Public Disclosure Authorized

Public Disclosure Authorized

PHN Technical Note 85-12

A BENEFIT-COST ANALYSIS OF NUTRITIONAL INTERVENTIONS FOR ANEMIA REDUCTION

by

Henry M. Levin
Stanford University

July 1985

Population, Health and Nutrition Department
World Bank

The World Bank does not accept responsibility for the views expressed herein which are those of the author(s) and should not be attributed to the World Bank or to its affiliated organizations. The findings, interpretations, and conclusions are the results of research supported by the Bank; they do not necessarily represent official policy of the Bank. The designations employed, the presentation of material, and any maps used in this document are solely for the convenience of the reader and do not imply the expression of any opinion whatsoever on the part of the World Bank or its affiliates concerning the legal status of any country, territory, city, area, or of its authorities, or concerning the delimitations of its boundaries, or national affiliation.

TABLE OF CONTENTS

LIST OF TABLES

PHN Technical Note 85-12

A BENEFIT-COST ANALYSIS OF NUTRITIONAL INTERVENTIONS FOR ANEMIA REDUCTION

ABSTRACT

Iron-deficiency anemia is one of the most prevalent nutritional disorders in both the industrialized and less-developed countries. The purpose of this paper is to evaluate potential interventions for reducing anemia with a benefit-cost analysis. The study begins with a discussion of the origins and prevalence of anemia and proceeds to some of the consequences of anemia on work capacity, work output, learning, and other outcomes. Specific estimates are made of the effects of reducing anemia on work output.

Both medicinal supplementation and fortification of food with iron are considered as interventions. Each intervention is evaluated for the costs of specific strategies in less-developed societies, with particular emphasis on cost estimates for Indonesia, Kenya, and Mexico. Estimates of benefits are calculated for the value of additional work output in labor-surplus societies as well as assessments of other benefits. The results of the cost and benefit analysis are used to construct benefit-cost ratios for evaluating the investment potential of anemia interventions.

Under a wide range of assumptions, the benefit-cost ratios are found to be substantially greater than one. This is especially true of dietary fortification where the benefit-cost ratios were found to be between 7 and 70 for the three illustrative countries. But even dietary supplementation was found to show a range of benefits to cost of from 4 to 38 for the most reasonable set of assumptions. The study concludes that benefit-cost ratios of nutritional interventions to reduce anemia appear to be large, and field trials should be carried out in specific settings to see if the overall findings of this study are supported in particular cases.

* * * * * * * * * * * * *

Prepared by: Henry M. Levin, Consultant to the World Bank
Stanford University

July 1985

SUMMARY AND CONCLUSIONS

Although anemia is a serious nutritional problem around the world, it is especially severe in the tropics where regional studies have commonly found more than half of the population to be anemic. Populations that are especially at risk are infants, children, and women and especially pregnant or lactating women. Nutritional interventions focus on increasing iron intake (and folate where indicated) as well as increasing the dietary intake of foods or agents that will increase iron absorption. Especially important in increasing iron absorption from existing sources is the addition of ascorbic acid to the diet and foods that are rich in heme sources of iron such as meat, poultry, and fish.

Such interventions can take the form of medicinal supplementation through orally taken or injected iron compounds or dietary fortification through the addition of the appropriate compounds to food vehicles found in the normal diet. The latter is generally to be preferred because it has a lower distribution cost and does not require changes in behavior in order to improve Hb. Such interventions have been shown to raise Hb levels dramatically, especially among those with severe anemia.

There are many studies on the effects of Hb on human behavior, but the evidence seems to be most substantial in the area of work capacity and work output. Work capacity refers to various physiological indicators of the capability for doing work such as maximum oxygen uptake and the heart rate and production of lactates for any particular level of work effort. Experimental studies have shown that when Hb of anemic subjects is raised through nutritional interventions, the maximum oxygen uptake rises; and heart rate and lactates associated with a given work effort decline. Quantitative estimates are provided in the report.

Summaries of a large number of studies that relate Hb and changes in Hb to work output show similar conclusions. Among a wide range of national settings and measures of work, it appears that a 1 percent rise in Hb is associated with between a 1 and 2 percent increase in work output. This finding is remarkably robust among different investigations. Other studies show the relation of Hb to intellectual growth and school achievement, morbidity, infection, and so on.

Given an understanding of the nature of interventions and the benefits that might result from them, the report attempts to estimate the monetary values of the costs and benefits. Costs are estimated for medicinal supplementation and for dietary fortification. In both cases, the costs are estimated by first stipulating the resources that would be required for the interventions such as personnel, facilities, transportation, supplies, and iron compounds or ascorbic acid. The costs of these resources are estimated under different assumptions regarding the markets for them in different settings. In addition, the cost estimates take account of additional caloric requirements of workers with higher work output as a result of anemia interventions.

Benefits are estimated by assessing the value of additional work output for agricultural workers in societies characterized by labor surpluses. They are predicated on the assumption that the additional output of a worker is equal to about half of the average wage of that worker in such a context. Benefits are also estimated for the non-labor market effects of reductions in anemia. The costs and benefits are calculated for agricultural workers in three countries: Indonesia, Kenya, and Mexico.

The estimated monetary value of benefits exceeds costs by substantial margins for all three countries for both supplementation and fortification. Under the most "reasonable" sets of assumptions, the benefit-cost ratios for fortification are estimated to be about 7 for Indonesia, 43 for Kenya, and 71 for Mexico. For supplementation, the comparable benefit-cost ratios are 6, 34, and 56. These high benefits relative to costs seem to hold under a wide variety of different assumptions regarding the calculations.

The overall conclusion is that nutrition interventions for reducing anemia appear to represent social investments that are highly productive and that ought to be considered seriously by the Bank. In addition, it would be useful to carry out field trials of interventions in which costs and benefits were estimated directly in order to see if the global results found in this study are supported by specific interventions at particular sites.

A BENEFIT-COST ANALYSIS OF NUTRITIONAL INTERVENTIONS FOR ANEMIA REDUCTION

I. INTRODUCTION

One of the most prevalent nutritional disorders in both industrialized and less-developed countries (LDC's) is iron-deficiency anemia (Baker and DeMaeyer 1979: 388-92; Charlton and Bothwell 1982; Fleming 1982; Masawe 1981). Anemia refers to a condition in which the hemoglobin concentration in the blood is considered to be below some normal value for a given population. Although anemia may be caused by other factors such as disease or blood loss, the most common cause is a deficiency of iron (Charlton and Bothwell 1982: 310-16). Such iron deficiency is typically a result of an inadequate intake of absorbable iron, relative to the needs of the body for forming hemoglobin and meeting other iron needs.

The hemoglobin level is particularly important, since it provides the oxygen-transport mechanism for the body. At low hemoglobin levels, the blood is restricted in its capacity to carry oxygen to the cells, limiting the ability of the body to produce energy and meet other functional needs. From a health-related perspective, the anemic person feels weak, listless, and may be more susceptible to infection. Work capacity is also impaired, and anemic children perform less well in school. Many of these behavioral outcomes of anemia have been summarized in reviews on the subject (e.g. Pollitt, Viteri, Saco-Pollitt, and Leibel 1982; Pollitt and Leibel 1976; Read 1975; Scrimshaw 1984).

The purpose of this study is to evaluate potential interventions for reducing iron-deficiency anemia in LDC's from the perspective of an investment in human resources as evaluated by a cost-benefit analysis (Sorkin 1976: 33-9). All investments have a cost which can be defined as the value of the resources utilized for the intervention (Levin 1983). The benefits are equivalent to the value of the outcomes that are produced by the intervention. In the case of interventions to reduce iron-deficiency anemia, the costs derive from the dietary iron supplements or fortification and the system for delivering them to insure that they are consumed by the appropriate populations. Potential benefits are associated with the improved feeling of well-being of the populations, improved fetal and child growth, lower morbidity and mortality, higher productivity both inside and outside of the workplace, more enjoyment of leisure, and more effective learning among students.

The case for using a cost-benefit analysis for evaluating programs for alleviating iron-deficiency anemia is straightforward. LDC's are characterized by a large number of challenges such as unemployment, health problems, nutritional deficiencies, poor education, inadequate housing and transportation. The potential responses to these problems are also many. Investments in health, nutrition, education, housing, transportation, water resources, and agricultural and industrial development all represent potential paths for improving the welfare of the population. But, it is likely that some investments will be relatively more productive in their impacts than others for any given resource outlay. The purpose of cost-benefit analysis is to ascertain if the benefits of a particular strategy exceed its costs and by how much. In this way one can compare the cost-benefit status of one alternative with others and can choose those alternatives which are likely to maximize the benefits to the society relative to their costs. In its ideal form, cost-benefit analysis provides a guideline for choosing investment priorities when resources are limited relative to the needs that they must address (Mishan 1976).

Ideally, this exploration would proceed from a case study or series of such studies in which interventions were undertaken under different sets of representative conditions. Precise measures would be available for all of the factors that were pertinent, and one need only place them into a benefit-cost framework to provide the necessary results. Unfortunately, no such case studies exist that provide systematic data for all of the pertinent relations. However, a large variety of studies exist that can be used to "construct" a picture of the magnitudes of benefits and costs of anemia interventions. The purpose of this study is to use available data to establish the overall parameters of benefits and costs for strategies to reduce nutritional anemia. A major emphasis will be on building a methodology that can be applied to new data as they arise or to specific field trials. In constructing this framework, a variety of assumptions will be used to establish linkages where more precise data are lacking. The attempt will be to make the methodology and assumptions transparent so that other assumptions can be imposed in order to see if they would modify the conclusions. This study should not be viewed as a substitute for one based upon field trials in specific settings, but only as an overall benefit-cost guide to anemia interventions.

The remainder of this report will be organized in the following way. Section II will discuss the prevalence and treatment of anemia. Section III will develop the potential benefits of anemia reduction, and Section IV will present the costs of interventions to reduce iron-deficiency anemia. Sections V and VI will develop specific calculations for costs and benefits respectively. The final section will integrate these results into a benefit-cost framework.

II. PREVALENCE AND TREATMENT OF ANEMIA

In this section we will present information on the prevalence of anemia and its treatment. Diagnosis of anemia is usually made on the basis of an evaluation of the hemoglobin content of the blood. Hemoglobin is a substance of iron (heme) and protein (globin) found in the red corpuscles of the blood that carries oxygen from the lungs to the tissues and some of the carbon dioxide from the tissues to the lungs. Each molecule of hemoglobin can carry four molecules of oxygen. In a non-anemic person, each liter of blood contains between 110 and 160 grams of hemoglobin. Hemoglobin accounts for about two-thirds of the 3.5 grams of iron in the healthy adult male. The standard test for anemia is to assess the concentration of hemoglobin, which is usually evaluated in grams per deciliter of blood (g/dl). An alternative measure is hematocrit which requires only a minute amount of blood and can be done in a small clinic or office. The hematocrit is about equal to the hemoglobin (Hb) concentration multiplied by 3, however it is a less reliable means of diagnosing anemia (Dallman 1982: 67).

Although groups like the World Health Organization (WHO) have established general criteria for determining if a person is anemic, the "normal" level of hemoglobin, at sea-level, will differ from person-to-person and population-to-population. For example, WHO (1968) defined the following levels of hemoglobin concentration in g/dl below which anemia is likely to be present: children 6 months to 6 years, 11; children 6 to 14 years, 12; adult males, 13; adult females, non-pregnant 12; and adult females, pregnant,11. However, these are considered to be general indicators of anemia rather than precise criteria. Likewise, iron requirements also differ among individuals and groups. Daily requirements of iron that must be absorbed to maintain homeostasis are estimated to range from .7 mg for infants and .9 mg for men to about 3 mg for women in the second half of pregnancy (Baker and DeMaeyer 1979:375).

One method of ascertaining if an individual is anemic is to establish an initial hemoglobin or hematocrit level followed by dietary supplement with iron and a subsequent measurement of hemoglobin or hematocrit. Those persons whose hemoglobin or hematocrit levels rise as a response to supplementation are considered to have been anemic. The larger the response, the more serious the anemia. For any population it is possible to relate different initial levels of hemoglobin concentrations with response rates to determine a "cutoff" value for Hb that would predict that persons below that level were anemic (Leibel, Pollitt, Kim and Viteri 1982). Cook and Finch (1979) have shown that alternative laboratory measurements of iron status may be more useful than Hb concentrations among some populations, particular those with mild iron deficiencies, and that in field trials it may be desirable to use multiple measures.

Anemia is a serious nutritional problem around the world, but especially in the tropics (Fleming 1977 & 1982; Masawe 1981; Woodruff

TABLE ONE

POPULATIONS AT RISK: ESTIMATED PERCENTAGE WITH HEMOGLOBIN CONCENTRATION BELOW THE NORM FOR NON-ANEMIC SUBJECTS

Country	Date	Age	Sex	Urban/Rural	% Anemic
Bangladesh	1976[2]	adult	F-pregnant	Urban	66a
Burma	1976[1]	adult	F-pregnant	Urban	82a
Burma	1972[2]	adult	F-pregnant	Urban	47-41a
Burma	1972[4]	pre-school	M/F		3-27c
Fiji (Indian)	1970[4]	adult	M		80c
North India	1968[1]	adult	F-pregnant	Rural	80a
North India	1973[4]	children	M/F		90b
		adult	M/F		48g/84c
South India	1968/1973[1]	adult	F-pregnant	Mainly Urban	57.4a
South India	1975[2]	children	M/F	Rural	76c
		adult	M	Rural	56c
		adult	F	Rural	81c
India	1975[2]	adult	F-pregnant	Urban/Rural	88a
Indonesia (East Java)	1980[2]	adult	F-Pregnant	Rural	37a
			F		30c
Indonesia (West & Central Java, Bali)	1973[2]	adult	F-pregant	Rural	65a
Jamica	1979[4]	pre-school	M/F		76c
Kenya	1957[3]	adult	M/F	Rural	32.3e
Latin America	1971[1]	adult	F-pregnant	Mixed	26.5a
Latin America	1971[4]	adult	M	Mixed	4c
Mauritius	1960[3]	pre-school	M/F		50d
Malaysia	1964[2]	adult	F-pregnant	Urban	75a
Mexico	1968[1]	adult	F-pregnant	Rural	26.6a
Nepal	1977[2]	adult	F-pregnant	Urban	35a
Pakistan	1970[2]	adult	F-pregnant	Urban	73a

TABLE 1: (continued)

Country	Date	Age	Sex	Urban/Rural	% Anemic
Philippines	1971[2]	adult	F-pregnant	Urban	63a
Philippines	2976[2]	adult	F-pregnant	Urban	72a
Philippines	1976[4]	pre-school	M/F		42c
		adult	M		7c
		adult	F		37c
Poland	1968[1]	adult	F-pregnant	Urban	21.8a
South Africa (Natal)	1976[3]	adult	M		44.3c
		adult	F		38.1c
Singapore	1972[2]	adult	F-pregnant	Urban Indian	20b
				Urban Malay	21b
				Urban Chinese	6b
Sri Lanka	1957[2]	adult	F-pregnant	Rural	50a
Sri Lanka	2974[4]	adult	F		50c
		adult	M		48g
Tanzania	1973[3]	adult	M/F	Rural	37.3f
Thailand (Bangkok)	1980[2]	adult	F-pregnant	Urban	80a
Thailand (Ubal)	1971[2]	adult	F-pregnant	Rural	48a
Thailand	1979[4]	pre-school	M/F		45c
		adult	M		35c
		adult	F		45c
Thailand	1980[2]	pre-school	M/F		15c
		children	M/F		33c
		15-49	M		15c
		15-49	F		18c
		over 49	M		34c
		over 49	F		51c

Criterion: a) Hb<11 b) Hb<10.5 c) WHO criteria--pre school<11, school children<12, adult males<13, adult females<12, pregnant females<11 d)Hb<10.8 e) Hb<8 f) Hb<10 g) Hb<12

Reference: 1) Baker & DeMaeyer, 1979 2) Baker, 1981 3) Masawe, 1981 4) Fleming, 1982

1972 & 1982). Table One shows populations at risk based upon a number of studies around the world. An attempt has been made to indicate the age, sex and pregnancy status, and urban-rural origin of the populations. In some of the studies, 80-90 percent of the population were found to be anemic. As expected, pregnant females seem especially at risk, but for adult males and females and children there are studies represented in the Table showing 80 percent or higher rates of anemia. There seems to be no particular pattern between urban and rural areas, with high incidences of anemia found in both.

A major recent survey of nutritional anemia among women in developing countries has been done by Royston (1982). Royston's review of the literature and summary of the statistics is unusually comprehensive with attempts to incorporate virtually all available data on hemoglobin concentration for women in developing countries according to pregant women, lactating women, non-pregnant women, and all women. His data suggest that it is common to find at least half the women below the norm on Hb for any particular classification, and in some cases the entire population is considered to be anemic.

Causes of Iron Deficiency

The treatment of anemia obvious depends upon its etiology. Fleming (1977) has delineated four factors that determine the iron status of the body: (1) iron intake; (2) absorption of iron; (3) physiological demands including growth, menstruation, and pregnancy; and (4) pathological loss through hemorrhage. With respect to iron intake, there are many organic and inorganic sources. For example, many typical foods have high iron content (Bogert, Briggs, and Calloway 1973: 269). Although a study in

Mauritius found an iron intake of only 5 mg a day and in India only 15-30 mg a day, a study in Ethiopia showed an intake of iron of as much as 180 mg a day (Fleming 1977: 316). Not only does the intake of iron vary widely among countries and regions and populations within countries, but the sources and forms of iron intake also vary considerably.

