COPENHAGEN CONSENSUS 2008

MALNUTRITION AND HUNGER

CHALLENGE PAPER

COPENHAGEN CONSENSUS CENTER

Copenhagen Consensus 2008 Challenge Paper

Hunger and Malnutrition

Sue Horton, Harold Alderman and Juan A. Rivera

Draft, May 11 2008

Sue Horton
Vice-President Academic, Wilfrid Laurier University
Waterloo On N2L 3C5, Canada
shorton@wlu.ca

Harold Alderman
Social Protection Advisor – Africa Region
World Bank, 1818 H Street NW
Washington DC, USA
halderman@worldbank.org

Juan A. Rivera
Director, Center for Research in Nutrition and Health
National Institute of Public Health, Mexico
jrivera@correo.insp.mx

Despite significant reductions in income poverty in recent years, undernutrition remains widespread. Recent estimates published in the Lancet (Black et al 2008) suggest that "maternal and child undernutrition is the underlying cause of 3.5 million deaths, 35% of the disease burden in children younger than 5 years, and 11% of total global DALY's" (Disability-Adjusted Life Years). Undernutrition can be indicated both by anthropometric indices (underweight, stunting and wasting) and with missing micronutrients in poor quality diets.

Undernutrition in turn has negative effects on income and on economic growth. Undernutrition leads to increased mortality and morbidity which lead to loss of economic output and increased spending on health. Poor nutrition means that individuals are less productive (both due to physical and mental impairment), and that children benefit less from education. The previous 2004 Copenhagen Consensus paper on the topic discusses these mechanisms in detail (Behrman, Alderman and Hoddinott, 2004, hereafter BAH 2004).

Reducing undernutrition is one of the Millennium Goals (Goal 1 aims to eradicate extreme poverty and hunger), and is also a key factor underpinning several others. Achieving goals in primary education, reducing child mortality, improving maternal health, and combating HIV/AIDS, malaria and other diseases all depend crucially on nutrition.

There are cost-effective interventions for improving nutrition. Section I below discusses the challenge in more detail, section II describes selected priority solutions, section III undertakes more detailed economic analysis of these solutions, and the fourth and final section discusses the implications of the analysis. This chapter builds on and updates previous detailed analysis from the 2004 Copenhagen Consensus (BAH 2004), and focuses on pushing the analysis for some solutions further than was possible at that time, adding analysis of some additional solutions, and incorporating what is new from the extensive research literature on nutrition interventions.

1. The Challenge

Available data tend to highlight nutritional deficiencies in the under-five population, where consequences are very obvious (high mortality, losses in cognitive development) – but obviously nutritional deficiencies are also important in the other 88% of the developing world's population. Nutrition in the under-fives depends critically on nutrition of their mothers during pregnancy and lactation. Black et al. (2008) summarize the most up-to-date data on nutritional status. The data they use include anthropometric measurements expressed relative to expected body measurements in healthy populations, and estimates of micronutrient deficiencies based on serum determinations and food intake. The FAO provides regular updates on world hunger, in the World Food and State of Food Security in the World Reports (hunger is measured by data on aggregate food availability and patterns of distribution).

South Asia alone accounts for almost half of the world's population of stunted children less than five (73.8 of the 177.7 million), and 10.3 of the 19.3 million severely wasted children. Africa accounts for another 56.9 million of the stunted and 5.6 million of the severely wasted (Black et al., 2008). (Stunted is defined as more than 2 standard deviations below the population standard for height-for-age, and severely wasted is more than 3 standard deviations below the standard for weight-for-height.) Underweight is declining in most regions, although only in a couple of regions (East Asia/Pacific, and Latin America/Caribbean) has it declined at a rate fast enough to meet the Millennium goals. Underweight is increasing in two regions (Eastern/Southern Africa; and Middle East/North Africa where three large countries are experiencing conflict): UNICEF (2006). Underweight (weight-for-age) is a less precise measure of chronic nutritional status, but trends in stunting and wasting are less readily available.

Micronutrient undernutrition is generally correlated with overall undernutrition, since poverty limits both the quality as well as quantity of food in the diet. There are some exceptions, such as iodine deficiency where iodine deficiency in the soil (dependent on geographic factors) has important impacts on dietary intake, if people rely mainly on local food.

