Pakistan Journal of Applied Economics, (1984), Vol. III No. 2, (107 – 138).

INTERACTIONS BETWEEN MALNUTRITION AND DISEASE: A simultaneous equations model applied to data from a low-income area of Karachi

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This paper examines the interactions between disease and malnutrition using cross-section data on pre-school children from a low-income area of Karachi. A simultaneous equations model is utilized in the study, the endogenous variables being the number of spells of diarrhoea and respiratory illness reported by the childrens' mothers during the preceding six months (measure of disease) and three alternative measures of malnutrition. The exogenous variables in the model include parents' schooling, weekly food expenditures, age and sex of the child, length of breastfeeding and other dietary measures, immunizations, sanitation practices and housing characteristics.
The results of the study indicate that there is, in fact, a high positive correlation between the incidence of disease and malnutrition but that, contrary to what is widely believed, the direction of causality appears to run primarily from malnutrition to disease, rather than vice-versa. The study's findings also indicate that neither the level of family food expenditures nor the education of either parent is significantly related either to the child's nutritional status or to the frequency of illness. On the other hand, the results point to the possible importance of the mother's own health and of infant feeding practices as determinants of the child's nutritional status.

I. Introduction

In recent years concern for nutrition and health has increased greatly among economists and planners, probably as the result of a shift in emphasis toward planning for "basic needs" as opposed to planning for maximum growth. A number of researchers [Berg (1973), L. Taylor (1977),

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Selowsky (1978)] have addressed the task of designing effective policies, or "interventions", to improve the nutritional status of a population, particularly of such vulnerable groups as pre-school children and women of child-bearing ages.[1] Despite the recent interest in identifying successful forms of intervention, relatively little is known about the factors which determine nutritional status and, in particular, little is known about the way malnutrition and disease interact to affect the overall health status of pre-school children. In the absence of such knowledge, attempts to reduce either the extent of malnutrition or the incidence of disease may be ineffective. As the authors of one popular text-book in nutrition have noted [Davidson et. al. (1975)] :

> Much practical experience has shown that one-sided public health programmes, aimed solely at improving diets or eradicating a single infectious disease, are relatively unsuccessful in raising the health of a community. This can best be improved by an attack on a broad front against all the factors that contribute to disease.

In support of the above view, C. Taylor (1977) cites evidence from one study in the Indian Punjab which found that infection control alone was more effective than nutritional supplements alone in improving the *nutritional* status of children under two, while Chowdhury and Chen (1977) have produced evidence from Bangladesh which suggests that malnutrition lowers resistance to disease.

The present study explores the interactions between disease and malnutrition, using cross-section data on pre-school children (i.e., children under 5) from one low-income area of Karachi. A simultaneous equations model is utilized in the study, the endogenous variables being the number of spells of diarrhoea and respiratory illness during the preceding six months (measures of disease) and one of three alternative measures of malnutrition (i.e., mid-arm circumference, weight-for-age, and the haemoglobin level). A wide range of explanatory variables are utilized in the study in an attempt to control for other influences.

The results of the study indicate that there is, in fact, a high positive correlation between the incidence of disease and malnutrition but that, contrary to what is widely believed, the direction of causality runs primarily from malnutrition to disease, rather than vice-versa. The results of the study also indicate that a higher frequency of one type of illness significantly increases the frequency of the other type of illness. Finally, the present study produces a number of surprising results, among them, that neither the level of family food expenditures nor the education of either parent is

[1] Examples of interventions include nutrition education, food subsidies, fortification, and school-feeding programs.

significantly related either to the child's nutritional status or to the frequency of illness.

The paper is divided into five sections. In addition to the introductory section I, section II discusses the theoretical specification of the model, while section III provides a brief description of the data set and some tabulations showing the extent of malnutrition and disease among the children in the sample as well as the extent to which malnutrition and disease are correlated. Section IV presents and discusses the estimation results, while section V (the final section) contains a summary of the findings and some conclusions.

II. Model Specification

The model considered in the present paper consists of three endogenous variables, one variable referring to the child's nutritional status and two variables referring to disease. In fact, three alternative measures of malnutrition are utilized – mid-arm circumference (NA), weight-for-age (NW), and the haemoglobin level (NH) – only one of which is utilized in any given version of the model.[2] The two disease variables (DD, DR) refer respectively to the number of spells of diarrhoea and respiratory illness in the preceding six months ("for which treatment was sought"). The definitions of the endogenous variables are provided below:

NA = child's mid-arm circumference (centimeters);

NW = child's actual weight as a percentage of the Harvard standard weight-for-age (both sexes combined);

NH = child's haemoglobin level (grams per 100 ml of blood);

DD = number of spells of diarrhoea "for which treatment was sought" during the past six months;

DR = number of spells of respiratory illness "for which treatment was sought" during the past six months.

Weight-for-age (NW) is the most widely accepted measure of malnutrition, being particularly sensitive to the sudden onset of malnutrition due to illness. The other two measures of malnutrition (NA, NH) were selected from a large number of possible indicators of nutritional status because these measures are relatively insensitive to age misreporting.[3] The two disease mea-

[2] A fourth measure of malnutrition, the Dugdale index of weight-for-height [Davidson et. al., (1975), p.567], was also utilized. The results were very similar to those obtained with the other measures and are, of course, available from the author on request.

[3] In a normal child, mid-arm circumference is bout 10 cm at birth and increases to about 16 cm at 12 months. During the next four years, however, it increases by a total of only about 1 cm [Ebrahim (1975), p.2]. Hence, for children between the ages of one and five years, mid-arm circumference provides a fairly good indicator of a child's nutritional status without reference to the child's age. Similarly, the haemoglobin level is high in the normal newborn (about 20 grams per 100 ml)

sures (DD, DR) were selected because most of the common diseases among pre-school children in low-income communities manifest themselves either in the form of diarrhoea (e.g., bacterial and amoebic dysentery, typhoid fever) or in the form of respiratory illness (e.g., whooping cough, tuberculosis, pneumonia, bronchitis).[4] It should be pointed out, however, that the distinction between malnutrition and disease, which is maintained throughout the present paper, is far from perfect. Diarrhoea, for example, is often a symptom of protein-calorie malnutrition, while a low haemoglobin level may result from certain diseases (e.g., hookworm, malaria) rather than from nutritional deficiency. Still, the distinction between malnutrition and disease is basically valid and useful.

The coefficients of the endogenous variables from the structural form of the model can be collected into a matrix, as follows:

$$\underset{\sim}{C} = \begin{bmatrix} -1 & c_{12} & c_{13} \\ c_{21} & -1 & c_{23} \\ c_{31} & c_{32} & -1 \end{bmatrix}$$

The next question of interest is whether any *a priori* restrictions can be placed on the elements of $\underset{\sim}{C}$ (apart from the normalization of the diagonal elements).

The coefficients c_{12} and c_{13} refer to the direct effects of DD and DR on nutritional status. The health and nutrition literature provides strong reason to expect both coefficients to be negative. Diarrhoea inhibits food absorption directly [Davidson et. al. (1975), p.71], while the common practice in Pakistan (and elsewhere) of starving children during bouts of diarrhoea and respiratory illness has been cited as an important cause of severe malnutrition [Jelliffe (1974c), pp.46, 53; Davidson et. al. (1975), pp.303, 624]. Pre-school children also tend to experience loss of appetite during serious illness [Stanfield and Jelliffe (1974), p.44], while infection itself increases the body's nutritional requirements [Davidson et. al. (1975), pp.620, 624]. Furthermore, according to R.H.R. White [(1974), p.109], in whooping

but it falls to about 11 grams per 100 ml of blood by 4 months, rising slowly from that age to a level of about 14 grams per 100 ml by the time the child is seven years of age [Stroud (1974a), p. 73].

4 Jelliffe [(1974a), p.1] lists the following as the most common health problems of pre-school children in the tropics: protein-calorie malnutrition, diarrhoea, pneumonia, malaria, intestinal worms (especially the hookworm and the roundworm), tuberculosis, anaemia, measles, whooping cough and accidents. Even in the case of measles, the most serious and common complications are respiratory illness (i.e., pneumonia and bronchitis).

cough, "severe repeated spasms of coughing, with vomiting, may lead to loss of weight and be responsible in poorly nourished children for their developing kwashiorkor," [also see Davidson et. al. (1975), p.624]. Finally, gastro-intestinal diseases may inhibit the absorption of iron (producing iron-deficiency anaemia), while diseases in general may depress bone marrow activity, thereby producing aplastic anaemia [Davidson et. al. (1975), pp.502, 508].

