AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

HUMAN NUTRITION: RESEARCH EVALUATION METHODOLOGY AND SOME APPLICATIONS*

Godfrey Lubulwa[1]

A paper for presentation at the 40th Annual Conference of the Agricultural and Resource Economics Society, 13-15 February 1996, The University of Melbourne, Victoria.

Abstract

Keywords: *Health, Nutrition, Cost-benefit analysis*

There has been some concern about the extent to which current processes for allocating agricultural research funds consider the impact of agricultural research on human nutrition. For example, Heywood (1993) has argued, perhaps too strongly that:

> 'Although till now various nutrition-related activities have been funded on an ad-hoc basis, the place of nutrition per se has not been clearly recognised. Nutrition is an important problem of human welfare. Agriculture, and agricultural research, could make a contribution to the solution of some of these nutrition problems.

Before that concern can be addressed, it is necessary to develop approaches to assess the impact of agricultural research on human nutrition. However it is important to note the warning by Calloway(1995) that 'because diets and food behaviours are complex, the nutrition problem is also complex'.

This paper has the following aims:

- to briefly outline the problem of human nutrition and discuss the possible sources of human nutritional impacts;
- to indicate the extent to which agricultural research can impact on human nutrition, human health and labour productivity;
- to propose a research evaluation model which takes into account human nutrition; and
- to briefly discuss three ACIAR-funded agricultural research projects involving human nutrition where the proposed model can be applied.

The paper concludes with the information requirements of the model.

---

1. Senior Economist, Economic evaluation Unit, Australian Centre for International Agricultural Research (ACIAR)

Contact details: Dr Godfrey Lubulwa
Senior Economist, Economic Evaluation Unit, ACIAR
GPO Box 1571, Canberra, ACT 2601
Telephone no: 06-248-8588, Fax no. 06-257-3051
e-mail: lubulwa@aciar.gov.au

---

* Comments by Dr Jeff Davis on an earlier draft of this paper are gratefully acknowledged.

CONTENTS

1 INTRODUCTION

There has been some concern about the extent to which current processes for allocating agricultural research funds consider the impact of agricultural research on human nutrition (for example, see Heywood, 1993). Before that concern can be addressed, it is necessary to develop approaches to assess the impact of agricultural research on human nutrition. However it is important to note the warning by Calloway(1995) that 'because diets and food behaviours are complex, the nutrition problem is also complex'. This paper addresses the following question: how can one incorporate human nutrition impacts in the economic evaluation of an agricultural research proposal? An example of such a proposal is given by Cribb (1995) in his description of a suite of projects to develop strains of corn, rice, wheat, beans and cassava which are enriched in minerals essential to human health and nutrition- but which also perform well in poor soils, under drought and with low levels of inputs.

This paper has five sections: Section 1 briefly outlines the problem of human nutrition; discusses the possible sources of human nutritional impacts and indicates the impact of malnutrition on human health and labour productivity. Section 2 proposes a research evaluation model which takes into account human nutrition. Section 3 briefly discusses three ACIAR-funded agricultural research projects involving human nutrition where the proposed model can be applied. Section 4 makes concluding remarks.

1.1 Human nutritional problems

This section summarises the human nutritional problems of significance and indicates possible ways of addressing them. Table 1 summarises the human nutritional problems and some of the possible causes of these problems. From Table 1 there are about 7 major categories of human nutrition problems as follows:

- Inadequate calorie intake;
- Inadequate protein intake;
- Inadequate intake of micro nutrients that are unevenly distributed in foods;
- Inadequate intake of micro nutrients required by humans but not plants;
- Inadequate intake of micro nutrients due to low bio-availability;
- Toxicity effects from excessive intake of essential micro nutrients; and
- Toxicity effects from ingestion of micro-toxins in foods.

As Table 1 suggests there may be areas of human nutrition which are best tackled using other instruments other than agricultural research - not every human nutritional problem can be solved by agricultural research. Many would even ask whether research is even an appropriate policy instrument for many of the problems related to malnutrition.

Agricultural research can in some cases have impacts on the nutritional status of people. Some of these effects are reflected in the demand for agricultural products, others are not. For example if the human nutrition problem is due to ignorance of individuals as to the value of say vegetables in a balanced diet, the solution may be education. Similarly if social constraints do not recognise the differential nutrition requirements for pregnant women, the solution to the associated nutrition problem may be in the form of programs to change those social constraints and not agricultural research. These are examples of the divergence between the private demand functions based on the individual's perception of the characteristics of commodities, and the 'social' demand function which is based on the true values of the characteristics of commodities.

Table 1: Nutritional problems, possible causes and solutions

CAUSES ⇒ PROBLEM ⇓	Poverty: lack of adequate and stable income*	Inappropriate processing methods	Presence of inhibitors or interference reducing absorption (tannins, phytate)	Absence of promoting or enhancing factors reducing intake (meat, fish, poultry, ascorbic acid)	Ignorance	Tastes and preference	Social constraints
1. Inadequate calorie intake	Agricultural research, poverty alleviation	Agricultural research	Agricultural research	Agricultural research, poverty alleviation	Education campaigns, advertisements	Education, preference changing programs	Education, programs to change social constraints
2. Inadequate protein intake	Agricultural research, poverty alleviation	Agricultural research	Agricultural research	Agricultural research, poverty alleviation	Education campaigns, advertisements	Education, preference changing programs	Education, programs to change social constraints
3. Inadequate intake of micro nutrients from animal foods	Agricultural research, poverty alleviation	Agricultural research	Agricultural research	Agricultural research, poverty alleviation	Education campaigns, advertisements	Education, preference changing programs	Education, programs to change social constraints
4. Inadequate intake of micro nutrients required by humans but not plants	Agricultural research, poverty alleviation	Agricultural research	Agricultural research	Agricultural research, poverty alleviation	Education campaigns, advertisements	Education, preference changing programs	Education, programs to change social constraints
5. Inadequate intake of micro nutrients due to low bio-availability	Agricultural research	Agricultural research	Agricultural research	Agricultural research	Education campaigns, advertisements	Education, preference changing programs	Education, programs to change social constraints
6. Toxicity effects from excessive intake of essential micro nutrients	Agricultural research	Agricultural research	Agricultural research	Agricultural research	Education campaigns, advertisements	Education, preference changing programs	Education, programs to change social constraints
7. Toxicity effects from ingestion of micro-toxins in foods	Agricultural research	Agricultural research	Agricultural research	Agricultural research	Education campaigns, advertisements	Education, preference changing programs	Education, programs to change social constraints

* Agricultural research is defined broadly in this table to include research which support or ensure that pricing policies are non-distortionary, and that property rights are well defined in the agricultural and related sectors

This divergence may be due to social conventions and beliefs or due to ignorance. Whatever the cause of the divergence the traditional measures of the change in consumer surplus would overstate or understate the benefits of research depending on the nature of the divergence between the private and social demand functions. This paper suggests a model which overcomes this problem. There rest of this section briefly discusses each one of these human nutrition problems.

Inadequate calorie and protein intake

It is common to refer to protein-energy malnutrition because the lack of protein and the lack of energy are usually related. At the most basic level the problem of malnutrition is one of inadequate dietary energy supply. FAO (1992) indicates that by the late 1980s 123 million people resided in countries where dietary energy supplies were grossly insufficient at less than 2000 kcal per person per day. Most of these countries are in Africa, and Asia (World Bank, 1992). In sub-Saharan Africa, food supplies reached critical levels because of severe drought coupled with civil unrest in some countries

The solution to the nutrition problem arising from inadequate intake of calories is likely to be increased stable food availability at the national, regional and household level. In some cases this may be brought about by technical research. However, in many cases what is required is a set of appropriate, non-distortionary policy changes. In some cases it may be possible to solve the problem of inadequate calorie intake by developing better technologies for non-food crops. The hypothesis in this case is that if a household cannot grow enough food by itself to ensure food security, it could produce cash crops which would increase its purchasing power enabling it to buy the food it cannot produce. However, FAO(1992) warns that:

> 'Improvements in dietary intake will not occur if the earnings from new cash crops are spent on items not related to food. Women's participation in new enterprises and control of the income is important if nutritional benefits are to be realised.'

Protein-energy malnutrition results in (see Heywood, 1993):

- low birth weights for infants;
- growth retardation of children;
- impaired resistance to infection leading to high infant mortality and high levels of morbidity,
- delayed motor development,
- delayed eruption of deciduous teeth which leads to delays in the introduction of solid food to children and results in further malnutrition problems;
- stunted intellectual development; and
- reduced lifetime incomes.

Inadequate intake of micro nutrients that are unevenly distributed in foods

Calloway (1995) categorises all the nutrients that are low in diets with adequate supplies of protein and energy as type 1 nutrients. These include:

- Vitamin A which occurs mainly in fatty tissues (egg yolk, milk fat, fatty fish) and in liver where it is stored. Vitamin A deficiency leads to night blindness, complete loss of vision in some cases, growth retardation, reproductive disorders and death from measles.

- Vitamin B_{12} is stored in liver of animals and Vitamin B_{12} deficiency may lead to macrocytic anaemia, damage to tissues and retarded growth.
- Vitamin C occurs in many vegetables and fruits and Vitamin C deficiency may lead to scurvy - a disease which is now rare.

Inadequate intake of micro nutrients required by humans but not plants

Nutrition problems in this category relate to what Calloway(1995) refers to as type 2 nutrients, that is nutrients which are deficient in water and soils and are thus deficient in crops but which are essential for human life. These include:

- iodine, lack of which leads to goitre, iodine deficiency diseases, dwarfing, mental retardation (cretinism), deafness, spontaneous abortion, neo-natal deaths and mental and physical slowness.
- selenium, lack of which leads to white muscle disease in animals and heart muscle disease in women and children.

Inadequate intake of micro nutrients due to low bio-availability

Nutrition problems in this category relate to what Calloway(1995) refers to as type 3 nutrients, that is nutrients which are deficient in human nutrition because of low bio-unavailability. Examples of nutrients in this category include:

- Iron which may be deficient in cases where the diet contains phytates (high fibre) or tannins which limit the absorption of iron by the body. Iron deficiency leads to anaemia, adverse outcomes in pregnancy, increased maternal mortality, low birth weights, pre-maturity, immunological disorders, reduction in physical work capacity and diminution in physical and mental capacity.

- Zinc may be deficient in cases where the diet contains phytates (high fibre) or tannins which limit the absorption of zinc by the body. Zinc deficiency may lead to retarded growth, retarded sexual development, depressed immunity, loss of hair and poor reproductive performance.

Toxicity effects from excessive intake of essential micro nutrients

Some micro nutrients while essential for human life are toxic if taken in excessive amounts. Examples of these include (Calloway, 1995):

- Iodine;
- Selenium where symptoms of toxic effects include loss of hair and nails and neurological damage. The recommended daily intake is about 50 micrograms.
- Iron where excessive intake may lead to liver damage. A dose of 30 milligrams per kilogram of body weight is toxic, and 60 milligrams per kilogram of body weight may be fatal (Calloway, 1995).

Toxicity effects from ingestion of micro-toxins in foods

Examples of research evaluations of projects in this category include:

- aflatoxins (Lubulwa and Davis, 1994), and
- cyanogenic glucosides in cassava (Lubulwa, 1995).

The ingestion of aflatoxins over a long time leads to increased incidence of primary liver cancer and to losses in the livestock sectors which use aflatoxin-contaminated grains as feed. On the other hand ingestion of cassava with high hydrogen cyanide potential leads to the development of konzo, tropical ataxic neuropathy and other disorders.