- Prior to widespread salt iodization in the developing world, an estimated 633 million individuals suffered from goiter (World Health Organization, 2003): currently 31% of developing-world households still do not consume iodized salt and are therefore not protected (UNICEF 2006). The lagging countries are in sub-Saharan Africa, South Asia and Central and Eastern Europe/Commonwealth of Independent States.
- UNICEF (2006) estimates that 100-140 million children (mainly in South Asia and sub-Saharan Africa) are still deficient in vitamin A, despite supplementation efforts in many countries.
- An estimated 2 billion individuals worldwide suffer from iron deficiency, of whom more than half are in South Asia. Progress has been very difficult although policy efforts are intensifying considerably. Age and reproductive status is as least as importance as poverty in determining iron deficiency.
- Zinc deficiency is hard to measure but tends to be correlated with iron deficiency and low animal food intake. IZINCG (2004) estimates that 20% of the world's population is at risk for deficiency based on food intake patterns.
- Concern over folate is relatively new. Although diets based on unrefined grains and beans (such as those in many rural areas of developing countries) tend to have good folate content, small studies for India and China find high incidence of birth defects, perhaps related to refined rice as the main staple. More work is needed.

The very significant societal and economic consequences of undernutrition are categorized in an entire section of BAH (2004). They group the consequences into resource losses due to higher mortality and morbidity, direct links between nutrition and physical productivity, and indirect effects on productivity via cognitive development and schooling, and provide an extensive literature survey. Many studies provide estimates of the billions of dollars of economic losses attributable to undernutrition, e.g. World Bank (2006), Horton (2004).

Since the publication of the 2004 Copenhagen Consensus volume, there have been additional research studies extending our knowledge of the consequences of undernutrition. Some of the more significant ones are longitudinal studies providing direct documentation of the effects in later life of undernutrition in early childhood, rather than relying on inference. In inferential studies, for example, micronutrient supplementation in childhood is known to increase cognitive scores, and cognitive scores in adulthood are known to affect wages and hence productivity, hence the effect of childhood supplementation on wages can be reliably inferred. BAH (2004) relied mainly on such studies, bolstered in some cases by comparison of twins or natural experiments. The new – and relatively few - longitudinal studies link data on childhood nutrition interventions directly to wages and other outcomes for those same individuals upon reaching adulthood. These studies confirm the general reliability of the inferential studies and also offer additional insights.

One important recent study tracks the consequences of an intervention supplying protein and micronutrients, originally undertaken between 1969 and 1977 in Guatemala. The individuals were re-surveyed in 2002-04, by which time the individuals were between 25 and 42 years old, and had participated in the intervention for varying numbers of years at varying ages below age seven. The results in one paper (Hoddinott et al., 2008) show that wages for men who had received supplements below age three had wage rates which were 34 to 47% higher than those of the controls, and annual incomes 14 to 28% higher. Effects for women were not significant, which the authors attribute to women's paid labor market participation being largely restricted to low productivity activities such as agricultural processing in this region.

Another paper from the same study documents that exposure to the supplement before age two was associated with increased schooling by 1.2 years for women, an increase in reading comprehension by 17% for men and women, and an increase in performance on Raven's test of Progressive Matrices of 8% (Maluccio et al., 2006). Even in the absence of direct wage benefits from schooling for women, plausibly there are benefits for the household from the increase in schooling of women.

Lozoff et al. (2006) provide a notable longitudinal study of iron supplementation in children ages 1 and 2, tracking the same individuals 18 years later in Costa Rica. In the original intervention, anemia was corrected with iron supplements in the treatment group but not in the control. Results are reported for children without anemia at the end of the intervention as compared to those with anemia (hence this compares children in the treatment group and non-anemic children in the control group, with anemic children in the control group). Obviously the non-anemic group contained a higher proportion of higher socioeconomic status (SES) households, which is a possible confounding variable. Children received cognitive tests at 5 different points up to age 19.

The results are quite striking and suggest that in the middle SES group, those with adequate iron status scored 8-9 points above those who remained anemic in early childhood, a difference that was maintained up to age 19. In the lower SES group, those with adequate iron status scored 10 points higher in early childhood, which increased to 25 points at age 19. These differences generate significant differences in educational attainment and earnings which are being monitored (the Costa Rica study is still ongoing).