Somewhat less consistent *a priori* information is available for the other coefficients in the $\underset{\sim}{C}$ matrix. Two of these coefficients ($c_{2\,1}$, $c_{3\,1}$) concern the effects of malnutrition on disease. Many specialists believe that malnutrition lowers resistance to a number of diseases. Thus, Jelliffe [(1974b), p.58] suggests that diarrhoea due to bacterial infection is particularly common among poorly nourished children, while White and Goodall [(1974), pp.89, 95] argue that malnutrition lowers the resistance of children to both pneumonia and tuberculosis.[5] White [(1974), p.110] further states that, with measles, complications are more common in poorly nourished children.

On the other hand, after summarizing the available evidence, Davidson et. al, [(1975), p.623] concludes that malnutrition is not likely to affect a person's susceptibility to disease. They suggest instead that other aspects of poverty besides malnutrition (e.g., substandard housing, illiteracy) are responsible for the higher incidence of disease in low-income groups. The same authors go on to state that, while malnutrition may not affect a person's susceptibility to infection, it does greatly affect the outcome of an infection:

> A moderately severe attack of pneumonia, dysentery or indeed of any infectious disease, which is easily survived by a healthy well-nourished patient, may be fatal in another who is debilitated and emaciated.

Since the disease variables in the present study (DD, DR) involve spells of illness "for which treatment was sought" (i.e., relatively serious illness, more likely to have been aggravated by malnutrition) and in light of the apparent controversy in the health literature concerning the role of malnutrition in disease, no *a priori* restrictions are imposed on the coefficients $c_{2\,1}$ and $c_{3\,1}$. Expectations are, however, that both coefficients will exhibit negative signs.

The remaining two coefficients in $\underset{\sim}{C}$ (i.e., $c_{2\,3}$, $c_{3\,2}$) embody the effects of a change in the incidence of one type of disease on the incidence of the

[5] According to White and Goodall, malnourished children are also more likely to develop pneumonia since they are frequently too weak to cough properly in other to remove plugs of mucous (p.87). It has also been suggested [Davidson et. al. (1975), p.323] that children with "rickets" (i.e., vitamin D deficiency) are more prone to develop broncho-pneumonia.

other type of disease. In other words, are children with frequent spells of diarrhoea more likely to develop respiratory illness, and vice-versa? The health literature suggests that this is the case. It is clear, to cite some examples, that diarrhoea can be a symptom of certain respiratory diseases (e.g., pneumonia), that both pneumonia and diarrhoea are common complications in measles, and that bronchitis and loose stools are frequently observed in children with malaria [Jelliffe (1974b), p.58; White (1974), p.111; Jelliffe and Musoke (1974), p.70]. According to White (p.112), pneumonia is also a common complication of typhoid fever (in which diarrhoea is frequently a symptom). It is also plausible that repeated infections of one type, while increasing the body's resistance to the type of infection, lower its resistance to other types of infection. For these reasons, while the available evidence is not sufficiently strong to justify the imposition of any *a priori* restrictions on the coefficients ($c_{2\,3}$, $c_{3\,2}$), both coefficients are expected to exhibit positive signs.

In addition to three endogenous variables — NA (or NW or NH), DD, and DR — there are a total of eighteen exogenous variables in the model (including the intercept). These are defined and listed below:

CT = constant term (one for all observations);

AC = age of child (in months);

SX = sex of child (one if male, zero if female);

EH = father's education (one if literate or more than four grades completed, zero otherwise);

EW = mother's education (same as above);

FD = weekly food expenditures (in hundreds of Rupees) per equivalent adult (i.e., children under 15 years of age equal to one-half an adult);

DI = diet change during pregnancy (one if mother adds special foods during pregnancy, zero otherwise);

VI = vitamins/minerals during pregnancy (one if taken, zero if not);

PS = parity-spacing ratio (parity of child divided by the mother's average birth interval);

BF = length of breastfeeding (in months, recorded to average length of breastfeeding completed by siblings under five in cases where child is still breastfeeding);

SD = age (in months) when solid foods first given to child (recoded to average for siblings under five for children who have not yet been given solid foods);

WN = weaning period (one if child was weaned during past six months, zero otherwise);

IM = immunization received (one if child has received any type of immunization, zero otherwise);

WM = round worm infection (one if mother has observed round worms in the child's stool, zero otherwise);

RM= number of rooms per family member;
WA= private water supply (one if family has a private water tap, zero otherwise);
TL = flush toilet (one if family has a flush toilet, zero otherwise);
RF = method of refuse disposal (one if family uses municipal service or throws refuse in open, zero if throws refuse into street).

The eighteen exogenous variables included in the model are by no means an exhaustive list of the possible determinants of malnutrition and disease. Still, the above list does contain most of the variables which are considered to be important by health specialists. Thus for example, D.B. Jelliffe [(1974a), p.2] has identified poor hygiene, poverty, and lack of education as the most important determinants of malnutrition and disease:

> If hygiene is poor (as judged by housing, water supply, and the disposal of excreta and rubbish), then illness will be common in all age-groups, especially among children. For example, overcrowded houses help the spread of tuberculosis and respiratory infections. A poor water supply results in children being dirty and developing various skin diseases. An absence of latrines, or a failure to use them, means that the ground will be soiled with stools with the easy spread of intestinal worms. Poor disposal of rubbish will lead to increased fly-breeding and likelihood of a spread of diarrhoeal disease.
>
> If a population is poor and there is little naturally obtained food, parents will be unable to buy necessary, but expensive, protein foods for their children, so that protein-calorie malnutrition is likely to occur.
>
> Lastly, the level of education is important. Illiterate parents with little knowledge of the needs of their children are likely to feed them on the wrong foods, so that again malnutrition can occur. They will also tend to give the child dirty water and food, so that diarrhoea may result.

The coefficients of the exogenous variables in the model can also be collected together into a matrix, as follows:

$$\underset{\sim}{B} = \begin{bmatrix} b_{1\,1} & b_{1\,2} & b_{1\,3} \cdots b_{1\,16} & b_{1\,17} & b_{1\,18} \\ b_{2\,1} & b_{2\,2} & b_{2\,3} \cdots b_{2\,16} & b_{2\,17} & b_{2\,18} \\ b_{3\,1} & b_{3\,2} & b_{3\,3} \cdots b_{3\,16} & b_{3\,17} & b_{3\,18} \end{bmatrix}$$

A certain number of restrictions must be placed on the elements of $\underset{\sim}{B}$ to achieve *identification*. Additional restrictions, beyond those necessary for identification, are desirable as well, since they increase estimation efficiency. In the context of the present model, such *a priori* restrictions amount to the statement that a given exogenous variable does not directly affect one or other of the endogenous variables.

In the case of the child's age (AC), it is clear that both NA and NH should be positively related to AC (i.e., $b_{1\,2} > 0$).[6] Although there is no physical relationship between NW and AC (since the former is already adjusted for age), in low-income families the gap between the nutritional requirements of pre-school children and the amount of food available to them tends to increase with age.[7] Accordingly, one would expect an age-adjusted measure of nutritional status such as NW to be negatively related to the child's age (i.e., $b_{1\,2} < 0$).

The other two age coefficients ($b_{2\,2}$, $b_{3\,2}$) are more difficult to pin down *a priori*. According to Jelliffe (1974b, p.58), diarrhoea is most common during the period of weaning. However, in the present model, the special circumstances surrounding the weaning period should be adequately reflected in the weaning variable (WN). Accordingly, it is assumed that age does not directly affect the incidence of either diarrhoea or respiratory illness (i.e., $b_{2\,2}, b_{3\,2} = 0$).