The absorption of iron from food depends on the source of the iron as well as other factors. Nutritionists distinguish between heme and non-heme sources of iron. Heme sources include meat, fish, and poultry. Iron is more readily absorbed from heme sources, than from the non-heme cereals and legumes that comprise the staple diet for most of the world (INACG 1982). Layrisse et al.(1969) and Layrisse and Martinez-Torres (1971) found that the mean absorption of iron in three major grains that often dominate the diet in developing societies (wheat, rice, and maize) was within the range of 1-7 percent, while for fish and meat the range was 12-20 percent. Even if heme forms of iron represent a small part of iron intake, their high levels of bio-availability mean that they are often the dominant source of usable iron.

Heme sources of iron (such as meat) are also important because they enhance iron absorption from non-heme sources. Thus, even small amounts of meat when added to cereal and legume diets can have a significant role in bio-availability of iron. Ascorbic acid is another significant factor in enhancing iron absorption along with other organic acids (Hallberg 1981). Many compounds have been found to inhibit absorption including carbonates, oxalates, phosphates, and phytates. Consumption of egg yolk and Indian tea are also important obstacles to absorption. Beyond these there will be different absorption rates among individuals because of differences in body chemistry as well as differences from chemical changes in food due to processing, storage, cooking, and interaction with other foods in a meal. Finally, absorption is highest when body stores of iron are most deficient and lower when storage iron is replenished or adequate.

Physiological factors affecting iron deficiency are those associated with the iron requirements of the body. There are special growth needs in infancy and childhood (Burman 1982) and adolescence (Lanzkowsky 1982). Pre-menopausal women need more iron than men because of the iron loss during menstruation, and pregnant women also have higher iron needs to meet the requirements of the fetus and placenta as do lactating women (Bothwell and Charlton 1981).

Pathological factors are those which cause bleeding with a resultant increase in iron requirements. The most common pathological factor in developing countries is that of hookworm infestation which has been estimated to affect almost half a billion people around the world (Charlton and Bothwell 1982:313). The number of worms and type will determine the blood loss and iron needs. Other types of parasites may also contribute to blood loss as well as any form of internal bleeding such as duodenal ulcers.

Dietary Interventions

In situations where there is a high prevalence of hookworm and other parasites that cause gastrointestinal bleeding, the alleviation of anemia will be problematic through nutritional interventions alone. Those situations may require investment to reduce parasite infestations such as anti-helminth drugs and sanitary water supplies as well as hygiene-education for the affected populations. However, even in these cases, dietary interventions may be in order. The purpose of dietary interventions is to increase the amount of iron intake and especially that of bio-available iron to replenish and maintain adequate hemoglobin concentrations.

Dietary interventions take two forms, supplementation and fortification (Baker and De Maeyer 1979: 393). Supplementation refers to the provision of an extra amount of nutrient in medicinal form. In this case, iron and other substances that enhance iron absorption can be given orally or by injection. Fortification refers to the addition of nutrients to foods to maintain or improve the quality of diet.

Callender (1982), INACG (1977), and Bothwell and Charlton (1981) among others have provided comprehensive reviews of the various forms of iron used for supplementation. Callender (1982) stresses that among the bewildering number of iron preparations available, the preferred choice is one that is highly absorbed and tolerated as well as having a low cost. With respect to absorption, reduced forms of iron are best. Also, it is generally accepted that the commonly used iron compounds (sulphate, lactate, fumarate, gluconate, glycine sulphate, and glutamate) with the same iron content given under standard conditions have about the same absorption rates (Brise and Hallberg 1962). Although "slow-release" preparations are designed to improve tolerance to iron, Callender (1982: 330-331) maintains that they have never been shown to have any significant advantage over simple iron preparations. All forms of iron are astringent and ingestion in large doses is frequently accompanied by nausea, abdominal pain, diarrhea, and constipation.

The level of supplementation must depend upon the degree of iron depletion, iron needs, bio-available iron from other sources, and absorption rates of supplemental intake. These factors will vary among populations, and clinical trials are usually recommended to determine optimal interventions (INACG 1977: 8-12; WHO 1975). A standard supplementary intervention for iron deficiency is 120-200 mg a day of ferrous sulphate or ferrous fumarate per adult with a smaller dosage for infants and children (Callender 1982: 332-334). Ferrous sulphate is one of the cheapest of all nutritional supplements, with costs estimated at only 68 cents a kilo in 1977 with other iron compounds ranging from two to seventeen times as costly as ferrous sulphate after adjusting for bio-availability (INACG 1977: 15; Bothwell and Charlton 1981: 44). It is important to note that while costs are still relatively low, they have risen by about 30 percent since 1977. Adding ascorbic acid to increase iron absorption from meals would increase costs, with both stabilized and unstabilized ascorbic acid estimated to cost between $10 and $11 per kilogram in 1982 (INACG 1982: 31). However, the additional cost may be justified. According to Bothwell and Charlton (1981: 52) the addition of 200 mg or more of ascorbic acid increases iron absorption by at least 30 percent.

In some cases, folate deficiency is also a cause of anemia, often in conjunction with iron deficiency. This is especially true for pregnant women. WHO has recommended that pregnant women with folate deficiencies should receive 2.5 to 4.0 milligrams of folic acid as a supplement (INACG 1977:21-22). The cost to UNICEF of 1000 tablets containing 60 mg of elemental iron in the the form of iron sulphate and 0.5 mg of folate was about $1.00 in 1981 of which the folate added only about 2 percent to total cost (DeMaeyer 1981: 366).

Dietary supplementation with iron is a short-run strategy designed to replete iron stores in a population. Its major weakness is the problem of getting compliance among the population to follow a regimen in which medicinal iron is taken on the recommended schedule and for the full period of supplementation. In contrast, dietary fortification is designed as a long-term strategy for maintaining iron status while requiring no special behavior on the part of its recipients.

The advantage of fortification of the existing diet is that the logistics and cost of delivery mechanisms for therapeutic supplementation are avoided while the population obtains iron through its daily diet. A major challenge is the choice of a food vehicle for fortification. WHO has set out the following criteria for choosing such a vehicle:

1- It is consumed by the vast majority of the target population in adequate amounts.

2- It is available for fortification on a large scale and at relatively few centers, so the fortification process can be adequately supervised.

3- The resultant product is stable under the extreme conditions likely to be encountered in storage and distribution.

4- The palatability of the vehicle, or other foods that the vehicle may be mixed with (e.g., in cooking) is unchanged (Baker and DeMaeyer 1979: 393-394; WHO 1975: 25-29).

In addition, WHO has suggested that iron compounds used in fortification must be readily absorbed when mixed with the vehicle and when the vehicle is added to the diet, must not cause changes in the color or taste of food, and must be stable under conditions in which it is used or stored (Baker and DeMaeyer 1979:394). Fortification strategies must begin with an analysis of the diet of the population and an evaluation of the appropriate vehicle and iron compound that are consistent with that diet.

The ideal vehicles for fortification may vary from country-to-country and perhaps, even region-to-region within country. In industrialized countries like the U.S. and Sweden, the fortification of wheat flour is common, improving the iron content of baked products and cereals. In the U.S. such enrichment has taken place since 1941 with iron levels in enriched wheat varying from about 29-36 mg/kg (INACG 1982: 14). However, in less-developed countries wheat is less likely to be centrally-milled or a dietary staple. The more common vehicles in the LDC's are salt, sugar, infant foods, condiments, and skimmed milk (WHO 1975: 27-28).

Because salt is consumed by all populations and is processed in relatively few centers, it has two important characteristics of a good vehicle. Perhaps its major drawback is that powdered iron and iron compounds tend to discolor salt, a process that is accelerated under high humidity. Also, the amount of salt intake may have to be high to provide adequate iron availability at a typical fortification level of 1 mg of iron per gram of salt (Food and Nutrition Board and UNICEF 1981). The addition of ascorbic acid or sodium hydrogen sulfate seems to reinforce absorbancy, perhaps offsetting this concern (WHO 1975: 27). Fortification of sugar is also attractive because it is widely consumed and often refined in just a few centers while not being discolored by certain iron compounds. However, fortified sugar does discolor tea, and very little refined sugar is consumed in many LDC's.

Since cereals and legumes represent the dietary staples in LDC's, the possibility of fortifying those must be considered (INACG 1982). Rice, wheat, and maize and other cereal grains are the most important source of energy for the world's populations (INACG 1982: 12-22). The problem with cereals is that their iron content is characterized by low bio-availability and absorption in the absence of heme forms of iron in the diet. Enrichment of such grains is possible, but there are a number of practical shortcomings. First, much of the production of these grains is done for home consumption or local markets, making central processing and distribution a difficult challenge. Second, although rice is the major staple for more than half of the world's population, it has not yet proven to be a satisfactory vehicle for fortification. Rice can be coated with an iron compound, but such a coating will be washed away during the rinsing and cooking process. Recent progress in fortifying rice may improve its feasibility as a future vehicle (Cook and Reusser 1983). Iron seems to be better absorbed in meals where wheat and rice are the main source of energy than in maize meals, although the form of the cereal will affect these results. For example, rolls made from maize starch do considerably better in iron bioavailability than maize porridge (INACG 1982: 19).

In general, it is agreed that the addition of small amounts of heme sources to the diet such as meat or fish (which unfortunately are either costly or unavailable in many instances) as well as foods with ascorbic acid may be more effective than iron fortification of cereals. The addition of iron to common spices and condiments is also a possibility. Typical cereal-based diets are bland, requiring the addition of sauces and other condiments to give them character. Many countries and regions of countries use specific sauces and condiments to flavor the diet. For example, in Thailand a fish sauce was used as a vehicle (Garby and Areekul 1974). The major drawback is that such sauces are often prepared in the household rather than in a central processing plant for market distribution.

Fortification of infant foods with various forms of iron and/or ascorbic acid is common. Specific vehicles include cereals, milk powders, and infant formulas. WHO recommends adding both iron salts and ascorbic acid to infant formulas in a ratio of iron:ascorbic acid of at least 1:10 (WHO 1975: 28). Skimmed milk fed to preschool children has also been used as a fortified vehicle.

Fortification with ascorbic acid is an important means for promoting iron absorption. Studies have found that salt fortified with ascorbic acid had the effect of increasing the absorption of the intrinsic iron in maize porridge or rice by 2-4 times (WHO 1975: 28). Indeed, even the addition of small amounts of ascorbic acid such as 25 mg to a simple maize meal tripled the absorption or iron, and 200 mg increased iron absorption six-fold (Hallberg 1981: 53-54). Dorman _et_ _al_. (1977) found that the addition of 50 mg of ascorbic acid through fortified sugar increased the absorption of iron nine-fold from maize-meal porridge. Finally, fortification of foods with folate should also be considered when its need has been established (WHO 1975: 29-30).

Table Two shows the results of a number of studies of iron supplementation and fortification. There are far more studies on supplementation than on fortification for a number of reasons. Supplementation can be done more easily in small trials than fortification, and the measurement of iron intake is more easily observed. In general, the following patterns seem to hold. When initial hemoglobin levels are low, iron supplementation is associated with very substantial rises in hemoglobin, even on the order of 60-100 percent. Relatively short periods of supplementation, for example 2-3 months, produce strong effects. However, it is likely that some dietary fortification would have to be present to sustain these gains.

The last two entries in the table show attempts at fortification. The Indian study used salt as the vehicle, while the study for Mauritius used wheat flour baked into bread. In the Indian study, results are available for three sites and several population groups. Only the results for 25-44 year olds are shown here, but they are also fairly representative of the other groups. Again, the general pattern that holds among the three sites is that the largest rises in Hb associated with fortification are found among populations with the most severe anemia. For example, the Calcutta females with mean initial Hb of 8.5 showed a 35 percent increase to 11.5, while the males in the Calcutta sample indicated an increase of similar magnitude from an Hb of 9.7 to 12.8 at the end of 12 months. Changes were considerably smaller at the two other sites where mean Hb levels were sufficiently high that the incidence of anemia--and especially severe anemia--was smaller.

III-- BENEFITS OF ANEMIA REDUCTION

The purpose of this section is to provide a summary of the benefits of anemia reduction. Such benefits can include a reduction in both maternal and infant mortality, in stunted growth and development, and in infection,

TABLE TWO

IRON INTERVENTIONS AND CHANGES IN HEMOGLOBIN LEVELS

STUDY	FORM OF IRON	AMOUNT	TIME PERIOD	Hb CHANGES
Sri Lanka males/females age 20-60 Edgerton, et al, 1979	Ferrous-Sulphate tab.	200mg/day	2months	10.8-12.8= 2 (19%)
Sri Lanka males/females age 39-54 Ohira, et al, 1981	Imferon I.V.	30-50/ml	1 week	Av. 5 groups Range=Before 6.4-14.1 After 7.6-14 = .66 (9%)
Norway males/females adolescents Vellar & Hermanson, 1971	Bivalent iron tab.	60mg/3Xday	9 months	11.8-13.4= 1.6 (14%) (females only)
Ireland females age 20+ Elwood & Hughes, 1970	Ferrous-carbonate tab.	150mg/day	2 months	10.5-12.5= 2 (19%)
Indonesia adult males Basta & Churchill, 1974	elemental iron	100mg/day	2 months	12-13.5= 1.5 (13%)
Indonesia adult males Basta et al, 1979	elemental iron	100mg/day	2 months	12-13.3= 1.3 (11%)
Tanzania males age 18-35 Davies & VanHaaren, 1973	oral iron	200mg/day	3 months	7.8-13.4= 5.6 (71%)
Venezuela males/females age 17-46 Gardner, et al 1975	iron dextron inject.		80 days	(F) 7.7-12.4= 4.7 (61%) (M) 7.1-14= 6.9 (97%)

TABLE TWO (continued)

STUDY	FORM OF IRON	AMOUNT	TIME PERIOD	Hb CHANGES
Guatemala adult men Viteri & Torun, 1974	elemental iron as ferrous sulphate	100mg/day- iron:5mg/day	6 months folic acid	9.5-14= 4.5 (47%)
India pregnant females (22 weeks) Sood et al, 1975	B12, folate & iron tab	100mg B12 fortnight 5mg folate-daily 120mg iron-daily	3 months	9.58-10.84= 1.26 (13%)
India pregnant females (22 weeks) Sood et al, 1975	B12, folate & iron tab	100mg B12 fortnight 5mg folate-daily 240mg iron-daily	3 months	9.43-10.82= 1.39 (15%)
Mauritius adult males Scott, 1960	ferrous sulphate-bread	extra 10 mg/ day	4 months	14.7-16.0= 1.3 (9%)
India males, females ages 25-44 Food & Nutrition Board and UNICEF 1981	elemental iron in salt	1mg/g salt	12-18 months	Madras (12mo) (M) 15.4-15.9= .5 (3%) (F) 12.4-12.9 = .5 (4%) Calcutta (12mo) (M) 9.7-12.8 = 3.1 (32%) (F) 8.5-11.5= 3 (35%) Hyderabad (18mo) (M) 13.7-14.4= .7 (5%) (F) 11.1-11.9= .8 (7%)

and rises in worker productivity of both market and home production, in feelings of well-being and in intellectual functioning. Clearly, a cost-benefit analysis should attempt to incorporate the value of all of these into a measure of benefits. However, some of these categories lack quantitative data on their relations to anemia (e.g. reduction in infection), and others are difficult to convert into monetary values even if the relational data were available. (e.g. feelings of wellbeing). Accordingly, most of the emphasis in this section will be on the relation between anemia on the one hand and work output and cognition or school attendance and progress on the other. The final section of this report will make an attempt to incorporate an estimate of all of the benefits in the construction of benefit-cost ratios.

Work Capacity

It is in the area of work capacity and work output that the reduction of anemia has the greatest demonstrable benefit. Both the underlying understanding of the effect of anemia on work capacity and the empirical literature provide strong support for this relation. Muscle cells need oxygen in order to function. Oxygen is carried by the hemoglobin through the bloodstream to the cells. If hemoglobin levels are low, then oxygen transport is impaired with a resultant limitation in human work capacity.

One measure of the effect of anemia on work capacity is its effect on maximal oxygen uptake (Astrand and Rodahl 1977: 334-344). Maximum oxygen uptake is the largest amount of oxygen that a person can take in during exercise. It is an indicator of the ability of a person to transport oxygen to the tissues, and it is considered to be a good indicator of fitness. The average middle age male has a maximal oxygen uptake of about 35-40 ml per kg of body weight per minute or about 2.5 liters of oxygen per minute (Bogert, Briggs, and Calloway 1973:482). Other indicators of fitness include the actual level of oxygen uptake and the heart rate for any exercise level (Astrand and Rodahl 1977: 344-347). The larger the actual level of oxygen uptake for any exercise level, the less that the body incurs an oxygen debt and accumulation of lactic acid. After the exercise is completed, an individual must take up additional oxygen to metabolize any accumulation of lactic acid. The lower the heart rate at any exercise level, the more fit is the individual to deliver oxygen to the tissues.

Experimental studies have found that increasing Hb concentrations through iron supplements is associated with an increase in oxygen uptake and lower heart rates. For example, Davies and Van Haaren (1973) divided male subjects between 18-35 years of age in Tanzania into two groups, those with low hemoglobin levels (Hb average = 7.8 g/dl) and those with high hemoglobin concentrations (Hb average = 13.7 g/dl). The subjects ingested 200 mg day of oral iron for three months with a resulting increase in Hb in the low group to 13.4 or 71 percent and a much smaller increase in the high group to Hb =14.1. A regimen of exercise was administered to both groups both before and after the iron supplementation.

