J. R. Statist. Soc. A (1991)
154, *Part* 1, *pp.* 157–174

Estimating Short and Long Run Income Elasticities of Foods and Nutrients for Rural South India

By ALOK BHARGAVA†

University of Houston, USA

[Received September 1989. Revised March 1990]

SUMMARY

This paper estimates expenditure–income elasticities of six categories of foods using the Institute for Crops Research in Semi-Arid Tropics panel data on households from rural south India. The results underscore the importance of distinguishing between the short and long run effects particularly for groups like milk and meat. The demand for intake of nutrients is next analysed using two time observations on individuals under three formulations. A simple dynamic demand system is specified for five nutrient groups which is then extended to incorporate the differences in quality of foods consumed by expressing the intake of nutrients as ratios to energy intake by the individuals. Lastly, an interdependent formulation is estimated under special assumptions on the pattern of correlation between the individual effects and the remaining nutrients. The limited length of the panel data raises some issues of identification in the third case that are also resolved. Overall, these data provide support for the view that increases in household incomes will in turn improve the intakes of nutrients.

Keywords: DYNAMIC DEMAND MODELS; FOOD AND NUTRITION POLICIES; INCOME ELASTICITIES; MAXIMUM LIKELIHOOD ESTIMATION; PANEL DATA

1. INTRODUCTION

The problems of undernutrition in developing countries are recognized to be of utmost importance by researchers in many disciplines as well as by the international agencies which provide aid and support to these countries. Since important policy decisions should be based on the circumstances prevailing in these countries, considerable effort has been devoted to analysing the dietary habits of at least some of the residents. A good example of the influence of statistical analysis of the data on policy decisions is the work by Sukhatme (1974) which challenges the view that improved nutrition is synonymous with increased intakes of protein. Rather, the inability of households to purchase food has been blamed for malnourishment (Sukhatme (1974), p. 167). The problems of nutrition are well known to economists in developed countries as well partly because of the analysis of 'minimum cost diets' by Stigler (1945) that in turn influenced the work on 'quality differentials' by Gorman (1980), Griliches (1961) and Lancaster (1966).

The analysis of nutritional well-being of individuals is on the periphery of several disciplines since food consumption habits are determined, among other things, by the nutrient requirements of the human body, the amount of money budgeted for food, cultural patterns, individual specific needs, etc. It should therefore be the case that a

---

†*Address for correspondence*: Department of Economics, College of Social Sciences, University of Houston, Houston, TX 77204-5882, USA.

0035-9238/91/154157 $2.00

multidisciplinary approach incorporating the various determinants of nutritional intake in the statistical analysis would enhance the value of the empirical results. Now, it is well known that it is practically impossible to define the *optimal* level of nutrient intake for an individual and the results from biomedical experiments can only recommend what may appear to be reasonable levels for the nutrients. An apparent shortcoming in these recommendations is the lack of substantive evidence on the manner in which different nutrients interact within the human body. The interactions between energy and protein, however, are recognized by many writers; Hutchinson (1969) notes that 'protein when divorced from carbohydrate in the diet is of no use in repairing the wear and tear of body protein'. Sukhatme's criticism of the emphasis on protein enrichment of diets in poor countries is in the same spirit.

A drawback in the analysis of data on nutritional intakes is the unavailability of successive observations (panel data) on the same individuals that could afford a systematic control of the individual-specific differences. Thus previous researchers have relied mainly on cross-sectional data (Langier, 1969; Timmer and Alderman, 1979) and in some situations restrictive assumptions have been invoked to avoid biases induced by the interindividual and intra-individual differences (Sukhatme, 1974). Fortunately, the Institute for Crops Research in Semi-Arid Tropics (ICRISAT) has surveyed individual members of 240 households in six south Indian villages with regard to their consumption of food in the previous 24 hours (Binswanger and Jodha, 1978). In each village, 40 households representing different socioeconomic groups were surveyed twice a year for 2 years (1976–77). The data on annual household food expenditures and four successive 24-hour recall observations on individuals' intakes of nutrients in three of the villages were made available to researchers.

Recently, Behrman and Deolalikar (1987) have analysed the ICRISAT consumption data from the standpoint of estimating expenditure elasticities (Engel curves) for six food categories and for nine nutrients. Although the point estimates of the former appear to be reasonable, there is practically no correlation between nutrient intake by individuals (or households) and household incomes (or expenditures) within static regression models (see also Ryan *et al.* (1984)). (Their results are sensitive to the specification of the model in levels *versus* differences since level is not controlling for individual effects. Also, it is well known that the within variance obscures relationships in 24-hour recalls (Liu *et al.*, 1978).) This has led these researchers to conclude that 'the World Bank (1981)-type optimism about the nutrients improvements to be expected with income gains ... seems fundamentally misleading' (Behrman and Deolalikar (1987), p. 505). Given the serious policy implications of their conclusions, this paper re-examines the role of incomes in determining the nutritional well-being of these Indian villagers. We estimate models which facilitate a distinction between the short and long run effects as emphasized by Gorman (1967), Nerlove (1972) and Phlips (1974). The analysis also incorporates some of the relevant socioeconomic and biomedical factors affecting the intakes of nutrients and elaborate econometric and computational techniques are used to estimate the relationships. The empirical results establish a causal link between the intake of nutrients and household incomes. This in turn provides support for the case advocated by the World Bank (1981) for improving nutrition in less developed countries by raising the incomes of the poor.

The structure of this paper is as follows. Section 2 estimates short and long run expenditure elasticities for six food groups (grains, sugar, pulses, vegetables, milk and meat) using household level data. Section 3 proceeds by estimating simple dynamic models for intakes of five nutrient groups (energy, protein, calcium and iron, vitamins A and C, and vitamin B). It is then argued that the demand for more nutritious foods would entail a change in the proportions in which the other nutrients are consumed in comparison with energy intakes. Thus the dynamic model is re-estimated with the intakes of nutrients expressed as ratios to energy intakes.

Section 4 develops an interdependent system for the five nutrient groups incorporating some suggestions of Hutchinson (1969), Stigler (1945), Sukhatme (1974) and Lancaster (1971). The present approach is somewhat different since it is impossible to consume even very basic foods like grains and not to consume, for example, riboflavin that is abundant in some more nutritious foods. Thus, in specifying a simultaneous equations system for the five nutrient groups, the identification of the parameters cannot be achieved by excluding any of the endogenous or the predetermined variables from the equations. Instead, specific assumptions are made on the pattern of correlation between the individual specific effects and the time varying variables (Bhargava and Sargan, 1983). These assumptions provide additional instrumental variables which enable the identification of the system given only two time observations (Appendix A). The robustness of the empirical results can be examined by using dietary surveys from less developed countries that are repeated more frequently (Beaton *et al.*, 1979; Block, 1982; Freudenheim *et al.*, 1987; Nelson *et al.*, 1989; Bhargava, 1989).