The next exogenous variable to be considered is the child's sex (SX). It is clear that anthropometric differences by sex occur even among normal children. In the Harvard standards, for example, average weights for girls are from 0.1 to 0.3 kilograms lighter than those for boys of the same age [Davidson et. al. (1975), p.565]. Similar sex differences exist for mid-arm circumference and for other aspects of anthropometry. Furthermore, if boys receive favoured treatment within the family, such biological differentials may be accentuated. Thus, although there is no biological reason to expect a sex difference in haemoglobin levels among pre-school children, the fact that iron is obtained primarily from solid foods raises the possibility that the coefficient of SX in the haemoglobin equation can provide a basis for testing the hypothesis that no sex discrimination exists with respect to nutrition. For these reasons, no *a priori* zero restriction is imposed on the coefficient of SX in the nutrition equation; instead, it is expected, at least for two of the three nutrition measures (NA, NW), that the coefficient will be positive (i.e., $b_{1\,3} > 0$). On the other hand, since there is no reason to expect systematic sex differentials in the incidence of most childhood diseases, it is assumed that SX does not directly affect either DD or DR (i.e., $b_{2\,3}, b_{3\,3} = 0$).

According to Jelliffe (see quotation above), the education of both parents (EH, EW) is likely to affect both the child's nutritional status and the incidence of disease. Educated parents should have a clearer idea of the types of foods required by pre-school children (i.e., $b_{1\,4}, b_{1\,5} > 0$), and

6 See, footnote 3 above.

7 Children in low-income communities tend to be maintained too long on breast milk alone. As the child gets older, his (her) diet becomes increasingly insufficient.

they should also know better how to protect their children from infectious disease (i.e., $b_{1\,4}, b_{2\,5}, b_{3\,4}, b_{3\,5} < 0$).

Theoretical expectations are also clear in the case of family food expenditures (FD). A higher level of food expenditures should increase both the quantity and quality of food available to the child and may additionally have an indirect effect on the child's nutritional status by improving the nutritional status of the mother.[8] For these reasons, FD is expected to exhibit a positive coefficient in the nutrition equation (i.e., $b_{1\,6} > 0$). On the other hand, there is no reason to expect that food expenditures have any direct effect on either of the disease variables (i.e., $b_{2\,6}, b_{3\,6} = 0$).

Similarly, diet changes (DI) and vitamin and/or mineral supplements (VI) taken during pregnancy are likely to affect the mother's nutritional status, and hence the child's (i.e., $b_{1\,7}, b_{1\,8} > 0$), but not the incidence of disease (i.e., $b_{2\,7}, b_{2\,8}, b_{3\,7}, b_{3\,8} = 0$).[9] The parity spacing ratio (PS) is a measure of the extent to which the mother's nutritional status may have been affected adversely from numerous pregnancies in rapid succession. In the absence of proper dietary supplements, each additional pregnancy and childbirth imposes a heavy burden on the mother's health, rendering her particularly susceptible to anaemia. Since the mother's depleted nutritional status tends to be transferred to her children, one expects PS to be inversely related to the child's nutritional status (i.e., $b_{1\,9} < 0$). On the other hand, no direct relationship is hypothesized between PS and the two disease variables (i.e., $b_{2\,9}, b_{3\,9} = 0$).

Infant feeding practices can affect both the child's nutritional status and the frequency of illness. In low-income countries, bottle-fed babies tend to be poorly nourished and to have a high incidence of disease.[10] Furthermore, prolonged breastfeeding (up to two years, or even longer) can provide a useful and inexpensive supplementary source of energy and proteins (as long as it is not used as a substitute for solid foods). Therefore, the length of breastfeeding (BF) should be positively related to the child's nutritional status (i.e., $b_{1\,10} > 0$).

[8] Davidson et. al. [(1975), pp.508, 636] cite evidence which suggests that the nutritional intake of the mother affects the birth weight of her children. Children with low birth weights are prone to be anaemic (since they are deficient in the quantity of blood at the time of birth) and are more likely to be smaller throughout infancy. It is also likely that the mother's nutritional status affects both the quantity and quality of her breast milk.

[9] Iron and vitamin A supplements taken during pregnancy are of particular value to the child, since neither of these are present in sufficient quantity in breast milk [Davidson et. al. (1975), pp.355, 507-508].

[10] Poor, illiterate mothers tend to dilute powdered milk preparations with too much water (in order to save on expensive dry milk preparations); accordingly, the infant receives insufficient energy and protein at each feeding. In unsanitary conditions, feeding bottles become readily contaminated with diarrhoea – causing bacteria, while the bacteria-killing substances found in breast milk are not available to bottle-fed children [Stanfield and Jelliffe (1974), pp.37-38].

Whereas breast milk alone is sufficient during the first four to six months of life, solid foods must be added to an infant's diet from about six months onward. Unfortunately, solid foods tend to be added at a much later age in many low-income settings. Under these conditions, the age at which solid foods are given (SD) should be inversely related to the child's nutritional status ($b_{1\ 11} < 0$).

Neither BF nor SD is assumed to have any direct effect on the incidence of disease (i.e., $b_{2\ 10}$, $b_{2\ 11}$, $b_{3\ 10}$, $b_{3\ 11}$ = 0). It has, however, been emphasized in the health literature that the weaning period (i.e., the period during which solid foods are added and breastfeeding is stopped) is a particularly dangerous period from the stand point of illness. According to Stanfield and Jelliffe [(1974), p.42], the child "will not only be in danger of malnutrition, but will also have lost the immunity obtained from the mother and be liable to severe, repeated infections." Accordingly, it is hypothesized that WN is positively related to both DD and DR (i.e., $b_{2\ 12}$, $b_{3\ 12} > 0$) but that there is no direct relationship between WN and the child's nutritional status (i.e., $b_{1\ 12} = 0$).

Immunization (IM) is assumed to affect the incidence of respiratory illness (particularly whooping cough and tuberculosis) but not diarrhoea (since most forms of diarrhoea cannot be immunized against); nor is immunization assumed to have any direct effect on the child's nutritional status (i.e., $b_{3\ 13} < 0$; $b_{1\ 13}$, $b_{2\ 13} = 0$). On the other hand, roundworm infection (WM), which does not generally produce either diarrhoea or respiratory illness (i.e., $b_{2\ 14}$, $b_{3\ 14}$ = 0), is assumed to affect the child's nutritional status adversely (i.e., $b_{1\ 14} < 0$).[11]

The last set of exogenous variables to be considered are those referring to housing conditions and to the method of refuse disposal. The number of rooms per family member (RM) indicates to what extent living conditions are crowded; RM is assumed to be inversely related to both DD and DR (i.e., $b_{2\ 15}$, $b_{3\ 15} < 0$). The availability of a private water tap (WA) implies that more water is available for cleaning and bathing purposes. Since diarrhoeal disease tends to be transmitted by contaminated fecal matter while most respiratory diseases are transmitted by airborne droplets, WA is assumed to be negatively related to DD (i.e., $b_{2\ 16} < 0$), but not to DR (i.e., $b_{3\ 16} = 0$). Similarly, the availability of a flush toilet (TL) and the disposal of refuse other than by throwing it into the street (RF) suggest the presence of less contaminated soil and fewer flies in the vicinity of the family's

[11] According to Jelliffe and Musoke [(1974), p.65], "in *very heavy* infections with up to hundreds of (round) worms, these large parasites become dangerous nutritionally, especially in poorly-fed, rapidly growing young children, as they use up a considerable portion of the food taken in by the child." Roundworm infection is treated as an *exogenous* disease variable in the present model since there is no basis for expecting that a child's susceptibility to infection with roundworms is related to his (her) nutritional status.

dwelling. For this reason, both TL and RF are assumed to be negatively related to DD (i.e., $b_{2\ 17}, b_{2\ 18} < 0$), but not to DR (i.e., $b_{3\ 17}, b_{3\ 18} = 0$). None of the housing variables is hypothesized to have any direct effect on the child's nutritional status (i.e., $b_{1\ 15}, \ldots, b_{1\ 18} = 0$).

Much of the preceding discussion can be effectively summarized by writing out the full model in equation form, as follows:

$$\begin{aligned} N = {} & c_{1\ 2}DD + c_{1\ 3}DR + b_{1\ 1}CT + b_{1\ 2}AC + b_{1\ 3}SX + b_{1\ 4}EH + \\ & b_{1\ 5}EW + b_{1\ 6}FD + b_{1\ 7}DI + b_{1\ 8}VI + b_{1\ 9}PS + \\ & b_{1\ 10}BF + b_{1\ 11}SD + b_{1\ 14}WM + u_1 \end{aligned} \tag{1}$$

$$\begin{aligned} DD = {} & c_{2\ 1}N + c_{2\ 3}DR + b_{2\ 1}CT + b_{2\ 4}EH + b_{2\ 5}EW + b_{2\ 12}WN + \\ & b_{2\ 15}RM + b_{2\ 16}WA + b_{2\ 17}TL + b_{2\ 18}RF + u_2 \end{aligned} \tag{2}$$

$$\begin{aligned} DR = {} & c_{3\ 1}N + c_{3\ 2}DD + b_{3\ 1}CT + b_{3\ 4}EH + b_{3\ 5}EW + \\ & b_{3\ 12}WN + b_{3\ 13}IM + b_{3\ 15}RM + u_3 \end{aligned} \tag{3}$$

where N refers to one of the three alternative nutrition measures (NA, NW, NH) and u is a random disturbance term.