Other human nutrition problems

There are many other possible sources of human nutritional problems, including:

- Research on non-food commodities competing with food production

In this case the production of food crops may be reduced and if income from non-food crops is not spent on food, households may have a deterioration in their nutritional status.

- Changes in the tastes and preferences of households

The important issues here relate to situations where distortions (due to ignorance or traditional beliefs based on misperceptions of commodities) in household preferences may lead to deterioration in household nutritional status.

- Policies which create markets for food commodities

These policies could also lead to changes in nutritional status of households. A recent example of this is the creation of markets for cassava in Zaire which seems to have led to cassava producers using shortcut methods of processing cassava leading to cassava products containing higher than safe levels of cyanide.

Policies in this category include the provision of infrastructure - construction of roads, improvement in transport facilities lowering the cost of transporting agricultural commodities to distant markets, urban development, population growth and other demographic changes; and employment expansion

However all these other sources of nutritional problems can be translated into one of the seven problems discussed above. Research addressing nutritional problems would fall in the standard agricultural research which aims at shifting the supply curve of agricultural food products. However standard models of research evaluation available in the literature as discussed in Davis et al (1987) and Alston et al (1995) would need some modification to capture the human health dimensions of malnutrition. The main reason for modification is that the demand functions of individuals for agricultural commodities and the market prices of those commodities may not reflect the human health dimensions of these commodities. For example, a recent ACIAR project (PN8806) demonstrated that peanuts and maize in many South East Asian markets were priced independently of the level of aflatoxin contamination in the grain. Thus grain which was highly contaminated with aflatoxins and thus with a higher likelihood of causing primary liver cancer to consumers ingesting it over long periods was priced the same as grain with much lower aflatoxin contamination levels.

1.2 Direct impacts of malnutrition on human health and labour productivity: a literature review

The main conclusion which can be drawn from the previous section is that human nutrition problems are intricately linked with human health problems. Thus a key element of a research evaluation model proposed in this paper attempts to capture the human health aspects of malnutrition. This section discusses selected literature which has to date attempted to quantitatively measure the impact of malnutrition and is based on Behrman(1993).

Martorell (1993) compared Guatamalan adolescents who when they were toddlers had taken a drink called Atole[1] in the period 1969-77 with Guatemalan adolescents who when they were toddlers had taken another drink called Fresco[2] in the same period. Martorell (1993) found that adolescents, particularly females who were exposed to Atole in the first three years of their lives were taller and had greater fat-free masses than those who received Fresco. Work capacity in terms of maximal oxygen consumption was significantly greater in males (but not in females) exposed to Atole in the first three years of their lives.

Wolgemuth et al (1982) found that labour productivity in Kenyan road construction workers increased due to calorie supplementation. For 47 workers were split into two groups: one group was given a 1000-calories per day supplement, while the other group was given a 200 calories per day supplement. Dirt dug per day increased 12.5 percent for the workers with a high-level supplement.

Immink and Viteri (1981) compare increments in harvests for two groups of Guatemalan sugarcane workers. One group received a high energy supplement and the other received a low energy supplement. They found that productivity of both groups rose during the supplementation period, but that there was hardly any difference between the productivity gains of the two groups.

Basta et al (1979) report on an experiment to investigate the impact of iron deficiency anaemia on the productivity of adult Indonesian male rubber plantation workers. Before the experiment analysis of productivity data showed that nonanemic tappers collected about 19 percent more latex than anaemic workers. Similarly, before the experiment analysis of productivity data showed that nonanemic weeders did about 20 percent more work than anaemic workers. The experiment involved 152 anaemic workers and 150 nonanemic workers. About half of the 302 workers were 100 mg of ferrous sulfate in dextrose daily for 60 days, while the other half were given an identical looking placebo. Labour productivity was measured by weight of latex delivered for tappers (about 70 percent of the sample). Labour productivity was measured by area of trenches dug by weeders (about 30 percent of the sample). Among the originally anaemic tappers all workers showed higher productivity after treatment, but only the iron recipients (and not the placebo recipients) achieved the productivity levels of the nonanemic workers.

Other studies include Sahn and Alderman (1988), Suhardjo (1986), Strauss (1986), Greene(1977) and Satyanayarana et al (1977). Most of this literature focuses on the direct

---

1 Atole is a hot gruel made of a vegetable protein mixture, dry skim milk, sugar and flavouring with 163 kcal and 11.5 grams of protein as well as many vitamins per 180 ml cup.

2 Fresco is a drink providing 59 kcal and no protein, vitamins or mineral supplement per cup.

impacts of malnutrition on labour productivity. However, in addition to these direct effects of nutrient intakes on labour productivity there may be other indirect effects, for example:

- malnutrition may affect cognitive achievement; and
- malnutrition may lower IQ and general ability of individuals.

Behrman (1993) provides a survey of experimental and socio-economic studies of the relationship between malnutrition cognitive achievement and ability and concludes that:

> 'There is some evidence that micro nutritional deficiencies in infants and small children may have negative effects on subsequent school performance. At this point however, the relation is fairly speculative, so it seem premature to comment upon the possible schooling and eventual productivity effects.'

The rest of the paper develops a model which takes into account these direct impacts on human health and labour productivity.

2 A RESEARCH EVALUATION MODEL INCORPORATING HUMAN NUTRITIONAL EFFECTS

This section describes a research evaluation model which can be used to evaluate project which have human nutritional effects. Its open economy variant while derivable would be difficult to compute Fortunately most human nutritional problems are country specific and do not have international trade dimensions.

2.1 The consumer and producer problem with a human nutrition focus: before research

The consumer's problem before research

The consumer's problem at time t is to plan his/her present and future consumption of agricultural commodities $Q(t,\pi)$ so as to:

$$\underset{Q(t,\pi)}{\max imise}\ \Sigma_{\pi=t}^{\pi=\infty}\left[\frac{1}{1+\delta}\right]^{(\pi-t)}\beta^{T}\log\begin{bmatrix} b_{11}(t.\pi) & \dots & b_{1n}(t.\pi) \\ . & \dots & . \\ b_{n1}(t.\pi) & \dots & b_{nn}(t.\pi)\end{bmatrix}\begin{bmatrix} Q_1(t,\pi)-\gamma_1 \\ \dots \\ Q_n(t,\pi)-\gamma_n\end{bmatrix} \quad (1)$$

subject to

$$\Sigma_{\pi=t}^{\pi=\infty}\left[\frac{1}{1+\delta}\right]^{(\pi-t)} p^{T}(t,\pi)Q(t,\pi)-\left[\frac{1+\rho}{\rho-i}\right]I(t)=0; \quad \rho\rangle i^{*} \quad (2$$

$$P_i(t,\pi)=(1+i^{*})^{(\pi-t)}\ P_i(t) \quad (3)$$

and

$$b_{ij}(t.\pi)=b_{ij}(t.t)(1+r_{ij})^{\pm(\pi-t)} \quad (4)$$

where

$Q(t,\pi)$ = $[Q_1(t,\pi), Q_2(t,\pi), \dots, Q_n(t,\pi)]$

$Q_i(t,\pi)$ is the quantity of agricultural commodity i which a consumer at time t plans to consumer at time π;

t	is the time at which the consumer is making the decision;
π	indicates time, $\pi = t, t+1, t+2, \ldots,$.
γ_i	is the subsistence quantity of the ith agricultural commodity;
δ	is the consumer's constant rate time preference;
$B(t,\pi)$	is, at time t, an nxn matrix of Lancasterian characteristics of agricultural commodities at time π. In the case of nutrition some of the elements in the B-matrix would represent some nutritional aspect of an agricultural commodity; for example, the protein or calorie content of a commodity, the hydrogen cyanide potential or the aflatoxin content of a commodity.
r_{ij}	is the expected rate of change of the jth characteristic of the ith agricultural commodity. The attributes of agricultural commodities, including those of nutritional significance are changing partly due to research and partly due to other factors. In most practical situations it is assumed that r_{ij} are zero for all commodities and all characteristics.
β	is an n-vector of constants in the consumer's utility function;
T	is used to denote a transpose of a matrix;
$P(t,\pi)$	is an n-vector of prices of agricultural commodities;
i^*	is the anticipated inflation rate;
ρ	is the market rate of interest;
$I(t)$	is the present value of the consumer's assets and future lifetime income stream.

The conditions for a solution to the above consumer problem are well-known (see for example, Lubulwa, 1983a, and 1983b). Lubulwa (1983a) indicated the conditions under which a solution to (1)-(4) is inter temporally consistent. Bouis (1990) solved a special case of (1)-(4) where there are only three attributes of food: bulk, variety and taste. A solution to the problem in (1)-(4) is given by the following equations (see Lubulwa, 1983a):

$$Q(t,\pi) = \gamma + \eta(t) \quad I^*(t) \left[\frac{1+\rho}{(1+\delta)(1+i^*)} \right]^{(\pi - t)} \qquad (5)$$

where

$$\eta(t) = \left[\frac{1+\delta}{\delta}\right]\left[\frac{1+\rho}{\rho+i^*}\right] \frac{diag\,(P(t,t))B^{-1}(t,t)[diag\,\beta]\{B^{-1}(t,t)^T P(t,t)\}^{-1}}{P(t,t)^T B^{-1}(t,t)(diag\,\beta)\{B^{-1}(t,t)^T P(t,t)\}^{-1}} \qquad (6)$$

$$I^*(t) = I(t) - \sum_{i=1}^{n} P_i(t,t)\gamma i \qquad (7)$$

Equation (5)-(7) gives the demand functions for agricultural food commodities over time. The demand for agricultural commodity i depends on the following:

- a subsistence level of the commodity given by γ_i in equation (5). This subsistence level would in some cases reflect a physiological minimum quantity required and we assume that quantities consumed do not fall below these levels.

- the super-numerary permanent income, $I^*(t)$, the income available after the purchase of subsistence quantities, γ_i. This is the income available for purchase of commodities over subsistence levels. How much a household spends on new or optional purchases will depend on the size of $I^*(t)$. The larger $I^*(t)$ is the more optional purchases a household can afford.

- the marginal budget share of commodity i given by $\eta_i(t)$. The interpretation of the marginal budget shares is clearer if in equation (5) one assumes that $\rho=\delta$, $i^*=0$, and then one differentiates with respect to $I^*(t)$. The marginal budget shares $\eta_i(t)$ give the change in the expenditure on commodity i resulting from a change in the households super-numerary permanent income. Obviously $\eta_i(t)$ must be non-negative and less than or equal to 1. If commodity i is off the households shopping list then $\eta_i(t)$ is zero for commodity i. On the other hand if $\eta_i(t)$ is 1 for commodity i, then all the changes in the households super-numerary permanent income $I^*(t)$ will be absorbed by adjustments in the purchases of commodity i with increases in $I^*(t)$ leading to increases in purchases of commodity i and decreases in $I^*(t)$ leading to decreases in purchases of the commodity. Usually $\eta_i(t)$ falls between zero and 1 with the constraint that

$$\eta_1(t) + \eta_2(t) + \ldots + \eta_n(t) = 1 \qquad (8)$$

Equation (8) means that a households is restricted to apportion between the different commodities no more than the available super-numerary permanent income $I^*(t)$. The marginal budget shares are defined in equation (6) where it is shown that they non-linearly depend on prices of commodities, $P(t,t)$, the attributes of agricultural commodities, $B(t,t)$, the interest rates- ρ, the impatience factor- δ, the rate of inflation- i^*, and the utility function parameters β.