2. ESTIMATING EXPENDITURE ELASTICITIES OF FOODS FROM HOUSEHOLD DATA

2.1. *Habit Persistence in Diets*

Although dietary habits in the Indian subcontinent have changed in the last few decades owing to overall increases in household incomes, one nevertheless senses a remarkable amount of continuity in the eating habits of the people. In general, these habits depend on the geographic location, caste and income group of the households. An example of the continuity is the practice of vegetarianism as a result of which generations have abstained from eating meat. Similarly, typical meals consist of rice or wheat (or some other grain like *bajra*) together with some pulses and vegetables (and meat). It is important to note that the proportions in which these foods are consumed depends on the notion that households have regarding their relative affluence. Thus, for example, households regarding themselves as poor would be accustomed to consuming rice with a very small quantity of pulses and practically no vegetables unless there is a substantial drop in the relevant prices or if they have received payments in kind. In contrast, wealthy rural households will generally consume some rice mixed with a greater proportion of pulses as well as some vegetables (and meat). The children in these households usually supplement their meals with some milk.

Now, if a hypothetical household regarding itself as marginally wealthy began to experience successive drops in income, then it would be reasonable to expect an immediate reduction in its consumption of milk (and meat). This would be gradually followed by a lowering of the proportions in which vegetables and pulses are consumed though the extent to which the proportions change will depend on the degree to which the lowering of incomes is perceived as a permanent drop by the members of the household.

From the above discussion, the two important aspects of analysing data on rural Indian households are, firstly, the perceptions of the households of their relative position within their village or their permanent incomes. Secondly, it is important to incorporate the fact that changes in eating habits will occur with some lag. From an empirical standpoint, these factors underscore the need for a clear distinction between the short run and the long run effects of changes in household incomes on the pattern of food consumption. In particular, it is very likely that the long run expenditure elasticities of more nutritious foods are considerably higher than their short run counterparts. However, some of these distinctions may not be fully visible in estimates using only two time observations. (It would have been useful to obtain the data for the entire 9 years. However, only the data on food consumption for the years in which the 24-hour recall surveys were carried out were compiled very accurately.)

2.2. *Habit Persistence and Demand Analysis*

The notion of habit persistence in empirical economic analysis has been long recognized in the works of Duesenberry (1949), Friedman (1957), Stone (1954) and Houthakkar and Taylor (1970). A formal treatment of short and long run models of utility and demand may be found in Gorman (1967), Pollak (1970), Phlips (1974) and Deaton and Muellbauer (1980). The reasoning underlying the long run class of models is that choices depend on tastes and tastes in turn depend on past choices. This is certainly consistent with the behaviour of the rural Indian households previously described. From the standpoint of estimating Engel curves, the previous work has relied on cross-sectional data (Prais and Houthakkar, 1955) which do not permit a distinction between the short and the long run effects. In this section, we focus on food consumption and assume that households maximize utility subject to the usual budget constraint. Habit formation may now be incorporated by assuming that the past choices affect current consumption with their influence declining geometrically over time. This is equivalent to introducing the past or the lagged value of the dependent variable as an explanatory variable into the model (Pollak, 1970). The resulting short run demand function can be then written as

$$Q_t = h(P_t, m_t, Q_{t-1}) \qquad (1)$$

where Q_t and P_t are respectively the vectors of quantities demanded and prices in time period t, Q_{t-1} is the past value of Q_t and m_t is the total expenditure in time period t. The estimation of such a (dynamic) model from panel data entails the treatment of the initial values of the dependent variable (Q_1) as endogenous in the system in so far as the number of time periods for which the data are available is small (Anderson and Hsiao (1981), Bhargava and Sargan (1983) and below). Thus for every food group we specify the model

$$y_{i1} = \sum_{j=0}^{m} z_{ij}\theta_j + \sum_{t=1}^{2} \sum_{k=1}^{n} x_{ikt}\delta_{kt} + u_{i1} \qquad (i = 1, \ldots, H) \qquad (2)$$

and

$$y_{i2} = \sum_{j=0}^{m} z_{ij}\gamma_j + \sum_{k=1}^{n} x_{ik2}\beta_k + \alpha y_{i1} + u_{i2} \qquad (i = 1, \ldots, H). \qquad (3)$$

Here, y_{i1} and y_{i2} are expenditures in 1976 and 1977 respectively of the ith household on the relevant food group ($H = 94$), the z are the time invariant regressors (z_{i0} being a constant term), the x are the time varying variables such as number of adult equivalent members and total expenditure, u_{i1} and u_{i2} are random error terms that are jointly distributed with mean zero and a finite (unrestricted) 2×2 variance-covariance matrix, and α is the coefficient of the lagged dependent variable. The unknown parameters γ, β and α in equation (3) will be estimated by an iterative maximum likelihood estimation procedure that filters out of the likelihood function the nuisance parameters δ and θ in equation (2) (Bhargava and Sargan, 1983). (Estimates of the instrumental variables were used as initial values in the numerical optimization of the log-likelihood function. A Fortran program written previously by the author was extended to use the vector version of the optimizing routine E04JBF of the Numerical Algorithms Group (1989) library.) It is not necessary to assume that the errors u_{it} are normally distributed for estimation or inferences (Bhargava, 1987) and they need not conform to the *simple* random effects decomposition

$$u_{it} = \eta_i + v_{it} \qquad (i = 1, \ldots, H;\ t = 1, 2) \tag{4}$$

where η_i are the individual or household-specific random variables.

2.3. *Random Effects and Exogeneity Assumptions*

It is helpful to elaborate on the complications arising from the presence of the random effects η_i in model (2)–(3). Firstly, the η_i represent individual or household-specific permanent characteristics that cannot be modelled within the equations to be estimated. In the analysis of individuals' intakes of nutrients presented later, the η_i could reflect the metabolic rates and/or the chemical work performed by the subjects, the latter being unmeasurable (Waterlow, 1989). These factors clearly affect the intakes of nutrients (y_{it}). And since, in short panel data, the correlation between y_1 and u_2 cannot be ignored, y_1 is treated as an endogenous variable in the system.

Secondly, some of the explanatory variables (the z or x) are likely to be determined outside the system and are therefore independent of the error terms u_{it}. Again in explaining the individuals' intakes of nutrients, the size (or income) of the households may be appropriately treated as predetermined.