Before proceeding to the estimation of the above model (section IV), section III briefly discusses the data set used in the present study and provides some descriptive evidence on the extent to which disease and malnutrition are correlated.

III. The Data

The data which are used to estimate the model described in the preceding section are drawn from a survey of 736 low-income households, conducted by Dr. R.J. Rahimtoola and her associates in the Department of Paediatrics, Jinnah Postgraduate Medical Centre, (JPMC) Karachi. The survey was carried out, between August 1976 and June 1977, as a baseline survey for the Childrens' Nutrition Project, in Mahmoodabad Colony, a low-income residential area of Karachi. According to Dr. Rahimtoola and her associates (1977), the survey site is a "slum area" marked by "unhealthy living conditions.":

> The houses are adjoining one another with no space in between. A row of eight to ten houses have a small space of about six feet at the back and front where another row of houses are present. The lanes have filthy water and rubbish thrown by the residents as they have

> no proper sanitation or refuse disposal system. Most of the houses have one room approximately 8' x 12' in size and a small courtyard 6' x 8' where cooking is done. . . . Some houses have a large open courtyard, about 10' x 12', where goats and fowl are kept. The children play in the courtyard and as conditions are unsanitary due to the animals, they have repeated infections. . . . Half the houses are dirty inside partly due to the carelessness of the families and partly due to lack of proper water supply and toilet facilities.

The sample was selected on a quota basis from the proximity of a dispensary operated by the Karachi Metropolitan Corporation (KMC). The KMC dispensary served as the project's field office. Research assistants visited the homes of the families to collect some of the data, while clinical examinations of the children were conducted at the KMC dispensary by members of the (JPMC) team.

The data available in the survey include basic information on family members (i.e., age, sex, education) and family size, monthly income and expenditure data (for food and medical care only), and certain housing characteristics (i.e., number of rooms in the family's dwelling, source of water supply, type of toilet facility, and method of refuse disposal). A variety of demographic data were also collected in the survey. These include the wife's fertility record (i.e., number of pregnancies, live births, abortions, miscarriages and stillbirths, the average interval between births, and the number of neo-natal, infant and pre-school deaths), information on the wife's diet during pregnancy (i.e., types of foods added, whether vitamin and/or mineral supplements taken), and the type of ante-natal, post-natal, and delivery care utilized (i.e., private physician, public hospital, MCH clinic, traditional *dai*).

In addition to the above, certain data were collected for all children under five years of age. These include data on the types of foods given as well as information on the length of breastfeeding (including reasons for its cessation) and the age at which solid foods were first given. The data on pre-school children also include information on past illness (i.e., the number of spells of diarrhoea and respiratory illness and whether the mother has observed roundworms in the child's stools). A variety of anthropometric measurements were also recorded for pre-school children, including the child's current height, weight, mid-arm circumference, chest size, and head size, together with the child's age and sex. The clinical examinations, which were also limited to children under five, yielded information on the condition of hair, eyes, skin, and various other parts of the body, as well as a clinical assessment of the child's general level of physical and mental development. Lastly, a number of laboratory examinations (i.e., haemoglobin, stool exam, blood test for malaria) were carried out for children under five.[12]

The survey data clearly indicate that most of the families in the sample live in conditions of poverty. Income is low (83 per cent of the families reported monthly incomes of less than 500 Rupees), illiteracy is high (42.7 per cent among husbands and 81.6 per cent among wives), average family size is also high (6.6 persons), housing conditions are poor (62.1 per cent of the families live in one-room houses), water is not freely available (91.7 per cent of the families rely on community taps), toilet facilities are primitive (89.1 per cent are private pit latrines), and sanitary conditions are conducive to the spread of disease (61.6 per cent of the families dispose of refuse by throwing it into the street).

The poor condition of the families in the sample is also reflected in the nutritional status of the pre-school children (Table 1). Overall, only 27.6 per cent of the children exhibit normal weight in relation to age (i.e., equal to 90 per cent or more of the Harvard standard). The rest of the children exhibit varying degrees of malnutrition. Almost one-third of the children suffer from second and third degree malnutrition (i.e., weight less than 75 per cent of standard weight-for-age).

TABLE 1

Nutrition status by age (percentages)

Nutrition Status (weight-for-age)	Ages (months)					Total Sample
	0–11	12–23	24–35	36–47	48–60	
Normal (90% or more of standard)	63.2	23.1	16.8	14.6	13.9	27.6
First Degree (75-90% of standard)	26.0	39.2	50.3	44.9	42.8	40.1
Second Degree (60-75% of standard)	9.1	25.8	25.9	34.8	41.3	27.0
Third Degree (60% or less of standard)	1.7	11.8	7.0	5.6	1.9	5.4
Total	100.0	100.0	100.0	100.0	100.0	100.0
N	231	186	185	198	208	1008

Source: Jinnah Department of Paediatrics Nutrition Survey.

12 Unfortunately, due to the unusually heavy rains which buffeted Karachi at the end of June 1977, and which left many areas inundated, stool examinations were carried out for only about half of the sample, while very few malaria tests were actually performed.

As one would expect *a priori*, the incidence of malnutrition varies significantly with the age of the child. The proportion normal declines monotonically with age, being dramatically lower among children in their second year (23.1 per cent) and reaching a minimum (13.9 per cent) among children in their fifth year. At the other extreme, the proportion of children with third degree malnutrition, (i.e., weight less than 60 per cent of standard weight-for-age) is lowest among children in their first year (1.7 per cent), is at its highest level (11.8 per cent) among children in their second year, and declines monotonically with age from that point. One can in fact discern a clear tendency for the distribution itself to narrow as children become older. Thus, the two tails of the distribution (i.e., the proportion normal and the proportion with third degree malnutrition) comprise 64.9 per cent of the children under one year of age, but their share in the overall distribution declines monotonically with age, reaching a low (15.8 per cent) among children between the ages of four and five years.

Mothers reported that their children experienced an average of 2.05 spells of diarrhoea and 1.75 spells of respiratory illness during the six months preceding the date of interview (Table 2).[13] The disease data also exhibit an interesting pattern in relation to the age of the child. The incidence of both types of illness is significantly lower among children in their first and fifth years of life. The data are thus consistent with the view that the incidence of disease increases during the weaning period, then diminishes, as the child develops his (her) immunity.

TABLE 2

Number of spells of diarrhoea and respiratory illness in the past six months by age (means and standard deviations)

Type of Illness	Ages (months)					Total Sample
	0–11	12–23	24–35	36–47	48–60	
Diarrhoea	1.40 (1.91)	2.39 (1.88)	2.57 (1.81)	2.50 (1.92)	1.60 (1.42)	2.05 (1.86)
Respiratory	1.17 (1.56)	2.00 (1.65)	1.91 (1.52)	2.04 (1.51)	1.74 (1.48)	1.75 (1.58)
N	233	186	187	198	208	1012

Source: Jinnah Department of Paediatrics Nutrition Survey.

[13] The responses refer only to spells of illness "for which treatment was sought".

A clear relationship is evident between the reported incidence of disease among children in the survey and their nutrition status (Table 3). Thus, the incidence of both diarrhoea and respiratory illness increases monotonically with the degree of malnutrition in the child and is

TABLE 3

Number of spells of diarrhoea and respiratory illness in the past six months by nutrition status (means and standard deviations)

Type of Illness	Nutrition Status				Total Sample
	Normal	I-Degree	II-Degree	III-Degree	
Diarrhoea	1.75 (2.05)	1.98 (1.65)	2.38 (1.91)	2.54 (1.84)	2.06 (1.86)
Respiratory	1.36 (1.53)	1.78 (1.57)	2.01 (1.55)	2.22 (1.65)	1.75 (1.58)
N	278	404	272	54	1008

Source: Jinnah Department of Paediatrics Nutrition Survey.

between 30 to 40 per cent higher in children with third degree malnutrition as compared to normal children. The data in Table 3 are therefore highly suggestive of the presence of significant interactions between malnutrition and disease. However, the observed relationship may be due to other factors, and for this reason, as well as to investigate the direction of causality, it is necessary to carry out a multivariate analysis.