After iron therapy both groups showed improved oxygen uptake (VO2) and maximal oxygen uptake (VO2 max). The latter was predicted from VO2 by using standard techniques. Heart rates were also lower, indicating that the higher concentration of hemoglobin permitted the heart to work less hard to deliver a given amount of oxygen. The low Hb group had increased its maximal oxygen uptake by 26 percent, while its average heart rate had declined by 15 percent. Changes were much smaller for the high group.

Elasticities were calculated to provide a standard measure for assessing the response of the various physiological measures of work capacity to changes in Hb. Although the concept and application of elasticities will be familiar to the economist, the non-economist should refer to any elementary textbook on economics for a discussion, for example, Heilbroner and Thurow (1975: 105-110). In this context, an elasticity will represent the percentage change in a work capacity or work output variable in response to a one percent change in Hb. An elasticity of 1 means that for each one percent change in Hb, there will be a 1 percent change in a specific measure of work capacity or work output. An elasticity of .5 means that a 1 percent change in Hb is associated with a .5 percent change in the pertinent measure of work capacity or output.

The advantage of using elasticities is that they represent a standardized method of characterizing responses to changes in Hb by representing them as the percentage increase (decrease) in a phenomenon associated with a one percent change in Hb. Although the elasticity is presented here as a constant or linear bi-variate relation, it is actually an estimate of a curvilinear relation between the two variables because it is a linear approximation of a logarithmic relation. That is, it is a linear estimate of the log of the dependent variable (work capacity or work output) and the log of the independent variable (hemoglobin). The elasticity assumes that when initial Hb is high, it will require a larger change in Hb to get an equivalent change in work capacity or work output than when initial Hb is low.

Elasticity = percentage change in work capacity or output/ percentage change in Hb.

In applying the use of elasticities to the results from Davies and Van Haaren (1977) presented above, each elasticity represents the percentage change in VO2, VO2 max, and heart rate for each one percent change in Hb. For the low Hb group the elasticity for VO2 max and heart rate were .36 and -.20, indicating that a one percent increase in Hb was associated with a .36 percent increase in VO2 max and a .20 percent decrease in heart rate. The comparable elasticities for the high group Hb group were .93 and -.24. The elasticities are actually larger for the subjects who had high initial Hb because the physiological changes are associated with very small improvements in Hb concentration.

Gardner _et_ _al_. 1975 administered iron dextron injections to highly anemic males and females in Venezuela. Initial Hb levels were 7.1 for males and 7.7 for females. After 80 days they had risen to 14.0 for the males and 12.4 for the females, increases of 97 percent and 61 percent respectively. Heart rates for a given exercise regimen declined from 155 to 113 for males and 152 to 123 for females, reductions of 26 percent and 15 percent respectively. The elasticities of heart rate with respect to Hb concentrations were -.44 for males and -.20 for females.

In cross-sectional studies by Davies (1973b) of males age 9-16 and by Davies, Chukweumeka and Van Haaren 1973 of males age 17-40, it was found that VO2, VO2 max, and heart rates varied in the expected ways with Hb. Comparisons of males with average Hb of 9.2 and those with Hb of 14.5 showed elasticities of .63 for VO2 max and -.36 for heart rates.

Work Output

The evidence suggests a consistent relation between Hb and various measures of work capacity. But, work capacity is not the same as work output. As the names imply, work capacity refers to the capability for performing work, while work output refers to the actual work that is achieved. Work capacity and work output may differ for a number of reasons.

First, work capacity is a limiting factor on the maximum amount of work that can be performed. If a job requires individuals to perform at sub-maximal levels, low Hb may not be a hindrance. The types of jobs that are likely to draw upon maximal aerobic capacities are those that are highly physical and require continuous exertion, jobs that require stamina. These jobs include much agricultural work, jobs in labor-intensive manufacturing that are typical of developing societies, jobs in infra-structure industries such as construction and mining, and various service jobs such as loading and unloading vehicles, transportation services by foot or foot-driven vehicles, and cleaning activities. They also include many household tasks such as cutting and carrying firewood, drawing water, and hand-grinding of grain. These jobs represent a very high proportion of work activities in developing societies. In contrast, such service occupations as office workers, cashiers, or sales clerks are less likely to draw upon the upper limits of oxygen uptake.

Of course, we should also bear in mind that even at lower levels of exercise, a fitter worker may be more proficient and produce more work output. The entire cardio-vascular system can work at a lower level of effort for delivering oxygen to the tissues, with less fatigue for the worker. But, a low Hb concentration is likely to be a limiting factor primarily for workers whose jobs are physically arduous.

Second, work output depends not only upon work capacity, but upon a large number of other factors that will determine the worker's activity. Among these are the mental and physiological capabilities of the worker such as intelligence, skills, motivation, size, strength, and stature. Other factors include the availability of work, access to tools and equipment, incentives to work, and supervision. Finally, outdoor work is especially affected by the weather so that rainfall can influence the amount of work that is achieved (Popkin 1978).

However, even given these differences, research has shown a close tie between Hb-related measures of work capacity and work output. For example, Davies (1973a) studied the relation of VO2 max to both productivity and absenteeism among 78 cane cutters aged 18-50 years old in Tanzania. Output per day was found to be positively related to VO2 max, and involuntary absences from work were found to be negatively related, both at significant statistical levels. When the levels of VO2 max (adjusted for body weight) on the one hand and daily productivity and absenteeism on the other were compared among groups of workers differentiated according to productivity, elasticities were very high. For example, the apparent elasticity of VO2 max on daily production between high and medium producers was over 2 and between medium and low producers was about 10. Comparable elasticities for the number of days voluntarily absent were 6 and 26. It should be emphasized that these elasticities are probably overstated, since other differences between the groups are not controlled in these analyses. Nevertheless, the potential relation is impressive.

Spurr et al. 1977 studied the nutritional status, bodily stature, and productivity of 46 sugar cane cutters between 18 and 34 years of age in Colombia. Iron status among these workers was relatively high with a range of Hb = 12.0-16.5 and a mean of Hb = 14.1. Differences in daily productivity were explained statistically by a regression equation in which VO2 max, percent body fat, and height were the explanatory variables. The VO2 max variable was statistically significant and an important determinant of productivity.

Table three shows the relation between hemoglobin levels and measures of work output for six studies that provide such data. Several measures of work output are used. These include the Harvard Step Test, Progressive Tread Mill, and measures of work output for latex tappers and weeders. The Harvard Step Test is a measure for selecting individuals according to their physical fitness that was developed during the Second World War. It requires an individual to repeatedly step up and down a 50 cm step at a particular rate designed so that only about one-third of the subjects

TABLE THREE

HEMOGLOBIN LEVELS AND MEASURES OF WORK OUTPUT

STUDY		Hb LEVELS		HARVARD STEP TEST (elast)		PROGRESSIVE TREADMILL (elast)			JOB ACTIVITIES (elast)	
1. Indonesia		Before	After	69.41	+(1.47)				Latex Tappers (kg/day)	
adult males		12	13.5	82.20					20.94	+(3.38)
Basta & Churchill, 1974,									29.78	
Basta *et al*. 1979									Weeders (sq.meter/day)	
									91	+(1.84)
									112	
2. Sri Lanka		Before	After							
10 males, 35 females,	L-L	6.4	7.6			6.2	9.5	+(2.83)		
age 39-54	L-H	7.5	8.8			11.1	16.6	+(2.55)		
Onira, *et al*. 1981	M-L	11.8	12.1			14.2	17.4	+(9)		
	M-H	11.9	12.3			15.9	16.5	+(1.12)		
	H-H	14.1	14.0			14.9	17.4	*		
3. Guatemala		Before	After							
adult males		9.5	14	47	+(1.21)					
Viteri & Torun, 1974				74						
4. Sri Lanka		Before	After						Tea (kg/day)	
females, age 20-60		7.5	11.5						15.6	+(.228)
Edgerton, *et al*. 1979									17.5	
									(drought season)	
5. Indonesia		Rentang								
males, age 25-28		Low = 8.6		64.0	+(0.38)					
Karyardi & Basta, 1973		High= 15.2		82.3						
		Saladarma								
		Low= 8.7		51.1						
		High= 15.6		74.4	+(0.58)					
		Halim								
		Low= 8.0		38.6						
		High= 15.6		76.5	+(1.03)					

TABLE THREE (continued)

STUDY		Hb LEVELS		HARVARD STEP TEST (elast)	PROGRESSIVE TREADMILL (elast)			JOB ACTIVITIES (elast)
		Before	After					
o. Sri Lanka females, age 22-65 Gardner, et al. 1977	L	6.5	8.5		10.4	13.7	+(1.031)	
	M	9.5	11.5		14.5	14.5	+(0)	
	H	12.5	13.5		16	18	+(1.56)	

*not calculated

should be able to perform the test for a 5 minute period (Astrand and Rodahl 1977: 344). The definition of HST scores is: greater than 89, excellent; 80-89, above average; 65-79, average to high average; 55-64, low average; less than 55, poor.

The progressive treadmill requires the subject to walk or jog at the speed of a treadmill which is set for a particular regimen that moves progressively faster and at a higher grade of climb, the longer the duration of the exercise. The measure of work output is the number of minutes that the individual is able to continue to exercise. However, since the longer the individual continues to exercise, the faster the speed, the amount of work output increases at a faster rate than is reflected in the length of the exercise period. This means that additional minutes for a performance of longer duration are more demanding than additional minutes beyond a shorter performance. Measures of job activity are determined by the activity itself. These include latex tapping, weeding, and tea picking.

The Hb levels in table three include before and after comparisons referring to Hb both before and after iron interventions for all cases except 5. In the case of study 2 and study 6, the subjects are also sub-divided into groups according to initial Hb levels. Study 5 compares separate anemic and non-anemic groups rather than the before-after intervention design.

Most of our attention will be devoted to the elasticity of work outputs with relation to the changes in Hb. In this case, each elasticity will refer to the approximate percentage change in work output for each percent change in Hb. Elasticities are shown in parentheses. Studies 1 and 3 show elasticities of over 1 for the Harvard Step Test, implying that percentage increases in Hb are associated with even greater percentage increases on the HST. For example, according to these two studies, a 10 percent increase in Hb would provide about a 15 percent increase in HST performance in the Indonesian sample in study 1 and a 12 percent increase in the Guatemalan sample in study 2. Since these represent the results comparing individuals both before and after iron supplementation, we can have a higher confidence in these results than in the somewhat lower elasticities generated in study 5 which compare anemic and non-anemic groups in three locations in Indonesia. However, it is also important to note that an evaluation of HST performance for individuals with different levels of HSB in Guatamala (Viteri and Torun 1974: 614) yields an estimated elasticity of about 1.6.

These relatively high elasticities are also supported by results for the progressive treadmill in studies 2 and 6 and the job activities in study 1. Study 2 breaks down the subjects into different initial Hb ranges. Although many of the elasticities are very high for the treadmill test, one should bear in mind that some of the result may be due to proficiencies gained in taking the test initially. In fact, the high-high Hb group shows a substantial improvement in the progressive treadmill without a change in Hb, suggesting results of practice, possible Hawthorne effects, or a combination of these and non-hematological effects of iron repletion that are associated with improvements in iron status. This latter explanation will be discussed below. Since additional minutes on the progressive treadmill are more arduous than previous minutes, the elasticities for the higher Hb groups are understated relative to the lower Hb groups.

Study 1 provides estimates for the same subjects for both the HST and for two job activities, latex tapping and weeding. The elasticity for the HST is less than half that for latex tapping and slightly lower than that for weeding. It may be that the HST task is too limiting to reflect the wider range of differences in job activities themselves. In any event, this evidence suggests that elasticities for the HST may understate what the elasticities would be for jobs for the same subjects. Although study 4 shows a very low elasticity of work output for tea pickers in Sri Lanka, the results were obtained during a drought when there was little tea to pick, regardless of work effort.

What is particularly interesting is the pattern of elasticities for groups with different initial Hb. One might expect that the elasticities would be higher for improvements in Hb among highly anemic populations, but no such pattern appears in the data. That is, the elasticities of responses in work output to changes in hemoglobin concentration seem to be similar for different levels of initial hemoglobin, even given that they are understated for higher levels of performance on the progressive treadmill. This pattern is probably not applicable to those populations with very appreciable iron stores, since it is unlikely that additional iron would improve their performance.

The overall results in Table Three suggest elasticities of work output in relation to increases in Hb of between 1 and 2. This suggests that a rise in Hb of 10 percent is associated with a rise in work output of between 10 and 20 percent. This range is further supported by an elaborate statistical study of road construction workers in the Philippines (Popkin 1978). Hemoglobin concentrations and other pertinent variables were used to explain differences in productivity with regard to the average daily output of workers in loading, unloading and tamping soil. The productivity measure was the number of cubic meters of firm soil per day achieved by the worker through the loading, unloading, and tamping process. Fifty-eight percent of the workers had hemoglobin levels of less than 13 with an average level for all workers of 12.4. A double-logarithmic regression in which daily soil output per worker was the dependent variable showed an elasticity of hemoglobin on work output of 1.45. The study also estimated non-logged regressions for days missed in the previous six weeks, the average time worked per day (based on time and motion evaluations), and the proportion of time worked in the day. Estimates of elasticities based on Popkin's data were: days missed, -3.55; time worked, 2.08; and percent of time worked, 1.79. Since the coefficient for days missed was not statistically significant, its precision is open to question; but the other coefficients were statistically significant. The range of elasticity results are consistent with those of the iron intervention studies in table three.

The only study that I am aware of that shows a lower elasticity on job activities is that of Kenyan road construction laborers (Wolgemuth, Latham, Hall, and Chesher 1982). These workers had unusually high levels of hemoglobin concentration for a rural region in an LDC, an average Hb of 13.3 and 13.0 for the two female samples and 14.71 and 14.53 for the two male samples. Although this study found that the impact of a dietary supplement which included caloric, protein, and iron inputs increased worker productivity by about 12.5 percent, the separate effects of the iron intervention on productivity were not isolated by the analysis. However, Hb was included as an explanatory variable in a regression equation on productivity for the pre-intervention sample. On the basis of the regression coefficient for Hb, my computed elasticity coefficient was .64. In interpreting this result, the very high average Hb and the high altitude for the sample should be taken into account.

With the exception of the Kenyan study and the Sri Lanka tea pickers in which the drought had intervened, the range of elasticities seems to be about 1 to 2 with 1.5 being the best overall approximation. But, how can one reconcile these high elasticities with the much smaller ones relating Hb and such physiological indicators as VO2 max or heart rates?

Such differences are perfectly consistent if one acknowledges that some of the effect of iron status on work output is likely to be correlated with, but independent of, Hb. With an improvement in iron status of the individual, both hemotological and non-hemotological factors may improve work performance so that measures of Hb and oxygen uptake may reflect only a partial picture of the underlying relations (Edgerton, Ohira, Gardner, and Senewiratne 1982: 146-150). To the degree that increases in iron intake and Hb are correlated, rises in Hb will serve as a statistical surrogate for other iron-induced improvements in work output.

In this respect, it is important to note the recent research focus on the non-hemotological effects of iron deficiency (Mackler and Finch 1982; Jacobs 1982; Oski 1979). Support for an additional non-Hb effect of iron status on work output is provided by Ohira, Edgerton, et al. (1981) and Edgerton & Ohira (1981) who found that persons matched on Hb, but with higher levels of serum iron had substantially higher performances on a treadmill. Also, Baker and DeMaeyer (1979: 386) cite a double-blind study by Ericsson in which subjects received an oral supplement of 120 mg of iron a day for three months resulting in increased work performance as measured on a bicycle ergometer, despite no increase in hemoglobin concentration. They conclude that this effect may be related to evidence in rat studies that iron deficiency is related to striated muscle dysfunction which is reversible with iron therapy. Effects of tissue iron deficiency are also summarized by Dallman (1981).

The presence of iron-induced effects on work performance that are not a result of elevated Hb is also consistent with the findings that the elasticities relating Hb to work output are considerably greater than those for VO2 max. If some of the improvement in work output associated with improved iron status is due to factors other than the effect on oxygen uptake--eg. effects on the muscles, brain, or nervous system--, then changes in Hb may also serve as a proxy for the correlated, but unmeasured, physiological and mental changes that affect work performance. This explanation is also supported by the very high elasticities that we calculated for VO2 max and both daily productivity and absenteeism in the Davies (1973) study. In that study, the elasticities between VO2 max and productivity were estimated to be 2 and 10 and those for VO2 max and absenteeism were estimated to be 6 and 26 for the different comparisons.

Finally, since our estimates of work output refer only to output on a particular activity (HST Or progressive treadmill) or daily work output at a particular job, they do not take account of effects of Hb in raising work output by reducing absenteeism. Workers with higher Hb will have higher daily outputs, and they will also work for more days of the month or year for reasons discussed in Davies (1973a). Thus, the elasticities for daily output would understate the elasticities of Hb with respect to monthly or annual work output. It is reasonable to conclude that an elasticity range of 1-2 is probably a conservative estimate of the relation between Hb and annual work output for the physically arduous tasks reflected in table three and that are so representative of work in labor-intensive agriculture and other work activities of LDC's.

Cognition and Schooling

A variety of studies has found effects of anemia on learning in infants, children, and adults (Leibel, Greenfield, and Pollitt 1979: 400-410). However, prior to very recent work, each of the individual studies has been open to reservations because of methodological shortcomings and inconsistencies in results. Moreover, differences in study populations, designs, and measures have produced a wide range of results so that a 1979 summary by noted authorities concluded that: "Despite strongly held clinical impressions and firm lay-person acceptance, there exists no unequivocal demonstration of an adverse effect of iron deficiency on intelligence, learning, attention, motivation, or general sense of well-being (Leibel, Greenfield, and Pollitt 1979: 431)."