Thirdly, some of the x (or the z) might be influenced by the random effects. For instance, η_i may affect the weight of the individual in the above example. This is because the characteristics determining the weight of a person may also be systematically affecting the individual's intakes of nutrients like energy and protein. For the time varying variables, a possible pattern of correlation is

$$x_{ijt} = \kappa_j \eta_i + x^*_{ijt} \qquad (j = 1, \ldots, r;\ i = 1, \ldots, H;\ t = 1, 2) \tag{5}$$

where the x^*_{ijt} are uncorrelated with the error term u_{it} (and η_i) and κ_j are constants. Here, the x_{ijt} are correlated with the u_{it} but this correlation is due to the random effects η_i. Thus a high realization of η_i will in turn raise (or lower) the levels of the observed time varying variables. The deviations of x_{ijt} from their time means, however, are uncorrelated with the error terms and can be used as additional instrumental variables (Bhargava and Sargan, 1983). Variables of this type will be referred to as 'special' endogenous time varying variables. In contrast, the correlation between y_1 and u_2 is of a general type and thus y_1 is a 'fully' endogenous variable of the system.

Finally, it would be desirable to assume a general form of correlation between the errors and the x. Unfortunately, this seems infeasible for a dynamic model given only two time observations. However, a static formulation can be estimated from two observations with some fully endogenous time varying variables. The empirical results for the intakes of nutrients problem indicate that the consequences of the incorrect enforcement of the decomposition (5) depend on the various properties of the models postulated (Bhargava, 1991). This is discussed further in Section 4.

2.4. *Empirical Results for Rural South Indian Households*

Table 1 reports the results for equation (3) estimated using data on six food groups (grains, sugar, pulses, vegetables, milk and meat) using household data from three villages. The regressors are dummy variables for two of the villages, number of adult equivalent members, its square and total expenditure. Food prices vary between villages but no data are available on price variations within villages. Thus price variables are not included in these relationships since they would be perfectly collinear with the village dummy variables. The relationship for grains is specified in logarithms since no household had a zero consumption and this transformation is useful for estimation involving cross-sectional data. The short and long run elasticities at sample means are also reported in Table 1; the latter is set equal to the former whenever the coefficient α is statistically insignificant at the 5% level. For the meat

TABLE 1

Maximum likelihood estimates of household expenditure elasticities of foods†

Variable	*Estimates for the following foods:*					
	Grains‡	*Sugar*	*Pulses*	*Vegetables*	*Milk*	*Meat* §
Constant	0.97	2.27	36.45	25.68	−66.37	−5.83
	(0.61)	(5.88)	(25.45)	(6.0)	(2.55)	(5.18)
Dummy 1	0.67	−24.09	−59.26	−22.92	−0.50	5.87
	(0.09)	(4.27)	(20.82)	(3.40)	(3.42)	(2.39)
Dummy 2	0.30	−7.54	−9.28	−4.28	−4.45	0.21
	(0.08)	(2.68)	(5.39)	(2.80)	(3.19)	(2.35)
No. of adult equivalents	−0.23	3.17	−1.22	−1.94	12.10	0.36
	(0.13)	(1.16)	(1.72)	(0.56)	(0.77)	(0.51)
(No. of adult equivalents)^2	0.06	−0.24	–	–	−0.74	–
	(0.05)	(0.08)			(0.07)	
Expenditure	0.841	0.035	0.062	0.056	0.062	0.016
	(0.058)	(0.007)	(0.012)	(0.007)	(0.007)	(0.006)
α	−0.197	0.347	−1.075	0.027	0.927	0.612
	(0.111)	(0.098)	(0.680)	(0.098)	(0.128)	(0.120)
Short run elasticity§§	0.841	0.640	1.674	0.813	1.094	0.579
Long run elasticity*	0.703	0.980	1.674	0.813	14.980	1.492
$\chi^2(2)$**	0.543	1.452	0.328	0.241	0.238	5.033
$2L$*°	453.7	−905.2	−1100.8	−850.8	−1223.1	−763.7

† 94 households, two time periods; asymptotic standard errors are given in parentheses.
‡ Sum of expenditures on rice, wheat, *jowar*, *bajra* and maize in logarithms.
§ Vegetarians excluded.
§§ Elasticities calculated at sample means.
* Long run elasticities (elasticity/$(1-\alpha)$).
** χ^2-test for the exogeneity of the expenditure variable against alternative (5).
° Twice the maximized value of the log-likelihood function.

food group, the estimates *exclude* 12 vegetarian households who consumed no meat and the parameters were estimated more precisely.

The noteworthy features of the results in Table 1 are that, firstly, the coefficients of the expenditure variable are invariably significant at any reasonable critical level. (The inclusion of the value of households' assets as a proxy for savings in the model did not alter the results.) Secondly, the long run elasticities of sugar, meat and, especially, milk are all higher than their short run counterparts. Thirdly, the long run expenditure elasticity for grains is lower than the short run elasticity (Houthakkar and Taylor, 1970) though the standard error for α is rather large. This suggests a slight tendency of a reduction in grain consumption in the long run as a result of increases in expenditures (or household incomes). Fourthly, α is insignificant in the pulses and the vegetables relationships. The prices of vegetables in India are greatly influenced by seasonal factors. Thus it is perhaps not surprising that the annual data used here cannot distinguish between the short and long run effects. For pulses, most households may have become accustomed to consuming them in roughly the same proportions though the more wealthy households might be consuming more expensive varieties.

Fifthly, the square of expenditure was significant in the grains and the meat equations but the results were qualitatively the same. However, the relationships are generally quadratic in the households' size variable. (The expenditure variables were also expressed in *per capita* terms with the adult equivalent scale, but the results in Table 1 provided a better fit because the relationship was non-linear.) Also, dummy variables for the caste and the education level of the head of the household were generally insignificant. This may be due to the loss of half the observations because the lagged value of the dependent variable was included as a regressor.

Lastly, likelihood ratio tests (see later) for the exogeneity of the expenditure variable against the alternative of correlation pattern (5) do not reject the null hypotheses; the criterion assumes a value slightly lower than the critical level (at 5%) only in the relationship for meat. In summary, the results presented in this section support the hypothesis of habit persistence in the diets of these Indian villagers. Also, from the estimated elasticities, it is reasonable to expect that nutritional surveys would indicate that members of relatively wealthy households are better nourished.

3. ESTIMATING EFFECTS OF INCOME ON INTAKE OF NUTRIENTS

3.1. *Some Issues in Modelling Demand for Nutrients*

The problems associated with the measurement of nutrient intakes and absorption by the human body are widely recognized in the nutritional literature (Nutrition Reviews, 1976; Shils and Young, 1988). For example, it is difficult to assess accurately the nutritive content of vegetables consumed since the manner in which they are processed could enhance or reduce (or even destroy) the vitamins present. Moreover, the absorption of any nutrient usually depends on the levels of other nutrients in the foods consumed. In fact, the absorption of calcium from spinach is hindered by oxalic acid and in general it cannot be measured without examining the excreta. In contrast, the absorption of iron is increased by ascorbic acid in the meal. Analogously, there are formidable difficulties in specifying a generic 'health production function' linking health ('output') to the intake of various nutrients ('inputs'); the former cannot be satisfactorily defined from an empirical viewpoint.

