THE RELATIONSHIP BETWEEN FOOD GROUPS AND NUTRIENTS USING CANONICAL CORRELATION: HOUSEHOLDS IN PUERTO RICO

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The relationship between the quantity of food groups and the nutrient availability of the foods used by households in Puerto Rico was analyzed. The study used canonical correlation and canonical redundancy analyses to examine the strength of the relationship. Results show a close relationship between the two sets of variables. Findings suggest that, although households may make purchasing decisions based on food groups, modeling general food consumption behavior on the basis of nutrient availability should have no appreciable consequences on the outcome.

Proper food selection is essential for good health and well-being. In addition, food expenditures account for a sizeable part of household budgets. Thus, modeling food consumption or dietary behavior is an important responsibility of consumer economists.

This study examines the degree of association between food group consumption and nutrient availability by households. The data come from USDA's Puerto Rico Nutrition Study 1984, the most recently available household food consumption survey. The statistical method employed is that of canonical correlation and redundancy analyses. This technique has not been used extensively in economic demand analysis. Rather, simultaneous equation systems, which incorporate theoretical structures, are commonly used. In contrast to simultaneous equation systems which relate a set of dependent variables to a set of independent variables, canonical correlation analysis can relate two sets of dependent variables, such as foods and nutrients.

Traditionally, researchers have followed either of two paths in modeling food consumption or dietary levels. The first approach is to model dietary levels directly by relating nutrient levels to socioeconomic characteristics, income, and (implicit) prices (Basiotis et al. 1983; Eastwood et al. 1986; Morgan 1986). In the second approach, dietary levels are modeled indirectly by relating food or food group intakes to sociodemographic characteristics, income, and prices (Davis 1982; Morgan et al. 1985; Tufts et al. 1987). Selection of the modeling approach has rested with the researcher's scientific and philosophical background, specific purpose of the analysis, theoretical framework used, and data availability. Choice of modeling approach can materially influence the outcome of such research. Furthermore, different specifications may contribute to varying results (Morgan 1986).

Modeling nutrient consumption directly is appealing for several reasons. The method provides an opportunity to make direct diet status assessment and interpersonal diet comparisons. Expressing nutrient consumption as a percentage of the Recommended Dietary Allowances (RDA) further facilitates assessment and interpersonal comparisons by removing different units of measurement. This modeling approach, however, rests on the rather unrealistic assumptions that consumers are well aware of the nutrient content of all foods facing them in the market place and that it is mostly the nutrient content of the foods (as characteristics) that guides the food consumption decision. High correlations among nutrients consumed by households, or individuals, can make statistical estimation problematic because of severe multicollinearity. Also, this problem may limit the interpretation and usefulness of the results.

The second approach appears to be more realistic, especially if one assumes that consumers have decided that, for example, citrus fruits are high in vitamin C and, hence, they explicitly include citrus fruits in their diets, not vitamin C (as a characteristic). Advantages of the food group consumption approach include better availability of data; more relevance to the food industry, including agriculture; and easier assessment of diet quality, when diet quality is measured by consumption of specific foods. Disadvantages include the lack of standardization in definition of food groups, which often results in incomparability among studies; differences in units of measurement, which hinder aggregation; difficulty in assessment of nutrient status; and introduction of statistical estimation problems when a large portion of the sample reports "0" (zero) intake of a given food group during the survey period (Tobin 1958).

Obviously, it would be desirable that conclusions reached by employing either modeling approach be identical in substance. Furthermore, it would be useful to be able to derive implications for both food group and nutrient consumption.

DATA AND VARIABLES

The source of data used in this study was the Puerto Rico Nutrition Survey 1984. This survey was conducted from August through December 1984 by National Analysts, a Division of Booz, Allen, & Hamilton, under contract with the U.S. Department of Agriculture (USDA).

The Puerto Rico Nutrition Study 1984 provided detailed information on the food used by 2,424 households from which food consumption, money value of food, quantity of food, and nutritional levels of the household food supply may be appraised. Household characteristics included income, age of house-

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hold members, household composition, education and employment of the heads, participation in food programs, and other factors that might affect food consumption. A summary description of these characteristics is given in Table 1. Only 2,180 are presented on this table because the remaining 244 (10 percent) had missing values--primarily income.