However, subsequent work by the same authors with 3 to 6 year old children (Pollitt, Greenfield and Leibel 1982) as well as assessments of the findings of Lozoff et al. (1982a) and Oski and Honig (1978) and Oski (1979) have led to the conclusions that iron deficiency "...has adverse effects on cognition, and that these are reversible following iron repletion. The effects are mild and most probably located at the level of information reception (Pollitt, Viteri, Saco-Pollitt, and Leibel 1982: 297)."

More recently, Popkin and Lim-Ybanez (1982) have published an extensive analysis of the relation between nutrition and school achievement for 132 children, ages 12-14, in three rural and three urban schools in the Greater Manila area of the Philippines. A significant positive relation was found beteen Hb and the language test score, with no statistically siginificant relation between Hb and science or mathematics scores. Hb seemed to have no relation to student ability to concentrate or student participation in extra curricular activities. However, it showed a significant, but slight, negative relation to the number of days absent.

Moock and Leslie (1982) studied childhood malnutrition and schooling among about 400 school-age children from subsistance farm families in Nepal. They attempted to explain the probability of a child being enrolled in school and the progress of a child in terms of the grade level attained by using a host of parental, family, community, and child characteristics including Hb of the child. Although hemoglobin was not found to be statistically related to either school outcome, two anthropometric indicators of nutritional status, height for age and weight for height were important determinants. The more important of these variables seems to be height for age, and Jamison (1981) found that height for age was an important determinant of grade attainment in China. Since stunting may occur through anemia, it is quite possible that anemia has an indirect effect on school enrollment and grade attainment through its retarding effects on growth. However, the evidence on the relation between Hb and school success or intellectual growth is not as consistent as that relating Hb to work capacity and work output.

Other Areas of Potential Benefit

Anemia is associated with a number of other areas of debilitation that might be reduced through appropriate interventions. Summaries of the effects of severe anemia during pregnancy have established an association with increased risk of both maternal and fetal mortality and morbidity (INACG 1977: 2). Even milder anemia has been associated with premature delivery and low birthweight (INACG 1977: 2; Baker and DeMaeyer 1979:386). There is also some evidence that iron deficiency is associated with lower weight gains among infants and children (Baker and DeMayer 1979: 384; Burman 1982; Oski 1979). Many researchers believe that iron deficiency may increase susceptibility to infection, although the evidence is not straightforward (Baker and DeMaeyer 1979: 384-385; INACG 1977: 2-3; Nutrition Reviews 1975: 103-105), and there is some support for the view that iron deficiency is a defense against certain types of infections and is a factor reducing the probability of heart disease (Callender 1982: 327). Symptoms commonly associated with anemia are fatigue, headaches, weakness, lightheadedness, and irritability. Such phenomena are difficult to define and measure, and various studies have found no evidence between the extent of these symptoms and the severity of anemia (Leibel, Greenfield, and Pollitt 1979:399).

This section has discussed a number of potential benefits of anemia reduction and focussed in some detail on the decreases in work capacity and output associated with iron-deficiency anemia. The remaining parts of the report will address the calculations of costs and benefits.

IV COSTS OF INTERVENTIONS

Thus far we have reviewed the types of benefits that one might expect from reducing iron deficiency anemia as well as their magnitudes. Special attention was devoted to those associated with work output. In this section, we will address the costs of potential interventions for addressing iron-deficiency anemia, and in the following sections we will attempt to calculate the monetary value of both costs and benefits.

There are two major issues when addressing costs. First is the matter of what constitutes a cost and how to measure it. Second is the question of what factors are likely to determine the costs of interventions. In general, the term cost is used to refer to the sacrifice of a valued alternative. When resources are used to reduce anemia, the cost to society is the value of what is being given up in the best alternative use of those resources. This criterion is important because it distinguishes the economic definition of cost from a bookkeeping or accounting definition and from the issue of funding. Budgetary data typically understate the true cost of an intervention by omitting the value of resources that are contributed (e.g. facilities or volunteers) or understating the value of resources that are subsidized.

A straightforward approach that has been developed to estimate the costs of interventions is the ingredients method (Levin 1983). This approach requires an identification of the specific ingredients or resources that are likely to be required. Once the ingredients are identified and described in adequate detail, the value of each is determined by using standard costing methods. These costs are aggregated to determine the cost of the overall intervention, and they are analyzed according to whether one is concerned with the average cost per client or unit of service or some other criterion. Finally, the data can be used to to ascertain which constituencies are bearing the costs of an on-going project.

The costs of the intervention for any service level will be influenced by several types of factors. The most important are obviously the types of resources that are required, the costs of those resources, and the productivity of the intervention in providing services. In the ideal case we would obtain information from field trials of a range of proposed interventions in a variety of settings in order to establish resource requirements, costs, and productivity. In the absence of these data, one can rely on documentation from previous studies. However, little systematic collection and analysis of cost data is available on anemia intervention programs. In part, cost studies of other health interventions can be used as a guideline for evaluating costs (Robertson 1984), and particularly those studies that are somewhat analogous to supplementation such as immunization programs (Creese _et al_. 1982) or anti-helminth drug programs (Stephenson _et al_. 1983). In the case, of iron fortification programs there seems to be at least some direct evidence on costs (Cook and Reusser 1983).

Required Ingredients

Based upon these studies as well as the obvious requirements of medicinal supplementation of iron compounds, supplementation would require the following basic ingredients:

(1) Personnel--The main personnel costs at the site level are those associated with the distribution of the iron supplements; record keeping; and health education. In a small village these responsibilities might be incorporated into a full-time community health worker. In a larger setting there might be a division of labor with supervisory personnel, community health workers, clericals, and warehouse personnel. However, the latter might be considerably less costly per client served because of the economies of scale from a high client density.

(2) Medicinal Supplements--Clearly, a central ingredient is that of the iron compounds, folic acid, and absorbency enhancers such as ascorbic acid.

(3) Transportation--In order to distribute the supplements and provide information or instruction to clients, a system of transportation is needed. This can vary from public transportation and bicycles in urban areas to motorbikes or motorcycles in outlying areas with reasonable roads to four wheel vehicles or even animal transport in extremely remote areas. Equipment, maintenance, and fuel requirements must be taken into account.

(4) Facilities--At the village level the facilities requirement is likely to be minimal with a small office and storeroom being sufficient. The iron compounds and other supplements do not normally require refrigeration or other special treatment, although extreme heat and humidity may require special arrangements. In urban areas, the intervention could utilize a small portion of a larger health facility. In addition to the facility, such related ingredients as supplies, maintenance, and energy needs must be included.

Within these general categories, it is the precise ingredients required for an intervention that will determine costs. Factors that must be taken into account on the nature of the intervention (e.g. supplementation or fortification approach) include the severity of anemia and its specific causes; cultural and dietary characteristics of the population; and the degree to which an intervention delivery mechanism already exists.

Obviously, the iron supplementation or absorption enhancers used must take account of the etiology and severity of the anemia. Cultural and dietary differences may affect the receptiveness of the population to different forms of supplementation. For example, some populations may require an educational component to inform and encourage the selection of iron-rich food sources or to increase the likelihood that the dietary supplement is taken on a daily basis for the entire regimen. If a health or nutritional delivery mechanism already exists, few additional resources may be required to provide medicinal supplementation for reducing anemia. The costs of adding iron compounds to an existing fortification program may also be low in comparison with developing a unique program for iron fortification. In both of these cases the marginal costs of "piggy-backing" the delivery of iron compounds or absorbancy enhancers on existing programs will be low because few additional ingredients will be needed.

Cost of Ingredients

A second factor influencing intervention costs is the cost of each ingredient. The same ingredient may be characterized by widely different costs in different societies, based largely on considerations unique to each setting. For example, the relative scarcity of different types of labor in different labor markets will affect its costs. Creese *et al.* (1982:624) found that the daily salaries of capable vaccinators in

Indonesia and Thailand in 1979 differed by more than 250 percent. Facilities, equipment, and transportation costs will be heavily conditioned by the availability and quality of roads or other thoroughfares. The design and construction of facilities requirements may vary according to climate or the need for security. Even regional differences within a society such as urban-rural distinctions in labor markets, transportation, or weather conditions can be important sources of cost differences. Finally, the cost of pharmaceuticals may vary according to whether they are imported or manufactured domestically, government policies on imports, and the competitive structure of pharmaceutical markets.

Productivity of Service Delivery

The costs for servicing a given population will depend upon the efficiency with which a supplementation unit or fortification program functions as well as the ability to reach the target populations. The discussion of factors affecting organizational efficiency is beyond the scope of this paper. However, a major determinant of productivity, the number of clients that the delivery system can efficiently serve, is closely tied to the size and density of the geographical area as well as its transportation facilities. The high population density and relatively good transportation found in many urban areas enables a larger population to be served by a given configuration of ingredients than in rural areas and especially rural areas characterized by great distances among the population and poor roads. Clearly, if an organizational model with a given set of resources can serve 10,000 persons annually in some areas, but only 200-300 in other areas, costs will vary enormously.

V- CALCULATING COSTS

With this background on costs, it is possible to estimate the costs of hypothetical interventions for reducing iron-deficiency anemia. We will consider separately the costs of fortification, supplementation where the delivery system exists, and supplementation in the absence of a delivery system. Based upon the previous discussion, it is impossible to determine costs for a generic intervention because of the range of different circumstances that are likely to be encountered. Accordingly, the emphasis will be on the establishment of a range of costs. In each case the assumptions will be stated and their consequences so that the reader can modify them for any particular population or situation to bring them in line with other realities.

Costs of Fortification

Although supplementation with therapeutic doses of iron is often recommended as a short-term measure for improving iron status in a population, over the long run it is crucial to improve the dietary intake and absorption of iron through fortification. Daily requirements of iron that must be absorbed to maintain homeostasis are estimated to be from about .7 mg for infants and .9 mg for men to about 3.0 mg for women in the second half of pregnancy (Baker and DeMaeyer 1979: 375). But, some iron needs will be met through the normal diet, so fortification need only meet the daily shortfall. For example, if 75 percent of iron needs are met from conventional sources, only 25 percent need be met through fortification. Given the absorption rates of 15-20 percent associated with iron fortified sugar administered through different beverages (Layrisse et al. 1976), this means that the additional dietary input of iron that would have to be satisfied by this vehicle would be about 1.5 mg for men and about 4.3 mg for women in the second half of pregnancy. Accordingly, the maintenance of adequate iron status through dietary fortification requires relatively small amounts of iron in comparison with therapeutic supplementation for repletion of iron under conditions of severe iron deficiency.

Iron fortification is believed to be the optimal approach for reducing iron deficiency anemia because it requires virtually no special effort on the part of the population and has very low costs. The low costs are due to the fact that fortification simply entails the addition of such substances as iron or ascorbic acid to a food vehicle that is widely consumed. The only costs beyond those of the food vehicle which would normally be consumed are those associated with the costs of the fortifying nutrients and stabilizers and their processing into the food vehicle as well as any special packaging or distribution requirements.

The relatively low cost of general fortification programs is illustrated by the case of wheat flour fortification in India (Bender 1979: 168). Beginning in 1970, each ton of wheat or atta has been fortified with: edible grade groundnut flour (45-50% protein) 50 kg, retinol 9.2 g, riboflavin 1.38 g, nicotinic acid 7.6 g, thiamin 1.5 g, calcium diphosphate 800 g, ferrous sulphate 96 g, and calcium carbonate 800 9. This fortification added only 4 percent to the cost of wheat flour. However, a serious deficiency was the fact that only about 15 percent of the flour that was consumed each year was processed by the large mills where fortification could take place, with the rest ground in small, hand operated mills for local consumption. In fact, that is the central challenge of fortification, finding a vehicle that is consumed by most of the target population in adequate amounts; capable of being fortified in a few processing centers; palatable and relatively unchanged in appearance as a result of fortification; and that is stable under conditions of storage, use, and distribution.

Sugar and salt tend to be centrally processed so that fortification of a relatively high proportion of consumption is feasible. In addition, they are excellent vehicles for appropriate iron compounds with respect to appearance, taste, stability, and effectiveness (Report of the Working Group on Fortification of Salt With Iron 1982; Layrisse _et al_. 1976). In addition, it has been shown that both salt and sugar can be used to carry both iron compounds and ascorbic acid as an absorption enhancer with good results on iron absorption (Sayers _et al_. (1974) and Derman _et al_. (1977). We will focus on the costs of salt and sugar fortification because these seem to be the most widely tested vehicles, evidence on their effectiveness is available from field trials, and cost data exist. In contrast, other promising fortification vehicles are still in the developmental stages or need field trials to judge their effectiveness and costs (Cook and Reusser 1983).

We will base our cost analysis of salt fortification on the actual costs cited in the Report of the Working Group on Fortification of Salt with Iron (1982) in large scale field trials over 12-18 months at three rural sites and an urban one in India, each site covering 4000 to 6000 inhabitants. Fortification consisted of 3.5 grams of ferric orthophosphate added to each kilogram of common salt. This level was estimated to provide an additional 10-15 mg of iron intake a day in adults (at about 1 mg of elemental iron per gram of salt). Statistically significant increases in

Hb were found in the three sites for which valid data were obtained--the evaluation at one site encountered operational difficulties. The strongest effects were found in Calcutta where increases of about 3 g/dl in Hb over initial levels were found in contrast to little or no change in control groups. Changes in Hb were smaller at other sites, in about the range of .8 g/dl in Hyderbad and about .5 g/dl in Madras, with important differences by gender and age. As we noted in the discussion of Table Two, the severity of anemia was much greater in Calcutta, almost certainly accounting for the substantially greater Hb response to fortification. The fortification effort added about 20 percent to the cost of the salt (Working Group on Fortification of Salt with Iron 1983: 1450) or an estimated $0.07 per person per year (Cook and Reusser 1983:652).

The analysis of sugar as a fortification vehicle draws upon the field trials carried out in Guatemala by Viteri _et_ _al_. (1981) in which two communities in the highlands and one community in the lowlands received fortified sugar over a 31 month period. The changes in the prevalence of anemia were compared at the beginning and end of the fortification trials and were compared with two communities that had been selected as controls. Sugar was fortified with NaFE EDTA at a ratio of 13 mg of iron per 100 g. sugar. Mean daily consumption of sugar was 40 g., so that the approximate daily iron intake from the fortification source was over 5 mg. The incidence of anemia was reduced substantially in all of the communities receiving fortification in contrast with the controls. Biochemical indices of iron status also substantiated the changes. According to Cook and Reusser (1983: 653), the iron fortification added about 1-2 percent to the cost of sugar or about $0.10 a year per person.

In summary, studies of iron fortification of sugar and salt have both concluded that costs are less than $0.10 a year per person. However, we have been unable to obtain any systematic documentation that would account for, in detail, the processing and distribution costs, although some of these costs for salt fortification are discussed in Working Group on Fortification of Salt With Iron (1982: 1450) and Food and Nutrition Board and UNICEF (1981: Annex 3). Accordingly, we will make the conservative assumption that these costs do not fully account for the resources required for the intervention and will assume that they represent a lower limit with $0.30 a year per person as an upper limit and $0.20 a year per person as the intermediate or "best" estimate of the costs of iron fortification.

Experimental studies have also been carried out in which ascorbic acid was added to rice meals along with ferrous sulphate (Sayers et al. 1974). In one of the experiments, 4 mg of ferrous sulphate was added to a rice meal and compared with the effects of adding 4 mg of ferrous sulphate and 60 mg of ascorbic acid. The apparent effect of adding the ascorbic acid was to raise iron absorption from 4.2 percent to 12.2 percent. The study also used common salt as a carrier for both the ascorbic acid and ferrous sulphate and found no evidence of discoloration or change of taste in a temperate climate, although it stated that this could change under hot and humid conditions.

Derman et al. (1977) have reported on adding ascorbic acid to cane sugar. The ascorbic acid was dissolved in distilled water and sprayed onto the dampened sugar which was subsequently dried under warm air. They found that the process did not alter consumer acceptability. The addition of 50 mg of ascorbic acid through this carrier was shown to improve the absorption of iron nine-fold from maize-meal porridge. The authors concluded that fortification with ascorbic acid alone may be highly desirable when iron deficiency results from low absorption from a primarily cereal-based diet. The cost of stabilized ascorbic acid was estimated to be about $10.70 per kilogram in 1982 (INACG 1982: 31) representing a cost of about $0.39 a year per person for 100 mg daily (50 mg of ascorbic acid in each of two daily meals). There would also be an additional cost for fortifying the 3.65 kg. of sugar used as the carrier. While no costs are provided, it would be surprising if this relatively simple fortification process exceeded $0.20 for this small quantity. Accordingly, we estimate the total cost to be less than $0.60 a year per person.

Costs of Supplementation

There are two issues regarding supplementation that need emphasis. First, medicinal iron supplementation should be viewed as a short-run therapeutic strategy to raise the iron status of a population to normal levels in a relatively short period of time (e.g. three months). Once this is done, dietary fortification is the proper long-run strategy to maintain appropriate iron levels. Accordingly, a benefit-cost analysis should not view supplementation as an alternative to fortification, but as a complement. Even in the absence of medicinal supplementation, fortification can improve iron status immensely as the Indian salt study showed for the Calcutta sample, raising Hb from 8.5 for females and 9.7 for males to 11.5 and 12.8 respectively.