The four rounds of nutritional surveys carried out by the ICRISAT attempted to reduce the problems in measuring nutritive content of foods consumed in these villages by comparing some of the nutritive values with the tabulations of Gopalan *et al.* (1971). An important feature of these data is that the *same* individuals were interviewed biannually and food intakes in the previous 24 hours were converted into nutrients. Naturally, this contains far more detailed information on the nutrient intakes by individuals than annual household expenditures on food groups. Thus it is of interest to analyse these data, while controlling for the individual specific differences. The effects of large internal variances, however, are notorious for obscuring relationships in 24-hour recall dietary surveys (Liu *et al.*, 1978). In the present situation, the estimated association between intakes of nutrients and household incomes might be weakened if there is excessive internal variation in the data.

It has long been recognized in demand analysis that goods may be demanded for the characteristics that they possess (Gorman, 1980). The simplest examples found in the literature (Lancaster, 1971; Ironmonger, 1972) refer to the demand for nutrients like vitamins that must be satisfied through the consumption of foods. The recent applications of such models to economic data has produced reasonable results (Pudney, 1981). In contrast, non-linear programming solutions to the diet problem have appeared previously though the results are dependent on very specific assumptions about the shapes of indifference curves (Langier, 1969).

A starting point for modelling the demand for nutrients would be to treat them analogously to other commodities (e.g. foods) and to estimate 'reduced form' relationships with household and village endowments and household expenditures as predetermined variables (Behrman and Deolalikar, 1987). Incorporating habit persistence would lead to model (2) and (3) above except that the dependent variables would now be the intakes of a particular nutrient. For comparison, eliminating the endogenous variable y_{i1} in equation (3), we obtain the unrestricted reduced form

$$y_{i2}=\sum_{j=0}^{m} z_{ij}\xi_j+\sum_{t=1}^{2}\sum_{k=1}^{n} x_{ikt}\mu_{kt}+v_{i2} \qquad (i=1,\ldots,H). \tag{6}$$

Relationship (6) allows the current level of intake of a nutrient to depend on the past values of the explanatory variables. Further, model (6) is consistent with more elaborate structural models which incorporate the interactions between different nutrients. For example, in the protein-energy relationship discussed by Sukhatme (1974), a dynamic structural model explaining the demand for dietary energy would relate energy to the predetermined variables as well the intakes of protein (and vice versa). Then, eliminating nutrient appearing as an explanatory variable, we obtain model (6) relating the demand for each nutrient to all the past and current values of the predetermined variables in the model. The direct estimation of such unrestricted relationships using cross-sectional data, however, entails the risk of imprecise estimation of the parameters. The criterion of relying on t-values to decide the importance of a variable may leave few relevant variables explaining the dependent variable. However, a procedure exploiting the panel nature of the data can enhance the efficiency of the estimates (Section 4). This section estimates simple dynamic models and the interdependence in the intakes of nutrients is fully recognized in Section 4.

3.2. *Data Manipulation*

In this section, data on the intakes of nine nutrients, namely energy, protein, calcium, iron, carotene, thiamine, niacin, riboflavin and ascorbic acid, are used to estimate directly the effects of household incomes on intakes of nutrients in a dynamic framework. The explanatory variables are household income, number of adult equivalents, two dummy variables for the villages and the height and weight of the individuals in the two time periods as in equations (2) and (3). (The incomes excluding rent of the households were used instead of the expenditure variable since there were difficulties in matching all the observations on households with those on individuals. Also, the square of the number of adult equivalent members was insignificant in most of the relationships estimated in Sections 3 and 4.) Given that the recollection of the younger members about food intakes may be inaccurate, it was decided to retain only individuals who were aged 10 years or older in 1976. Also, the two rounds were averaged to produce a figure for the year and we thus obtained data on 364 individuals for 2 years. (Data from individuals with single observations in each of the years were retained.)

The preliminary results for the nine nutrients indicated that the variation in the data was much too large to afford precise estimation of the parameters for all the nutrients. The nutrients were therefore grouped by expressing the data on a particular nutrient in terms of the percentages of the recommended daily allowances (Stigler, 1945; Langier, 1969; Ryan *et al.*, 1984). Five groups were then obtained, namely energy, protein, (calcium and iron), (carotene and ascorbic acid—referred to as vitamins A and C) and vitamin B (comprising thiamine, riboflavin and niacin). (If calcium and iron were considered individually, poor results were obtained for both. Also, a combination of all vitamins into a single group did not produce an improvement in the results.) The rationale for combining calcium and iron was alluded to earlier in that the absorption of these minerals is greatly influenced by the presence of other nutrients. Also, vitamins A and C were combined as the diets contained practically no fruits so that the prime sources of these nutrients were leafy vegetables.

3.3. *Empirical Results for Simple Dynamic Relationships*

Table 2 reports the results for the dynamic relationships (3) in logarithms for the five nutrient groups. In each case, the estimated coefficient of incomes is statistically significant though the elasticities seem low. The estimates of the lagged dependent variable α in the energy and calcium and iron relationships, however, are unacceptably large and the optimization routine indicated that some of these models were not well specified (the instrumental variables estimates were sometimes quite different from the maximum likelihood estimates). An examination of the unrestricted reduced form (6) estimates for each of these groups showed that the *lagged* values of incomes were statistically significant in explaining the current nutrient intake for all but the vitamins A and C relationship. For vitamin B, both the lagged and the current values of incomes were significant at the 5% level.

The only individual specific regressors in Table 2 are the heights and the weights of the individuals; the remaining variables are common to all members of the households. This will probably leave much of the variation in the data unexplained. Now, the facts that the human body can use its own adipose tissue to meet energy

TABLE 2

Maximum likelihood estimates of income elasticities of nutrients in the simple dynamic models†

Variable	*Estimates for the following nutrients:*				
	Energy	*Protein*	*Calcium and iron*	*Vitamins A and C*	*Vitamin B*
Constant	−0.646	1.362	10.617	0.114	1.208
	(3.230)	(1.821)	(5.241)	(0.362)	(1.928)
Dummy 1	−0.007	−0.069	0.794	−0.207	−0.230
	(0.093)	(0.149)	(0.379)	(0.126)	(0.082)
Dummy 2	−0.274	−0.293	0.641	0.071	−0.283
	(0.051)	(0.048)	(0.323)	(0.079)	(0.049)
No. of adult equivalents	−0.064	−0.164	0.052	−0.365	−0.169
	(0.064)	(0.049)	(0.119)	(0.065)	(0.051)
Income	0.066	0.106	0.007‡	0.095	0.127
	(0.032)	(0.034)	(0.048)	(0.047)	(0.027)
Weight	−0.169	0.098	0.109	0.113	0.203
	(0.332)	(0.165)	(0.131)	(0.155)	(0.051)
Height	−0.159	−0.391	−3.609	0.198	−0.119
	(0.518)	(0.476)	(1.744)	(0.048)	(0.437)
α	1.409	0.947	2.387	0.454	0.582
	(0.608)	(0.358)	(0.790)	(0.330)	(0.205)
$2L^*$	1937.9	1793.9	1482.2	730.0	1496.2

† All variables are in logarithms; 364 individuals; two time periods.