IV. Estimation Results

The model discussed in section II was estimated with data from the Jinnah Department of Paediatrics Survey. For estimation purposes, the sample was limited to children between the ages of one and five years. This reduced the sample size from 1012 to 779 children. Children under one year of age were excluded from the estimation sample for two reasons. First, the disease variables (DD, DR) refer to spells of illness in the *preceding six months,* and children under six months of age at the time of the survey would not have had a full six months of exposure (i.e., the distribution would be truncated). Second, as shown by the data in Tables 1 and 2, the problems of disease and malnutrition do not really begin to take on serious dimensions until the second year of life.

In addition to the observations lost by eliminating children under one year of age from the estimation sample, 126 additional observations were excluded due to missing data on one or more of the independent variables. Most of these observations were lost due to missing data on BF. In cases where a child was still breastfeeding, the average length of breastfeeding for siblings under five (if present) was substituted for the child's own length of breastfeeding.[14] This procedure eliminated what otherwise would have been a built-in relationship between BF and AC, while making it possible to include a large number of children in the estimation sample who were still breastfeeding. Unfortunately, since the data of infant feeding practices were recorded only for children under five, there were a number of cases for which sibling data were unavailable.

Table 4 lists the means and standard deviations of the variables for the estimation sample (N = 653). For the reader's convenience, the symbols and definitions of the variables are also listed in Table 4. The matrix of zero-order correlation coefficients for all variables is provided in Appendix A.

TABLE 4

Variable means and standard deviations
(N = 653)

Symbol		Definition	Mean	Standard Deviation
NA	=	Mid-arm circumference (cm.).	13.50	1.31
NW	=	Weight-for-age (per cent of Harvard standard).	74.00	11.80
NH	=	Haemoglobin level (grams per 100 ml).	8.24	1.29
DD	=	Diarrhoea (number of spells in past 6 months).	2.25	1.79
DR	=	Respiratory illness (same as above).	1.90	1.54
CT	=	Constant term (= one).	1.00	0.00
AC	=	Child's age (months).	34.40	13.80
SX	=	Child's sex (one if male, zero if female).	0.51	0.50
EH	=	Father's education (one if literate or primary).	0.57	0.49
EW	=	Mother's education (same as above).	0.21	0.41
FD	=	Food expenditures per adult equivalent (Rs./week).	16.90	4.98
DI	=	Diet changes during pregnancy (one if yes).	0.35	0.48
VI	=	Vitamins/minerals during pregnancy (one if yes).	0.17	0.37
PS	=	Ratio of parity to average birth interval.	1.97	1.49
BF	=	Length of breastfeeding (months).	17.00	7.65
SD	=	Age at which solid foods given (months).	14.50	5.84
WN	=	Weaning period (one if weaned during past 6 months).	0.12	0.32
IM	=	Immunization (one if child immunized).	0.33	0.47
WM	=	Roundworms (one if observed by mother).	0.29	0.45
RM	=	Number of rooms per family member.	0.23	0.14
WA	=	Water supply (one if private water tap).	0.05	0.22
TL	=	Toilet (one if flush toilet).	0.07	0.26
RF	=	Refuse disposal (one if does not throw in street).	0.39	0.49

Source: Jinnah Department of Paediatrics Survey.

[14] A similar procedure was followed in the case of children who had not yet been given solid foods at the time of the survey.

Three alternative estimation techniques were utilized: ordinary least squares (OLS), two-stage least squares (2-SLS), and three-stage least squares (3-SLS).[15] The OLS estimates, which are *biased* and *inconsistent* in simultaneous equations models, are used for purposes of comparison, since consistently large differences between them and the 2-SLS and 3-SLS estimates can be taken as evidence of simultaneity. Both the 2-SLS and 3-SLS estimates, though biased in "small" samples, are nevertheless consistent.[16] Since 653 observations can almost surely be considered a "large" sample, the degree of bias in the 2-SLS and 3-SLS estimators should be small. In addition, the 3-SLS estimates have the property of asymptotic efficiency, whereas the 2-SLS estimates do not have this property.[17]

The estimation results are reported in Tables 5, 6 and 7 for the three alternative measures of nutritional status. Even a quick glance at the results is suggestive of several conclusions. First, as is often the case with micro data, the R^2's are quite low, ranging from a high of 0.32 (mid-arm circumference) to a low of 0.07 (haemoglobin). Second, most of the statistically significant coefficients involve relationships between the endogenous variables rather than between the endogenous and exogenous variables. In fact, 33 out of 54 possible coefficients involving the three endogenous variables are statistically significant at the 0.10 level or higher, while only 26 of a possible 207 coefficients involving relationships between the endogenous and exogenous variables (excluding the constant term) are statistically significant at the sample level.

Third, the OLS estimates are quite different from the 2-SLS and 3-SLS estimates, particularly with respect to the endogenous variables. The results suggest, therefore, that the use of consistent estimation techniques does make a difference. To cite one example, the OLS estimates imply (with the exception of haemoglobin) that there is two-way causality between malnutrition and disease (i.e., malnutrition leads to a higher incidence of disease while a higher incidence of disease increases the extent of malnutrition). Both the 2-SLS, and 3-SLS estimates suggest, on the other hand, that causality runs in only one direction, from malnutrition to disease, and not vice versa. Although the latter results are surprising, given the strong theo-

15 For a description of 2-SLS and 3-SLS estimates, consult Goldberger [(1964), pp.329-352].

16 *A consistent estimator* is one which may be biased in small samples but whose bias disappears as the sample size increases (i.e., asymptotically unbiased) and whose variance approaches zero as the sample size approaches infinity (i.e., the distribution collapses on the true value of the unknown parameter). See Goldberger [(1964), pp.125-130] for a fuller discussion of the properties of estimators.

17 An *efficient estimator* is one whose variance is smaller than that of any other estimator no matter what the sample size. An *asymptotically efficient* estimator is one which has the property of efficiency when the sample size is very large.

TABLE 5

Regression results — mid-arm circumference (NA)
(t ratios in parentheses)

Equation	NA			DD			DR		
Estimation Method	OLS	2-SLS	3-SLS	OLS	2-SLS	3-SLS	OLS	2-SLS	3-SLS
NA	–	–	–	–0.174 (3.31)**	–0.352 (3.07)**	–0.292 (2.76)**	–0.142 (3.13)**	0.233 (1.19)**	0.290 (1.78)*
DA	–0.049 (1.93)*	–0.593 (0.90)	–0.807 (1.50)	–	–	–	0.235 (7.20)**	0.858 (2.70)**	0.988 (4.18)**
DR	–0.096 (3.24)**	–0.213 (0.17)	0.083 (0.08)	0.313 (7.15)**	0.524 (2.03)**	0.919 (5.82)**	–	–	–
CT	11.800 (44.50)**	13.300 (19.70)**	13.400 (21.20)**	4.280 (5.84)**	6.240 (3.44)**	4.630 (2.98)**	3.060 (4.50)**	–3.440 (1.04)	–4.460 (1.67)*
AC	0.047 (14.40)**	0.033 (4.96)**	0.031 (4.92)**	–	–	–	–	–	–
SX	0.271 (3.14)**	0.193 (1.38)	0.172 (1.92)*	–	–	–	–	–	–
EH	0.027 (0.29)	0.073 (0.29)	0.022 (0.10)	–0.036 (0.25)	–0.063 (0.42)	–0.141 (0.96)	0.198 (1.64)*	0.164 (1.07)	0.158 (1.03)
EW	0.113 (1.01)	0.062 (0.32)	0.030 (0.17)	0.048 (0.27)	0.009 (0.05)	–0.073 (0.41)	0.096 (0.64)	0.109 (0.58)	0.108 (0.58)
FD	0.008 (0.89)	0.023 (0.90)	0.018 (0.93)	–	–	–	–	–	–
DI	0.171 (1.71)*	0.081 (0.57)	0.082 (1.01)	–	–	–	–	–	–