- the discount factor $[(1+\rho)/(1+\delta)(1+i^*)]^{(\pi-t)}$. If one is time t, then $t=\pi$ and the discount factor is equal to 1. If $\rho=\delta$, $i^*=0$, that is the rate of interest and the impatience factor are equal and inflation is assumed to be zero then current and future expenditures are equally weighted.

The producer's problem before research

Let the producer's supply function be of the following form:

$$Q^S(t, t) = a + bP(t,t) \qquad (9)$$

where

$$Q^S(t, t) = Q_1^S(t, t), Q_2^S(t, t), \ldots, Q_n^S(t, t)$$

Equation (9) and equations (5)-(7) imply that in equilibrium the following holds:

$$a + b\,P(t,t) = \gamma + \eta \quad I^{*}(t)\left[\frac{1+\rho}{(1+\delta)(1+i^{*})}\right]^{(\pi-t)} \qquad (10)$$

This implies that

$$P(t,t) = Diag(b)\left[\gamma - a\right] + Diag(b)\ \eta I^{*}(t)\left[\frac{1+\rho}{(1+\delta)(1+i^{*})}\right]^{(\pi-t)} \qquad (11)$$

The before research solution is thus described by equations (5)-(7), (9) and (11) where (5)-(7) describe the demands for the n agricultural food commodities, equation (9) describes the supply equations for the commodities and equation (11) describes the market clearing prices for the n commodities.

2.2 The after research solution

There are many types of research that could have nutritional impacts. From the equations (5) and (6) research activity leading to any of the following changes could have nutritional impacts:

- A change in subsistence quantities consumed, γ. However these could be changed by other forces (e.g., sociological factors). Agricultural research is unlikely to influence this factor.

- Changes in the interest rates, ρ, in the inflation rate i^* or in the consumer time preference factor δ, which could be brought about by better economic policies at the macro- or micro-economic levels in a given country.

- A change in the price of the agricultural commodity without changing the characteristics matrix. This could be brought about by changing the cost of producing the agricultural commodity. Even in this case, however, it is still necessary to consider changes in the prices and quantities of n commodities. Just et al (1982) argued that if research on one commodity affects the prices and quantities of other commodities, the measure of welfare in one market adequately captures the impacts on all markets affects. This may not always be the case when the focus is human nutrition, particularly when there is a divergence between the private and social demand functions for the commodity targeted by research. The impact of changes in related markets may have counter-intuitive implications for human nutrition, human health and labour productivity. An interesting special case of the above problem is where the characteristics matrix is diagonal and all the cross price elasticities are zero. In this case changing an element b_{ii} on the diagonal of the characteristics matrix B is equivalent to a change in the price of the ith commodity and it would then be appropriate to use single commodity research evaluation models (see Davis et al, 1987, for examples).

- Changes in elements of the characteristics matrix B due to biological changes in commodities. Some of these changes may be brought about by agricultural research.

- Changes in elements of the characteristics matrix B due to changes in perceptions of consumers. Some of the changes in B(t,t) may be brought by other factors, for example education. In these cases where education plays a role it is helpful to interpret the B(t,t) matrix before research as a perceived matrix of the attributes of agricultural commodities. The perceived attributes may be different from the actual

attributes B*(t,t). An education or information campaign changes the perceived matrix in such a way that after the campaign B(t+1, t+1) = B*(t,t). This change leads to changes in the optimal solution because the budget shares before research based on misperceptions of the characteristics matrix are likely to be revised after consumers are made aware of the true values of the matrix. This change in perceptions may of course be based on agricultural research which for example may check, correct, and publicise the information on the true attributes of commodities.

Suppose that at time t+1 research on an agricultural commodity changes the values of some of the elements in the characteristics matrix B(t,t) so that B(t+1,t+1) ≠ B(t,t). Then a consumer taking into account the characteristics matrix would revise their optimal solutions as follows:

$$Q(t+1,\pi) = \gamma + \eta(t+1) \quad I^*(t+1)\left[\frac{1+\rho}{(1+\delta)(1+i^*)}\right](\pi-[i+1]) \qquad (12)$$

where

$$\eta(t+1) = \left[\frac{1+\delta}{\delta}\right]\left[\frac{1+\rho}{\rho+i^*}\right]\frac{diag\,(P(t+1,t+1))B^{-1}(t+1,t+1)[diag\,\beta]\{B^{-1}(t+1,t+1)^T P(t+1,t+1)\}^{-1}}{P(t+1,t+1)^T B^{-1}(t+1,t+1)(diag\,\beta)\{B^{-1}(t+1,t+1)^T P(t+1,t+1)\}^{-1}} \qquad (13)$$

$$I^*(t+1) = I(t+1) - \sum_{i=1}^{n} P_i(t+1,t+1)\gamma i \qquad (14)$$

The change in the characteristics matrix leads to changes:

- in the budget shares of the different commodities,
- in the equilibrium prices of both the commodity which is the subject of research; and
- the prices of other agricultural commodities which are related to that commodity.

To find the after research vector of prices it is assumed that markets for both the commodity which is the subject of research and the other agricultural commodities which are related to that commodity do clear after research. Thus:

$$a + b\,P(t+1,t+1) = \gamma + \eta(t+1) \quad I^*(t+1)\left[\frac{1+\rho}{(1+\delta)(1+i^*)}\right](\pi-[t+1]) \qquad (15)$$

This implies that

$$P(t+1,t+1) = Diag(b)[\gamma - a] + Diag(b)\,\eta(t+1)I^*(t)\left[\frac{1+\rho}{(1+\delta)(1+i^*)}\right](\pi-[t+1]) \qquad (16)$$

where the after research supplies are given by the following equation:

$$Q^S(t+1,t+1) = a + bP(t+1,t+1) \qquad (17)$$

Equations (12)-(17) describe the after research equilibrium for a situation where human health effects are important. When human nutrition is the focus of research it is necessary to carry the analysis further before calculating the welfare impacts.

2.3 Determining the level of nutritional deficiency

First of all estimate the level of nutritional deficiency with respect to at least the following variables:

- calorie intake;
- protein intake;
- intake of micro nutrients that are unevenly distributed in foods (see Calloway, 1995)- for example
  - vitamin A
  - vitamin B12
  - vitamin c
- intake of micro nutrients required by humans but not plants (see Calloway, 1995)- for example
  - iodine
  - selenium
- intake of micro nutrients due to low bio-availability - for example
  - iron
  - zinc
  - niacin
- Toxicity effects from excessive intake of essential micro nutrients- for example
  - iodine
  - selenium
  - iron; and
- Toxicity effects from ingestion of micro-toxins in foods- for example
  - hydrogen cyanide
  - aflatoxins B1, B2, G1, G2
  - other mycotoxins

These could form the minimum set of the elements quantified in the characteristics matrix B for agricultural food commodities. To estimate before research nutritional deficiency with respect to nutrient Zj it is necessary to do the following:

- disaggregate the before research consumption levels by appropriate consumer groups (by income or geography), that is estimate Q_{iht}, the consumption of agricultural good i by group h at time t - before research. This estimation should be done for all commodities included in the analysis and for all groups. Per Pinstrup-Andersen et al (1976) used 22 agricultural commodities and six income groups. It is necessary to estimate the proportion of each of the commodities included in the analysis consumed by the different consumer groups

- Let the first n1 characteristics ($Z_1, ..., Z_{n1}$) refer to nutrients which are necessary for human health. For each one of these characteristics let ($Z^*_1, ..., Z^*_{n1}$) be the required levels of the nutrients for good health. Assume that ($Z^*_1, ..., Z^*_{n1}$) are also the maximum levels of the nutrients after which the consumer derives no human health benefits from higher levels of consumption.

- Let the remaining characteristics ($Z_{n1+1}, ..., Z_n$) refer to characteristics which have toxicity or other negative human health impact. For each one of these characteristics let ($Z^*_{n1+1}, ..., Z^*_n$) be the maximum safe levels of the characteristics after which the consumer suffers negative human health effects from higher levels of consumption of the characteristic.

- assuming that information about the B matrix is available, estimate Z_{jht} the 'before research' daily intake of nutrient Z_j by group h as follows:

$$\begin{bmatrix} Z_{1ht} \\ Z_{2ht} \\ \bullet \\ \bullet \\ Z_{nht} \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \bullet & \bullet & b_{1n} \\ b_{21} & b_{22} & \bullet & \bullet & b_{2n} \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ b_{n1} & b_{n2} & \bullet & \bullet & b_{nn} \end{bmatrix} \begin{bmatrix} Q_{1ht} \\ Q_{2ht} \\ \bullet \\ \bullet \\ Q_{nht} \end{bmatrix} \qquad (18)$$

Then the groups intake of different nutrients is compared with minimum requirements for those nutrients. The following comparison is done for each nutrient and for each of the consumer groups in the analysis

$$\begin{bmatrix} Z_{1ht} \\ Z_{2ht} \\ \bullet \\ \bullet \\ Z_{nht} \end{bmatrix} - \begin{bmatrix} Z^*_{1t} \\ Z^*_{2t} \\ \bullet \\ \bullet \\ Z^*_{nt} \end{bmatrix} = \begin{bmatrix} R_{1ht} \\ R_{2ht} \\ \bullet \\ \bullet \\ R_{nht} \end{bmatrix} \qquad (19)$$

where $R_{jht} = 0$, implies for $(Z_1, ..., Z_{n1})$ that individuals in group h have adequate supplies of the characteristics $(Z_{1h}, ..., Z_{n1h})$. If $(Z_{1h}, ..., Z_{n1h}) >$ or $= (Z^*_1, ..., Z^*_{n1})$ for all groups h, then any project designed to increase the amounts of $(Z_1, ..., Z_{n1})$ will not yield any human health benefit.

$R_{jht} < 0$ implies for $(Z_1, ..., Z_{n1})$ that individuals in group h have inadequate supplies of the characteristics $(Z_1, ..., Z_{n1})$. If $(Z_{1h}, ..., Z_{n1h}) > (Z^*_1, ..., Z^*_{n1})$ for some group h, then a project designed to increase the amounts of $(Z_{1h}, ..., Z_{n1h})$ for some h will yield human health benefits.

$R_{jht} > 0$, implies, $(Z_{n1+1}, ..., Z_n)$, that individuals in group h may be suffering from toxicity effects from the ingestion of Z_j, in excess of Z^*_j, the maximum safe amount of the nutrient or toxin;

The outcome of this analysis is a table indicating the level of nutritional deficiency or adequacy for the different groups and selected nutrients or toxins. The research project which increases the supply of the nutrient Z_i will only have an impact on those groups which are shown to be deficient in the nutrient. In the case of toxic elements a benefit is obtained from a research project designed to reduce the toxic elements in a commodity if the nutritional deficiency analysis identifies some group which is ingesting more than the maximum safe levels of the toxin.