Clearly, if improvement in nutrition can be achieved the benefits will be appreciable. But in order to assess the value of interventions as investments one also needs to know what resources are required to achieve a given improvement. Although poverty is a major underlying cause of malnutrition, programs to increase income or provide food to the poor are not necessarily the only (or the fastest) way to intervene. Environmental factors often adversely affect nutrition (for example intestinal parasites and infections lead to nutrient losses). Education also has important impacts. The mother's diet during pregnancy, her breastfeeding practices and weaning practices all have critical impacts on her baby, and nutritional deficiencies prior to about age two are crucial for nutritional status throughout the rest of life. Thus, in addition to interventions aimed addressing poverty and low food intake, improvements in sanitation and in access to education can address underlying causes of malnutrition.

Technology can also be used to enhance nutrition. Developed countries have widely used food fortification (for the majority of the population) and supplementation (for specific groups) to improve nutrition and developing countries have additional options with the advances in biotechnology. There are also circumstances where undernutrition is related to special situations of the population, such as refugees, and HIV/AIDS. However, we are not addressing solutions for these special populations in this chapter, despite their importance.

To summarize, while there have been a few key studies on the benefits of reducing malnutrition in terms of deaths averted, health care costs reduced and productivity increased since BAH (2004), these largely confirm the estimates in that study. In contrast, new information on how to achieve results and improve delivery systems have substantial implications for program design. The next section focuses on a limited number of these promising solutions, based on some of the causal pathways identified above.

2. **Solutions**

We can group interventions to improve nutrition into at least three broad categories: highly cost-interventions which involve or are similar to primary health interventions;

cost-effective interventions which largely involve behavior change; and finally cost-effective but more costly interventions which transfer food and/or income to beneficiaries. In this section, because of the emphasis on costs and cost-effectiveness levels we focus on the first two categories only.

Highly cost-effective interventions improving nutrition include micronutrient interventions and the distribution of anthelminths over a wide range of age groups. Additionally, antibacterial/antiparasitic measures can be targeted for pregnant women (which improve birthweight). Treated bednets also have the side-benefit of improving nutrition although they are not examined here since their benefits are not accurately appraised unless one includes all the benefits of reducing malaria, not just those measured by birth outcomes. A considerable amount of attention is currently being devoted to research on micronutrient interventions. Micronutrients were examined at length in the previous study (BAH 2004). Section 2.1 updates that discussion, with extensions to some topics (zinc and folic acid) not previously treated at length. Section 2.2 is devoted to anthelminths which were mentioned but not analyzed in detail in BAH (2004). Recent studies confirm that anthelminths are highly cost-effective ways to improve both nutritional status as measured anthropometrically, and iron/anemia status. Finally, measures to improve birthweight were analyzed in BAH (2004), but insufficient new material was available to warrant discussion here.

Behavior change can be a cost-effective way to improve nutrition, with modest costs per beneficiary. Households may not be able to afford to increase the amount of food they can consume, but may be able to change the way it is allocated among household members, or the type of food that is consumed, or the way that it is prepared and served, in ways that can enhance nutrition. Education concerning the needs of pregnant and lactating women, of the importance of breastfeeding, and how to feed infants and young children, can have significant impacts on nutrition. Section 2.3 discusses one key behavior change that has a proven track record - breastfeeding promotion in hospitals/health units at the time of birth. Studies suggest that the switch to baby-friendly practices is highly cost-effective in increasing breastfeeding. BAH (2004) previously mentioned breastfeeding promotion, but did not undertake detailed economic analysis.

All these potential solutions (micronutrients, anthelminths and baby-friendly practices for promotion of breastfeeding) are highly cost-effective, but tackle only a modest proportion of undernutrition. It will be argued that the next most cost-effective extension is to nutrition education, particularly focused on the needs of pregnancy, breastfeeding, and preschool children particularly below the age of two. This is discussed in section 2.4. Although touched on in BAH (2004) it was not analyzed in detail. Section 2.4 focuses on nutrition education occurring in the community. Although nutrition messages delivered by the mass media may support other initiatives and are potentially a way to reach many people inexpensively, there is no recent literature suggesting that media messages alone can significantly change nutrition behavior.

These solutions (ranked by cost-effectiveness) are largely consistent with a recent authoritative survey of effectiveness in the Lancet (Bhutta et al., 2008), which states that "Of available interventions, counseling about breastfeeding and fortification or supplementation with vitamin A and zinc have the greatest potential to reduce the burden of child morbidity and mortality". They also conclude that "interventions for maternal nutrition (supplements of iron, folate, multiple micronutrients, calcium, and balanced energy and protein) can improve outcomes for maternal health and births" (p417).