Second, the establishment of a delivery mechanism for a single dietary intervention does not make a great deal of sense for populations that are typically suffering from several dietary deficiencies or health problems.

Medicinal iron supplementation should be considered as one of a number of nutritional or health interventions provided by an overall system for delivering such services. There is a large fixed cost for establishing a health care or nutritional supplementation delivery system, a cost that can be shared among many interventions. For example, the marginal cost of providing an additional medicinal supplement under an existing delivery system may be little more than the cost of the supplement.

The construction of a delivery system to be used exclusively for iron supplementation would be both costly and wasteful, given the underutilization of its capacity to deliver jointly a variety of nutritional and health services. Accordingly, the most reasonable basis for making cost estimates for supplementation is to assume a "shared" delivery system in which the marginal or average cost per intervention is the pertinent one. At best, the single service delivery system for iron supplements should be viewed as an upper limit on costs.

The estimates of costs for supplementation will be based upon two different overall assumptions. In the first case it will be assumed that a delivery system exists that requires only the marginal addition of the dietary supplements in which case it is only the cost of the supplements that will be included. In the second case it will be assumed that a shared delivery system is used for at least four different dietary supplements or health services. We will attribute one-fourth of the overall costs of the delivery system to the anemia intervention as well as all of the costs of the iron and ascorbic acid supplements.

The strict marginal cost assumption for medicinal supplementation assumes that a nutritional or health care delivery system is already in place that provides a capability for delivering an additional service at only the additional cost of the supplement. In both the workplace and the community, such delivery mechanisms exist. For example, in both factories and farms, meals are sometimes provided to workers. Providing iron or ascorbic acid as medicinal supplements or in fortified meals would entail mainly the cost of the nutritional supplements. Likewise, the existence of community health delivery systems will enable the provision of an additional nutritional service along with other dietary and health interventions. In these cases, the marginal cost of providing medicinal supplements would be limited to the costs of the supplements themselves.

Based upon the interventions in Table Two, a typical intervention would provide 100-200 mg of ferrous sulphate a day for 2-3 months. Such a supplement would be expected to increase Hb by from 20-50 percent, depending upon the initial Hb, the specific populations, and the existence of parasites as well as other pertinent factors. In 1981 the cost to UNICEF of 1000 tablets of 60 mg of iron sulphate with .5 mg of folate was about $1.00 (DeMaeyer 1981:366) or about $1.10 a year for 180 mg per day. The U.S. government depot from which the U.S. Public Health Service obtains pharmaceuticals was charging $7.80 for 1000 tablets of 500 mg of ascorbic acid in March 1984 or a cost of less than $3.00 a year for one tablet a day. Presumably, the cost would be somewhat lower for a regimen of three tablets of 100 mg a day of ascorbate taken with meals to increase iron absorption. Or course, all ascorbic acid costs might be higher in developing societies unless the pharmaceuticals were purchased in large quantities and distributed by a multi-national organization such as UNICEF.

The supplemental intervention would be based upon using either medicinal iron or ascorbic acid. In the case of inadequate iron intake, the iron supplement would be the likely choice. In the case of inadequate absorption of iron, the ascorbic acid might be chosen. The massive iron supplement would not require absorption enhancers, and there is little evidence that enhancers can improve absorption of medicinal iron. Accordingly, the marginal cost of supplementation with an existing delivery mechanism would cost about $1.10 a year per person for iron with folate to about $3.00 a year per person with ascorbic acid.

The development of a delivery system for anemia interventions and other purposes requires more discussion. While we will refer generally to the requirements and costs of such a system, we will be particularly concerned with the approximate costs of the system when applied to Indonesia, Kenya, and Mexico. These countries will serve as illustrations for the benefit-cost analysis. The delivery system could be built around a community or village-based health care approach (Djukanovic and Mach 1975; Hetzel 1978; PAHO 1973; WHO 1979). Such a system makes heavy use of community resources as well as health auxiliaries or community health workers. The model is a general one with vastly different forms of implementation and cost implications in different societies (Robertson 1984).

Health auxiliaries are persons who have completed all or most of primary school and are literate in basic reading, writing, and computational skills. They are typically drawn from the local community, so that they will relate well to the populations whom they are serving.

They can deliver nutritional supplements and provide information on their use and the importance of taking the entire regimen. They are also able to provide innoculations and other health services.

Such personnel are given short training programs to assist them in learning the health functions that they will serve, the specific tasks that they will perform, and the information that they will need to answer basic questions and to provide health education. While they may work directly under supervisory personnel in larger centers, health auxiliaries in rural areas will have only occasional and intermittent contact with more highly training personnel or administrators.

The basic model that will be used here assumes that a health auxiliary can serve a large village of 1000 inhabitants or several smaller ones that add up to 1000 (e.g. two adjacent villages of 500 inhabitants each). Creese et al. (1982) has reported daily wages in 1979 of midwives and sanitarians in Indonesia, the Phillipines, and Thailand. Pay rates vary from $2.24 a day for a vaccinator in Indonesia or $560 a year for 250 days to $5.90 a day for a midwife in Thailand or about $1500 a year. We will assume that it is the higher figure that is necessary to obtain the skills and experience required. This figure is probably somewhat high for Indonesia where the cost of an inoculator for 250 days was less than $600 a year according to Creese's figures and for Kenya where according to Stephenson et al. (1983: 183), community field workers were used to provide antihelminth medications to children at a cost of $2.50 a day or about $625 for a 250 day year. In contrast, it may be low for Mexico, a factor that is taken account of in Section VII where a sensitivity analysis is done using the assumption of a very high cost of auxiliary health personnel, $4,500 a year.

Facilities for a single health auxiliary are likely to be minimal, requiring a small office with storage facilities. In rural areas the facility is likely to be constructed from local materials and by local labor at very low cost. We assume that in urban areas the costs will be higher. Accordingly, we estimate the cost of the facility at about $2,500 in low cost rural areas and about $10,000 in high cost urban areas, with about $5,000 in the middle range. Of course, in many cases the space requirements will be met by a room in a larger facility such as a community health center in an urban area or a school, church, or home in a rural area. If it is part of a larger facility in an urban area, the marginal cost of the space should certainly be less. Using a 10 percent interest rate, the annualized cost of a $10,000 facility with a 20 year life is about $1,175 and the annualized costs of $5,000 and $2,500 are $588 and $294 respectively (Levin 1983: 70).

Transportation can be provided by public systems, bicycle, moped, motorcycle, automobile, or four-wheel drive vehicle. In urban areas, public transportation, bicycles, and mopeds are feasible, while in rural areas the road conditions will determine the appropriate means of transport. Based upon current prices, we will assume the following purchase costs: bicycles $200; moped $800; motorcycle $2,500; small automobile $6,000; four wheel drive vehicle $10,000. Assuming a 6 year life and 10 percent interest rate for each, annual costs are: bicycle $46; moped $184; motorcycle $574; automobile $1,378; and four wheel drive vehicle $2,296.

We will assume operation and maintenance costs for each are about equal to the annualized cost of the vehicles so that the total annual cost will be: bicycle $92; moped $368; motorcycle $1148; automobile $2,756; and four wheel drive vehicle $4,592.

Although it is difficult to estimate the cost of materials and supplies (exclusive of medicinal supplements), it would seem that $1,000 would be sufficient. This would be used for records, communications, written information for literate clients, office supplies, and energy.

Table Four provides estimates of the annual cost of delivering medicinal supplements to reduce anemia. The ingredients for service delivery are estimated on the basis of low cost, medium cost, and high cost assumptions. Personnel costs and supplies are similar in all three cases, but different assumptions are made on facilities and transportation costs as discussed above. The total cost per year is about $3,200 for the low cost case, $5,800 for the medium cost case, and $8300 for the high cost case. Since it is also assumed that there are at least three other nutrional or health interventions that would be carried out under this approach, we divide the total costs by four to obtain the average costs for the anemia intervention. These values are divided by 1000 inhabitants to obtain per capita costs of service delivery. Clearly, the estimates would be lower if this service delivery model could cover more clients as in urban areas, and it would be more costly in very sparse areas where the population is too dispersed to be able to serve 1000 persons by this model.

TABLE FOUR

ESTIMATED ANNUAL COST FOR DELIVERING MEDICAL SUPPLEMENTS TO REDUCE ANEMIA (BASED ON SERVICE FOR 1,000 PERSONS)

Ingredients	Low Cost	Medium Cost	High Cost
Personnel	$1,500	$1,500	$1,500
Facilities	294	588	1,175
Transportation	368 (moped)	2,756 (auto)	4,592 (4 wheel drive)
Supplies	1,000	1,000	1,000
Total Cost	$3,162	$5,844	$8,267
Average Cost (Total Cost ÷ 4)	$ 791	$1,461	$2,067
Per Capita (÷ 1,000)	$ 0.79	$ 1.46	$ 2.07
Including Ferrous Sulphate	$ 1.89	$ 2.56	$ 3.17
Including Ascorbic Acid	$ 3.79	$ 4.46	$ 5.07

Population density has been a very important factor in explaining costs of immunization programs (Creese *et al*. 1982:629).

The per capita costs of service delivery are less than $1.00 for the low cost assumptions, about $1.50 for the medium cost assumptions, and a bit over $2.00 for the high cost assumptions. To these we must add the costs of the medicinal supplements resulting in costs of almost $2.00 a person with ferrous sulphate or almost $4.00 with ascorbic acid for the low cost model; about $2.50 with ferrous sulphate and $4.50 with ascorbic acid for the medium cost model; and about $3.00 with ferrous sulphate and $5.00 with ascorbic acid for the high cost model.

Higher Caloric Needs

The final identifiable cost for both fortification and supplementation is associated with the higher energy needs for non-anemic persons who are engaged in strenuous activities. Supplementation and fortification results in Table Two suggest increases in Hb of 7-50 percent or more from interventions. Using an elasticity of Hb on work output of 1.5, these Hb changes translate into potential increases in work output of between 30 and 75 percent. The reader is reminded that the elasticity represents the precentage change in work output associated with a one percent change in Hb. Thus, an elasticity of 1.5 suggests that each one percent increase in Hb is associated with a 1.5 percent increase in work output. Clearly such increases in work output would require an increase in energy to sustain over the long term (Viteri *et al*. 1971). This issue has been reflected in studies that have attempted to ascertain the conditions under which the cost of a higher caloric input for workers is justified by the value of the higher agricultural output that will be produced as well as the implications of the phenonmenon for rural labor markets (Immink and Viteri 1981 a & b; Mirralees 1976; Leibenstein 1958; Stiglitz 1976).

The obvious challenge is to ascertain what the additional caloric needs would be under different assumptions about gains in Hb and increases in work exertion. Although studies exist on how energy requirements increase among work activities of different intensities, our data on work output refer to higher levels of output for the same work activity. Energy needs depend also upon the temperature of the work environment and weight of the individual worker. For these reasons, generalization on the relation between higher work output and higher energy needs for the many different situations and populations in LDC's is problematic. Bogert, Briggs, and Calloway (1973: 44) provide data from a Canadian study that evaluated the energy requirements of different occupations among men and women and categorized them according to the intensity of activity and by weight of subjects. The requirements in kcal per day for persons in the 50th percentile according to weight, for men and women, were 2300 and 1900 respectively for sedentary activity; 2850 and 2400 for light activity; 3650 and 3000 for moderate activity; and 4250 and 3550 for heavy manual work or athletic training. A shift from sedentary activity to heavy manual work entailed an increase in daily requirements of 1950 calories for men and 1650 for women.

However, the average Canadian man at 72 kg and Canadian woman at 56 kilograms were considerably heavier than the average member of the at-risk populations in developing societies. While we have no overall weight factor for the latter groups, 60 kg would seem to be a more reasonable weight for men, a level about 17 percent less than the Canadian average. In the

Canadian data, a reduction in weight of 17 percent was associated with a reduction in the need for additional calories of about 14 percent. Accordingly, we might expect the increase in calories for workers in LDC's who shift from sedentary to heavy manual work to increase by about 1710 calories for males and by about 1450 for women. For a workforce that is about two-thirds male, the average increase would be about 1600.

Finally, this increase must be related to percentage increases in work output to be consistent with our measures of the effects of increases in Hb. Accordingly, we will assume that a shift from sedentary work to heavy manual work is equivalent to a 100 percent increase in work output in our data. This means that for every 10 percent increase in work output, there will be an additional daily caloric requirement per worker of 160 calories.

In order to provide an approximate cost for additional caloric intake, we will use the calorie content of a major food staple and its price. According to Watt and Merrill (1963:52), uncooked rice and corn meal both have a caloric content of about 365 calories/100 g. The unsubsidized price (reflecting the full cost) of rice in Indonesia in 1980 was about U.S. $0.34 per kg (Mears 1981:551) or a daily cost of about U.S. $0.0093 daily for an amount that would be expected to provide about 100 more calories. Corn meal was in the same range in Mexico. On the basis of 200 days of work a year, the additional cost of 100 calories would be about $1.86 a year, and for 300 days it would be $ 2.79. This means that for a daily increase of 400 calories--the amount associated with a 25 percent increase in work output--the annual cost would be almost $7.50, and for 800 additional calories, almost $15.00 for 200 days of work.

However, we should bear in mind that unlike the estimated costs of fortification and supplementation, these costs for additional energy requirements are per worker costs, rather than per capita ones. They must be divided among the entire population to make them consistent with the other cost estimates. Further, we will also show that some of the additional energy intake required for higher work output of a given worker will be offset by lower requirements for workers who are displaced in a labor surplus situation. Both of these adjustments will be discussed and implemented in Section VII. In the next section we will make estimates of benefits of the interventions, and in the final section we will combine them with costs to obtain benefit-cost results as well as addressing their policy consequences.

VI CALCULATING BENEFITS

Section III provided a survey of potential benefits of anemia reduction. Specific attention was devoted to the benefits of increased work output because the evidence on this dimension was substantial and consistent, its value can be estimated in labor markets, and it is clearly a major social benefit of reducing anemia. In this section, we will calculate the value of the benefits. While most of the attention will be devoted to the benefits of additional work output, we will also estimate the value of the other benefits of anemia reduction.

Before making these calculations, it is important to point out the labor market context for which benefits will be estimated. To a large degree labor markets in developing societies are composed predominantly of agricultural workers. For example, in 1979 about 71 percent of the labor force was engaged in agricultural activities in low-income countries as defined by the World Bank, and 43 percent of the labor force was in this sector in the middle-income countries (World Bank 1981:170-171). In the low income countries, about equal proportions--14-15 percent--were engaged in manufacturing and services. In the middle-income countries, the proportion in manufacturing was about 23 percent and in services was about 34 percent.

These countries were generally characterized by large labor surpluses and high rates of unemployment. They also had many localized labor markets, each characterized by different wages according to region of the country, urban-rural distinctions, season, and industry composition. Much of agricultural, handicraft, and housing output is produced for home consumption, and many markets do not approach the perfectly competitive model as large agricultural estates or factories dominate particular labor markets.

It is important to consider the implications of these labor markets for estimating benefits of higher work output. Raising iron status of workers was shown to be associated with higher work capacity and output. Although the relation is pertinent to even sub-maximal human activity, it is particularly pertinent to activities that make heavy and continuous physical demands on workers such as those in agriculture, construction, road-building, and many of the other activities of the primary labor force in developing societies.

While these findings might enable us to predict the increase in work output associated with an increase in Hb, the placing of a valuation on additional work output is more problematic. For example, productivities and wages differ substantially both within and among societies, so there is no possibility of a single estimate for valuing such added work output. In addition, the existence of surplus labor and high levels of unemployment will mean that some of the additional work output of the employed labor force will be translated into a need for fewer workers and greater unemployment.

Keeping these factors in mind, we can set out a number of steps for estimating benefits of anemia reduction. First, we need to stipulate the probable effect of specific types of interventions on Hb and their likely impact on work output. Second, we need to estimate the pecuniary value of the additional work output. This will require ascertaining an appropriate measure for assessing the value of additional output for any particular time unit (e.g. hour or day) and multiplying that by the number of hours or days of work per year to obtain an annual estimate. Third, the value of additional work output per person will have to be adjusted for the number of persons who are not in the productive labor force but are benefitting from the intervention to obtain a per-capita benefit. This will provide an overall estimate of the benefit per capita of the additional work output associated with a particular fortification or supplementation approach. Finally, an estimate must be made of the value of non-labor market benefits such as higher levels of home production, lower morbidity, improved physical stature and learning, and reduced mortality (particularly infant and maternal) which when added to the value of additional work output will provide a total benefit per capita.

Effects of Interventions on Hb

Based upon the various interventions described in Table Two and in the text, we wish to estimate the probable range of effects of interventions on

Hb. Effects range from about 5-30 percent for the different sites of the Indian salt study, based upon my reanalyses of the appropriate appendix tables in Food and Nutrition Board and UNICEF (1981). However, the higher figure for the Calcutta site seems so far above the other estimates that we will assume an upper value of 20 percent and a most likely value of 10 percent. We should bear in mind that the expected incremental change in Hb refers to the difference in Hb concentration expected in the absence of fortification versus that with fortification.

With respect to iron supplementation studies, most of the impacts on Hb are in the range of 10-50 percent although several are higher and at least one approaches 100 percent. It should be noted that supplementation is a short-run strategy to replenish iron stores among severely anemic persons. Low initial Hb in these populations and high iron intake are necessarily associated with a larger Hb response than in the less anemic populations receiving iron fortification. We will use 10 and 50 percent as the high and low values respectively for estimating the incremental change in Hb associated with iron supplements and 25 percent as the most likely value. We do not have evidence from field trials on the probable effects of ascorbic acid interventions.

