin C, thiamin, riboflavin, niacin, and vitamin B-6. These vitamins are measured in milligrams (vitamin (I)). The second group of vitamins includes folate and vitamin B-12, which are measured in micrograms (vitamin (II)). Vitamin A (international units), carotenes (retinol equivalent), and vitamin E (alpha-tocopherol equivalents) were not included in the analysis as the

inclusion of these three variables would require the estimation of 12 additional parameters, making estimation difficult.

There are 4,495 households which completed the food use questionnaires used in the 1987-88 NFCS. Due to missing values in the five food groups and nutrients used in this study, only 4,155 households were used in the analysis.

The dependent variables, q_i s, are converted from total amounts consumed by the household to average quantities per meal equivalent; or the quantities consumed by the household divided by the total number of meals eaten by household members. Nutrient contents, a_{jk} , are defined as the average nutrients per unit of food consumed; or the total amount of nutrient divided by the quantity of the food consumed. The basic Rotterdam model without any nutrient variables and model (7) were estimated with all symmetry, homogeneity, and adding up restrictions imposed. The likelihood ratio test statistic for model selection (Amemiya, p. 141-6) for the basic Rotterdam model and (7); is 1,828.6; an indication that nutrients have significant impacts on the demand for the food groups. Based on the values of these test statistics, only the results of model (7) are presented. Results of model (7) are summarized in Tables 1 and 2.

Table 1 shows the parameter estimates for model (7). Note that, these are conditional demand parameter estimates. In other words, these parameters are estimates for the food demand subsystem (see Theil, 1980; Chapter 9) and the full demand system parameter estimates are conditioned on how total budget is allocated to broad commodity groups, including the food group. As shown in Table 1, all income and price parameter estimates are at least two times greater than their respective standard errors. All parameter estimates for the income variable ($\log Q$) are positive and less than unity, all own-price parameter estimates are negative and all cross-price parameter estimates are positive indicating substitution relationship.

Income elasticity, compensated price elasticity, and nutrient elasticity estimates were derived at sample means and presented in Table 2. Income elasticity estimates

indicate that if food expenditure is increased by one percent, the expenditures for the meats, vegetables and fruits, and other groups would increase by more than one percent (luxuries in the food group); the expenditures for the dairy and cereal groups would increase by less than one percent (necessities in the food group). All own-price demand elasticity estimates are negative and all cross-price demand elasticity estimates are positive. The cross-price elasticities are, as expected, small in comparison to own-price demand elasticity estimates.

Two types of nutrient demand elasticity estimates are presented in Table 2: own-nutrient demand elasticities and cross-nutrient demand elasticities. The own-nutrient demand elasticity shows the percentage change in the demand for a food item due to a percent change in the particular nutrients found in the food item. The cross-nutrient demand elasticity shows the percentage change in the demand for a food item due to a one percent change in nutrients found in other food groups. For example, the result in Table 2 shows that if the fat content in the meats group had a negative impact on the demand for meats and had positive impacts on the demand for the rest four food groups

The results presented in Table 2 show that nutrients had either positive or negative impacts on the demand for the five food groups examined in this study. Of the total 19 own-nutrient elasticity estimates, 13 were positive and six were negative. A positive elasticity estimate indicates that the nutrient decreases the perceived price for the food items consumed and the negative parameter estimate increase the perceived price.

Results of own-nutrient elasticity estimates show that all three nutrients had positive impacts of the demand for the dairy group. Fat content in the meats group decreases the demand for meat items and the protein and mineral contents in the meats group increases the demand for meats. The vitamin C, thiamin, riboflavin, niacin and vitamin B-6 contents in vegetables and fruits had negative impacts on the demand for vegetables and fruits; however, the folate and mineral contents in vegetables and fruits had positive impacts on the demand for vegetables and fruits. The impact of fiber contents in

vegetables and fruits was negative but statistically not different from zero. Results also show that folate, and mineral contents in cereals increase the demand for cereals; and the first vitamin group contents decrease the demand for cereals. The own-nutrient impact of carbohydrate contents in cereals was negative and the impact of fiber contents on the demand for cereals was positive but statistically insignificant. The results for the other group show that carbohydrate and mineral contents increase the demand for the other food group and fat contents decrease the demand for the other food group.

Intuitively, there could be an upper limit for each nutrient consumed in a meal; i.e., one can eat only a limited quantity of food. If this were true, then the cross-nutrient coefficients should all be negative; i.e., an increase in the nutrient content in one food should decrease the demand for other food items that have the same nutrient. However, food items can be used in combinations to produce different dishes and the upper limits for nutrients are difficult to set. As a result, cross-nutrient elasticities across food groups could be positive or negative, depend on how each food item was used. As a result, the interpretation of these cross-nutrient elasticities becomes difficult. Therefore, no specific interpretations will be given to these own-nutrient and cross-nutrient elasticities as the interpretations are only limited by one's imagination.

Concluding Remarks

This study explored the roles of nutrients in the demand for food through utility theory. The findings of this study support the argument that nutrients play an important role in the demand for food. The results show that the demand system approach used in this study is promising. The signs of all income and price parameter estimates are consistent with expectation, i.e., positive and less than unity income elasticities; negative own-price elasticities, small and positive cross-price elasticities.

The impacts of nutrients on the demand for food groups are difficult to interpret. One would expect that certain nutrients would increase the demand for certain food

groups. For example, one would expect the fat content in the dairy group would decrease the demand for dairy or the fiber content in the vegetables and fruits group would increase the demand for vegetables and fruits for a health-conscious person. Results found in this study show the opposite. On the other hand, some results are encouraging. These results include the positive impact of minerals content on the demand for all five food groups and the negative impact of fat content on the demand for the meats group. However, a consistent pattern according to the dietary guidelines was not present.