Information on food used by surveyed households was obtained in an interview with the person identified as most responsible for food planning and preparation. Trained Puerto Rican interviewers used an aided-recall questionnaire schedule and recorded the kind (such as ground beef and skim milk), the form (such as fresh, canned or frozen), the quantity, and cost, if purchased, of each food and beverage used in the household during the 7 days prior to the interview. Respondents also reported the number of meals eaten from home food supplies during the week by household members and others. Households were contacted at least 7 days before the interview and asked to keep informal notes, such as shopping lists, menus, and grocery receipts to assist them in recalling the food used during the 7-day period. The questionnaire was printed in both Spanish and English to accommodate the respondent's preference.

Household food consumption reported in this survey was measured at the level at which food comes into the kitchen ("household"). It was food that disappeared from household supplies during the survey week, whether eaten, discarded, or leftovers fed to animals. Thus, the data should be interpreted as consumption in the economic, rather than the physiological, context.

Measurement of Food Quantity

The foods reported in this study were grouped by nutritional content or by main ingredient content. For example, the milk group consists of fresh fluid milk, processed milk products (such as cheese), cream and cream substitutes, frozen desserts containing milk, mixtures with milk as the main ingredient (such as cream of mushroom soup and cheesecake). The food quantity measure, expressed in pounds, was the weight of food used by household during the survey week. The food groups used for this study were the following:

(1) milk, milk products
(2) meat, poultry, fish
(3) other high-protein food
(4) vegetables
(5) fruits
(6) grain, grain products
(7) fats and oils
(8) miscellaneous

Table 1.--Selected Characteristics of Households in Puerto Rico 1984

Household Characteristic	Unit of Measure	All Households	Urbanization: Central City	Suburban	Nonmetropolitan
Total households	Number	2,180	586	335	1,256
Household size, 21-meal-at-home-equiv. person	Number	3.38	3.05	3.29	3.56
Money value of food at home per household in a week	Dollars	77.72	73.42	80.96	78.86
Expense for food away from home per household in a week	Dollars	12.47	15.06	15.24	10.53
Money income before taxes, previous year:					
Under $5,000	Percent	42	33	28	50
$5,000-$9,999	Percent	27	25	29	28
$10,000-$14,999	Percent	13	16	15	10
$15,000-$19,999	Percent	8	11	11	6
$20,000 and over	Percent	10	14	18	6
Mean income	Dollars	8,884	11,277	11,680	7,027
Tenure:					
Owned	Percent	78	63	79	85
Rented for cash	Percent	18	32	17	11
Occupied without rent	Percent	4	5	4	4
Status in Nutrition Assistance Program:					
Participating	Percent	37	26	24	46
Not participating	Percent	63	74	76	54
Mean NAP income, month	Dollars	58.27	39.85	36.91	72.79

The last group was not used in this study, since it comprised many varied food items of different weights with varying nutritional value when measured in per pound-basis (such as powdered beverage mixes and ready-to-drink beverages). The quantities of food used were converted to nutritive values of food, and the values of each nutrient in all items used during the seven days were summed.

Measurement of Nutrient Availability

The survey data provided nutritive values for food energy and 14 nutrients (protein, calcium, iron, magnesium, phosphorus, vitamin A, thiamin, riboflavin, vitamin B_6, vitamin B_{12}, vitamin C; also, fat, carbohydrate, and preformed niacin). The basis for the nutritive values was the "Composition of Foods...Raw, Processed, Prepared," (Watt and Merrill 1963) and other supplements published by the Nutrient Data Research Branch of the Human Nutrition Information Service (HNIS), USDA. When a nutritive value was not available for a reported food, HNIS staff members imputed a value from a similar food. Also, nutritive value of some foods specific to Puerto Rico were obtained through a contract with Applied Social Research Inc. in Puerto Rico.

Recommended Dietary Allowances (RDA) are established for the first 11 of the 15 diet components listed above. Since the number of nutrients was large, it was essential to determine which nutrients are more critical than others in the household decision-making process.

Table 2.--Percentage of Households Meeting the Recommended Dietary Allowances (RDA), Puerto Rico 1984 and United States 1977

Nutrient	Portion (%) of Sample Meeting RDA	
	Puerto Rico[a]	United States[b]
Food Energy	86	78
Protein	98	99
Calcium	76	70
Iron	88	84
Magnesium	84	78
Phosphorus	96	98
Vitamin A	64	83
Thiamin	91	89
Riboflavin	90	96
Vitamin B_6	76	68
Vitamin B_{12}	79	91
Vitamin C	94	95
7 key nutrients[c]	53	57
11 key nutrients[d]	49	53

[a] Sample size for total households is 2,424 in Puerto Rico Nutrition Study 1984.

[b] Sample size for total household is 3,473 in Nationwide Food Consumption Survey 1977-78, Spring.