VI	0.081 (0.65)	−0.081 (0.42)	−0.036 (0.30)	–	–	–	–	–	–
PS	−0.013 (0.44)	0.012 (0.20)	0.013 (0.32)	–	–	–	–	–	–
BF	0.011 (1.92)*	0.012 (0.46)	0.013 (0.66)	–	–	–	–	–	–
SD	−0.009 (1.23)	0.0006 (0.04)	−0.0005 (0.06)	–	–	–	–	–	–
WN	–	–	–	−0.026 (0.13)	−0.146 (0.67)	0.007 (0.04)	−0.040 (0.22)	0.105 (0.43)	0.044 (0.20)
IM	–	–	–	–	–	–	0.086 (0.69)	0.069 (0.42)	0.033 (0.47)
WM	−0.044 (0.46)	0.088 (0.35)	0.063 (0.34)	–	–	–	–	–	–
RM	–	–	–	−0.474 (0.96)	−0.338 (0.66)	−0.250 (0.63)	−0.068 (0.16)	0.187 (0.34)	0.252 (0.50)
WA	–	–	–	−0.412 (1.07)	−0.297 (0.74)	−0.046 (0.35)	–	–	–
TL	–	–	–	0.170 (0.53)	0.158 (0.47)	−0.036 (0.38)	–	–	–
RF	–	–	–	−0.358 (2.51)**	−0.240 (1.56)	−0.051 (0.70)	–	–	–
N	653	653	653	653	653	653	653	653	653
R2	0.32	–	–	0.12	–	–	0.11	–	–

** Statistically significant at the 0.05 level.
* Statistically significant at the 0.10 level.

TABLE 6

Regression results – weight for age (NW)
(t ratio in parentheses)

Equation	NA			DD			DR		
Estimation Method	OLS	2-SLS	3-SLS	OLS	2-SLS	3-SLS	OLS	2-SLS	3-SLS
NW	–	–	–	–0.012 (2.07)**	–0.047 (1.93)*	–0.031 (1.44)	–0.010 (2.08)**	0.009 (0.37)	0.017 (0.82)
DD	–0.444 (1.66)*	–3.020 (0.30)	0.481 (0.07)	–	–	–	0.246 (7.58)**	0.590 (2.94)**	0.777 (5.28)**
DR	–0.612 (1.98)**	–6.650 (0.50)	–10.400 (0.81)	0.327 (7.50)**	0.678 (2.54)**	1.150 (6.44)**	–	–	–
CT	71.300 (25.80)**	82.400 (11.90)**	81.500 (13.30)**	2.790 (6.13)*	4.640 (2.30)**	2.55 (1.49)	1.81 (4.23)**	–0.273 (0.13)	–1.190 (0.69)
AC	0.082 (2.41)**	–0.023 (0.33)	0.004 (0.06)	–	–	–	–	–	–
SX	4.090 (4.54)**	3.230 (2.24)**	2.860 (2.29)**	–	–	–	–	–	–
EH	0.953 (0.99)	2.180 (0.83)	2.800 (1.09)	–0.040 (0.28)	–0.076 (0.46)	–0.166 (1.05)	0.200 (1.65)*	0.174 (1.30)	0.160 (1.20)
EW	0.970 (0.83)	1.050 (0.53)	1.460 (0.74)	0.052 (0.29)	–0.011 (0.06)	–0.078 (0.41)	0.096 (0.65)	0.101 (0.62)	0.098 (0.61)
FD	–0.075 (0.78)	0.124 (0.47)	0.125 (0.52)	–	–	–	–	–	–
DI	2.100 (2.02)**	1.360 (0.93)	1.350 (1.53)	–	–	–	–	–	–

VI	−0.755 (0.58)	−1.710 (0.87)	−1.050 (0.86)	–	–	–	–	–	–
PS	−0.587 (1.87)*	−0.224 (0.36)	−0.136 (0.26)	–	–	–	–	–	–
BF	0.123 (2.04)**	0.227 (0.86)	0.268 (1.06)	–	–	–	–	–	–
SD	−0.075 (0.97)	0.020 (0.14)	0.022 (0.23)	–	–	–	–	–	–
WN	–	–	–	0.080 (0.39)	0.071 (0.31)	0.029 (0.13)	0.044 (0.24)	−0.002 (0.01)	−0.047 (0.25)
IM	–	–	–	–	–	–	0.132 (1.06)	0.056 (0.40)	−0.041 (0.59)
WM	0.122 (0.12)	1.950 (0.76)	2.100 (0.92)	–	–	–	–	–	–
RM	–	–	–	−0.503 (1.01)	−0.283 (0.52)	−0.161 (0.30)	−0.101 (0.24)	0.077 (0.16)	0.138 (0.31)
WA	–	–	–	−0.387 (1.00)	−0.062 (0.14)	−0.311 (1.80)**	–	–	–
TL	–	–	–	0.156 (0.48)	0.124 (0.35)	−0.016 (0.15)	–	–	–
RF	–	–	–	−0.416 (2.93)**	−0.306 (1.90)**	0.022 (0.25)	–	–	–
N	653	653	653	653	653	653	653	653	653
R2	0.09	–	–	0.12	–	–	0.10	–	–

** Statistically significant at the 0.05 level.
* Statistically significant at the 0.10 level.

TABLE 7

Regression results – haemoglobin level (NH)
(t ratios in parentheses)

Equation	NA			DD			DR		
Estimation Method	OLS	2-SLS	3-SLS	OLS	2-SLS	3-SLS	OLS	2-SLS	3-SLS
NY	–	–	–	–0.040 (0.76)	–0.618 (2.43)**	–0.542 (2.46)**	–0.030 (0.67)	0.307 (1.02)	0.469 (1.86)*
DD	–0.007 (0.24)	–0.361 (0.52)	–0.556 (0.87)	–	–	–	0.253 (7.81)**	0.747 (2.88)**	0.925 (5.16)**
DR	–0.020 (0.59)	–0.408 (0.30)	–0.054 (0.04)	0.336 (7.72)**	0.630 (2.30)**	1.050 (6.19)	–	–	–
CT	7.980 (26.10)**	9.330 (13.00)**	9.250 (13.70)**	2.250 (4.92)**	6.310 (2.75)**	4.840 (2.55)**	1.290 (3.01)**	–2.490 (0.86)	–4.130 (1.78)*
AC	0.014 (3.82)**	0.002 (0.29)	0.003 (0.42)	–	–	–	–	–	–
SX	0.019 (0.19)	–0.066 (0.45)	–0.040 (0.43)	–	–	–	–	–	–
EH	0.028 (0.26)	0.118 (0.43)	0.058 (0.23)	–0.049 (0.35)	–0.074 (0.44)	–0.144 (0.88)	0.193 (1.59)	0.161 (1.09)	0.144 (0.99)
EW	0.036 (0.28)	0.016 (0.76)	–0.016 (0.08)	0.054 (0.30)	–0.050 (0.24)	–0.096 (0.49)	0.092 (0.62)	0.109 (0.61)	0.106 (0.60)
FD	0.0006 (0.06)	0.019 (0.69)	0.012 (0.54)	–	–	–	–	–	–
DI	–0.026 (0.22)	–0.111 (0.74)	–0.077 (0.97)	–	–	–	–	–	–

VI	0.294 (2.06)**	0.163 (0.80)	0.145 (1.19)	–	–	–	–	–	–
PS	–0.091 (2.63)**	–0.059 (0.92)	–0.051 (1.05)	–	–	–	–	–	–
BF	0.016 (2.44)**	0.022 (0.81)	0.017 (0.72)	–	–	–	–	–	–
SD	–0.024 (2.75)**	–0.014 (1.02)	–0.013 (1.22)	–	–	–	–	–	–
WN	–	–	–	0.075 (0.36)	0.071 (0.30)	–0.009 (0.04)	0.039 (0.22)	–0.023 (0.11)	–0.026 (0.12)
IM	–	–	–	–	–	–	0.138 (1.11)	0.047 (0.30)	–0.028 (0.42)
WM	–0.040 (0.35)	0.126 (0.47)	0.096 (0.45)	–	–	–	–	–	–
RM	–	–	–	–0.521 (1.04)	–0.122 (0.21)	–0.028 (0.06)	–0.134 (0.32)	0.004 (0.01)	0.051 (0.99)
WA	–	–	–	–0.435 (1.12)	0.048 (0.10)	–0.169 (1.21)	–	–	–
TL	–	–	–	0.151 (0.46)	0.133 (0.36)	0.049 (0.57)	–	–	–
RF	–	–	–	–0.419 (2.94)**	–0.256 (1.51)	0.045 (0.59)	–	–	–
N	653	653	653	653	653	653	653	653	653
R2	0.07	–	–	0.11	–	–	0.10	–	–