Suppose that agricultural research shifts the supply functions of both the commodity targeted by research and of other commodities. Then it is possible to repeat the above steps and estimate the nutritional deficiencies after research as follows:

$$\begin{bmatrix} Z_{1ht+1} \\ Z_{2ht+1} \\ \bullet \\ \bullet \\ Z_{nht+1} \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \bullet & \bullet & b_{1n} \\ b_{21} & b_{22} & \bullet & \bullet & b_{2n} \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ b_{n1} & b_{n2} & \bullet & \bullet & b_{nn} \end{bmatrix} \begin{bmatrix} Q_{1ht+1} \\ Q_{2ht+1} \\ \bullet \\ \bullet \\ Q_{nht+1} \end{bmatrix} \qquad (20)$$

The intake of different nutrients by a given group h (which could for example be an income group) is compared with minimum requirements for those nutrients. The following comparison is done for each nutrient and for each of the consumer groups in the analysis

$$\begin{bmatrix} Z_{1ht+1} \\ Z_{2ht+1} \\ \bullet \\ \bullet \\ Z_{nht+1} \end{bmatrix} - \begin{bmatrix} Z^*_{1t} \\ Z^*_{2t} \\ \bullet \\ \bullet \\ Z^*_{nt} \end{bmatrix} = \begin{bmatrix} R_{1ht+1} \\ R_{2ht+1} \\ \bullet \\ \bullet \\ R_{nht+1} \end{bmatrix} \qquad (21)$$

where $R_{jht+1} = 0$, implies for $(Z_1, .., Z_{n1})$ that after research individuals in group h have adequate supplies of the characteristics $(Z_{1h}, ..., Z_{n1h})$.

$R_{jht+1} < 0$ implies for $(Z_1, ..., Z_{n1})$ that after research individuals in group h still have inadequate supplies of the characteristics $(Z_1, ..., Z_{n1})$.

$R_{jht+1} > 0$, implies, $(Z_{n1+1}, ..., Z_n)$, that after research individuals in group h may still be suffering from toxicity effects from the ingestion of Z_j, in excess of Z^*_j, the maximum safe amount of the nutrient or toxin;

The outcome of this analysis is a table indicating the level of nutritional deficiency or adequacy for the different groups and selected nutrients or toxins after research.

It is then possible to quantify the direct and indirect effects of a change in the supply of agricultural commodities on nutrition using the following equation:

$$\begin{bmatrix} \Delta Z_{1ht+1} \\ \Delta Z_{2ht+1} \\ \bullet \\ \bullet \\ \Delta Z_{nht+1} \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \bullet & \bullet & b_{1n} \\ b_{21} & b_{22} & \bullet & \bullet & b_{2n} \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ b_{n1} & b_{n2} & \bullet & \bullet & b_{nn} \end{bmatrix} \begin{bmatrix} \Delta Q_{1ht+1} \\ \Delta Q_{2ht+1} \\ \bullet \\ \bullet \\ \Delta Q_{nht+1} \end{bmatrix} \qquad (22)$$

where

ΔZ_{jht+1} is the change in nutritional characteristic j for group h at time t + 1;

ΔQ_{jht+1} is the change in quantity consumed of agricultural commodity j;

The direct effects of a change in the supply of commodity j will generally have opposite signs t the indirect effect. For example a change in supply of commodity j in order to increase the intake of calories and protein will lead to an increase in the intake of calories from the increased consumption of commodity j. However, given that the consumer has a budget constraint this increase will lead to a decrease in the intake of calories and protein from other

commodities whose consumption may fall in order to accommodate the increased purchases of commodity (see Per Pinstrup-Andersen et al (1976) for an empirical demonstration of this.

However, if a change in the supply of commodity does not lead to changes in the budget shares and supplies of other commodities then the only nutritional effects will be the direct effects which are given by the following equation:

$$\begin{bmatrix} \Delta Z_{1ht+1} \\ \Delta Z_{2ht+1} \\ \bullet \\ \bullet \\ \Delta Z_{nht+1} \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \bullet & \bullet & b_{1n} \\ b_{21} & b_{22} & \bullet & \bullet & b_{2n} \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ b_{n1} & b_{n2} & \bullet & \bullet & b_{nn} \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \Delta Q_{jht+1} \\ \bullet \\ 0 \end{bmatrix} \qquad (23)$$

where

ΔZ_{jht+1} is the change in nutritional characteristic j for group h at time t + 1;

ΔQ_{jht+1} is the change in quantity consumed of agricultural commodity j;

2.4 Determining the human health and labour productivity impacts of human nutrition-related research

There are three main approaches to the study of disease in a community. One approach estimates disability-adjusted life years lost due to premature death and increased morbidity. Examples of this approach include World Bank (1993). The aim in computing life years lost is to give some impression of the nature and degree of ill health in a community. This approach does not generally produce a monetary cost of disease.

A second approach estimates the monetary cost of disease Examples of this approach include Crowley et al. (1992). This paper uses the second approach because it generates a meaningful, though partial, monetary measure of the cost of disease. It is partial because it does not cover all impacts of disease. For example, it does not incorporate the effects of disease on quality of life or human suffering, for which satisfactory measures are still being developed (Crowley et al 1992). Disease leads to the following categories of cost (see Crowley et al , 1992):

- the cost of mortality which relates to the cost of productive capacity lost when people die prior to reaching the end of their productive life;
- the cost of morbidity which relates to value of production loss resulting from hospitalisation and the cost of health care services consumed when an individual is sick;
- the costs incurred by governments and hospitals in the provision of medical services for individuals suffering from primary liver cancer; and
- the cost of intangibles - pain, suffering, anxiety and reduction in quality of life.

This second approach determines the finite value of life (Crowley et al. 1992) using either

- the human capital method; or
- the willingness to pay method.

The human capital method equates the value of life with the present value of expected future earnings. The willingness to pay method uses contingency valuation surveys to ask people

how much they would be willing to pay to avoid different levels and types of risks The willingness to pay approach is inappropriate when people surveyed cannot perceive the risk whose cost they are asked to assess

This paper suggests a third approach where the impacts of disease due to mal-nutrition for example is estimated by deriving the impacts of the labour market in a given situation.

The demand for labour

The demand for labour is given by the following simple linear demand equation

$$D_{Lhg} = \mu_{hg} + \sigma_{hg} w_{hg} \qquad (24)$$

where:

D_{Lhg} is the demand for labour measured in terms of the number of working hours demanded for employment from individuals of age g in group h;

μ_{hg} and σ_{hg} are respectively the intercept and the slope of the demand function for labour of age g in group h;

w_{hg} is the market wage rate for labour for workers g years old and in group h.

The labour force at time t

Let N_{igh} be a measure of the ith human health impact on individuals in age group g in consumption group h associated with under consumption or over consumption (depending on whether one is dealing with deficiency or toxicity) of various nutritional characteristics. N_{igh} is a proportion by which labour supply by individuals of age g in group h is reduced as a result of being deficient in nutrient i. For example Wolgemuth et al (1982) found that labour productivity in Kenyan road construction workers increased due to calorie supplementation. For 47 workers were split into two groups: one group was given a 1000-calories per day supplement, while the other group was given a 200 calories per day supplement. Dirt dug per day increased 12.5 percent for the workers with a high-level supplement. In this case N_{igh} is estimated to be 0.125 where i is the calorie content of a food. Lack of adequate calories leads to a reduction of labour supply. The malnutrition adjusted labour force would the be (1-0.25)x the total labour supply.

The ith human health impact could be a mortality rate due to deficiency with respect to a nutrient. Through a literature review of relevant medical literature, it is possible to define, a matrix H whose elements give the proportion by which the labour supply is reduced as a result of the different human health impacts (mortalities, and cases of morbidity) associated with under consumption or over consumption (depending on whether one is dealing with deficiency or toxicity) of various nutritional charateristics. The matrix H with the matrix on nutritional deficiency are then used to estimate the after research incidence by age group and consumer group of the different human health impacts.

$$\begin{bmatrix} N_{1gh} \\ N_{2gh} \\ \bullet \\ \bullet \\ N_{nht+1} \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} & \bullet & \bullet & H_{1n} \\ H_{21} & H_{22} & \bullet & \bullet & H_{2n} \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ H_{n1} & H_{n2} & \bullet & \bullet & H_{nn} \end{bmatrix} \begin{bmatrix} R_{1ht+1} \\ R_{2ht+1} \\ \bullet \\ \bullet \\ R_{nht+1} \end{bmatrix} \qquad (24)$$

where

R_{jht+1} is as defined in equation (21).

The calculations in equation (25) can be done for each of the h consumer groups and each of the g age groups depending on the availability of data required to support the calculations.

The main hypothesis of this paper is that an appropriate way to estimate the research benefits from human nutrition related projects is to use a labour market model. Micro-economic theory indicates that changes in the aggregate size of the human population and its detailed age-sex composition lead to shifts in the supply function of labour (see Hirshleifer, 1980). Negative human health effect of nutrition lead to a reduction in the working hours available from an individual as follows:

- in the case of death (say from primary liver cancer due to prolonged exposure to aflatoxins in grains) the working hours available from an individual are reduced to zero;

- when human health effects of nutrition are in the form of morbidity, the working available from an individual are reduced due to absences on sick days an when the individual is hospitalised;

- In many cases, negative human health effects lead to stunted intellectual development or reduced cognitive ability, mental retardation or reduced capacity for physical work. These effects too can be modelled as a reduction in the supply of labour. That is compared to an individual who does not suffer from the negative human health effects of nutrition, the malnourished individual can only supply a fraction of what a well-nourished individual can supply.

Thus negative human health effects of nutrition are likely to lead to a shift to the left of the supply function of labour. The total number of working hours available in the economy are reduced. On the other hand, positive human health effects of nutrition are likely to lead to a shift to the right in the supply function for labour. A labour market model then seems to be a possible model to use in modelling the human health and labour productivity effects of human nutrition research. Shifts in the supply curve of labour lead to changes in the wage rate in an economy.

The labour force at time t is defined to include only those individuals in the country who are of working age at the end of t-1. The minimum age, g*, for entry in the labour force varies from country to country.

Introduce the following definitions:

w^{*0}_{gh} is the before research equilibrium wage rate for individuals g years old in group h who do not suffer from human health and productivity effects of malnutrition;

w^0_{gh} is the before research wage rate received by individuals g years old in group h

Γ^0_{hg} is the before research total labour supply from individuals of age g in group h in a country - where g is greater than or equal the minimum working age g*;

S^0_L is the malnutrition-adjusted supply of labour before research.

S^0_L can be written in terms of the human health effects of nutrition estimated in equation (25) as follows:

$$S_L = \sum_{h=1}^{H} \left\{ \sum_{g=g^*}^{G} \left[1 - N^0_{1hg} - N^0_{2hg} - \ldots - N^0_{nhg}\right] \Gamma^0_{hg} \right\} \qquad (26)$$

$$S_{Lh} = \left\{ \sum_{g=g^*}^{G} \left[1 - N^0_{1hg} - N^0_{2hg} - \ldots - N^0_{nhg}\right] \Gamma^0_{hg} \right\} \qquad (27a)$$

and

$$S_{Lhg} = \left\{ \left[1 - N^0_{1hg} - N^0_{2hg} - \ldots - N^0_{nhg}\right] \Gamma^0_{hg} \right\} \qquad (27b)$$

In micro-economic theory the supply of labour depends on the wage rate. Thus:

$$\Gamma^0_{hg} = \theta_{hg} + \varsigma_{hg}\, w^0_{hg} \qquad (28)$$

where

θ_{hg} and ζ_{hg} are respectively the intercept and slope of the supply function;

Equation (27) is interesting because it suggests that the human health effects of nutrition can be modelled as a form of wastage of labour (see Davis, 1993 for a wastage model for agricultural commodities). Γ_{hg} is the population in age group g and consumption group h. If all the human health effects due to mal-nutrition were zero then S_{Lhg} would be equal to Γ_{hg} and there would be no wastage. However with non-zero human health effects S_{Lhg} the number of working hours available from group h is less than Γ_{hg}.