[c] 7 key nutrients are protein, calcium, iron, vitamin A, thiamin, riboflavin, and vitamin C.

[d] 11 key nutrients are protein, calcium, iron, magnesium, phosphorus, vitamin A, thiamin, riboflavin, vitamin B_6, vitamin B_{12}, and vitamin C.

Table 2 shows the percentages of households meeting the RDA for food energy and nutrients. These percentages are compared with those from a similar survey conducted in the spring of 1977 for the 48 conterminous States (USDA 1985). Fewer households in Puerto Rico (less than 87 percent) met the RDA for food energy, calcium, magnesium, vitamin A, vitamin B_6, and vitamin B_{12} than for other nutrients. Because the two B vitamins are frequently found in similar foods, or correlated, vitamin B_{12} was dropped from this study.

The "problem" nutrients that are identified here--calcium, magnesium, vitamin A, vitamin B_6--are consistent with those found in other studies (Pao and Mickle 1981; Hama and Chern 1988). Various food products contribute to these nutrients. Calcium is found abundantly in milk and milk products. Certain green leafy vegetables (such as mustard greens, turnip greens, kale, and collards) are also important sources of calcium when eaten frequently. Vegetables account for a major share of the vitamin A. The meat, poultry, and fish group furnishes vitamin A. Grain products, vegetables, and milk and milk products supply nearly equal shares of magnesium in household diets. Dry beans and peas, soybeans, and nuts are also considered good sources of magnesium. The principal source of vitamin B_6 is the meat, poultry, and fish group.

PROCEDURES

Predicting the values of one or more variables from other variables is an important concern in economics and other sciences. Techniques for analyzing such relationships include simple correlation analysis, multiple regression analysis, systems of multiple regression equations, and canonical correlation analysis. The first two examine the relationship of one variable with one or more other variables. Systems of regression equations and canonical correlation analysis examine relationships between two sets of variables. Proper use of systems of regression equations requires the guidance of well-developed theoretical relationships. Use of canonical correlation analysis does not. Thus, canonical correlation is the technique of choice when explaining relationships between two sets of variables without the benefit of a rigorous theoretical framework.

The theory of canonical variables and canonical correlation allows us to summarize the interrelationship between two sets of variables. More specifically, the canonical correlation technique yields a linear combination to each of two sets of variables such that the simple correlation between the two linear combinations is maximized. These composites, or canonical variables, may be interpreted as indices that represent their respective sets of variables. The maximum number of canonical variables constructed is equal to the smaller number of variables in the two original sets. These pairs of canonical variables are orthogonal, or uncorrelated, to all other canonical variables.

Hotelling (1935, 1936) originally developed the concept of canonical correlation. He used this analytic procedure to study the relationship between a set of mental test variables and a set of physical measurement variables. The technique permitted him to determine and characterize the number and nature of the independent relations of the mind and the body by extracting from a multiplicity of correlations in the system (Kshirsagar 1972). Canonical correlation, however, is not unique to psychological or educational research. It is equally applicable to anthropometry, botany, economics, and other disciplines. Tinter (1946), Waugh (1942), and Bartlett (1948) provided early applications of the technique to economics. For these different fields of research, canonical analysis is used as a tool for reducing and understanding a whole interacting complex system. Canonical variables are used to help deepen the understanding of the original variables and may even suggest new measures.

An extensive theoretical derivation of the canonical correlation model is beyond the scope of this study, but it may be found elsewhere (Anderson 1971; Johnston 1972; Kshirsagar 1972; Mardia et al. 1979). An intuitive approach to explaining the model is to think in a stepwise fashion. First, the technique derives a linear combination of each set of variables so that the covariance between the components is maximized. That is, if Z_1 and Z_2 are two sets of variables of interest, then find vectors of coefficients or weights c and d so that if

$$x = c_1' Z_1 \quad \text{and} \quad y = d_1' Z_2$$

the correlation between x and y is maximized. This correlation is the first canonical correlation and x and y are called the first canonical variables. Then we can derive the second canonical variables, that is, linear combinations of Z_1 and Z_2 (uncorrelated to the first x and y), that have the second largest correlation. This is the second canonical correlation. The procedure is repeated for a number of iterations equal to the smaller number of variables in the two sets.