Sections 2.1 through 2.4 describe the proposed solutions and provide references to the evidence base. A summary of cost-effectiveness/benefit: cost data is collated from the literature (note that unless specified otherwise, in sections 2.1 through 2.4 the discount rate used is 3%, where a discount rate is appropriate; also, unless otherwise specified, an incidence rather than prevalence methodology is used: methodology is discussed in section 3.1 below). The detailed economic analysis of each solution is postponed until the third section, where sensitivity analysis (for example to different discount rates) is also undertaken.

2.1 Micronutrient interventions

A considerable amount of effort in the last couple of decades has been focused on reducing micronutrient deficiencies. This relies on a very extensive literature on the adverse effects of deficiencies in terms of mortality, morbidity and economic costs and the availability of inexpensive technologies to provide micronutrients.

International attention was first focused on iodine deficiency, which thanks to iodized salt has been considerably reduced as a global problem. Nevertheless, UNICEF (2006) estimates that 31% of developing-world households are still not consuming iodized salt, although efforts underway in lagging areas (particularly Eastern and Central Europe/Commonwealth of Independent States) are leading to improvements. Low coverage remains a problem particularly in South Asia (India, Pakistan, and Bangladesh) and some sub-Saharan African countries.

There has been relatively little significant new work on iodine interventions since BAH (2004). Salt iodization, costing around $0.05/person per year and averting significant cognitive losses, with a benefit:cost ratio of the order of 30:1, remains a key priority (recalculated as incidence based, from Horton, 2006); no additional discussion is needed to reiterate the estimates of benefits and cost already available. For those areas where salt iodization is not currently feasible, recent recommendations are for a single annual large oral dose of iodized oil for children and pregnant and lactating women (de Benoist, 2007). While more expensive than fortification, this is likely still very cost-effective, but few program data exist (areas requiring iodized oil are by generally areas which are more remote and hard to reach or where an inadequate regulatory environment makes commercial fortification patchy).

In the early 1990's meta-analyses indicating the importance of vitamin A in reducing severity of infection and mortality led to concerted efforts to undertake mass-dose vitamin A supplementation of children 6-24 months, often in conjunction with immunization campaigns. More recently, as vertical polio immunization campaigns are phasing out, there is a need to shift the mode of delivery for vitamin A either to the primary health care system (where this has good coverage) or Child Health Days. UNICEF (2006) estimates that there are still 100-140 million children (17-25% of children under five in developing countries) who are still deficient in vitamin A, mainly in South Asia and sub-Saharan Africa. Section 2.1.1 below discusses some new findings and policy implications

Iron is the third of the "big three" micronutrients, and progress has been harder to make than for the other two. Unlike the other two, single annual or semi-annual mass doses are not feasible. Iron supplementation programs have had mixed results, and although iron fortification is currently taking off in developing countries, coverage of many vulnerable populations remains problematic. Section 2.1.2 discusses what is new since BAH (2004).

One possible reason that attention to zinc deficiency has only been recent preoccupation it that measuring zinc status in populations is difficult. Zinc deficiency in children is known to be associated with stunting, but the benefit: cost ratios for increased adult productivity due to zinc supplementation in early childhood (higher wages/higher productivity are associated with increased stature) are considerably less than for iron. However, therapeutic treatment of diarrhea with zinc supplements below the age of one year is highly cost-effective, and recent work suggests that supplementation of young infants may also be cost-effective in reducing infection and hence mortality and morbidity. Section 2.1.3 discusses results for zinc (mentioned, but not in much detail, in BAH 2004).

Work on folate is just beginning in developing countries. Chile and Mexico are among the first developing countries to use folic acid fortification in flour. This is the subject of section 2.1.4, but work on benefits and costs in developing countries is still at a very early stage.

There are cross-cutting issues regarding the delivery of micronutrients. Fortification tends to have a lower unit cost than supplementation and hence is preferable if feasible, particularly if the deficiency is of importance across a wide range of population groups. Supplementation tends to be used if a sub-population is of particular interest and the micronutrient is more costly (vitamin A). Supplementation is also necessary if particular population groups (pregnant and lactating women for example) have extraordinary needs which cannot be met by fortification alone (e.g. iron). If supplementation is the mode, then we need to consider the costs of distribution and of ensuring adherence with recommended frequency of intake, and in some cases (e.g. iron in malarial areas) the costs of screening the population prior to providing supplements. Of course, for many if not all micronutrients, a global cost effective strategy likely requires a mix of fortification and supplementation.