** Statistically significant at the 0.05 level.
* Statistically significant at the 0.10 level.

retical reasons for expecting a strong effect of disease on malnutrition and a weak effect in the reverse direction (see the theoretical discussion in section II), the consistent results for two alternative measures of malnutrition and for the two theoretically more appropriate estimation techniques suggest that the commonly accepted interpretation of the high correlation between disease and malnutrition may not be correct.[18]

Fourth, there is a great deal of consistency in the results for all three measures of malnutrition and, in some cases, the consistency extends to all three estimation techniques. Perhaps the most surprising example is that of family food expenditures (FD). FD is statistically insignificant in all regressions. Although its estimated coefficient is positive in 8 out of 9 cases, its t-statistic is never greater than unity. These results may be due to a hierarchical distribution of food within the family such that the needs of preschool children are satisfied only after those of adults and older children are satisfied.

Another set of consistent, yet surprising, results are obtained with respect to the education variables (EH, EW). *A priori* expectations were that both education variables would be positively related to children's nutrition status, and negatively related to disease. In fact, neither education variable is statistically significant as a determinant of any of the endogenous variables. Although positive in 17 out of 18 cases, the estimated coefficients of EH and EW are statistically insignificant in all of the nutrition equations. Similarly, while negative in most of the equations with DD as the dependent variable, the education coefficients are never statistically significant. In the case of DR, they consistently exhibit the wrong sign (positive); and in two cases (both OLS-estimated equations), the coefficient of EH is even statistically significant at the 0.10 level. These unexpected results may be due in part to the fact that the dependent variable refers only to spells of respiratory illness "for which treatment was sought." It may be the case that only relatively well-off parents seek medical treatment for their children's common respiratory illnesses and that husband's education is in this case proxying for household income.

Some of the more interesting estimation results are of a more specific nature. Thus, for example, the OLS estimates imply that both infant feeding practices and the mother's own nutrition status are important determinants of their children's nutrition status. Although the statistical significance of some of these relationships may be due to the biased character of the OLS estimates, in most cases the OLS estimates do not differ much from the 2-SLS and 3-SLS estimates, and it is the larger standard

18 The 2-SLS and 3-SLS results imply that the model is *recursive* rather than *simultaneous*. However, OLS estimators remain inconsistent in such a model as long as the disturbance terms (u_1, u_2, u_3) are correlated between equations [Theil (1971), pp.460-461].

errors associated with the latter two sets of estimates which are responsible for their lack of statistical significance. For this reason, the OLS results probably merit some discussion.

For example, length of breastfeeding (BF) is positively and significantly related to all three nutrition measures. These results tend to confirm the nutritionists' view that prolonged breastfeeding provides a useful supplementary source of nutrients. In the regression with weight-for-age as the dependent variable, the coefficient of BF suggests that an additional year of breastfeeding increases a child's weight in relation to his (her) standard weight-for-age by about 1.5 percentage points (or by about 3 percentage points if one accepts the statistically less significant 2-SLS and 3-SLS estimates).[19]

The age at which solid foods are first given to the child (SD) is inversely related, as expected, to all three nutrition measures and is statistically significant in the regression with the haemoglobin level (NH) as the dependent variable. The closer relationship between SD and NH is not surprising, since breastmilk is a poor source of iron and it is only after an infant is started on solid foods that his (her) iron stores begin to increase.

Diet changes during pregnancy (DI) are positively and significantly related to two of the three measures of nutritional status (mid-arm circumference and weight-for-age), although the magnitudes of the 2-SLS and 3-SLS estimates are only about half as large as those of the OLS estimates. The third nutrition measure (haemoglobin) is positively and significantly related to the taking of vitamin and mineral supplements by the mother during pregnancy (VI). The significant relationship between NH and VI is not surprising since the mother's and hence the infant's haemoglobin level should be closely related to the taking of vitamin and mineral supplements during pregnancy. Still, it is possible that the variables DI and VI may be a proxy for some other unobserved variable (e.g., "general nutritional awareness").

The last of the variables referring to the mother's nutritional status, the parity spacing ratio (PS), is inversely related, as expected, to all three nutrition measures and is statistically significant in two cases (NW, NH). The fact that PS is most strongly related to the haemoglobin level (NH) is not surprising, since it is typically the woman's stores of iron which are most seriously depleted by repeated, closely-spaced births under conditions of marginal nutrition. The magnitude of the coefficient suggests that after having given birth eight times in the space of sixteen years (i.e., PS = 4.0), the haemoglobin level of an additional child would be on average about 0.4

[19] A quadratic term in length of breastfeeding was included in the regressions (unreported) but was found to be statistically insignificant.

lower (compared to a sample mean of 8.2) than that of the first child, *ceteris paribus.*

As mentioned above, the OLS results indicate that there is two-way causality between disease and malnutrition, whereas the 2-SLS and 3-SLS results indicate that there is only one direction of causality, running from malnutrition to disease. In addition, all of the results point to a strong two-way relationship between the incidence of diarrhoea and that of respiratory illness. For example, the 3-SLS estimates in Table 5 indicate that an additional spell of diarrhoea gives rise to an additional spell of respiratory illness, and vice versa. It is not altogether clear why there should be such a strong association between these two forms of illness.

Another difference between the OLS results, on the one hand, and the 2-SLS and 3-SLS results, on the other hand, occurs with respect to the effect of nutrition status (however measured) on the incidence of respiratory illness. The OLS results imply, as expected, that malnutrition increases the incidence of respiratory illness (significantly, in the case of NA and NW), while both the 2-SLS and 3-SLS results imply an inverse relationship between these same variables (also significant, in the case of the 3-SLS estimates with NA and NH). It is difficult to explain the latter results. One possibility may be that respiratory illness is so often fatal among malnourished children that only relatively well-nourished children could present a history of repeated bouts of respiratory illness (i.e., a problem of sample truncation). In any case, this possibility points to the kinds of problems which may arise with retrospective studies limited to surviving children.

The results with respect to the child's sex (SX) are of some interest. SX is statistically significant (positive) in all but one of the regressions with NA and NW as the dependent variables. This is as expected since the Harvard standards indicate that male children tend to be larger than female children. Also, as expected, no significant difference between males and females is observed in the case of haemoglobin (NH). The results suggest, therefore, that males are not systematically favoured over females in terms of their access to foods rich in iron (i.e., principally solid foods).

Finally, in addition to FD, EH, and EW (which were discussed above), several variables which were included in the model out of theoretical considerations are statistically insignificant in most, and in some cases all, regressions in which they are specified. These include the binary variables indicating whether the child was weaned during the preceding six months (WN), whether the child has been immunized (IM), and whether the mother has observed roundworms in the child's stools (WM). The results with respect to the weaning variable are perhaps most difficult to explain, given the clear pattern in the descriptive data (Table 2) indicating a steep increase in the incidence of both types of illness between the ages of one and four years.

Perhaps most of the effect of this variable is lost when children under one year of age are excluded from the estimation sample. The insignificance of the immunization variable (IM) is not difficult to explain, since most of the recorded immunizations were for smallpox, a disease no longer endemic (and which in any case is not marked by either diarrhoea or respiratory illness).

With the exception of the variable referring to the method used by the family to dispose of refuse (RF), the housing variables are consistently insignificant as determinants of disease. This is somewhat surprising since it implies that crowded and unsanitary living conditions do not significantly increase the reported incidence of disease. In the case of WA and TL, part of the problem may be purely statistical in nature – the relatively low proportions of the sample households with either a private water tap or a flush toilet (0.07 and 0.05, respectively) and the fairly high correlation between WA and TL ($r = 0.58$). The fact that RF is statistically significant, at least in the OLS estimated regressions, is all the more interesting because the same variable was found to be statistically significant as a determinant of infant and pre-school mortality in a study utilizing the same data set [Knowles, (1979)]. Still, it is a bit puzzling why the refuse disposal practices of only one household would have a significant effect on health. (What about the refuse disposal practices of one's neighbours?) Although the relationship undoubtedly warrants additional research, it is more likely that RF is a proxy for some unobserved determinant of disease.