Canonical redundancy analysis, invented by Stewart and Love (1968), explains how well the original variables can be predicted from the canonical variables. A rigorous derivation may be obtained from Cooley and Lohnes (1971) and van den Wollenby (1977). Redundancy analysis is useful since it expresses the amount of actual overlap between the two sets of variables that are packaged in the first canonical relationship. That is, redundancy analysis shows, through the first canonical correlation, what proportion of the variance in vector variable Z_1 is found to be redundant to the variance in vector variable Z_2 (Cooley and Lohnes 1971).

Given the consumption of a specific food by the household, nutrient availability is derived by multiplying the quantity of the food item by the nutritive value per pound of that food. It is expected that the canonical variables, indexing consumption of food group quantities and nutrient availability, will be correlated. Since nutrients are derived from individual foods, however, the degree of correlation depends on the level of aggregation used. Also, the predictability of individual food groups or nutrients, given the consumption of nutrients or food groups, respectively, is not known.

For this study, seven food groups and five nutrients were calculated for 2,424 households in Puerto Rico. Canonical correlation analysis was used to derive summary indices of the seven food groups and five nutrients and to determine the degree of association between the indices. Although alternative types of food group and nutrient measures were tested, the results presented here are for the aggregate amounts of food (by food group) used by the household from the household food supply during the 7-day survey period and for the aggregate nutritive values (by nutrient groups) from these foods. Details of alternative measures, such as nutrients per household size in 21-meal-at-home equivalent and in nutrition units, are described by Smallwood and Blaylock (1984). The computer software used to perform the analysis was the CANCORR procedure of the Statistical Analysis System (SAS 1985).

RESULTS

Results of the canonical correlation and redundancy analyses are reported in Tables 3.A through 3.C and Tables 4.A and 4.B. Because the variables were not measured in the same units, standardized variables were used for the analysis. Tables 3.A through 3.C summarize the findings from the first, second, and third canonical correlations. The fourth and fifth canonical correlations are not shown because they were judged to be not informative enough.

The coefficients of the first canonical food group variable are in the first column of Table 3.A. These coefficients may be thought of as weights, indicating the relative contribution of the respective food group in the total food group variation. Thus, milk and milk products as well as grain and grain products are the most heavily weighted food groups in the food group index. As expected, all seven weights are positive, indicating a direct relationship between consumption of any of the food groups and the first food group canonical variable (index).

Similarly, the coefficients (weights) for the first canonical variable or index of the five nutrients are shown in the first column of Table 3.B. Food energy, a measure of the quantity of food, and calcium have the largest weights. These demonstrate the contribution of food energy and calcium in the overall household nutrient consumption pattern. As with food groups, all coefficients of the first nutrient canonical variable are positive. That is, increased availability of any of the five nutrients, on the average, would increase the value of the nutrient index.

Some coefficients from the second and third canonical variables for food groups are difficult to explain--milk products (for both canonical variables), and grain products, fats and oil (for third canonical variable) took on negative values. This is in contrast to the strong positive influence found in the first canonical variable. Similarly for nutrients, calcium and vitamin B_6 (for the second canonical variable), and food energy and

Table 3.A--Canonical Correlation Analysis: Standardized Canonical Coefficients for Food Groups

Food Group	Quantity1	Quantity2	Quantity3
Milk, milk products	0.3596	-1.0650	-0.3112
Meat, poultry, fish	0.1988	0.1823	0.3198
High-protein foods	0.0823	0.0222	0.1264
Vegetables	0.1790	0.1103	0.7497
Fruits	0.0988	0.0487	0.3012
Grain, grain products	0.3485	0.4220	-0.3933
Fats and oils	0.1485	0.3608	-0.6769

Table 3.B--Canonical Correlation Analysis: Standardized Canonical Coefficients for Nutrients

Nutrient	Nutrient1	Nutrient2	Nutrient3
Food energy	0.5261	1.3730	-2.2311
Calcium	0.3018	-1.6761	-0.3799
Vitamin B_6	0.1753	-0.0501	1.9446
Magnesium	0.0495	0.2190	0.6915
Vitamin A	0.0065	0.0218	0.0817

Table 3.C--Canonical Canonical Analysis: Canonical Correlations between Food Groups and Nutrients

	First	Second	Third
Correlation	0.9897	0.9460	0.8197

calcium (for the third canonical variable) took on negative values. This indicates that the dimensions measured by the second and by the third canonical variables are different from the first canonical variable.

The estimated canonical correlations between the first food group and nutrient indices are shown in Table 3.C. Given that the algorithm used to construct canonical variables maximizes their correlation, the estimated correlation of 0.99 is not particularly surprising. Note, however, that high correlation does not necessarily imply a high proportion of variance explained by each canonical variable (Lambert et al. 1988).