Effects of Changes in Hb on Work Output

Based upon the results presented in Table Three and the text, we will assume that the elasticity of Hb changes on work output will be between 1 and 2 with the most likely value being 1.5. That means that for every increase of 1 percent in Hb, there will be an expected increase in work output of between 1 and 2 percent with the most likely increase being 1.5 percent. When these elasticities are applied to the expected changes in Hb resulting from the interventions, we obtain the estimated impact of the

TABLE FIVE

ESTIMATED IMPACT OF IRON INTERVENTIONS ON WORK OUTPUT

	Hb/Work Output Elasticity		
	1	1.5	2
Fortification:			
△ Hb = 5%	5%	7.5%	10%
△ Hb = 10%	10%	15%	20%
△ Hb = 20%	20%	30%	40%
Supplementation:			
△ Hb = 10%	10%	15%	20%
△ Hb = 25%	25%	37.5%	50%
△ Hb = 50%	50%	75%	100%

interventions on work output as shown in Table Six. This table shows the estimated increase in work output for arduous, physical occupations (e.g. labor intensive agriculture, road-building, construction) for the different assumptions regarding both Hb changes and the elasticities of Hb on work output. Many of the assumptions suggest dramatic effects. For example, even an increment in Hb of 20 percent and an elasticity on work output of 1.5 would suggest more than a 30 percent increase in work output.

Pecuniary Value of Work Output

The value of work output in different societies and in different parts of the same society will differ enormously. Factors determining the value include the organization of work, capital intensity, technology, and economic structure, and overall level of economic development as it affects the value of labor, goods, and services. In a perfectly competitive market economy that meets all of the textbook assumptions of large numbers of buyers and sellers, perfect factor mobility, flexible prices and wages, perfect information, and full employment of all resources, the equilibrium wage is assumed to approximate the value of worker productivity at the margin. However, labor markets in developing societies do not appear to approach this standard. Especially in agricultural production, much of output is produced on traditional family or community farms with very small holdings and no hired labor. Hired labor is found on the large plantations and estates, with labor markets dominated by a single employer or at the most a few employers. Traditional attachments to villages and poor transportation reduce labor mobility, and poor access to capital markets limits capital mobility. With a rapidly growing population and labor supply, there is a labor surplus even at subsistence wages or wages slightly above subsistence levels.

Now consider the social value of additional output. For the self-contained traditional farm, additional output can increase home consumption and raise the standard of living. But, if there is underemployment among family members comprising the work force of the traditional farm, the higher capability to produce output may not be fully realized. This is especially likely to be so during the seasonal lulls in agricultural activity created by weather or crop cycles. Of course, during periods of high employment (e.g. harvesting), the additional capabilities of workers can be put to full use. The same is true of hired labor. During periods of underemployment and unemployment, the higher output of less anemic workers may only serve to displace other workers who would have had more employment. However, during periods of peak labor demand, the higher work output attributible to anemia reduction should translate into higher social output. At one extreme, when there is a slack demand for labor and high unemployment or underemployment, increases in the productivity of one group of employed workers will just displace other workers who would have been employed, resulting in no net increase in social output.

At the other extreme, during periods of peak labor demand, the additional productivity of any worker will also increase total social output. Thus, the social value of additional output of a particular worker over a year is likely to be greater than zero, but less than his or her average productivity over the year (Gittinger 1982: 258-63; McDiarmid 1977).

Any estimate of the value of increased output associated with higher work capacity must take these employment effects into account. One method of estimating the additional output of a worker whose iron status has been improved is to begin by estimating his or her productivity as a reflecting of earnings. The gross value of the additional output due to greater work capacity can be estimated by applying the appropriate percentages in Table Five to expected earnings for that type of labor. But, this method does not take account of the displacement of other workers in a labor surplus situation, when worker productivity is increased. In order to adjust for this effect, economists attempt to assess the social opportunity cost of the "marginal" worker by asking how much of his/her output represents a gain in output for the society. That is, if such a worker were removed from production, to what degree would the employment of another--unemployed or underemployed--worker compensate for the loss of output of the first worker.

Extensive analysis of the Indonesian labor market has suggested that the marginal opportunity cost of rural agricultural labor is about one-third of the going agricultural wage for the year as a whole (The World Bank 1983: 127-8). However, in the LDC's, hired agricultural labor is typically employed on large estates by a single employer or a few large employers in any local labor market. Given the monopsonistic nature of such labor markets, it is likely that wages are below the competitive equilibrium of the classical labor market in which wages are assumed to be equal to the productivity of the marginal worker. Accordingly, agricultural earnings as a measure of social productivity have both an upward bias--in not taking account of social opportunity costs of labor--and a downward bias because they are often determined monopsonistically. In this report we will assume that the true social benefit of additional output will be equal to half of the increase in the annual earnings associated with greater productivity. This value is based upon two assumptions: the marginal value product is 50 percent higher than the monopsony wage and the social opportunity cost of the marginal worker is one-third of his or her individual productivity.

A study by Gillian Hart (cited in The World Bank 1983: 126) of a Javanese village in 1975-76 found that adult men had annual earnings of about $161 and women $58. Assuming eight hour days, the number of days worked per year was 234 for the men and 150 for the women. Given approximately a 200 day a year average and a weighted wage (Rp 30.7), we can estimate annual earnings at about $118. Using the 50 percent adjustment factor to obtain the social value of output, this would translate into $59. Adjusting it on a per-capita basis requires taking into account non-earners as well as earners. Although children do perform some work on both family holdings and in the general labor market, we will assume that only persons between 15 and 64 comprise the productive population. According to The World Bank (1981: 170-1), the population 15-64 years of age constitutes about 55 percent of the total population in low and middle-income countries. Therefore, the per-capita value of social output at the margin is about $32.50 a year in this example.

The estimated impact of iron interventions on work output in Table Five can then be combined with these estimates in a straightforward way to obtain the value of increases in work output associated with anemia reduction. For example, the intermediate value for the change in Hb associated with interventions is 10 percent. Assuming the intermediate elasticity of 1.5, this suggests an increase in work output of 15 percent. Multiplying this percentage times $32.50 yields an increased output per capita of about $4.88. For supplementation we can take the intermediate value of 25 percent for change in Hb and use an elasticity of 1.5, suggesting an increase in work output of 37.5 percent. Multiplying this percentage times $32.50 yields an increased output per capita of about $12.19.

In the comparisons of benefits with costs, we will use this approach to estimate the benefits from additional work output. In addition to the Indonesian example, we will use the agricultural wage in Kenya and Mexico as further illustrations. In each case we will assume 200 days a year of work and a marginal social benefit of work equal to half of the additional output. We will also use an estimate of 55 percent for the working population. It should be noted that these techniques will tend to provide a conservative estimate of the value of additional work output from anemia reduction by using the relatively low agricultural wage as a criterion and by assuming that only the population 15-64 are doing productive work. This means that the higher productivity of persons in higher level occupations is not included and that the work output of very young and very old workers has not been included in the calculations.

Adjusting for Other Benefits

The methodology set out above was designed to capture the benefits of immediate increases in work output associated with iron interventions. As such it ignores the long term benefits associated with improved health, vigor, and physical and mental growth of the population. In order to obtain a total estimate of social benefits from anemia reduction, we need to take account of these additional benefits. These long-term benefits include lower morbidity and mortality, greater physical stature, higher productivity outside of the workplace, improved quality of leisure time, greater learning and faster school advancement, and improved feelings of well-being. Most of these were discussed above, and each has some value to society. For example, lower morbidity and mortality is associated with a reduction in both human suffering as well as health care needs. Higher productivity outside of the workplace means a greater number and variety of self-produced goods and services as well as an improved capability of the family to care for itself and its offspring. Greater learning and more rapid school advancement improve the productivity of school resources resulting in lower costs per completion and level of achievement as well as contributing to reducing scarcities of skilled labor. Improved feelings of well-being clearly have value.

But, as difficult as the estimation of the benefits of short-term increases in work output may appear, the other benefits are infinitely more difficult to estimate. For example, lack of longitudinal data means that estimates of the effects of child nutrition programs on adult productivity require an even larger number of crucial assumptions and speculation on relationships than the short-term effects of anemia reduction estimated above (Selowsky 1981). Accordingly, we have little direct guidance on the subject.

However, we might speculate on the pertinence of some parallel estimates of these types of benefits for education. The usual approach to estimating the economic value of additional education is to ascertain the additional labor market earnings associated with an additional year of schooling. In an extremely comprehensive article, Haveman and Wolfe (1984) have estimated the magnitude of non-market effects of education on economic well-being. These include improving child quality through home activities, improvements in health, improvements in labor market search and some 16 other categories of benefits not tied to market productivity and wages. On the basis of their analysis and computations they conclude that the standard estimates of labor market returns to an additional year of schooling "...may capture only about one half of the total value (p. 401)."

If this finding were also true with regard to the effects of programs that provide a major improvement in health, we might expect that the overall marginal social benefit of anemia reduction would be twice the value of the additional work output alone. On the basis of this assumption, we will set the upper limit of the adjustment at 100 percent, the lower limit at 25 percent, and the intermediate value at 50 percent. This suggests that the additional benefits not measured in the work output section will be assumed to be a minimum of 25 percent and a maximum of 100 percent while we will assume that the intermediate value is the best estimate (in the absence of more direct information). Applying the 50 percent value would raise the social benefits of the fortification example set out above from $4.88 to $7.32 and for supplementation from $12.19 to $18.29.

VII CALCULATING BENEFIT-COST RATIOS

Finally, we have reached the stage where we can calculate benefit-cost ratios for the interventions. For Indonesia we have set out an illustration of benefits for 1975-76 data. For Mexico and Kenya we use wage data from the International Labor Office (1983: Table 21). For 1980 the estimated wages of agricultural workers at the existing exchange rate was $1150 for Mexico and $689 for Kenya on the assumption of a 200 day work year.

Summary of Benefits

Tables Six, Seven, and Eight present the estimated per capita benefits of the anemia interventions for Indonesia, Kenya, and Mexico respectively. Each table begins with the annual earnings per agricultural worker and divides it by half to obtain the estimated social benefit of an additional worker for 200 days a year. This amount is multiplied by .55 to obtain a per capita estimate on the basis that only 55 percent of the population is working. The per capita social benefit is then applied to the estimates of gains in work output in Table Five, after adjusting it upward by fifty percent to take account of other benefits of anemia reduction. Separate estimates are made for fortification and supplementation. Thus, under different assumptions about intervention-induced changes in Hb and the effects of changes in Hb on work output, the estimated social benefits, per capita, are presented.

In order to understand the construction of the tables, it is useful to review the various steps. Annual earnings per agricultural worker are based upon the available sources set out above. In the case of Kenya and Mexico, they refer to national estimates for 1980 reported by the International Labor Office (1983). In the case of Indonesia, the figure is

TABLE SIX

ESTIMATED BENEFITS PER CAPITA OF ANEMIA INTERVENTIONS IN INDONESIA

Annual Earnings per Agricultural Worker	$118
Social Benefit (divide by .5)	59
Per Capita (multiply by .55)	32.5

Benefits per capita for different changes in Hb and Work Elasticities (per capita social benefit of additional work output with 50 percent upward adjustment for other benefits)

	Work Output Elasticity		
	1	1.5	2.0
Fortification			
△ Hb = 5%	$2.45	$3.66	$4.88
△ Hb = 10%	4.88	7.32	9.75
△ Hb = 20%	9.75	14.63	19.50
Supplementary:			
△ Hb = 10%	$4.88	$7.32	$9.75
△ Hb = 25%	12.20	18.29	24.38
△ Hb = 50%	24.38	36.57	48.75

TABLE SEVEN

ESTIMATED BENEFITS PER CAPITA OF ANEMIA INTERVENTIONS IN KENYA

Annual Earnings per Agricultural Worker	$689
Social Benefit (multiply by .5)	344.5
Per Capita (multiply by .55)	189.5

Benefits per capita for different changes in Hb and Work Elasticities (per capita social benefit of additional work output with 50 percent adjustment for other benefits)

	Work Output Elasticity		
	1	1.5	2.0
Fortification:			
Δ Hb = 5%	$14.21	$21.32	$28.42
Δ Hb = 10%	28.42	42.64	56.84
Δ Hb = 20%	56.84	85.26	113.70
Supplementation:			
Δ Hb = 10%	$28.42	$42.63	$56.84
Δ Hb = 25%	71.06	106.59	142.12
Δ Hb = 50%	142.12	213.18	284.24

TABLE EIGHT

ESTIMATED BENEFITS PER CAPITA OF ANEMIA INTERVENTIONS IN MEXICO

Annual Earnings per Agricultural Worker	$1,150
Social Benefit (multiply by .5)	575
Per Person (multiply by .55)	316

Benefits per capita for different changes in Hb and Work Elasticities (per capita social benefit of additional work output with 50 percent upward adjustment for other benefits)

	Work Output Elasticity		
	1	1.5	2.0
Fortification			
Δ Hb = 5%	$23.70	$35.55	$47.40
Δ Hb = 10%	47.40	71.10	94.80
Δ Hb = 20%	94.80	142.20	189.60
Supplementation			
Δ Hb = 10%	$47.40	$71.10	$94.80
Δ Hb = 25%	118.50	177.75	237.00
Δ Hb = 50%	237.00	355.50	474.00

TABLE NINE

ESTIMATED COSTS OF ANEMIA INTERVENTIONS PER CAPITA

A. Costs of Supplements and Delivery Per Capita

	Low	Medium	High
Fortification (per capita cost)			
Iron	$0.10	$0.20	$0.30
Ascorbic Acid		0.60	
Supplementation (per capita cost)			
Ferrous Sulphate	$1.89	$2.56	$3.17
Ascorbic Acid	3.79	4.46	5.07

B. Social Costs of Additional Energy Requirements Per Capita

	Work Output Elasticity		
	1	1.5	2.0
Fortification			
Δ Hb = 5%	$0.28	$0.41	$0.55
Δ Hb = 10%	0.55	0.82	1.10
Δ Hb = 20%	1.10	1.64	2.20
Supplementation			
Δ Hb = 10%	$0.55	$0.83	$1.10
Δ Hb = 25%	1.38	2.06	2.75
Δ Hb = 50%	2.75	4.13	5.50

derived from a regional study for 1975-76 by Gillian Hart (as cited in World Bank, 1983: 126). The adjustments to obtain the social value of a marginal worker and the per capita values were discussed previously. These are adjusted upward by 50 percent to incorporate the other benefits of anemia reduction. The total social benefits per capita of a marginal worker are estimated to be $48.75 in Indonesia, $284.25 in Kenya, and $474.00 in Mexico.

In order to convert these values into benefits from the interventions, we must multiply them by the expected increase in work output per agricultural worker. Table Five shows the percentage increase in work output associated with different changes in Hb and different elasticities relating changes in Hb to changes in work output. These percentages are multiplied by the per capita value of total social benefits for an agricultural worker to obtain an estimate of the social benefit per capita of the interventions. For example, if fortification increases Hb by 10 percent and a work elasticity of 1.5 is assumed, the expected increase in work output from fortification would be 15 percent according to Table Five. When this increase in work output is multiplied times the appropriate figures for total social benefits per capita of an additional agricultural worker, the results are an annual expected benefit from the intervention of $7.32 in Indonesia, $42.64 in Kenya, and $71.10 in Mexico.

Thus, the bottom sections of Tables Six, Seven, and Eight show the expected social benefits attributible to fortification and supplementation under different assumptions about the effects of the interventions on Hb and the effects of increases in Hb on work output.

These can be compared directly with the costs of the interventions.

Summary of Costs

Table Nine provides a summary of estimates of the costs of the anemia interventions. The costs of fortification and supplementation are presented as they were computed in Section V. In the second part of Table Nine we have presented the estimated costs of the additional energy requirement. Using the caloric value of rice and the unsubsidized price of rice in Indonesia as well as estimates of the additional energy requirements associated with greater work activity, it was estimated that a 100 percent increase in work output would require almost 1600 additional calories a day at an annual cost of almost $30.00 per worker.

But, in Section VI we assumed that only one-third of the additional output per worker represented a net addition to social output. Presumably, a higher level of output for any particular worker will partially displace employment of other workers who could have produced that additional output in a labor surplus situation. This means that although the energy requirement for a more productive worker will rise, it will fall for workers whose work efforts are displaced by the higher work output of others. To be consistent with the assumption that only one-third of the output of the marginal agricultural worker is a contribution to social output (because it is assumed that two-thirds of the output simply displaces that of other capable workers whose unemployment rises), we must also assume that two-thirds of the rise in energy input of a more productive worker is offset by a decline in energy requirements of displaced workers. This means that the social costs of additional energy requirements for higher individual work output will be only about one-third of the increase in cost for individual workers whose work output increases.

In summary, the social costs of additional energy requirements are based upon taking one-third of the estimated cost of the additional energy requirements associated with an increase in work output. This provides an estimate of the social cost per worker of additional energy inputs. However, since we have adjusted all benefits to a per-capita measure, this cost must also be adjusted to a per-capita measure by multiplying by .55 as discussed in section VI. Thus, the annual social cost, per capita, of additional energy intake for a fortification intervention that increases Hb by 10 percent with a work elasticity of 1.5 is estimated to be $0.82. For a supplementation intervention that increases Hb by 25 percent with a work elasticity of 1.5, the annual social cost per capita of the additional energy requirement is $2.06.