Fortification of complementary foods (foods targeted to weaning age children) is an alternative to targeted supplementation. Commercially-prepared complementary foods typically reach higher income, more urbanized households and this tends to have been left more to the market as an initiative. The Oportunidades Program in Mexico is an example where a fortified complementary food has been provided free to children below five in the poorest five million households. A less costly alternative has been development of "home fortification", i.e. the provision of micronutrients which can be added to infant foods in the home. Examples are "Sprinkles" (a multiple-micronutrient sachet developed by Stan Zlotkin and colleagues at the Hospital for Sick Children, Toronto), and Plumpy' Nut (a ready-to-use-therapeutic food based on peanuts). Studies of Sprinkles suggest that they can be cost effective when the effects of the iron and zinc components are analyzed (see sections 2.1.2 and 2.1.3). Plumpy'Nut is very useful for special populations such as severely malnourished children needing nutritional rehabilitation

Finally, biofortification (through improved agricultural technology) is potentially very attractive, but its practical implementation has not progressed very far since BAH 2004. It is therefore covered but without much detail in section 2.1.5.

2.1.1 Vitamin A

Until recently, recommendations on the use of vitamin A focused on provision to lactating women up to eight weeks postpartum, and to children between 6 and 72 months, which is estimated to reduce mortality below the age of three by 23%, with estimates of cost per death averted of $64-$294 (Ching et al., 2000, $289-$489 for Nepal through community health workers (Fiedler, 2000: both Fiedler and Ching are cited in BAH 2004), and $100-$500 for eight low income Asian countries (Horton, 1999).

New evidence suggests that a comparable mortality reduction can be obtained by supplementation of neonates (Rahmathullah et al., 2003, where Indian infants were supplemented 1 or 2 days after delivery, and the benefits were observed from 2 weeks to 3 months). This may in future change the recommendations for vitamin A supplementation, although ensuring that neonates receive the vitamin A may be difficult, in countries with large rural populations and a low proportion of births occurring with trained birth attendants present. Neonatal supplementation is only likely to be an attractive option if it can be packaged with other postpartum care. Darmstadt et al.. (2005) include neonatal vitamin A in the package of desirable add-ons to their evidence-based package for neonatal care.

Given that mortality rates in the first three months are typically higher than in the current age range covered (6-36 months), it is likely that supplementation of neonates will be even more cost-effective than supplementation of the older age groups – although this will depend heavily on the how the cost of supplementation increases when targeting neonates.

New results on cost-effectiveness of programs include estimates from Child Health Days in Ethiopia, where a package of interventions (vitamin A, de-worming, nutrition screening and measles vaccinations) reach more than 10 million beneficiaries nation-wide in the Enhanced Outreach Strategy, at an average cost per child per round of US$0.56 (Fiedler, 2007a). The cost – which includes staff and training costs - increased to $1.04 per round per child if measles vaccine was included. There are two rounds per year. Fiedler estimates the cost per death-averted (due to the vitamin A component) as $228 per life saved, or $9 per DALY saved, in the variant excluding measles vaccination. This is conservative and does not take into account benefits from the other components of the intervention, namely de-worming and nutrition screening. The results are likely replicable in other countries with mortality rates as comparably high as those in Ethiopia, in an environment where primary health care is sufficiently weak that the “campaign” strategy works well.

The cost data ($0.56 per round) above are consistent with estimates by Neidecker-Gonzalez et al. (2007) for Africa for distribution of vitamin A capsules; they estimate that the costs are $1.00 per round for Asia and $1.50 per round for Latin America, and that the cost of the capsule is a relatively small fraction of the cost, whereas personnel costs for training, distribution etc. are larger.

2.1.2 Iron

Shifting an individual from anemic to non-anemic status has strong productivity benefits. Horton and Ross, 2003, summarize the productivity benefits for adults as 5% in light manual work and 17% in heavy manual work. There are also effects attributable to cognitive benefits and associated schooling improvements of 4% in all other work.