In a linear model such as this, if estimates of the supply and demand elasticities are available, the following relationships hold:

$$\zeta_h = \varepsilon_{sh}\, S_{Lh} / w_h$$

$$\theta_h = (1 - \varepsilon_{sh})\, S_{Lh}$$

$$\sigma_h = -\varepsilon_{dh}\, S_{Lh} / w_h$$

$$\mu_h = (1 - \varepsilon_{dh})\, S_{Lh}$$

where

ε_{sh} is the labour supply elasticity for individuals in group h and
ε_{dh} is the demand elasticity for workers in group h;

Equilibrium in the labour factor market is achieved where the aggregate demand function for labour and the aggregate supply function for labour intersect. That intersection point determines the equilibrium wage 'w*' and the equilibrium level of market employment.

An employer who is a labour market price-taker will employ labour from sub-group of age g in group h, until its hire-price whg equals its marginal revenue product defined as marginal revenue times marginal product of labour.

Where there are human health and labour productivity impacts associated with human nutrition then the before research wage rate for individuals in sub-age group g in group h is related to the market or equilibrium wage rate as follows:

$$w^0{}_{hg} = \left\{ \left[1 - N^0{}_{1hg} - N^0{}_{2hg} - \ldots - N^0{}_{nhg}\right] w_{hg}{}^{0*} \right\}$$

The supply curve of labour for individuals in age sub-group g and group h can be re-written as follows:

From equation (27b)

$$S^0{}_{Lhg} = \left\{ \left[1 - N^0{}_{1hg} - N^0{}_{2hg} - \ldots - N^0{}_{nhg}\right] \Gamma^0{}_{hg} \right\}$$

Thus

$$S^0{}_{Lhg} = \left[1 - N^0{}_{1hg} - N^0{}_{2hg} - \ldots - N^0{}_{nhg}\right] \left\{ \theta_{hg} + \varsigma_{hg}\, w^0{}_{hg} \right\}$$

$$S^0{}_{Lhg} = \left[1 - N^0{}_{1hg} - N^0{}_{2hg} - \ldots - N^0{}_{nhg}\right] \left\{ \theta_{hg} + \varsigma_{hg} \left[1 - N^0{}_{1hg} - N^0{}_{2hg} - \ldots - N^0{}_{nhg}\right] w^{0*}{}_{hg} \right\}$$

The excess supply L_{EShg} of labour of age g from group h is given as:

$$L_{EShg} = SL_{hg} - DL_{hg} \qquad (29)$$

The market equilibrium wage rate "before research" is given by solving the following:

$$\Sigma_{h=1}^{H} \Sigma_{g=g*}^{G} L^0{}_{EShg} = \Sigma_{h=1}^{H} \Sigma_{g=g*}^{G} \left(S^0{}_{Lhg} - D^0{}_{Lhg} \right) = 0 \qquad (30)$$

where:

$L^0{}_{EShg}$ is the before research excess supply of labour of age g from consumer group h

$S^0{}_{Lhg}$ is the before research supply of labour of age g from consumer group h

$D^0{}_{Lhg}$ is the before research demand for labour of age g from consumer group h.

It can be shown that the equilibrium wage rate associated with the system of equations (24) - (30) is given by the following equation:

$$w^* = \frac{\sum_{h=1}^{H}\sum_{g=g^*}^{G}\left\{\left[\,1 - N^0{}_{1hg} - N^0{}_{2hg} - \ldots - N^0{}_{nhg}\,\right]\theta_{hg} - \mu_{hg}\,\right\}}{\sum_{h=1}^{H}\sum_{g=g^*}^{G}\left\{\left[\,1 - N^0{}_{1hg} - N^0{}_{2hg} - \ldots - N^0{}_{nhg}\,\right]^2 \varsigma_{hg} + \sigma_{hg}\right\}} \qquad (31)$$

The impact of research

The impact of a research project with a human nutrition focus is observed in the changes such a project make on the human health effects (N_{1hg}, N_{2hg}, ..., N_{nhg}). However changes in these human health effects could be brought about through a variety of sources including:

- a reduction in the unit cost of producing a commodity with targeted characteristics; or
- changing the attributes of a commodity

After Research

The technologies resulting from agricultural research with a human nutrition focus can be represented in the following manner. Let

ΔN_{jhg} be the change, due to research, in the jth malnutrition-related human health effect on individuals of age g in group h.

The "after research" wage rate is found by substituting these changes in the appropriate equations a .d solving for the equivalent of equation (30) which gives:

$$w^{**} = \frac{\sum_{h=1}^{H}\sum_{g=g^*}^{G}\left\{\left[\,1 - (N^0{}_{1hg} + \Delta N_{1hg}) - (N^0{}_{2hg} + \Delta N_{2hg}) - \ldots - (N^0{}_{nhg} + \Delta N_{nhg})\,\right]\theta_{hg} - \mu_{hg}\,\right\}}{\sum_{h=1}^{H}\sum_{g=g^*}^{G}\left\{\left[\,1 - (N^0{}_{1hg} + \Delta N_{1hg}) - (N^0{}_{2hg} + \Delta N_{2hg}) - \ldots - (N^0{}_{nhg} + \Delta N_{nhg})\,\right]^2 \varsigma_{hg} + \sigma_{hg}\right\}} \qquad (32)$$

2.5. A diagrammatic representation of the model

This section, using a set of four diagrams summarises the model suggested in preceding sections. The diagrams are based on a simple situation where there are only two commodities and there is only one characteristic or nutrient of interest. They are intended to give an indication of how the different parts of the model are linked.

Figure 1 gives the households choice situation A consumer maximises utility by choosing to consume the quantities of good 1 and good 2 at the point where the consumer's indifference curve is tangent to the budget line. The bottom part of the Figure 1 shows the relationship between the quantity of commodity 1 and the amount of nutrient or characteristic 1 consumed.

The left hand part of Figure 2 is a reproduction of the bottom part of Figure 1. The right hand side of figure 2 shows the relationship between nutrient deficiency and the effects of malnutrition. These effects as indicated earlier are multi-dimensional. Take the example of reduction in capacity for physical or intellectual work. Z* is the required intake of nutrient j to prevent an individual from suffering from negative effects of malnutrition If an individual consumes Z* of the nutrient j, Figure 2 suggests that the individual would be getting enough

of nutrient j and so there would be no reduction in ones capacity for work. However if one consumes less than Z* then the impacts of malnutrition are small but non-zero. These increase to as the level of nutritional deficiency with respect to nutrient j increase.

So if a research project changes the supply function of commodity 1 and thereby reduce the relative price of the commodity, one would consume more of commodity 1 and will thereby increase one's intake of characteristic j. However, the research project will not yield research benefits to an individual is already (before research) consuming Z*.

For individuals who are deficient with respect to nutrient j a project that increase the supply of commodity 1 will move them up along the curve CZ* and thereby reduce their level of nutritional deficiency.

Figure 3 suggests that the human health and labour productivity effects of malnutrition can be modelled in terms of their impact on the supply of labour In figure 3, Quadrant I relates the supply of labour of individuals in a given group h to the market wage rate W*. The wage rate W* can be interpreted as the average wage rate As the average wage rate increase individuals in group h will supply more of their labour. The wage rate is on the horizontal axis, while on the vertical axis is the total supply of labour. The axis is labelled 'Labour units-u' to signal that these labour units available from group h have not been adjusted for the effects of malnutrition.

Quadrant II in Figure 3 adjusts the total supply of labour from group h for the effects of malnutrition In Figure 3, Quadrant II the line OJ adjusts the total supply of labour for malnutrition. The line OJ embodies the malnutrition effects in Figure 2. In Quadrant one can draw different lines similar to OJ for every point on CZ* in Figure 2. When the level of nutrient j consumed is equal to or more than Z*, then the corresponding line is a 45 degree line which indicates that the total supply of labour is not reduced by the presence of malnutrition effects. However, if the consumption of characteristic Z is less than Z*, then in Quadrant II of Figure 2, the distances OM will be less than OK meaning than the effective supply of labour (OM) is less than the physical supply of labour (OK).

Quadrant III represents the labour market for group h. W_h* is the equilibrium wage rate for group h. L_h* is the equilibrium level of employment for workers from group h. Quadrant IV relates the average wage rate W* and W_h* will only be equal when there are no malnutrition effects.

Figure 4 shows the effect of research which reduces some of the malnutrition effects. A project based on commodity 1 changes the slope of line in Quadrant II from V'V to J'J. This translates into a shift in the labour supply curve from S_{Lh}(before) to S_{Lh} (after). The shaded area gives the benefits from nutrition related agricultural research and is estimated by an equation suggested below.

Figure 1 Household demand for commodities and characteristics or nutrients

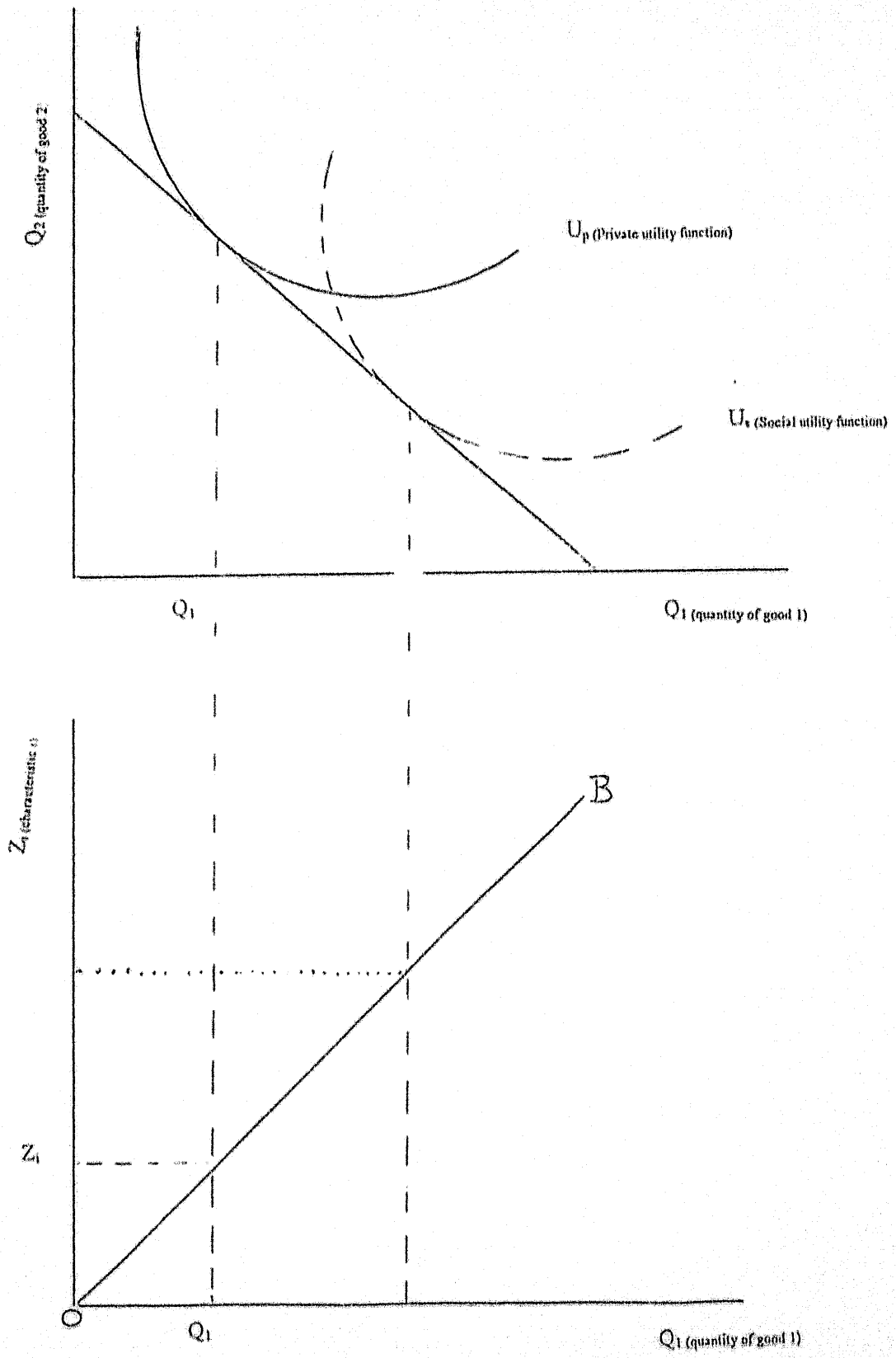


Figure 2 Household intake of characteristics or nutrients, and malnutrition effects