There are at least two possible explanations about the mixed findings of the nutrition impact on the demand for food. The first one is, perhaps, the average Americans eat what they like to eat. For example, the food needs to taste delicious, smells good, and looks appetizing. Therefore, nutrients played only a partial role in average Americans' diet. This first possible explanation is supported by the findings in a recent USDA study (USDA). The second possible explanation is that the average Americans only know certain particular food items that are rich in some highly advertised nutrients. For example, milk is rich in calcium and orange juice is rich in vitamin C. This study used aggregated food groups and nutrient groups. The aggregation of food items and nutrient components could make the direct association between a specific nutrient and a specific food item disappear. As a result, the impact of certain nutrients on the demand for food becomes obscure.

Table 1. Demand Parameter Estimates

	Intercept	LogQ	Prices				
			Dairy	Meats	Veg&Fruit	Cereals	Other
Dairy	0.3675 (0.0728)	0.1054 (0.0025)	-0.0418 (0.0022)	0.0140 (0.0015)	0.0086 (0.0012)	0.0067 (0.0012)	0.0125 (0.0011)
Meats	0.8822 (0.0916)	0.3471 (0.0045)		-0.0636 (0.0044)	0.0151 (0.0017)	0.0139 (0.0016)	0.0205 (0.0016)
Veg&Fruit	0.2056 (0.0677)	0.2143 (0.0031)			-0.0604 (0.0031)	0.0146 (0.0015)	0.0221 (0.0014)
Cereals	-0.9275 (0.0746)	0.1431 (0.0026)				-0.0492 (0.0023)	0.0141 (0.0012)
Other	-0.5278 (0.0656)	0.1901 (0.0034)					-0.0692 (0.0029)

	Nutrient Demand Parameter (γ_{jk})				
	Dairy	Meats	Veg&Fruit	Cereals	Other
Carbohydrates	-0.5045 (0.2090)	-1.1017 (0.2458)	-0.2444 (0.1093)	0.4529 (0.1716)	-0.1827 (0.0226)
Fats	-0.2389 (0.0534)	0.4038 (0.1026)			0.0004 (0.0000)
Minerals	-2.7411 (0.2761)	-2.3623 (0.2139)	-1.8032 (0.1356)	-0.3418 (0.0925)	-0.6142 (0.0492)
Vitamin I			0.8987 (0.0875)	0.4864 (0.0573)	
Vitmin II			-0.5123 (0.0854)	-0.3216 (0.0571)	
Fiber			0.0951 (0.0784)	-0.0794 (0.0631)	

^aNumbers in parentheses are standard errors of parameter estimates.

Table 2. Demand elasticity estimates^a

	Dairy	Meats	Veg&Fruit	Cereals	Other
Income and Compensated Price Elasticities					
Income	0.8461*	1.0235*	1.0088*	0.8700*	1.1927*
Price – Dairy	-0.3357*	0.0414*	0.0406*	0.0404*	0.0785*
Price – Meats	0.1127*	-0.1874*	0.0711*	0.0843*	0.1289*
Price – Veg & Fruit	0.0692*	0.0446*	-0.2844*	0.0886*	0.1387*
Price – Cereals	0.0534*	0.0409*	0.0686*	-0.2987*	0.0882*
Price – Other	0.1004*	0.0606*	0.1041*	0.0854*	-0.4342*
Nutrient Elasticities (β_{ijk}/w_i)					
Dairy					
Protein	0.1693*	-0.0209*	-0.0205*	-0.0204*	-0.0396*
Fats	0.0802*	-0.0099*	-0.0097*	-0.0097*	-0.0187*
Minerals	0.9201*	-0.1135*	-0.1112*	-0.1109*	-0.2150*
Meats					
Protein	-0.1241*	0.2065*	-0.0784*	-0.0929*	-0.1420*
Fats	0.0455*	-0.0757*	0.0287*	0.0340*	0.0520*
Minerals	-0.2661*	0.4427*	-0.1680*	-0.1991*	-0.3044*
Veg & Fruit					
Carbohydrates	-0.0169*	-0.0109*	0.0695*	-0.0216*	-0.0339*
Vitamin I	0.0622*	0.0400*	-0.2556*	0.0796*	0.1247*
Vitamin II	-0.0354*	-0.0228*	0.1457*	-0.0454*	-0.0711*
Fiber	0.0066	0.0042*	-0.0271	0.0084	0.0132
Minerals	-0.1247*	-0.0803*	0.5129*	-0.1597*	-0.2502*
Cereals					
Carbohydrates	0.0242*	0.0185*	0.0311*	-0.1353*	0.0399*
Vitamin I	0.0260*	0.0199*	0.0334*	-0.1453*	0.0429*
Vitamin II	-0.0172*	-0.0132*	-0.0221*	0.0961*	-0.0284*
Fiber	-0.0042	-0.0032	-0.0054	0.0237	-0.0070
Minerals	-0.0183*	-0.0140*	-0.0235*	0.1021*	-0.0301*
Other					
Carbohydrates	-0.0183*	-0.0111*	-0.0190*	-0.0156*	0.0793*
Fats	0.0000*	0.0000*	0.0000*	0.0000*	-0.0002*
Minerals	-0.0617*	-0.0372*	-0.0639*	-0.0525*	0.2667*

^aIncome and price elasticities are estimated at sample means.

*Statistically different from zero at $\alpha = .005$ level.

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