‡ Significant with inclusion of the square of income.

needs and that many of these households are living close to the subsistence level together imply that most of these individuals are consuming low quantities of nutrients in comparison with their dietary energy intakes. Thus, a possible procedure for reducing the high level of unexplained variation would be to re-estimate the simple relationships in Table 2, but now expressing the intakes of nutrients as ratios to the energy intakes. Thus, for example, individuals with high basal metabolic rates will probably consume higher quantities of energy but the proportions of their intakes of other nutrients will be determined by the incomes of the household to which they belong. Such ratios have been used in other nutritional studies.

Table 3 reports the results for the nutrient/energy ratios. For both the protein and the vitamin B equations, incomes significantly influence the proportions in which these nutrients are consumed and the short and the long run elasticities are as expected. The calcium and iron and vitamins A and C relationships, however, are not as supportive in so far as the income and long run effects are concerned. However, the appropriate comparisons of the maximized values of the likelihood functions in Tables 2 and 3 show that the data support the transformation of nutrients in the form of ratios to energy intakes. Moreover, the large estimates of α in the first three relationships of Table 2 and the lack of similarity between these results and those reported in the first two columns of Table 3 indicate that the former models are misspecified. Indeed, the conversion of the intakes of nutrients in ratio forms partially incorporates the interdependence between the nutrients and in turn enhances the performance of the simple models. This transformation also causes a distinction between the relative and the absolute income elasticities of nutrients which is discussed later.

TABLE 3

Maximum likelihood estimates of relative income elasticities of nutrient/energy ratios†

Variable	*Estimates for the following nutrients:*			
	Protein	*Calcium and iron*	*Vitamins A and C*	*Vitamin B*
Constant	−0.400	−10.661	−4.128	−2.074
	(0.760)	(0.800)	(3.298)	(0.586)
Dummy 1	−0.087	−0.197	0.056	−0.125
	(0.062)	(0.059)	(0.155)	(0.042)
Dummy 2	−0.013	−0.057	0.393	0.012
	(0.015)	(0.076)	(0.078)	(0.029)
No. of adult equivalents	−0.069	−0.111	−0.241	−0.067
	(0.016)	(0.071)	(0.082)	(0.030)
Income	0.042	0.291	0.081	0.288
	(0.010)	(0.187)	(0.069)	(0.058)
Income^2	—	−0.017	—	−0.013
		(0.009)		(0.003)
Weight	0.004	−0.269	−0.167	0.003
	(0.063)	(0.067)	(0.237)	(0.059)
Height	0.048	2.176	0.607	0.152
	(0.210)	(0.037)	(0.237)	(0.059)
α	0.623	−0.103	0.128	0.505
	(0.224)	(0.191)	(0.323)	(0.164)
$2L^*$	3222.7	1837.0	759.3	2294.5

† All variables are in logarithms; the square of income is included in the calcium and iron and vitamin B equations.

4. INCORPORATING INTERDEPENDENCE BETWEEN NUTRIENTS

4.1. *Hierarchical Structure of Nutritional Wants*

The intakes of energy, protein, minerals and vitamins are all essential for maintaining proper health of a human body. Households living close to the subsistence level, however, may not be able to afford adequate quantities of all the desirable nutrients. Consequently, it would be necessary for them to rank various foods from the viewpoint of satisfying the most immediate needs of their members. Indeed, it is quite common in these villages to find separate arrangements especially for staple products like grains and pulses that are relatively good sources of energy and protein. Such agreements are often formed on the basis of the work performed during the harvest seasons but even for semi-skilled services such as those provided by barbers and carpenters some payments are made in kind. These undoubtedly reduce the risk of facing hunger. The income earned from other sources may then be spent on more nutritious foods like vegetables, milk and meat, though the quantities actually purchased will be determined by food prices and by household incomes. The situation facing these households could perhaps be characterized by the well-known phenomenon of the 'hierarchy of human wants' (for example Georgescu-Roegen (1966)).

From the standpoint of empirical work, the examples illustrating hierarchy in the economics literature (Lancaster, 1971; Ironmonger, 1972) cannot be easily translated into practical procedures for analysing individuals' demands for nutrients. Firstly, characteristics like energy, protein, minerals and vitamins are generally found in most foods though in different proportions. Thus the demand for any particular nutrient is accompanied by automatic increases in intakes of other nutrients. Secondly, although it is true that the demand for vitamins will manifest itself only after a household has attained a certain level of income, it is not straightforward to model the levels at which this will be observed. Indeed, with the exception of vitamin C, the remaining nutrients on which the data are available are found in minute quantities even in grains and pulses. Thus a simple hierarchical formulation where the demand for energy, protein, calcium and iron, vitamins A and C and vitamin B are satisfied in that order would simply be misleading. It is essential to distinguish between the intakes of minerals and vitamins (through staple foods), and the demand for foods that are *rich* sources of these nutrients.

Lastly, the non-market arrangements prevailing in these villages complicate the models of demand for nutrients; some of the demand functions may be viewed as 'conditional' demand functions arising from utility maximization subject to quantity restrictions (Pollak, 1969). If the arrangements pertain solely to staple foods, then it might be reasonable to introduce the quantities consumed of the two vital nutrients (energy and protein) as 'explanatory' variables into the demand functions for the remaining nutrients. This would only be an approximate empirical procedure since some minerals and vitamins are present in the staple foods. However, precise data on the non-market arrangements are unavailable and agreements about vegetables (especially if they can be preserved as pickles) will invalidate these formulations. Thus an alternative approach is pursued here.

4.2. *Interdependence in Nutritional Intake*

It was noted by Stigler (1945) that 'the optimum quantity of any nutrient depends on the other nutrients available' and that 'the ultimate health function will doubtless be very complex'. Although knowledge about the nutritional requirements of human beings has advanced in the last four decades, there are still large gaps in the understanding of the manner in which the various nutrients interact to maintain good health. Moreover, some biomedical evidence suggests that the nutritional needs of the human body can influence the tastes of individuals.