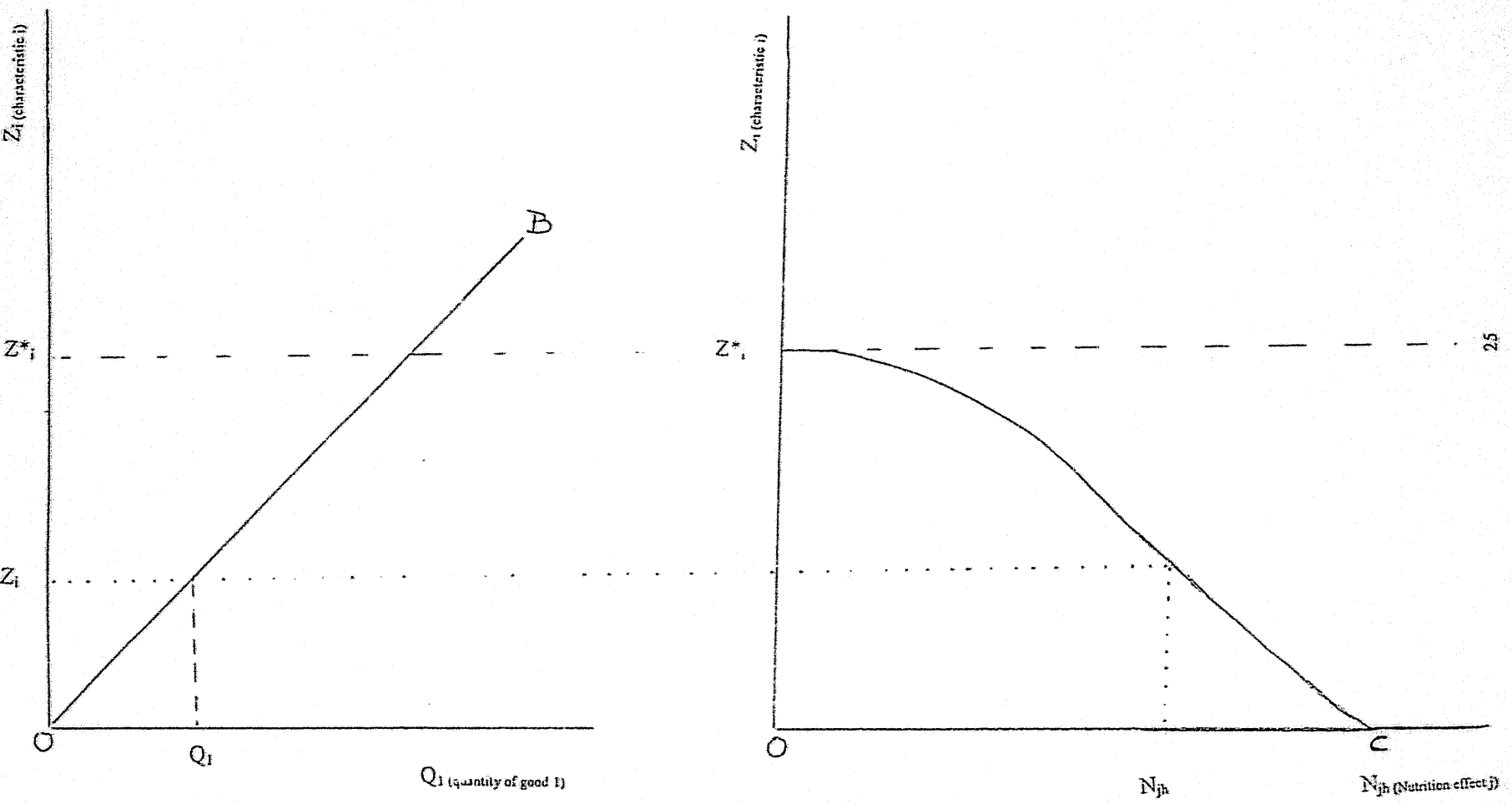
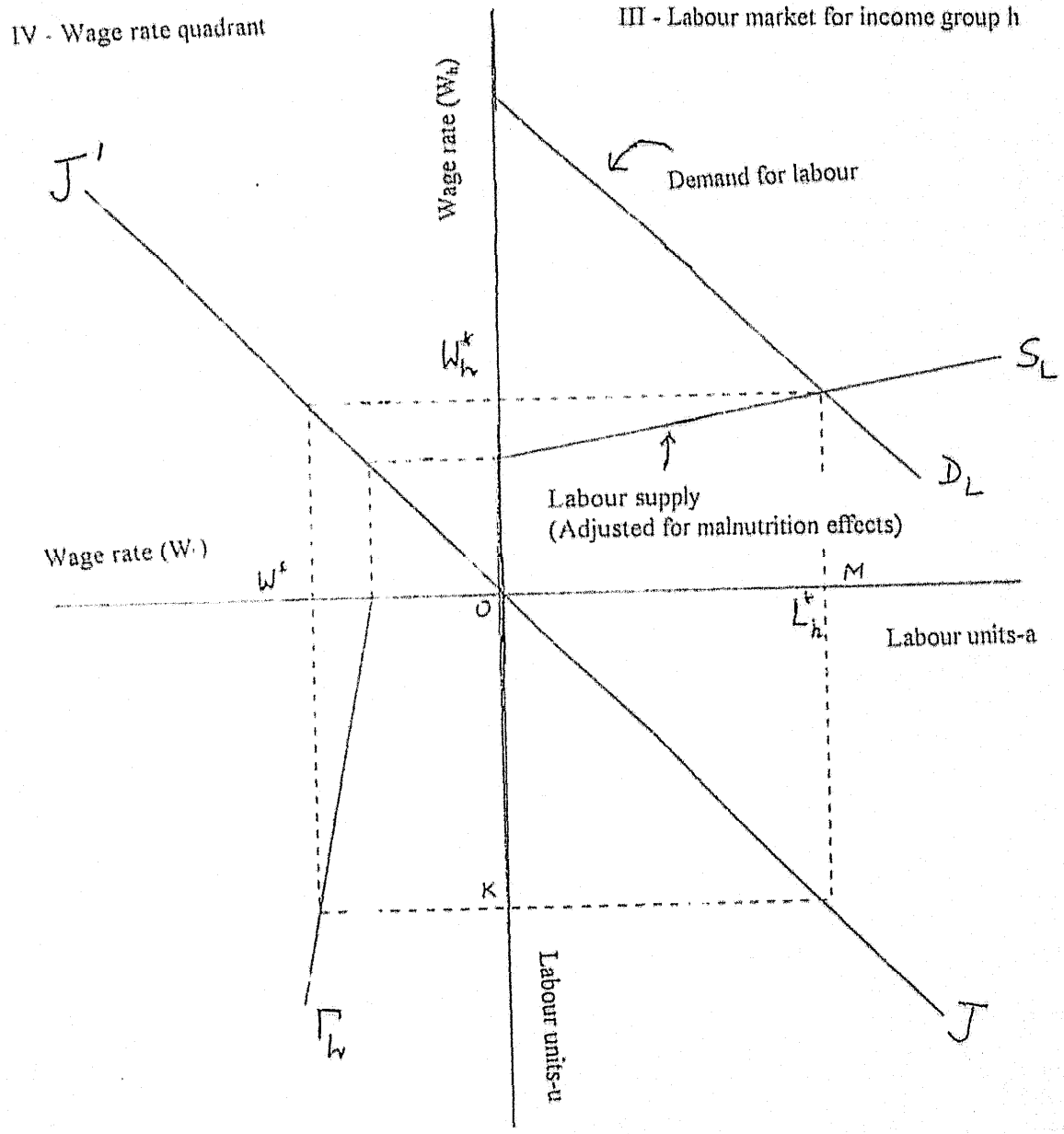


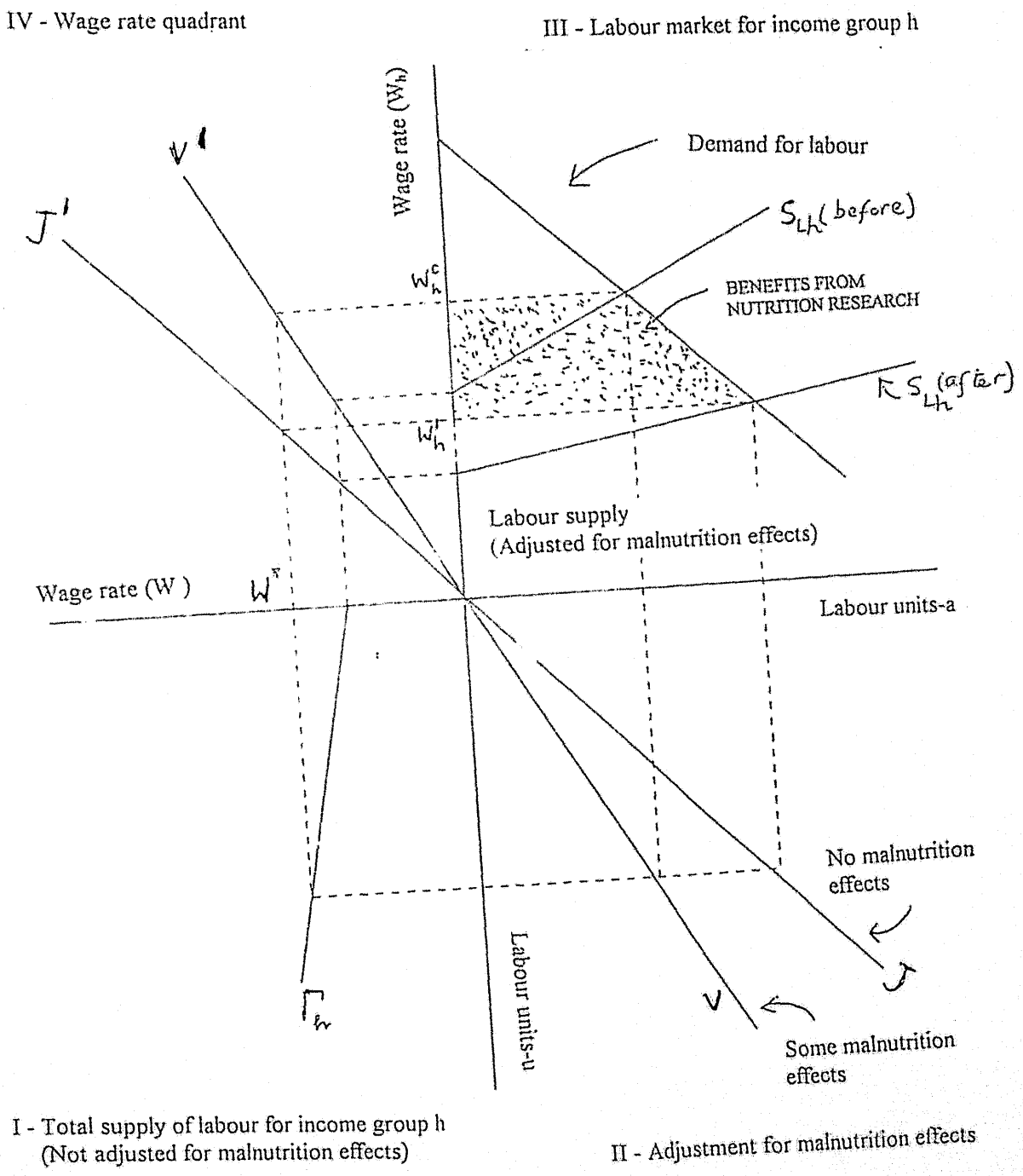
Figure 3: Before research: The labour market with no malnutrition effects



I - Total supply of labour for income group h
(Not adjusted for malnutrition effects)

II - Adjustment for malnutrition effects

Figure 4: Before and after research: The labour market with malnutrition effects



2.6 Revised equations for estimating welfare impacts of human nutrition-related research

Research which addresses human nutrition and labour productivity impacts of malnutrition is assumed to focus on some agricultural commodity. However, the impact of such research is measured in term of whether it reduces or increases human health effects of malnutrition and whether it has an impact on labour productivity. Thus while the research may be focused on a certain commodity and may in turn lead to changes in the quantities produced and the prices of various commodities, the equations used to estimate the benefits of that research are expressed in terms of the wage rate.