Benefit-Cost Ratios

Table Ten provides a summary of benefits and costs of fortification for Indonesia, Kenya, and Mexico. The costs are taken from Table Nine and are divided between the costs of fortification and those pertaining to additional energy requirements under different assumptions regarding change in Hb and work output elasticities. These assumptions pertain to three different conditions in which "low" refers to the lowest work elasticity and Hb, "medium" refers to an intermediate value for each, and "high" refers to the upper limit for each in this study. The costs per capita of fortification and additional energy input are considered to be similar for the three countries. Benefits are taken from Tables Six, Seven, and Eight for the appropriate contingencies regarding change in Hb and work output elasticities.

TABLE TEN

PER CAPITA BENEFITS AND COSTS OF FORTIFICATION

	Indonesia	Kenya	Mexico
A. Costs (medium)			
Fortification			
Iron	$0.20	$0.20	$0.20
Ascorbic Acid	0.60	0.60	0.60
Additional Energy Intake			
Low (Hb = 5%; Elasticity = 1)	$0.28	$0.28	$0.28
Med. (Hb = 10%; Elasticity = 1.5)	0.82	0.82	0.82
High (Hb = 20%; Elasticity = 2)	2.20	2.20	2.20
B. Benefits			
Low	$2.45	$14.21	$23.70
Med.	7.32	42.64	71.10
High	19.50	113.70	189.60
C. Benefit-Cost Ratio Iron Fortification (Including energy requirements)			
Low	5	30	49
Med.	7	42	70
High	8	47	79

TABLE ELEVEN

PER CAPITA BENEFITS AND COSTS OF SUPPLEMENTATION

	Indonesia	Kenya	Mexico
A. Costs (medium)			
Ferrous Sulphate (alone)	$1.10	$1.10	$1.10
Ascorbic Acid (alone)	3.00	3.00	3.00
Delivery Systems with Ferrous Sulphate	2.56	2.56	2.56
Delivery System with Ascorbic Acid	4.46	4.46	4.46
Additional Caloric Intake			
Low ($\triangle$Hb = 10%; Elasticity = 1)	0.55	0.55	0.55
Med. ($\triangle$Hb = 25%; Elasticity = 1.5)	2.06	2.06	2.06
High ($\triangle$Hb = 50%; Elasticity = 2)	5.50	5.50	5.50
B. Benefits			
Low	$4.88	$28.42	$47.40
Med.	18.29	106.59	177.75
High	48.75	284.24	474.00
C. Benefit-Cost Ratios (including energy requirements)			
Ferrous Sulphate (alone)			
Low	3	17	29
Med.	6	34	56
High	7	43	72
Delivery System with Ferrous Sulphate			
Low	1.6	9	15
Med.	4	23	38
High	6	13	59

For all three countries and under all assumptions, the benefits of iron fortification exceed the costs by a wide margin. The medium values represent our "best" estimate of the appropriate benefit-cost ratios. These range from 7 in Indonesia and 42 in Kenya to 70 in Mexico. Even assuming a rise in Hb of only 5 percent and a work elasticity of 1 for the country with the lowest agricultural earnings, Indonesia, the benefit-cost ratio is 5. Although we have not shown estimates for ascorbic acid, they can be calculated readily from the information provided and are also high. Under no set of conditions in the table would they be less than about 3, and under the medium set of conditions they would range from 5 for Indonesia to 30 for Kenya to 50 for Mexico. Benefit-cost ratios remain strong even when the "high" estimate of $0.30 for fortification from Table Nine is used. It should also be noted that even the $ 0.20 cost of fortification used for the benefit-cost estimates is considerably above the $0.07-0.10 cost reported in fortification studies. Of course, they would be considerably higher if we assumed a 35 percent increase in Hb as in the Calcutta example of the Indian salt study.

Table Eleven presents benefits and costs for supplementation. Costs are presented separately for the medicinal supplements, the delivery system with the medicinal supplements, and additional energy requirements for the low, medium, and high assumptions on work output. Again, the "low" assumptions represent the lower limit expected for work output elasticity and change in Hb; the "high" assumptions represent the upper limit; and the "medium" assumptions represent the "best" estimates. The benefit-cost ratios are presented for interventions for the medicinal supplements alone--in this case ferrous sulphate--as well as with the delivery system. They also include the costs of the increased energy requirements.

The cost of ferrous sulphate alone is relevant only when there already exists a delivery system so that the marginal cost will be limited to the cost of the supplement alone. Existing employer and community nutritional or health programs might be pertinent to this assumption. In all cases, the benefit-cost ratios exceed 1 by a good margin, ranging from 6-58 for the medium benefit category. When the costs of service delivery are added, the benefit-cost ratios remain high with a range of 4-38 in the medium range category. The low benefit assumptions for Indonesia are the one exception to high ratios with only a 1.6 figure. Even when the high cost service delivery assumptions from Table Nine are used the ratios remain substantial for almost all cases except the Indonesian low benefit case which falls to about 1.3. But, we should bear in mind that the Indonesian ratio is probably understated because of the high value assumed for the community health worker and the fact that earnings for Indonesia are taken from a 1975-76 study. It is likely that agricultural wages were somewhat higher in 1980 on the basis of productivity increases over that period (World Bank 1983: 47-51). With a cost for the health auxiliary of about $600 a year as posited in Section V, the benefit-cost ratio would rise to over 2.

One area in which costs might be understated is the cost of health personnel in the Mexican case. Although the high cost figure among three Asian countries was selected and it does appear to be a high estimate for both Indonesia and Kenya, it is likely to be low among more developed societies. Accordingly, one test of the robustness of the results would be to assume that the cost of the community health auxiliary rises from $1,500 a year to $4,500 a year for Mexico, a rise of $3,000 or $3.00 a person for the population base of 1000. Even with this higher cost, raising the cost of delivery of ferrous sulphate to $5.56 a year per person in Mexico, the benefit-cost ratios would remain substantial, between 8 and 43.

Under a wide variety of assumptions, the benefit-cost ratios of both fortification and supplementation exceed unity by a considerable margin. It should also be borne in mind that most of the assumptions regarding benefits should impart a conservative bias to our estimates. For example, we utilize the relatively low earnings for agricultural workers; we assume that a modest portion of the population is economically active; we do not adjust the elasticities for additional daily work output to take account of lower absenteeism from higher Hb; a substantial downward adjustment is made for unemployment and underemployment; and the value of the benefits not calculated in short-term labor market effects is set at only an additional 50 percent rather than 100 percent as had been estimated for the case of education. Further, the benefits estimates do not take account of fortification and supplementation trials in which the results exceeded substantially the rises in Hb used in this study. Many of the costs are also stipulated on the high side, and the costs of additional energy requirements are included. Accordingly, we conclude that under a fairly reasonable set of circumstances, interventions to reduce anemia represent highly productive investments in LDC's.

Policy Implications

According to our estimates, it appears that both dietary fortification and supplementation can be highly desirable investments for reducing anemia in LDC's. Typical benefit-cost ratios range from 7 to 70 for fortification and 4 to 38 for supplementation for the three countries. Even when a variety of higher-cost or lower-benefit assumptions are stipulated, benefit-cost ratios remain substantial. Other analysts should feel free to evaluate the methodology and to use different assumptions and data sets to see if the ratios are appreciably modified when changes are made to conform with other situations.

It is important to emphasize that fortification and supplementation should be viewed more as complements than substitutes. Supplementation is a short-term strategy to raise the iron status of a population to normal levels. Fortification is a long-term strategy to maintain adequate iron status. Not only are the benefit-cost ratios higher for fortification than for supplementation, but they rest on fewer assumptions about behavior since they require no special actions on the part of the population. In contrast, supplementation requires that the population take the complete regimen of medicinal iron or ascorbic acid as prescribed or that it is provided through daily meals on plantations, in factories, and in schools. To the degree that there is variance in this behavior, it will also affect benefit-cost ratios. It is important to note that the benefit-cost ratios of supplementation are so high that even sub-optimal consumption of the supplements is likely to be associated with high returns to investment.

There are a number of issues that ought to be emphasized in the interpretation and use of these findings. First, there may be other alternatives for reducing anemia that also ought to be considered. We did not focus on interventions for reducing anemia associated with blood loss from parasites such as hookworm and schistosomiasis. Stephenson et al.

(1983) have shown that at least for children the cost of controlling roundworms was modest in a four year project in Kenya. To the degree that parasites are an important cause of anemia, anti-helminth projects should be evaluated for their relative cost-effectiveness in improving Hb and other outcomes.

Second, we did not consider the fact that some members of society may be hypersusceptible to iron toxicity, so that some screening may have to be considered (Omenn 1982). This is also a consideration in calculating the variance in consumption of fortified foods among the population. Third is the issue of financing interventions for anemia reduction. Although the benefit-cost ratios may be high for society and even for individuals, there may be a reluctance by the populations benefitting from the interventions to pay for them from incomes that are close to the margin for survival. A societal mechanism should probably be established that will provide a sound financial basis for the interventions.

Finally, the estimation of benefits and costs in this report assumes that it is important to consider basing public policy decisions on available data, even when the data are incomplete. This evaluation suggests great promise overall in the productivity of investments in anemia reduction. However, in any particular situation it is still highly desirable to carry out field trials which will establish more precise estimates on costs and benefits (WHO 1975) for each situation in which it is being considered.

BIBLIOGRAPHY

Andersen, H. T. and H. Barkve. "Iron Deficiency and Muscular Work Performance," in The Scandanavian Journal of Clinical and Laborabory Investigation, Vol. 25, Suppl. 114, 1970.

Astrand P. "Physiological Factors Limiting Work Performance and Capacity," in Iron Deficiency and Work Performance L. Hallberg and N. S. Scrimshaw (eds.), proceedings of workshop held at the Massachusetts Institute of Technology, April 28-May 1, 1981.

Astrand, P. O. and K. Rodahl. Textbook of Work Physiology (New York: McGraw-Hill Book Co. 1977).

Baker, S. J. "Nutritional Anaemias, Pt. 2: Tropical Asia," in Clinics in Haematology, Vol. 10, (October 1981), pp. 843-871.

Baker. S. H. and E. M. DeMaeyer. "Nutritional Anemia: Its Understanding and Control with Special Reference to the Work of The World Health Organization," The American Journal of Clinical Nutrition, Vol, 32 (February 1979), pp. 368-417.

Barnum, H. N., D. Tarantola and I. Setiady. "Cost Effectiveness of an Immunization Programme in Indonesia," Bulletin of the WHO Vol. 58 (1980) pp. 499-503.

Barrett, D. E. "An Approach to the Conceptualization and Assessment of Social-Emotional Functioning in Studying Nutrition--Behavior Relationships." American Journal of Clinical Nutrition, Vol. 35, pp. 1222-1227.

Basta, Samir Sanad. "Effect of Anemia," American Journal of Clinical Nutrition, Vol 31 (February 1978), pp. 197-201.

Basta, Samir Sanad and A. Churchill. "Iron Deficiency Anemia and the Productivity of Adult Males in Indonesia," International Bank for Reconstruction and Development, Staff Working Paper No. 175 (April 1974).

Basta, Samir Sanad, Soekirman, Darwin Karyadi, and Nevin S. Scrimshaw. "Iron Deficiency Anemia and the Productivity of Adult Males in Indonesia," American Journal of Clinical Nutrition, Vol. 32 (April 1979), pp. 916-925.

Beard, John, Clement A. Finch and Bruce Mackler. "Deleterious Effects of Iron Deficiency," Progress in Clinical Biological Research, Vol. 77 (1981), pp. 305-310.

Bender, A. E. "Food Enrichment," in The Importance of Vitamins to Human Health, T. G. Taylor (ed.) (Baltimore: University Park Press, 1979), Chap. 17.

Bjorn-Rasmussen, E. Hallberg and L. Rossander. "Absorption of 'Fortification' Iron," in British Journal of Nutrition, Vol. 37 (1977).

Bogert, Jean L., George M. Briggs, and Doris Howes Calloway. "Nutrition and Physical Work Performance," in Nutrition and Physical Fitness, (1973) ninth edition, (Philadelphia: W. B. Saunders Company), pp. 481-491.

Bothwell, Thomas H. and Robert W. Charlton. Iron Deficiency in Women (Washington, DC: INACG, 1981).

Brise, H. and L. Hallberg. "Absorbability of Different Iron Compounds," in Acta Med. Scand. Vol. 171 (supplement 376, 1962).

Burman, David. "Iron Deficiency in Infancy and Childhood," in Clinics in Haemotology, Vol. 11, No. 2 (June 1982), pp. 339-351.

Callender, Sheila T. "Treatment of Iron Deficiency," in Clinics in Haematology, Vol. 22, No. 2 (June 1982).

Chandra, R. K. and P. M. Newberne. Nutrition, Immunity and Infection: Mechanisms of Interactions, (New York: Plenum Press 1977).

Charlton, Robert and Thomas H. Bothwell. "Definition, Prevalence and Prevention of Iron Deficiency," in Clinics in Haematology, Vol. 11, No. 2 (June 1982), pp. 327-338.

Charlton, Robert, et al. "Anaemia, Iron Deficiency and Exercise: Extended Studies in Human Subjects", in Clinical Science and Molecular Medicine, Vol. 53 (1977), pp. 537-547.

Cook, J. D. and C. Finch. "Assessing Iron Status of a Population," in American Journal of Clinical Nutrition, Vol. 32 (October 1979), pp. 2115-2119.

Cook, J. D. and M. E. Reusser. "Iron Fortification: An Update," in The American Journal of Clinical Nutrition, Vol. 38 (October 1983), pp. 648-659.

Creese, A. L. and R. Henderson. "Cost-Benefit Analysis and Immunization Programmes in Developing Countries,: in Bulletin of the WHO, Vol. 58 (1980), pp. 471-497.

Creese, A. L., N. Sriyabbaya, G. Casabal and D. G. Wiseso. "Cost-Effectiveness Appraisal of Immunization Programmes," in Bulletin of the WHO, Vol. 60 (1982) pp. 621-632.

Dallman, Peter. "Biochemical and Hematologic Indices of Iron Deficiency," in Iron Deficiency: Brain Biochemistry and Behavior, E. Pollitt and R. L Leibel (eds.) (New York: Raven Press, 1982), pp. 63-78.

Dallman, Peter. "Tissue Iron Deficiency: General Concepts," in L. Hallberg and N. Scrimshaw (eds.) Iron Deficiency and Work Performance, proceedings of a workshop held at Massachusetts Institute of Technology, April 28-May 1, 1981.

Dallman, Peter R. and Martti A. Simes. Iron Deficiency in Infancy and Childhood, (Washington, D.C.: INACG, 1979).

Davies, C.T.M. "Relationship of Maximum Aerobic Power Output to Productivity and Absenteeism of East African Sugar Cane Workers," in British Journal of Industrial Medicine, Vol. 30 (1973a), pp. 146-154.

Davies, C.T.M. "Physiological Responses to Exercise in East African Children, II: The Effects of Shistosomiasis, Anaemia and Malnutrition," in Journal of Tropical Pediatrics, Vol. 19, No. 2, (June 1973b), pp. 115-119.

Davies C.T.M., A.C. Chukweumeka and J.P.M. Van Haaren. "Iron Deficiency Anemia: Its Effect on Maximum Aerobic Power and Responses to Exercise in African Males aged 17-40 Years," in Clinical Science, Vol. 44, No. 6 (June 1973), pp. 555-562.

Davies, C.T.M. and J.P.M. Van Haaren. "Effect of Treatment of Physiological Responses to Exercise in East African Industrial Workers with Iron Deficiency Anaemia," in British Journal of Industrial Medicine, Vol. 30, No. 4 (1973), pp. 335-340.

Deinard, Amos, et al. "Iron Deficiency and Behavioral Deficits," in Pediatrics, Vol. 68, No. 6 (December 1981).

DeMaeyer, E.M. "The Role of WHO in the Control of Nutritional Anaemia," in Nutrition in Health and Disease and International Development: Symposia From the XXII International Congress of Nutrition, pp. 363-370 (New York: Alan R. Liss, Inc, 1981).

Derman, D., et al. "Iron Absorption from a Cereal-Based Meal Containing Cane Sugar Fortified with Ascorbic Acid," in British Journal of Nutrition, Vol. 38 (1977).

Djukanovic, V. and E. P. Mach (eds.) Alternative Approaches to Meeting Basic Health Needs in Developing Countries, joint UNICEF/WHO study, (Geneva: WHO, 1975).

Edgerton, V. R. and Yoshi Ohira. "Human Studies on the Relationship Between Iron Deficiency and Work Performance," in Iron Deficiency and Work Performance, L. Hallberg and N. S. Scrimshaw (eds.), Proceedings of workshop held at the Massachusetts Institute of Technology, April 28-May 1, 1981.

Edgerton, V. R. et al. "Effects of Iron Deficiency Anemia on Voluntary Activities in Rats and Humans," in Iron Deficiency: Brain Biochemistry and Behavior, E. Pollitt and R. L. Leibel (eds.) (New York: Raven Press 1982), pp. 141-160.

Edgerton, V. R., *et al.* "Iron-deficiency Anaemia and its Effects on Worker Productivity and Activity Patterns," in *British Medical Journal*, Vol. 2 (1979) pp. 1546-1549.

Edgerton, V. R., et al. "Elevation of Hemoglobin and Work Tolerance in Iron-Deficient Subjcets," in *Journal of Nutritional Science Vitaminology*, Vol. 27 (1981), pp. 77-86.

Elwood, P.C. and Dafydd Hughes. "Clinical Trial of Iron Therapy on Psychomotor Function in Anaemic Women," in *British Medical Journal*, Vol. 3, (1970), pp. 254-255.