Now, the primary purpose of this study is to investigate the link between individuals' intakes of important nutrients and household incomes. Given the difficulties in quantifying the health value of nutritional intake, it is reasonable to separate out the issue of the specification of a health production function. Instead, we approach the data on the intake of nutrients from the standpoint of demand analysis, recognizing that the quality of foods consumed must depend on both the physiological needs of the individuals as well as on households' incomes. The fact that the consumption of more nutritious foods entails the intake of small quantities of the nutrients cheaply available, then, suggests that it would be very informative to quantify the effects of household incomes on the intake of any specific nutrient, *holding the quantities consumed of the other nutrients constant*. Such a formulation would seem consistent with the notions of interdependence in nutritional intakes advanced by Hutchinson (1969), Stigler (1945) and Sukhatme (1974). However, there are problems in identifying the system because the remaining nutrients appear as endogenous explanatory variables in every relationship. But if these problems could be circumvented perhaps under the special correlation patterns (5), then the income elasticities of nutrients may be obtained from solving the interdependent system. Since we have only two time observations, the special form of endogeneity of the time varying variables will be maintained as an assumption in this investigation.

4.3. *The Model and its Identification*

It will be convenient to rewrite model (1) and (2) in a slightly different form owing to the special endogenous nature of some of the time varying variables. Thus we write the complete system

$$y_{i1} + \tilde{\mu}' z_{i1} + \sum_{t=1}^{2} \mu_t' x_{i1t} + \mu_2^{+\prime} x_{i22}^{+} = u_{i1} \qquad (i = 1, \ldots, H), \tag{7}$$

$$B y_i + \gamma_1' z_i + \beta_2' x_{i22} + \beta_1' x_{i12} = u_{i2} \qquad (i = 1, \ldots, H), \tag{8}$$

$$-\bar{x}_{i2} + \sum_{t=1}^{2} F_t x_{i1t} + F_2^{+} x_{i22}^{+} + \tilde{F} z_{i1} = u_{i3} \qquad (i = 1, \ldots, H), \tag{9}$$

$$-x_{ij2} + x_{ij2}^{+} + \bar{x}_{ij} = 0 \qquad (i = 1, \ldots, H;\ j = n - k - 1, \ldots, n). \tag{10}$$

Here, $B = (\alpha, -1)$, z_{i1} is an $(m+1) \times 1$ vector of exogenous time invariant variables, and x_{i1t} and x_{i2t} are $k \times 1$ and $(n-k) \times 1$ vectors of exogenous and special endogenous time varying variables respectively. μ, γ and β are all vectors of unknown coefficients and the F are matrices of unknown coefficients in the reduced form (9). Also, the correlation pattern (5) is assumed for the endogeneity of the time varying variables, and x_{i22}^{+} are the deviations of x_{i22} from their time means, i.e. with $T = 2$

$$x_{i22}^{+} = (x_{i22} - x_{i21})/2.$$

Correlation structure (5) adds only $n - k$ time means as endogenous variables in the system and the x_{ij2}^{+} provide precisely the same number of instrumental variables that can be used for estimating the system. A likelihood ratio test can be applied to test the validity of the exogeneity assumption for the time varying variables against the alternative pattern (5). The test statistic is

$$2(L_{\text{endog}}^{*} - L_{\text{exog}}^{*}) + H \log(\det W_{22}) \tag{11}$$

where L^{*} represents the maximized value of the log-likelihood functions under the treatment of the time varying variables as, respectively, special endogenous and exogenous, and W_{22} is an estimate of the unrestricted variance matrix corresponding to the errors on equation (9). Expression (11) is asymptotically distributed as a χ^2-variable with $2(n-k)$ degrees of freedom.

Now assuming no endogenous time invariant variables in the model, and defining the data matrix of the exogenous variables as

$$Z^{+} = [Z_1 \colon X_1 \colon X_2^{+}],$$

we have the following result on identification (see Appendix A for the proof).

Proposition. If

(a) $\text{Plim}_{H \to \infty} (Z^{+\prime} Z^{+}/H)$ is positive definite,
(b) $k > 0$ and
(c) $T = 2$,

then model (8) is identified.

4.4. *Empirical Results*

Table 4 reports the results for each of the five nutrient groups where the remaining four nutrients appear as explanatory variables. First, focusing on the exogeneity of the nutrient variables with correlation structure (5) as the alternative hypothesis, the vitamins A and C relationship clearly accepts the null hypothesis for all the four regressors at any reasonable significance level. The vitamin B equation would also accept the null hypothesis at about the 4% level but a closer examination revealed that it is the vitamin A and C group that is mainly increasing the value of the test statistic; thus it is reasonable to accept the null hypothesis. The calcium and iron relationship, however, rejects the exogeneity null hypothesis at the 5% level and the results in Table 4 treat the nutrients as special endogenous variables. Similarly, the exogeneity null hypotheses are rejected in the energy and protein relationships. It was noted earlier that decisions to consume foods containing high quantities of vitamins are likely to succeed those regarding staple foods. Thus the acceptance of the exogeneity null hypotheses for the vitamin groups might be viewed as an indication of a hierarchical structure in the demand for these nutrients. (The coefficients for the other nutrients are expected to be non-zero because the nutrients are present in minute quantities in most foods.)

Secondly, the relationships are generally non-linear in household incomes and the

TABLE 4

Maximum likelihood estimates of relative income elasticities of nutrients in the interdependent system†

Variable	*Estimates for the following nutrients:*				
	Energy	*Protein*	*Calcium and iron*	*Vitamins A and C*	*Vitamin B*
Income	−0.352	0.329	0.324	0.082	0.124
	(0.086)	(0.088)	(0.057)	(0.058)	(0.004)
Income^2	0.020	−0.019	−0.022	–	−0.004
	(0.005)	(0.005)	(0.003)		(0.001)
No. of adult equivalents	0.049	−0.026	−0.013	−0.284	−0.006
	(0.021)	(0.020)	(0.061)	(0.085)	(0.020)
Weight	0.175	−0.227	−0.333	−0.075	0.023
	(0.058)	(0.049)	(0.096)	(0.139)	(0.007)
Height	−0.811	0.635	1.668	0.015	−0.352
	(0.083)	(0.065)	(0.223)	(0.067)	(0.010)
Energy	–	1.013	1.019	0.785	−0.029
		(0.132)	(0.166)	(0.301)	(0.005)
Protein	0.760	–	−0.227	−1.099	1.084
	(0.090)		(0.223)	(0.352)	(0.007)
Calcium and iron	0.219	−0.098	–	0.422	0.046
	(0.043)	(0.035)		(0.099)	(0.024)
Vitamins A and C	0.012	−0.030	0.072	–	0.015
	(0.016)	(0.017)	(0.043)		(0.016)
Vitamin B	−0.108	0.287	0.376	0.388	–
	(0.051)	(0.044)	(0.147)	(0.193)	
α	0.031	0.084	0.148	0.332	0.022
	(0.043)	(0.047)	(0.080)	(0.122)	(0.024)
$2L^*$	7734.1	7737.2	7080.1	849.5	2655.4
$\chi^2(8)$	37.02	22.81	17.55	2.58	16.96