The canonical redundancy analysis results are displayed in Table 4.A and 4.B. The last rows of these tables show that the first pair of canonical variables is a relatively good predictor of the opposite set of variables. In some respects, the proportion of explained total variance or predictability of nutrient availability from the food group index is quite good at 75 percent. The first canonical variable of the food groups provides an excellent predictor of the nutrients studied, explaining between 93 to 80 percent of the variation, variation, as indicated by the squared multiple correlations. The exception was for vitamin A, with a poorer predictor at 28 percent.

In contrast, the predictability of food quantities from the first nutrient availability index prove to be weaker at 44 percent. The squared multiple correlations indicate that the first canonical variable of the nutrients has some predictive power for each of the seven food groups, ranging from a "good" predictor at 59 percent of the variance for grain products to a poorer predictor at 25 percent for fruits.

The second and third columns of Tables 4.A and 4.B provide cumulative proportions of the variance of each original variable explained by the first two

Table 4.A--Canonical Redundancy Analysis: Squared Multiple Correlations between Food Group Quantity and Canonical Variables of Nutrient Availability

Food Group	Nutrient1	Nutrient2	Nutrient3
Milk, milk products	0.5580	0.9281	0.9373
Meat, poultry, fish	0.5084	0.5348	0.5804
High-protein foods	0.2835	0.2905	0.2963
Vegetables	0.4746	0.4958	0.6665
Fruits	0.2535	0.2543	0.3701
Grain, grain products	0.5935	0.6839	0.7296
Fats and oils	0.3999	0.5201	0.6214
Standardized Variance of Food Group Quantity in Cumulative Proportion:			
Own Variables	0.4480	0.5495	0.6546
Opposite Variables	0.4388	0.5296	0.6002

Table 4.B--Canonical Redundancy Analysis: Squared Multiple Correlations between Nutrient Availability and Canonical Variables of Food Group Quantity

Nutrient	Quantity1	Quantity2	Quantity3
Food energy	0.9322	0.9675	0.9733
Calcium	0.7970	0.9599	0.9622
Vitamin B_6	0.8576	0.8696	0.9386
Magnesium	0.8814	0.8874	0.9080
Vitamin A	0.2791	0.2791	0.3432
Standardized Variance of Nutrient Availability in Cumulative Proportion:			
Own Variables	0.7652	0.8135	0.8617
Opposite Variables	0.7495	0.7927	0.8251

or three opposite canonical variables. The three food group canonical variables, together, are excellent predictors of individual nutrients--explaining more than 90 percent of the variation for all nutrients except vitamin A. With the exception of milk and milk products (94 percent), the three nutrient canonical variables explained between 73 to 30 percent of individual food group variability.

SUMMARY AND CONCLUSIONS

Relationships between sets of food groups and sets of nutrients were explored for households in Puerto Rico. The statistical technique utilized was canonical correlation and canonical redundancy analyses. The results indicate that sets of aggregate food groups consumed and sets of aggregate nutrient availability were highly related. The main implication is that, although households appear to be making food purchasing decisions based on food groups, modeling food consumption behavior on the basis of nutrient availability should not appreciably change the outcome.

The results, however, display enough unexplained variations between food group and nutrient availability to warrant tailoring further in-depth analysis of these measures separately. If the focus of the research is nutrients, then the analysis should be carried out with nutrients only; if the topic concerns food groups, then the study should measure food quantities only.

On the other hand, if the subject matter deals with generalizations on diets, then these results indicate that the methodological approach has no impact. That is, whether the generalization is made by analyzing nutrient availability or food quantities, the outcome would be quite similar. From a practical viewpoint, however, it may be preferable to approach the topic from food groups since it is easier for consumers to understand foods than nutrients. Furthermore, this point is corroborated by the redundancy analysis results, which indicate a stronger predictive value of nutrients from food group index than food groups from nutrient index. Several limitations of this paper should be cited. First, the study was based on a specific set of five nutrients. Other combinations of nutrients should be considered, depending on the sample to be analyzed. For example, iron may be included when studying women's diets.

Second, our study used survey information collected from households in Puerto Rico, a population with food use and an economy that differ from the 48 conterminous States. For this reason, analysis should be performed using recent food consumption data from the mainland United States.

Another area that requires attention is the use of data reported for foods from the household food supply. With a greater number of consumers eating away from home, it is suggested that analysis be done for food at home and away from home. A study comparing the relationship between food groups and nutrients for different sex-age categories and different socioeconomic factors would provide important information to nutrition educators and consumer economists.

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