Fleming, Alan F. "Iron Deficiency in the Tropics," in *Clinics in Haematology*, Vol. 11, No. 2 (June 1982), pp. 365-388.

Fleming, Alan F. "Iron-Deficiency in the Tropics," in *Scandanavian Journal of Haematology* (1977), supplement 32, pp. 315-321.

Food and Nutrition Board and UNICEF, New Delhi, India. "The Use of Common Salt Fortified with Iron: A Report on Collaborative Studies," (August 15, 1981).

Garby, L. and S. Areekul. "Iron Supplementation in Thai Fish Sauce," in *Annals of Tropical Medicine and Parasitology*, Vol. 68, (1974), pp. 467-476.

Gardner, Gerald W., et al. "Cardiorespiratory, Hematological and Physical Performance Responses of Anemic Subjects to Iron Treatment," in *American Journal of Clinical Nutrition*, No. 28 (September 1975), pp. 982-988.

Gardner, Gerald W., et al. "Physical Work Capacity and Metabolic Stress in Subjects with Iron Deficiency Anemia," in *American Journal of Clinical Nutrition*, Vol. 30 (June 1977), pp. 910-917.

Gittinger, J. P. *Economic Analysis of Agricultural Projects*, (Baltimore, MD.: Johns Hopkins University Press 1982).

Habicht, J.P. "Delivery of Primary Care by Medical Auxiliaries: Techniques of Use and Analysis of Benefits Achieved in Some Rural Villages in Guatemala," in *Medical Care Auxiliaries*, Scientific Publication No. 278, (Washington, DC: Pan American Health Organization, 1973), pp. 24-37.

Hallberg, L. "Effect of Vitamin C on the Bioavailability of Iron from Food," in J. N. Counsell and D. H. Hornig (eds.) *Vitamin C* (Englewood, N.J.: Applied Science Publishers 1981), Chap. 3.

Hallberg, L. and N. Scrimshaw (eds.). *Iron Deficiency and Work Performance*, proceedings of a workshop held at the Massachusetts Institute of Technology, Cambridge, Massachusetts, April 29-May 1, 1981. Sponsored by the U. N. University in collaboration with the International Nutritional Anemia Consultative Group (INACG).

Haveman, Robert H. and Barbara L. Wolfe. "Schooling and Economic Well-Being: The Role of Nonmarket Effects,: in The Journal of Human Resources, Vol. 19 (Summer 1984), pp. 377-407.

Heilbroner, Robert L. and Lester C. Thurow. Understanding Micro-economics, Third Edition. (Englewood Cliffs, NJ: Prentice-Hall Inc., 1975.

Henshall, J.D. "Ascorbic Acid in Fruit Juices and Beverages," in J. N. Counsell and D. H. Hornig (eds.) Vitamin C (Englewood, N.J.: Applied Science Publishers 1981), Chap. 9.

Hetzel, Basil S. (ed.) Basic Health Care in Developing Countries: An Epidemological Perspective, (Oxford: Oxford University Press, 1978). (Handbook sponsored by IEA and WHO)

Immink, M. and F. E. Viteri. "Energy Intake and Productivity of Guatemalan Sugarcane Cutters: Part 1." In Journal of Development Economics, Vol. 9 (1981a), pp. 251-271.

Immink, M. and F. E. Viteri. "Energy Intake and Productivity of Guatemalan Sugarcane Cutters: Part 2." In Journal of Development Economics, Vol. 9 (1981b), pp. 273-287.

International Labour Office. 1983 Yearbook of Labour Statistics, 43rd Issue, (Geneva: ILO) pp. 539-629.

INACG (International Nutritional Anemia Consultative Group). The Effects of Cereals and Legumes on Iron Availability, (Washington, D.C.: The Nutrition Foundation 1982).

INACG (International Nutritional Anemia Consultative Group). Guidelines for the Eradication of Iron Deficiency Anemia, (Washington, D.C. 1977).

Jacobs, A. "Non-haematological Effects of Iron Deficiency," in Clinics in Haematology, Vol. 11, No. 2 (June 1982).

Jamison, Dean. "Child Malnutrition and School Retardation in China," World Bank Discussion Paper #81-27 (supp. paper IV to annex B of World Bank Report #3391-CHA) (Washington, D.C.: World Bank 1981).

Karyadi, H. D. "Evaluation of Nutritional Anaemia Intervention Among Anaemic Female Workers on a Tea Plantation," in Iron Deficiency and Work Performance, L. Hallberg and N. S. Scrimshaw (eds.) proceedings of workshop held at the Massachusetts Institute of Technology, April 28-May 1, 1981.

Karyadi, Darwin and Samir Basta. "Nutrition and Health of Indonesian Construction Workers: Endurance and Anemia," International Bank for Reconstruction and Develpopment, International Development Association Staff Working Paper No. 152, (April 1973).

Latham, Michael C. and Lani S. Stephenson. "Nutrition, Health and Worker Productivity," an executive summary for the World Bank (1981).

Lanzkowsky, Philip. "Iron Deficiency in Adolescents," in Adolescent Nutrition Myron Winick (ed.) (New York: John Wiley and Sons 1982).

Layrisse, M., C. Martinez-Torres, and C. M. Renzl. "Sugar as a Vehicle for Iron Fortification: Further Studies," in American Journal of Clinical Nutrition, Vol. 29 (March 1976), pp. 274-279.

Layrisse, M. and C. Martinez-Torres. "Food Iron Absorption: Iron Supplementation of Food," in Progress in Hematology, Vol. 8 (1971), pp. 137-160.

Layrisse, M., et al. "Food Iron Absorption: A Comparison of Vegetable and Animal Foods,: in Blood, Vol. 33 (1969), pp. 430-443.

Leibel, Rudolph L. "Behavioral and Biochemical Correlates of Iron Deficiency," in Journal of the American Dietetic Association , Vol. 7., No. 4 (October 1973), pp. 398-404.

Leibel, Rudolph L., Daryl B. Greenfield, and Ernesto Pollit. "Iron Deficiency: Behavior and Brain Biochemistry," in M. Winick (ed.) Nutrition: Pre and Postnatal Development (New York, Plenum 1979), pp. 383-439.

Leibel, Rudolph L., Ernesto Pollitt, Insun Kim, and Fernando Viteri. "Studies Regarding the Impact of Micronutrient Status on Behavior in Man: Iron Deficiency as a Model," in The American Journal of Clinical Nutrition, No. 35 (May 1982), 1211-1221.

Leibenstein, H. "Underemployoment in Backward Economies: Some additional Notes," in Journal of Political Economy, Vol. 66 (1958), pp. 256-258.

Levin, Henry M. Cost-Effectiveness: A Primer (Beverly Hills, CA: Sage Publications 1983).

Levin, Henry M. "Cost-Effectiveness in Evaluation Research," in M. Guttentag and E. Struening, Handbook of Evaluation Research, Vol. 2, (Beverly Hills, CA: Sage Publications 1975), Chapter 5.

Lozoff, Betsy, Gary Brittenham, Fernando Viteri, Abraham Wolf, and J. Urrutia. "The Effects of Short-Term Oral Iron Therapy on Developmental Deficits in Iron-Deficient Infants," Journal of Pediatrics, Vol. 100 (1982a) pp. 351-357.

Lozoff, Betsy, Gary Brittenham, Fernando Viteri, and Juan Urrutia. "Behavioral Abnormalities in Infants with Iron Deficiency Anemia,: in Iron Deficiency, Brain Biochemistry and Behavior, E. Pollitt and R. Leibel (eds.) (New York: Raven Press 1982b), pp. 183-194.

Lozoff, Betsy, Gary Brittenham, Fernando Viteri, Abraham Wolf. "Developmental Deficits in Iron-Deficient Infants: Effects of Age and Severity of Iron Lack,: in Journal of Pediatrics Vol. 10, No. 6, (December 1982c).

MacDougall, L.G. et al. "Immune Response in Iron-Deficient Children: Impaired Cellular Defence Mechanisms with Altered Hormonal Components" in Journal of Pediatrics, Vol. 86 (1975).

Mackler, Bruce and Clement Finch. "Iron in Central Nervous System Oxidataive Metabolism," in E. Pollitt and R. L. Leibel (eds.) Iron Deficiency: Brain Biochemistry and Behavior (New York: Raven Press 1982), pp. 31-38.

Margolis, Harold S., et al. "Iron Deficiency in Children: The Relationship Between Pretreatment Laboratory Tests and Subsequent Hemoglobin Response to Iron Therapy," in American Journal of Clinical Nutrition, Vol. 34 (October 1981), pp. 2158-2168.

Masawe, Aaron Eben John. "Nutrtional Anaemias Part 1: Tropical Africa," in Clinics in Haematology, Vol. 10, No. 3 (October 1981).

Massaro, Thomas F. "Effect of Iron Deficiency on Learning, in E. Pollitt and R. L. Leibel (eds.)Iron Deficiency: Brain Biochemistry and Behavior (New York: Raven Press), pp. 125-140.

McDiarmid, O. J. Unskilled Labor for Development: Its Economic Cost (Baltimore, MD: Johns Hopkins University Press 1977).

Mears, Leon. The New Rice Economy of Indonesia, (Gadjah Mada University Press 1981).

Mirralees, J. A. "A Pure Theory of Underdeveloped Economics," in L. G. Reynolds (ed.) Agriculture in Development Theory, (New York: Wiley 1976).

Mishan, E. J. Cost-Benefit Analysis, (New York: Praeger Publishers 1976).

Moock, Peter R. and Joanne Leslie. "Childhood Malnutrition and Schooling in the Terai Region of Nepal," World Bank Report (1982).

Nutrition Reviews. "The Relationship Between Infection and the Iron Status of an Individual," Vol. 33, No. 4 (April 1975), pp. 103-105.

Ohira, Y. et al. "Work Capacity After Iron Treatment as a Function of Hemoglobin and Iron Deficiency," in Journal of Nutritional Science Vitaminology, Vol. 27 (1981), pp. 87-96.

Ohira, Y. et al. "Work Capacity, Heart Rate and Blood Lactate Responses to Iron Treatment," in British Journal of Haematology, Vol. 41 (1979), pp. 365-372.

Omenn, Gilbert S. "Predictive Identification of Hypersusceptible Individuals," in Journal of Occupational Medicine, Vol. 24 (May 1982).

Oski, Frank A. "The Nonhematologic Manifestations of Iron Deficiency," in American Journal of Disabled Children, Vol. 133 (March 1979), pp. 315-322.

Oski, Frank A. and Alice S. Honig. "The Effects of Therapy on the Developmental Scores of Iron-Deficient Infants," in Journal of Pediatrics, Vol. 92 (1978), pp. 21-15

Oski, Frank A. "Reply to the Editor", in Journal of Pediatrics (January 1976).

Pan American Health Organization (PAHO). "Medical Auxiliaries," proceedings of a symposium heald during thw 12th meeting of PAHO Advisory Committee on Medical Research Scientific Publications #278 (Washington, D.C.: PAHO/WHO 1973).

Pollitt, Ernesto and Rudolph L. Leibel (eds.) Iron Deficiency: Brain Biochemistry and Behavior (New York: Raven Press 1982).

Pollitt, Ernesto and Rudolph L. Leibel. "Iron Deficiency and Behavior," in The Journal of Pediatrics, Vol. 88, No. 3 (March 1976), pp. 372-381.

Pollitt, Ernesto and Nita Lewis. "Nutrition and Educational Achievement: Part 1: Malnutrtion and Behavioral Test Indicators," in Food and Nutrition Bulletin, Vol. 2, No. 3.

Pollitt, Ernesto, Fernando Viteri, Carmen Saco-Pollitt, and Rudolph L. Leibel. "Behavioral Effects of Iron Deficiency Anemia in Children,: in Iron Deficiency: Brain Biochemistry and Behavior, E. Pollitt and R. L. Leibel (eds.) (New York: Raven Press 1982), pp. 195-228.

Popkin, Barry M. "Nutrition and Labor Productivity," in Social Science and Medicine, Vol. 12C (1978), pp. 117-125.

Popkin, Barry M. and M. Lim-Ybanez. "Nutrition and School Achievement,: in Social Science and Medicine, Vol. 16 (1982), pp. 53-61.

Read, Merrill S. "Malnutrition and Behavior" in Applied Research in Mental Retardation, Vol. 3 (1982), pp. 279-291.

Read, Merrill S. "Malnutrition and Human Performance," in Malnutrition, Behavior and Social Organization (New York: Academic Press 1977).

Read, Merrill S. "Anemia and Behavior," in Nutrition, Growth and Development, Modern Problems in Pediatrics, Vol. 14 (Basel: Karger 1975) 189-202.

Read, Merrill S. "Malnutrition, Hunger, and Behavior," in Journal of the American Dietetic Association, Vol. 63, No. 4 (October 1973).

Report of the Working Group onFortification of Salt with Iron. "Use of Common Salt Fortified with Iron in the Control and Prevention of Anemia--A Collaborative Stuay," American Journal of Clinical Nutrition, Vol. 35 (June 1982), pp. 1442-1451.

Robertson, Robert. "Review of Literature on Costs of Health Services in Developing Countries," for the World Bank (January 31, 1984).

Royston, E. "The Prevalence of Nutritional Anemia in Women in Developing Countries: A Critical Review of Available Information,: in Rapport Trimestriel de Statistiques Sanitaires Modiales, Vol. 35 (1982), pp. 52-91.

Sayers, M. H., et al. "Iron Absorption from Rice Meals Cooked with Fortified Salt Containing Ferrous Sulphate and Ascorbic Acid," British Journal of Nutrition, Vol. 31 (1974).

Scrimshaw, Nevin. "Functional Consequences of Iron Deficiency in Human Populations," in Journal of Nutrition, Science, and Vitaminology, Vol. 30 (1984), pp. 47-63.

Selowsky, Marcelo. Nutrition, Health, and Education: The Economic Significance of Complementarities at Early Age", World Bank Reprint Series: Number 218 from Journal of Development Economics, Vol. 9, (1981) pp. 331-346.

Sood, S. K., et al. "WHO Sponsored Collaborative Studies on Nutritional Anaemia in India: I. The Effects of Supplemental Oral Iron Administration to Pregnant Women,: in Quarterly Journal of Medicine, Vol. 44 (1975).

Sorkin, Alan L. Health Economics in Developing Countries (Lexington, MA: Lexington Books 1976).

Spurr, G. B., M. Barac-Nieto, and M. G. Maksud. "Productivity and Maximal Oxygen Consumption in Sugar Cane Cutters," in The American Journal of Clinical Nutrition Vol. 30 (March 1977), pp. 316-321.

Stephenson, L., D. Crompton, M. Latham, S. Arnold, and A. Jansen. "Evaluation of a Four Year Project to Control Ascaris Infection in Children in Two Kenyan Villages,: in Journal of Tropical Pediatrics, Vo. 29 (June 1983).

Stiglitz, J. F. "The Efficiency Wage Hypothesis, Surplus Labour, and the Distribution of Income in L.D.C.'s," in Oxford Economic Papers (new series), Vol. 28, (1976), pp. 185-207.

Stott, G. "Anemia in Mauritius," in Bulletin of the WHO, Vol. 23 (1960).

Vellar, Odd D. and Lars Hermansen. "Physical Performance and Hematological Parameters,: in Acta Medical Scan. (Supplement), Vol. 522 (1971) pp. 1-40.

Viteri, Fernando E. and Benjamin Torun. "Anemia and Physical Work Capacity," in Clinics in Haematology, Vol. 3, No, 3 (October 1974), pp. 609-626.

Viteri, Fernando E., et al. "Iron Fortification in Developing Countries," in A. E. Harper and G. K. Davis (eds.) Nutrition in Health and Disease and International Development: Symposia from the XII International Congress of Nutrition. Progress in Clinical and Biological Research, Vol. 77 (New York: Alan R. Liss 1981), pp. 345-354.

Viteri, Fernande E., et al. "Determining Energy Costs of Agricultural Activities by Respirometer and Energy Balance Techniques," in American Journal of Clinical Nutrition, Vol. 24 (December 1971), pp. 1418-1430.

Watt, Bernie K. and A. L. Merrill. Composition of Foods, Agricultural Handbook #8, U.S. Department of AGriculture (Washington,D.C. 1963).

Webb, Thomas E. and Frank A. Oski. "Iron Deficiency Anemia and Scholastic Achievement in Young Adolescents," in The Journal of Pediatrics, Vol 82, No. 5 (May 1973), pp. 827-830.

Wolgemuth, June, et al. "Worker Productivity and the Nutritional Status of Kenyan Road Construction Laborers," in American Journal of Clinical Nutrition Vol. 36 (July 1982), pp. 68-78.

Woodruff, A. W. "Recent Work on Anaemias in the Tropics," in British Medical Bulletin, Vol. 28, No. 1 (January 1972), pp. 92-95.

Woodruff, A. W. "Recent Work Concerning Anemia in the Tropics," in Seminars in Hematology, Vol. 19, No. 2 (April 1982), pp. 141-147.

World Bank. World Development Report 1981, (New York: Oxford University Press).

World Bank. Wages and Employment in Indonesia, report no. 35.86-IND (Washington, D.C.: The World Bank 1983).

World Health Organization (WHO). "Training and Utilization of AUX. Personnel for Rural Health Teams in Developing Countries," technical report series no. 633 (Geneva: WHO 1979).

World Health Organization (WHO). "Control of Nutritional Anaemia with Special Reference to Iron Deficiency,: WHO technical report series #580, report of an IAEA/USAID/WHO joint meeting (Geneva: WHO 1975).

World Health Organization (WHO). Nutritional Anemias, series no. 405 (Geneva: WHO 1968).