† All the variables are in logarithms; the energy, protein and calcium and iron equations treat the other nutrients as special endogenous variables—see the χ^2-values; the coefficients of the constant term and the village dummy variables are not reported.

coefficients are statistically significant. These results support the hypothesis that, with increases in household incomes, foods containing greater proportions of the last four nutrient groups will be consumed. The negative sign of the income coefficient and the positive sign of its square in the energy relationship further confirm this. Thirdly, solving the interdependent system (7)–(10) but retaining terms up to the first order, the respective income elasticities of the five nutrient groups are 0.129, 0.179, 0.125, 0.176 and 0.316. The first-order approximation is necessary here as the squared income term appears as a regressor in four of the equations. Its rigorous justification would also require the calculation of the joint variance–covariance matrix of the parameters of the whole system. (The simultaneous estimation of the complete system is necessary for computing the covariance matrix of the estimated parameters in different equations. To economize on storage space, the full data set is never read into the computer. Thus the simultaneous estimation of the equations will require a considerable amount of additional programming.)

The seemingly low estimates of the income elasticities may be rationalized to some degree by the nature of the 24-hour recall data. Furthermore, we might reasonably expect households with low incomes to spread their consumption of more nutritious foods over the year especially to coincide with religious festivities. The fact that no interviews were conducted during festival periods, then, suggests that the income elasticities of nutrients may have been underestimated. Fourthly, the long run effects are much larger for the calcium and iron and the vitamins A and C relationships. Since the diets in these villages contained virtually no fruits, the implications for the intake of vitamins A and C are encouraging. The vitamin B relationship, however, does not afford a distinction between the short and the long run effects. (For income elasticities in static models, see Bhargava (1991).)

In summary, the results in Table 4 show that, in these villages, foods containing higher proportions of the desirable nutrients are consumed with increases in household incomes. This conclusion is conditional on the assumed form of endogeneity (5) for the remaining nutrients appearing as regressors. This condition might seem restrictive but has commonly been invoked in dynamic error components models (for example Anderson and Hsiao (1981)). Although statistical tests for the hypotheses maintained cannot be applied to the present models with two time observations, the non-rejection of the exogeneity null hypotheses in the last two relationships suggests that the conclusions may not be critically dependent on the correlation patterns postulated.

5. CONCLUSION

This paper has estimated short and long run income elasticities of foods and nutrients using data from south India. The specifications for food groups are consistent with the economic hypothesis of habit formation and the data provided good support for the theory. The analysis of demand for nutrients, however, is very complicated. The incorporation of the interdependence in nutritional intakes led to models that showed significant effects of household incomes on the intake of nutrients. The estimated income elasticities of nutrients from the dynamic interdependent system, while sensitive to the approximations used, seem somewhat larger than their static counterparts. Nevertheless, the results demonstrate better nutrition with increases in household incomes, thereby supporting the position of the World

Bank (1981) for raising incomes in developing countries.

Finally, the analyses of the various aspects of nutrition in developing countries will be greatly facilitated by the availability of surveys that continuously record food intakes for several days and are also repeated several times during the year. These are routine features of epidemiological surveys in developed countries (for example Freudenheim *et al.* (1987) and Nelson *et al.* (1989)) though the number of subjects observed has typically been small. In less developed countries, the internal variances in intakes of nutrients tend to be much larger and seasonal factors can create serious food shortages. Thus the benefits from elaborate nutritional surveys such as the accurate assessment of the incidence of undernutrition and more precise estimation of parameters that are of interest in policy making should offset the costs.

ACKNOWLEDGEMENTS

The author is indebted to Jere Behrman, Marc Nerlove, Bob Pollak and Amartya Sen for helpful discussions and to two referees for many thoughtful criticisms of an earlier draft. Thanks are also due to the Cornell Theory Center for supercomputer time.

APPENDIX A: PROOF OF THE PROPOSITION

We premultiply equation (8) by a $1 \times 2(n-k)$ vector

$$[h_0 : 1 + h_1 : h_2 : h_1^*] \tag{A.1}$$

and show that h_0, h_1, h_2 and h_1^* are all zero.

The set of transformed equations can be written as

$$-h_0 d_2' + (1 + h_1)B = B_1, \tag{A.2}$$

$$h_0 \tilde{\mu}' + (1 + h_1)\gamma_1' + h_2 \tilde{F} = \gamma_1' - \gamma_1^{*\prime}, \tag{A.3}$$

$$h_0 \mu_1' + h_2 F_1 = 0, \tag{A.4}$$

$$h_0 \mu_2' + (1 + h_1)\beta_1' + h_2 F_2 = \beta_1' - \beta_1^{*\prime}, \tag{A.5}$$

$$(1 + h_1)\beta_2' - h_1^{*\prime} = \beta_2' - \beta_2^{*\prime}, \tag{A.6}$$

$$h_0 \mu_2^{+\prime} + h_2 F_2^+ + h_1^* = 0, \tag{A.7}$$

$$h_2 = h_1^*. \tag{A.8}$$

Here $d_2' = (0, 1)$, $B = (\alpha, -1)$, B_1 is the transformed version of B with α replaced by $\alpha_1 = \alpha - \alpha^*$, h_0 and h_1 are scalars, h_2 and h_1^* are $1 \times (n-k)$ vectors and γ^* and β^* are the transformed versions of γ and β respectively. From equation (A.2), on equating the coefficients, we immediately have that

$$\begin{aligned} h_1 &= 0, \\ h_0 &= \alpha^*. \end{aligned} \tag{A.9}$$

Thus we may rewrite the previous equations as

$$\alpha^* \tilde{\mu}' + h_2 \tilde{F} = -\gamma_2^{*\prime}, \tag{A.10}$$

$$\alpha^* \mu_1' + h_2 F_1 = 0, \tag{A.11}$$

$$\alpha^* \mu_2' + h_2 F_2 = -\beta_1^{*\prime}, \tag{A.12}$$

$$h_1^* = \beta_2^*, \tag{A.13}$$

$$\alpha^* \mu_2^{+\prime} + h_2 (I + F_2^+) = 0. \tag{A.14}$$

On combining equations (A.8) and (A.13), we have $h_1^* = h_2 = \beta_2^*$ which can be satisfied only if $h_1^* = h_2 = 0$. Thus, from equation (A.11), $\alpha^* = 0$ and, consequently, $\beta_1^* = 0$, $\beta_2^* = 0$ and $\gamma_1^* = 0$. Hence all the parameters in the model are identified.