In a labour market equilibrium the wage rate should be set to equal the marginal revenue product of labour given by the product of the marginal physical product of labour and the marginal revenue derived from producing a given output. It is thus appropriate for the estimation of the benefits of research with potential to change the marginal physical product of labour to be estimated using equations involving the wage rate.

Equation (27b) shows aspects of the problem before research. The equation focuses on the labour market part of the problem and relates the total supply of labour of age g from group h to the mal-nutrition-adjusted supply of labour.

In situations where mal-nutrition is a problem, equation (27b) indicates that the mal-nutrition adjusted labour supply is less than the total supply of labour. This equation uses estimates of the before research human health effects of malnutrition which were denoted as (N_{1hg}, N_{2hg}, ..., N_{nhg}) in earlier sections. As discussed earlier the estimates of (N_{1hg}, N_{2hg}, ..., N_{nhg}) depend on the quantities consumed of various commodities, the characteristics matrix of those commodities, the prices of the commodities and the income of the household.

Note though that (N_{1hg}, N_{2hg}, ., N_{nhg}) could change for a variety of reasons For example, (N_{1hg}, N_{2hg}, ..., N_{nhg}) could change because research has led to one or more of the following:

- a reduction in the unit cost of producing a commodity with targeted characteristics;
- an increase in the supply of an agricultural commodity through a reduction in spoilage rates; or
- a change in the attributes of a commodity.

Each one of these will have a different commodity space diagram. However, if the research has an impact on human health and labour productivity, it will lead to a change in (N_{1hg}, N_{2hg}, ..., N_{nhg}).

If for a certain group (N_{1hg}, N_{2hg}, ..., N_{nhg}) are zero, then there is equality between the total un-adjusted supply of labour and the mal-nutrition adjusted supply of labour. In otherwise that particular group does not suffer from mal-nutrition-related human health and productivity effects.

The equilibrium wage rate w^0gh is given by the point of intersection of the demand and supply functions. The corresponding equilibrium hours worked by individuals from this group are given by L^0

Equation (31) shows the after research situation. When research changes (N_{1hg}, N_{2hg}, ..., N_{nhg}), this translates into a pivotal shift of the supply function. This leads to an increase in the supply of labour and a drop in the wage rate. The new equilibrium wage rate w^1gh is given by the point of intersection of the demand and supply functions. The corresponding after research equilibrium hours worked by individuals from this group are given by L^1

For a given sub-market involving individuals of age g and group h, the benefit from research can be estimated as follows. Let B_{hg} be the research benefit accruing to individuals of age g in group h. Then B_{hg} is given by the following equation:

$$B_{hg} = L^0 * \Delta w_{hg} + 0.5 * \Delta w_{hg} * \Delta L_{hg}$$

where

Δw_{hg} = $(w^0_{hg} - w^1_{hg})$ is the difference between the before and after research wage rates

ΔL = $(L^1 - L^0)$ is the difference betwen the after research and before research mal-nutrition adjusted labour supply

Total research benefits in a country are given by the following equation

$$\sum_{h=1}^{H}\sum_{g=g^*}^{G}[\ B_{hg}\ ] = \sum_{h=1}^{H}\sum_{g=g^*}^{G}[\ L^0_{hg} * \Delta w_{hg} + 0.5 * \Delta w_{hg} * \Delta L_{hg}\ ] \qquad (33)$$

3. Some possible applications of the model

The model proposed in this paper has not yet been applied in the evaluation of any project. This section briefly discusses two projects recently funded by ACIAR whose economic evaluations could be improved with the application of this model if the required information is available. One project dealt with the problem of hydrogen cyanide in cassava (see Lubulwa, 1995a, 1995b) while another dealt with aflatoxins in maize and peanuts (Lubulwa and Davis, 1994, 1995).

3.1 Hydrogen cyanide in cassava in Africa

Lubulwa (1995a, 1995b) describes a completed project assessment of an ACIAR project PN9007 entitled 'Cassava cyanide: Improved techniques for estimation and influence of environment on concentration' and an associated small project entitled 'Cassava safety: Development and evaluation of simple tests of the cyanogenic potential of cassava flour and cassava tubers'. The most important source of impact from this project is the discovery, during the duration of project PN9007, of cultivars of cassava with very low hydrogen cyanide potential. At the time of the review of the project (Wheeler and Dahniya, 1994), the project's

research outputs had not yet been expressed in terms of new cassava varieties or changes in cassava agronomy. However, it is estimated that the project is likely to have an impact on new cassava varieties, at the earliest, in 10 years' time (Dr Howard Bradbury, May 1995, Australian National University, Personal communication). The time lag between the end of the project and the start of impact is due to the length of time it takes for breeders to take the results of a research project and incorporate them in a new cultivar ready for release to farmers. The problem is that hydrogen cyanide potential is just one of many cassava attributes that farmers look for in a cassava cultivar.

Cassava is the most important food crop in the humid and semi-humid tropics of Africa but it contains, in about 10 to 1 ratio, cyanogenic glucosides called linamarin and lotaustralin. These two glucosides are hydrolysed by the enzyme linamarase, also present in cassava, with the rapid liberation of cyanohydrins that break down to highly toxic hydrogen cyanide.

These glucosides are present in all parts of the cassava plant ranging from the tuber, the tuber's peel and the cassava leaf. Acute intoxication and sometimes death from ingestion of cassava has been reported in the past (Bokanga et al, 1994). In addition to fatal effects of consuming cassava with high hydrogen cyanide potential, regular exposure to sublethal quantities of cyanide, either in the diet or inhaled during cooking, may cause various disorders including (see Bokanga et al, 1994):

- epidemic spastic paraparesis (Cliff, 1994) known in central Africa as konzo - konzo occurs abruptly and affects mainly women in the fertile age group and children above the age of three (Howlett, 1994), and leads to the crippling and in some cases the death of affected women and children;
- tropical ataxic neuropathy, TAN (Osuntokun, 1994) - this condition develops slowly with a patient progressively getting worse, attacks both male and females of all age groups with a mean age of 40, and with peak incidence in the 5th and 6th decades of life (Howlett, 1994, Osuntokun, 1994);
- the worsening of iodine deficiency disorders (Bokanga et al, 1994) including:

- goitre, the enlargement of the thyroid gland; and
- cretinism, a severe form of mental retardation; and

- risk of diabetes (Bokanga et al, 1994).

Lubulwa (1995a, 1995b) estimated the potential human health effects that are likely to flow from the adoption of the results from the project. The assessment focuses on the possible reduction in the incidence of konzo and TAN after the adoption of results from the project. The analysis excludes other effects because of lack of data.

3.2. Aflatoxins in Southeast Asian foods

Lubulwa and Davis (1994, 1995) identified from the scientific literature five potential impacts of fungi and aflatoxins, namely:

- quality deterioration in the agricultural products;
- spoilage of the agricultural products;
- mutagenic and carcinogenic effects on humans who consume aflatoxin-contaminated food over a long time-period;
- livestock health and productivity effects arising from the use of aflatoxin-contaminated feedstuffs, the emphasis is on increases in mortality rates and reductions in feed to weight conversion ratios for chickens, ducks, egg layers, and pigs; and
- the loss of export markets due to aflatoxin regulations restricting international trade in aflatoxin-contaminated grains.

Research under the two ACIAR projects provided information which made it possible to assess the magnitude of these impacts in the South East Asian context. In Lubulwa and Davis (1994), very detailed information was available about the aflatoxin content of maize and peanuts in Indonesia Philippines and Thailand. However no information was available on the other nutrients (protein , calories, etc.) for these two commodities. This imbalance in the quantity and quality of information available about the characteristics matrix is likely to be one of the constraints in the application of this model.

4 Concluding remarks

The next step is to apply the model suggested in this paper to estimate the benefits from research projects which have a human nutrition focus. The first candidates in this activity will be those for which there has been some estimates made, namely: the projects on cyanide in cassava (Lubulwa, 1995a, 1995b) and the projects on aflatoxins in grains (Lubulwa and Davis, 1994, 1995).

This section concludes the paper by briefly discussing the information requirements which need to be met before the model can be applied in the estimation of benefits from human-nutrition related research projects. The information requirements of the model incorporating human nutrition impacts are compared with those of research evaluation models (see Davis et al, 1987) routinely used in the Economic Evaluation Unit of ACIAR in estimating research benefits from supply shifting agricultural research.

The table below indicates data requirements for the models in Davis et al (1987) and the research evaluation model proposed in this paper which has a focus on human nutrition impacts. The table indicates that the human nutrition research evaluation model is the most demanding in terms of information.

There are likely to be three data sub-sets which might be difficult to compile prior to the application of the human nutrition research evaluation model:

- It is necessary to resolve the issue of the number of agricultural commodities to include in the analysis. In the Columbian study, Per Pinstrup-Anderson et al (1976) included the following 22 commodities: Beef, Pork, Eggs, Milk, Rice, Milk, Rice, Maize, Beans, Lentils, Peas, Other grains, Potatoes, Cassava, Vegetables, Tomatoes, Plantain, Oranges, Other fruits, Bread and pastry, Butter and margarine, Sugar, Cooking oils and fats, Processed food. However, the issues relating to level of aggregation and to the mix of commodities need to be resolved possibly on a case by case basis

- The information on cross price elasticities is likely to be difficult to compile given that most data sets tend to focus on own price elasticities

- The information on the characteristics matrix would have to be collected from studies on the nutrient content of different foods. The nutrient composition of foods is unlikely to vary by much from country to country and thus it may be possible to use a single characteristics matrix in evaluating projects based in different countries.