V. Summary and Conclusions

This paper is concerned with the interactions between malnutrition and disease among pre-school children. It has tried to determine whether a high incidence of disease contributes to malnutrition and whether malnutrition in turn tends to foster a higher incidence of disease. The main purpose of the study is to determine to what extent health and nutrition policies can be mutually reinforcing or, conversely, the chances for one type of policy to succeed in isolation of the other.

The paper utilizes cross-section data from one low-income area of Karachi to estimate a simultaneous equations model with three endogenous variables: two disease variables (i.e., number of spells of diarrhoea and respiratory illness) and one of three alternative nutrition measures (i.e., mid-arm circumference, weight-for-age, and the haemoglobin level). The exogenous variables in the model include the child's age and sex, the education of both parents, family food expenditures per equivalent adult, the length of breastfeeding, the age at which solid foods are given, the ratio of the child's parity to the mother's average birth interval (a measure of the mother's nutrition status), two binary variables referring to the mother's diet during pregnancy (whether special foods are added and whether vitamins or minerals are taken), binary variables referring to whether the child was weaned in the preceding six months, whether it has been immunized, and whether the mother has observed roundworms in his stools, and, finally, a set of housing-related variables (the number of rooms per family member, whether a private water tap and flush toilet are available, and whether the family disposes of its refuse other than by throwing it into the street).

The results of the study indicate that there is a strong positive correlation between disease and malnutrition but that the direction of the relationship is one-way rather than two-way (i.e., from malnutrition to disease rather than vice-versa). The study also finds that diarrhoea and respiratory illnessess are mutually reinforcing: the incidence of either type of illness tends to increase *pari passu* with the other type. The study finds, surprisingly, that the level of family food expenditures does not affect the nutritional status of pre-school children and that the education of neither parent is a significant determinant of either the child's nutrition status or the incidence of disease. On the other hand, the study does encounter fairly strong evidence pointing to the importance of infant feeding practices and the mother's own nutritional status as determinants of the child's nutritional status. The study encounters no evidence suggesting that male children are better nourished than female children. Finally, several variables, in addition to food expenditures and parent's education, are consistently insignificant as determinants of both nutrition status and disease. These include variables referring to whether the child was recently weaned, whether it has been immunized, whether roundworms were observed, and most of the housing-related variables (the sole exception being the method of refuse disposal, which was significantly related to the incidence of diarrhoea).

If accepted at face value, the present study's findings suggest that the outcome of nutrition programs is more or less independent of progress made in other health programs (i.e., disease control, immunization). However, this conclusion is so contrary to the generally accepted view as to warrant further study.[20] The other conclusion which follows immediately from the present study's findings is that improved nutritional status would contribute to the success of health programs directed at pre-school children. This conclusion is much more consistent with the views of nutritionists and public health specialists.

[20] An apparent problem with the present study is the use of disease measures which refer to spells of illness during the preceding six months, while the nutrition measures refer to the time of interview. In addition, only spells of illness for which "treatment was sought" are recorded in the survey.

Another conclusion which follows from the results of the present study is that policies intended to provide low-income families with marginal increases in food consumption may not affect the nutritional status of pre-school children. The present study's findings suggest that a more direct approach to the problem, such as supplementary feeding programs for both mothers and children, would be more effective.

Finally, one may conclude from the results of the present study that increases in literacy rates will not have much effect on the nutritional status and health of pre-school children. If education is to make a contribution in these areas, efforts should be made to introduce nutrition and health subjects directly into the primary school curriculum. The present study suggests that a "more-of-the-same" approach to primary education, at least in Pakistan, would not yield much in terms of improved health and nutrition among pre-school children.

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APPENDIX A

Zero-order correlation matrix

	NA	NW	NH	DD	DR	AC	SX	EH	EW	FD	DI
NA	1.00	0.65	0.29	−0.20	0.18	0.52	0.14	0.04	0.05	0.01	0.09
NW	–	1.00	0.03	−0.13	−0.11	0.14	0.19	0.05	0.04	(−)0.00	0.09
NH	–	–	1.00	−0.06	−0.04	0.17	0.03	0.03	0.03	0.03	0.05
DD	–	–	–	1.00	0.30	−0.17	−0.04	−0.01	−0.03	0.05	−0.05
DR	–	–	–	–	1.00	−0.09	−0.04	0.06	0.03	0.09	−0.01
AC	–	–	–	–	–	1.00	0.05	0.02	(−)0.00	−0.08	−0.01
SX	–	–	–	–	–	–	1.00	−0.04	−0.02	).01	−0.04
EH	–	–	–	–	–	–	–	1.00	0.28	0.12	0.17
EW	–	–	–	–	–	–	–	–	1.00	0.13	0.15
FD	–	–	–	–	–	–	–	–	–	1.00	0.21
DI	–	–	–	–	–	–	–	–	–	–	1.00
VI	–	–	–	–	–	–	–	–	–	–	–
PS	–	–	–	–	–	–	–	–	–	–	–
BF	–	–	–	–	–	–	–	–	–	–	–
SD	–	–	–	–	–	–	–	–	–	–	–
WN	–	–	–	–	–	–	–	–	–	–	–
IM	–	–	–	–	–	–	–	–	–	–	–
WM	–	–	–	–	–	–	–	–	–	–	–
RM	–	–	–	–	–	–	–	–	–	–	–
WA	–	–	–	–	–	–	–	–	–	–	–
TL	–	–	–	–	–	–	–	–	–	–	–
RF	–	–	–	–	–	–	–	–	–	–	–

	VI	PS	BF	SD	WN	IM	WM	RM	WA	TL	RF
NA	0.08	−0.08	0.12	0.03	−0.15	−0.17	0.05	0.07	0.11	0.09	0.18
NW	0.02	−0.11	0.09	−0.04	0.01	−0.05	0.01	0.08	0.14	0.10	0.07
NH	0.10	−0.13	0.10	−0.09	0.01	−0.05	0.00	0.09	0.14	0.10	0.09
DD	−0.08	0.04	−0.03	0.09	0.03	0.07	0.03	−0.06	−0.08	−0.04	−0.14
DR	−0.02	0.04	0.08	0.05	0.02	0.06	0.08	−0.02	−0.03	(−)0.00	−0.06
AC	0.03	−0.07	0.14	0.04	−0.29	−0.19	0.16	−0.04	0.03	0.02	0.08
SX	−0.04	−0.08	0.05	−0.01	−0.05	−0.03	(−)0.00	−0.04	−0.05	−0.02	0.01
EH	0.15	−0.05	−0.04	−0.05	0.02	−0.09	0.04	0.07	0.12	0.12	0.05
EW	0.14	0.01	−0.08	−0.13	−0.01	−0.14	0.05	0.13	0.30	0.27	0.23
FD	0.11	−0.24	0.04	−0.01	0.08	0.09	0.06	0.27	0.10	0.11	−0.01
DI	0.36	−0.11	0.05	−0.04	0.00	0.02	−0.04	0.11	0.04	0.13	0.17
VI	1.00	−0.04	0.01	−0.01	−0.04	−0.09	−0.05	0.07	0.11	0.08	0.19
PS	–	1.00	−0.05	0.01	0.05	0.02	0.02	−0.20	(−)0.00	−0.20	−0.02
BF	–	–	1.00	0.13	0.10	−0.04	0.05	−0.04	−0.02	0.02	0.06
SD	–	–	–	1.00	0.01	0.04	0.03	−0.04	−0.06	−0.06	−0.17
WN	–	–	–	–	1.00	0.11	−0.01	0.04	−0.02	−0.01	−0.06
IM	–	–	–	–	–	1.00	−0.02	0.06	−0.08	−0.04	−0.22
WM	–	–	–	–	–	–	1.00	0.07	0.01	0.04	0.05
RM	–	–	–	–	–	–	–	1.00	0.24	0.28	0.07
WA	–	–	–	–	–	–	–	–	1.00	0.58	0.21
TL	–	–	–	–	–	–	–	–	–	1.00	0.18
RF	–	–	–	–	–	–	–	–	–	–	1.00

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