REFERENCES

Anderson, T. W. and Hsiao, C. (1981) Estimation of dynamic models with error components. *J. Am. Statist. Ass.*, **76**, 598–606.

Beaton, G. H., Milner, J., Corey, P., McGuire, V., Cousins, M., Stewart, E., de Ramos, M., Hewitt, D., Grambsch, P. V., Kassim, N. and Little, J. A. (1979) Sources of variance in 24-hour dietary recall data: implications for nutrition study design and interpretation. *Am. J. Clin. Nutr.*, **32**, 2546–2559.

Behrman, J. R. and Deolalikar, A. B. (1987) Will developing country nutrition improve with incomes?: a case study for rural south India. *J. Polit. Econ.*, **95**, 492–507.

Bhargava, A. (1987) Wald tests and systems of stochastic equations. *Int. Econ. Rev.*, **28**, 789–808.

——— (1989) Malnutrition and the role of individual variation with evidence from India and the Philippines. To be published.

——— (1991) Identification and panel data models with endogenous regressors. *Rev. Econ. Stud.*, **58**, in the press.

Bhargava, A. and Sargan, J. D. (1983) Estimating dynamic random effects models from panel data covering short time periods. *Econometrica*, **51**, 1635–1660.

Binswanger, H. and Jodha, N. S. (1978) *Manual for Instruction for Economic Investigators in ICRISAT's Village Level Studies.* Hyderabad: International Crops Research Institute for Semi-Arid Tropics.

Block, G. (1982) A review of validation of dietary assessment methods. *Am. J. Epidem.*, **115**, 492–505.

Deaton, A. S. and Muellbauer, J. (1980) *Economics and Consumer Behavior.* Cambridge: Cambridge University Press.

Duesenberry, J. S. (1949) *Income, Saving, and the Theory of Consumer Behavior.* Cambridge: Harvard University Press.

Freudenheim, J. L., Johnson, N. E. and Wardrop, R. L. (1987) Misclassification of nutrient intake of individuals and groups using one-, two-, three-, and seven-day food records. *Am. J. Epidem.*, **126**, 703–713.

Friedman, M. (1957) *A Theory of the Consumption Function.* Princeton: Princeton University Press.

Georgescu-Roegen, N. (1966) *Analytical Economics: Issues and Problems.* Cambridge: Harvard University Press.

Gopalan, C., Rama, B. V. and Balasubramanian, S. C. (1971) *Nutritive Value of Indian Foods.* Hyderabad: National Institute of Nutrition.

Gorman, W. M. (1967) Tastes, habits and choices. *Int. Econ. Rev.*, **8**, 218–222.

——— (1980) A possible procedure for analyzing quality differentials in the egg market. *Rev. Econ. Stud.*, **47**, 843–856.

Griliches, Z. (1961) Hedonic price indexes for automobiles: an econometric analysis of quality change. In *Price Indexes and Quality Change: Studies in New Methods of Measurements* (ed. Z. Griliches). Cambridge: Harvard University Press.

Houthakkar, H. S. and Taylor, L. D. (1970) *Consumer Demand in the United States*, 2nd edn. Cambridge: Harvard University Press.

Hutchinson, R. (1969) *Food and the Principles of Dietetics*, 12th edn. London: Arnold.

Ironmonger, D. S. (1972) *New Commodities.* Cambridge: Cambridge University Press.

Lancaster, K. (1966) A new approach to consumer theory. *J. Polit. Econ.*, **74**, 132–157.

——— (1971) *Consumer Demand: a New Approach.* New York: Columbia University Press.

Langier, J. D. (1969) *Economical and Nutritional Diets using Scarce Resources.* East Lansing: Michigan State University Press.

Liu, K., Stamler, J., Dyer, A., McKeever, J. and McKeever, P. (1978) Statistical methods to assess and minimize the role of intra-individual variability in obscuring the relationship between dietary lipids and serum cholestrol. *J. Chron. Dis.*, **31**, 399–418.

Nelson, M., Black, A. E., Morris, J. A. and Cole, T. J. (1989) Between-and-within subject variation in nutrient intake from infancy to old age: estimating the number of days required to rank dietary intakes with desired precision. *Am. J. Clin. Nutr.*, **50**, 155–167.

Nerlove, M. (1972) Lags in economic behaviour. *Econometrica*, **40**, 221–251.

Numerical Algorithms Group (1989) *Library of Computer Programs, Mark 12.* Oxford: Numerical Algorithms Group.

Nutrition Reviews (1976) *Present Knowledge in Nutrition*, 4th edn. Washington DC: Nutritional Foundation.

Phlips, L. (1974) *Applied Consumption Analysis.* Amsterdam: North-Holland.

Pollak, R. A. (1969) Conditional demand functions and consumption theory. *Q. J. Econ.*, **83**, 70–78.

——— (1970) Habit formation and dynamic demand functions. *J. Polit. Econ.*, **78**, 60–78.

Prais, S. J. and Houthakkar, H. S. (1955) *The Analysis of Family Budgets.* Cambridge: Cambridge University Press.

Pudney, S. E. (1981) Instrumental variable estimation of a characteristics model of demand. *Rev. Econ. Stud.*, **48**, 417–433.

Ryan, J. G., Bindinger, P. D., Rao, N. P. and Pushpamma, P. (1984) *Determinants of Individual Diets and Nutritional Status in Six Villages of South India.* Hyderabad: International Crops Research Institute for Semi-Arid Tropics.

Shils, M. E. and Young, V. R. (1988) *Modern Nutrition in Health and Disease*, 7th edn. Philadelphia: Lea and Febiger.

Stigler, G. J. (1945) The cost of subsistence. *J. Farm Econ.*, **27**, 303–314.

Stone, J. R. N. (1954) Linear expenditure system and demand analysis: an application to the pattern of British demand. *Econ. J.*, **64**, 511–527.

Sukhatme, P. V. (1974) The protein problem, its size and nature. *J. R. Statist. Soc.* A, **137**, 166–199.

Timmer, C. P. and Alderman, H. (1979) Estimating consumption parameters for food policy analysis. *Am. J. Agric. Econ.*, **61**, 982–994.

Waterlow, J. C. (1989) Nutritional adaptation and variability. *Eur. J. Clin. Nutr.*, **43**, 203–205.

World Bank (1981) *World Development Report.* Washington DC: World Bank.