- The information on the incidence of human health negative effects would be obtained from medical literature or obtained in form of subjective assessment from scientist with expert knowledge of the different human health effects and how they interact with nutrition following the practice in World Bank(1993)

While the information requirements of the research evaluation model incorporating human nutrition effects are onerous, attempts have to be made to compile that data. Without such data it is likely that funding of some projects designed to address human nutrition problems will be a waste of scarce resources. Alternatively, without that data it would be difficult to judge whether projects with a human nutrition focus will have achieved their objectives. The problem is that in the case of human nutrition related projects it is not enough that

- there has been a reduction in the unit cost of producing a commodity with targeted characteristics; or
- that there has been a change in the attributes of a commodity.

These are not enough because:

> 'Increases in nutrient supply will make a positive contribution to human nutrition only if the consumer is deficient in the particular nutrient in absence of the supply increase. Nutrient supply increases of equal magnitude but originating from different commodities may have different impacts on human nutrition because the distribution of the additional supply among consumer groups differs. Hence, it is essential to estimate not only expected increases in nutrient supply but also what proportion of the supply

increase will be consumed by deficient consumer groups and the resulting adjustments in the consumption of other foods' Per Pinstrup-Andersen et al (1976).

According to the model suggested here it is essential to go on and estimate the impact on the labour market and on human health costs which in turn enables one to estimate the monetary value of the benefits from human nutrition related research. The model proposed in this paper is a first step toward a comprehensive evaluation of human nutrition related research.

Data requirements of the research evaluation model incorporating human nutrition impacts

	Information type	Required by models in Davis et al (1987)	Required by models in Davis et al (1987)	Required by the human nutrition research evaluation model ?
		CLOSED ECONOMY	OPEN ECONOMY	
1	Quantity consumed and produced of the commodity targeted by research	Yes	Yes	Yes
2	Quantity consumed and produced globally of the commodity targeted by research	No	Yes	No
3.	Farmgate price of the commodity targeted by research	Yes	Yes and globally	Yes
4.	Wastage rate of the commodity targeted by research	If research is aimed at reducing product spoilage	If research is aimed at reducing product spoilage	If research is aimed at reducing product spoilage
5.	Postharvest cost of the commodity targeted by research	If research is aimed at reducing product spoilage	If research is aimed at reducing product spoilage	If research is aimed at reducing product spoilage
6	Own price demand and supply elasticities of the commodity targeted by research	Yes	Yes and globally	Yes
7	Quantity consumed and produced of other commodities not targeted by research	No, except probably when project involves new commodity	No	Yes
8	Transport costs to and from the world market for commodity targeted by research	No	Yes	No
9	Quantity consumed and produced of other commodities not targeted by research	No	No	Yes
10	Farmgate prices of the of other commodities not targeted by research	No, except probably when project involves new commodity	No	Yes
11	Wastage rate of the other commodities not targeted by research	No	No	Yes, if research is aimed at reducing product spoilage
12	Postharvest cost of the other commodities not targeted by research	No	No	Yes, if research is aimed at reducing product spoilage
13	Own price demand and supply elasticities of other commodities not targeted by research	No	No	Yes
14	Cross price elasticities of demand and supply of the commodity targeted by research with respect to prices of other commodities	No	No	Yes
15	Household income	No	No	Yes
16	Budget share for the commodity targeted by research	No	No	Yes
17	Budget shares for other commodities not targeted by research	No	No	Yes
18	Characteristics matrix for agricultural commodities	No	No	Yes
19	The matrix of the incidence of mal-nutrition related human health effects	No	No	Yes
20.	Inflation rate, time preference discount rate	Yes	Yes	Yes

REFERENCES

Alston, M. A., G. W. Norton and P. G. Pardey, 1995, Science under scarcity. Principles and practice for agricultural research evaluation and priority setting, Published for International Service for National Agricultural Research, Cornell University Press, Ithaca and London.

Basta, S. S., Samir, M. S. Soekirman, D. Karyadi and N. S. Scrimshaw. 1979. Iron-deficiency anemia and the productivity of adult males in Indonesia. The American Journal of Clinical Nutrition, Volume 32, pp. 916-925.

Behrman, J. R. 1993. The economic rationale for investing in nutrition in developing countries. World Development, Vol. 21. No 11, pp. 1749-1771.

Bokanga, M., Essers, A. J. A., Poulter, N., Rosling, H. and O. Tewe. Editors, 1994. International workshop on cassava safety, Ibadan, Nigeria, March 1-4 1994, Acta Horticulturae, International Society for Horticultural Science.

Bouis, H. E. 1990. Evaluating demand for calories for urban and rural populations in the Philippines: Implications for nutrition policy under economic recovery. World Develpment, Vol. 18, No. 2, pp. 281-299, 1990.

Calloway, D. H. 1995. Human nutrition: Food and micronutrient relationships. Agricultural Strategies for Micronutrients. Working Paper 1, International Food Policy Research Institute, Washington D.C.

Cliff, J. L. 1994. Cassava safety in times of war and drought in Mozambique. In Bokanga, M., Essers, A. J. A., Poulter, N., Rosling, H. and O. Tewe. Editors, 1994. International workshop on cassava safety, Ibadan, Nigeria, March 1-4 1994, Acta Horticulturae, International Society for Horticultural Science.

Cribb, J. 1995. Researchers sow seeds of nutrition. The Weekend Australian, February 11-12, 1995, P44

Crowley, S., K. Antioch, R. Carter, A. Waters, L. Conway, and C. Mathers(1992), The cost of diet-related disease in Australia, National Health and Medical Research Council, Australia, September 1992.

Davis J. S., 1993, "A Model for Evaluation of Waste Reducing Postharvest Research", Contributed Paper for the 37th Annual Conference of the Australian Agricultural Economics Society, Sydney University, February.

Davis, J. S., P. A. Oram and J. G. Ryan, 1987, Assessment of agricultural research priorities: an international perspective. ACIAR monograph 4. Australian Centre for International Agricultural Research, Canberra; and International Food Policy Research Institute, Washington.

FAO(1991), Trace elements in human nutrition in *Food Nutrition and Agriculture, Volume* 1 Issue 2/3 1991.

FAO(1992), Nutrition and development in *Food Nutrition and Agriculture, Volume Issue* 5/6 1992.

Frisch, R. 1959. A complete scheme for computing all direct and cross deamnd elasticites in a model with many sectors. Econometrica 27 (1959): 177-196.

Greene, L. S. 1977. Hyperendmic goiter, cretinism, and socila organisation in highland Ecuador. in Greene, L. S. Editor, 1977. Malnutrition, Behaviour, and socila organisation, Academic Press, New York.

Heywood, P. 1993. Nutrition and agricultural research. Report of a consultancy to the Australian Centre for International Agricultural Research. July 1993.

Hirshleifer, J. 1980. **Price theory and applications**. Second Edition. Prentice-Hall International, London.

Howlett, W. P. 1994. Konzo: A new human disease entity. In Bokanga, M., Essers, A. J. A., Poulter, N., Rosling, H. and O. Tewe. Editors, 1994. International workshop on cassava safety, Ibadan, Nigeria, March 1-4 1994, Acta Horticulturae, International Society for Horticultural Science.

Immink, M. and Viteri, V. 1981. Energy intake and productivity of Guatemalan sugarcane cutters: An empirical test of the efficiency wages hypothesis, parts I and II, Journal of Development Economics. Volume 92, pp. 251-287.

Just, R. E., D. L. Hueth and A. Schmitz (1982), *Applied Welfare Economics and Public Policy*, Prentice-Hall, Inc., Englewood Cliffs.

Lubulwa, G. 1983a. Commodity charactersitics and intertemporal inconsistency. Scottish Journal of Political Economy. Vol. 30. No. 1, February 1983.

Lubulwa, G. 1983b. A consumer with a time varying B-matrix. Recherches Economiques de Louvain. Volume 49, No. 1 March 1983.

Lubulwa G. (1995a): Completed project assessment: Cassava cyanide- Improved techniques for estimation, and influence of environment on concentration (PN9007) Economic Evaluation Working Paper series Draft, August 1995. ACIAR, Canberra. Paper presented at the Sixth Symposium of the International Society of Tropical Root Crops - Africa Branch (ISTRC- AB), October 22-28, 1995, Capital City, Lilongwe, Malawi.

Lubulwa, G (1995b), The human health benefits of research to reduce the hydrogen cyanide potential in cassava cultivars in Africa. in Okoroda, M. A.(Editor, Forthcoming) Root crops and Poverty Alleviation, International Society of Tropical Root Crops - Africa Branch (ISTRC- AB), IITA, Ibadan, Nigeria.

Lubulwa, A. S. G. and J. S. Davis 1994. Estimating the social costs of the impacts of fungi and aflatoxins,. in Highley et al. (1994, Editors), Stored Products Protection, Proceedings of the 6th International Working Conference in Stored-Product Protection, National Convention Centre, Canberra, 17 - 23 April 1994,. *CAB, International*, Wallingford, Oxford.

Lubulwa, G. and J. S. Davis. 1995. Completed project economic assessment of two ACIAR projects on fungi and aflatoxins (PN8806 and PN9104): a discussion of methodology issues and some estimates of potential benefits. In Highley E. et al. Editors. Forthcoming. Mycotoxin contamination in Grains. Papers presented at the 17th Technical Seminar on grain postharvest Technology 25-27 July 1995, Orient Star Hotel, Lumut, Perak, Malaysia. ACIAR Technical Paper Reports No. 37, ACIAR, Canberra.

Martorell, R. 1993. Enhancing human potential in Guatemalan adults through improved nutrition in early childhood. Nutrition Today. January/February 1993. pp. 6-13.

Osuntokun, B. O. 1994. Chronic cyanide intoxication of dietary origin and a degenerative neuropathy in Nigerians. In Bokanga, M., Essers, A. J. A., Poulter, N., Rosling, H. and O. Tewe. Editors, 1994. International workshop on cassava safety, Ibadan, Nigeria, March 1-4 1994, Acta Horticulturae, International Society for Horticultural Science.

Per Pinstrup-Anderson, N. Ruiz de Londono, and E. Hoover. 1976. The impact of increasing food supply on human nutrition: implications for commodity priorities in agricultural research and policy. *American Journal of Agricultural Economics*, May 1976.

Pudney, S. E. 1980. Disaggregated demand analysis: The estimation of a class of nonlinear demand systems. *Review of Economic Studies*, Vol 47, 1980.

Pudney, S. E. 1981. Instrumental variable estimation of a characteristics model of demand. *Review of Economic Studies*, Vol 48, 1981.

Satyanarayana, K. A., Nadamuni, N., Bina C., and B. S. N. Rao. 1977. Body size and work output. The American Journal of Clinical Nutrition, Volume 30, pp322-325

Strauss, J. 1986.Does better nutrition raise farm productivity? Journal of Political Economy, Volume 94. April 1986. pp297-320.

Suhardjo. 1986. The effect of iron intervention on work productivity of tea pickers (Bogor Agricultural University,Bogor, Indonesia), quoted by Behrman, J. R. 1993. The economic rationale for investing in nutrition in developing countries. World Development, Vol. 21. No 11, pp. 1749-1771.

Wheeler, J. L. and Dahniya, M. T. 1994. ACIAR Project 9007 Review Report. Cassava Cyanide: Improved techniques for estimation and influence of environment on conentration. A Review Report, March 1994. ACIAR, Canberra

Wolgemuth, J. C., M. Latham, A. Hall, A. Chester, and D. Crompton. 1982. Worker productivity and the nutritional status of Kenyan road construction laborers. American Journal of Clinical Nutrition. Vol 36 pp. 68-75.

World Bank. 1992. The World Bank Atlas. 25 Anniversary Edition. The World Bank. Washington DC

World Bank (1993), *World Development Report 1993, Investing in Health*, Oxford University Press, New York.