Anemia and iron status, although correlated, are not synonymous (see for example discussion in Horton and Ross 2003). The literature is also shifting to use hemoglobin levels as a continuous variable, rather than anemia cutoffs, as a better measure, since there are decrements in function and response to interventions even below the defined anemia cutoff.

New studies of effects since BAH 2004, include the longitudinal study in Costa Rica confirming the cognitive benefits already discussed in section 1(Lozoff et al., 2006). There have also been some useful new systematic literature surveys of the effects of iron supplementation. Sachdev et al.’s (2005) survey concludes there are positive effects on mental development scores in children (particularly for children who were initially anemic or iron-deficient, and more strongly in children more than two years old). Similarly, Gera et al.’s (2007) survey shows that the effect of iron supplementation of children on hemoglobin is stronger where children were initially anemic. However, the effects of supplementation of iron on children's growth are not generally significant (Sachdev et al., 2006). These reviews confirm the value of early targeted interventions and reinforce the view that calculations of benefits should also include those attributable to cognitive development. Nevertheless, local conditions affect average response. For example, supplementation has a smaller impact in malaria hyperendemic areas, and where children already consume iron-fortified food (Gera et al., 2007).

There are ongoing studies of effectiveness of supplementation programs at scale, trying to resolve why effects from efficacy studies prove elusive at broader scale. One finding is that using anemia status is a less sensitive indicator than hemoglobin status (Stoltzfus et al., 2004).

A new and extremely significant finding from a large-scale trial in a population with high rates of malaria, is that iron supplementation of young children is associated with increased hospital admissions and mortality. The authors (Sazawal et al., 2006) recommend that iron supplementation in areas with high rates of malaria only be given to children who have been tested as iron-deficient, since the deleterious effects were for non iron-deficient children. This has led to a change in the international guidelines (Stoltzfus, 2007), which now suggest that iron fortification should still be a priority, as should iron supplementation of pregnant women and iron-deficient children, but universal iron supplementation (with tablets, syrups or Sprinkles) should be avoided for young children at high risk of severe malaria. Testing, of course, increases costs in areas where it is necessary.

Some recent studies look at the costs and potential impacts of home fortification (Sprinkles) and conclude that the benefit: cost ratio of Sprinkles interventions (containing iron as well as other micronutrients) can be as high as 37:1 if one assumes that a course of intervention for four months between the ages of 6 months and one year largely protects an infant against anemia throughout childhood (Sharieff et al., 2006). Sprinkles are currently at the stage of use at program scale in several countries including Bangladesh, Mexico and Mongolia, and were used at scale in the Indonesia province of Aceh following the tsunami.

Internationally there is considerable effort being devoted to iron fortification, particularly of flour. The Flour Fortification Initiative has the goal of fortifying 70% of roller mill wheat flour with iron and folic acid, by the end of 2008. The rate was 20% when the initiative started in 2004 and had reached 26% by 2006 (http://www.sph.emory.edu/wheatflour/progress.php; downloaded July 29, 2007). GAIN (the Global Alliance for Improved Nutrition) currently has projects for fortification of wheat flour in ten countries (in almost all, folic acid is included), and of maize flour in another three. GAIN is also supporting projects for iron fortification of soy sauce in China, and fish sauce in Vietnam (http://www.gainhealth.org/gain/ch/en-en/index.cfm?page=/gain/home/about_gain/progress_report2). The Micronutrient

Initiative and WHO-EMRO has assisted 13 countries in the Middle East to reach the current level of 7 million metric tons of flour being fortified with at least iron and folic acid (MI and WHO-EMRO, 2007).

Iron fortification has a very high benefit-cost ratio, estimated as 8.7:1 (Horton and Ross, 2003; Horton and Ross, 2006: median for 10 countries). The cost of iron fortification varies according to the iron compound used and the food vehicle but can be $0.10-$0.12 per person per year. Fortification, however, requires that there exists a product that is purchased by a target population regularly and in sufficient quantities to convey the iron requirement. It also is administratively easier to the degree that processing is concentrated in a few mills or manufacturers. To offset the bias towards more refined or highly processed flours, trials using hammer mills at a village level are also underway.

While subsidies are often expensive and are not generally a cost effective means of improving nutrition, where such programs are underway for other reasons – for example, school feeding – the marginal cost of adding fortificants is small and often achieve significant benefits. For example, in some districts iron fortification has been added to the flour provided in India's long standing and controversial public distribution system, and in Mexico it is added to subsidized milk.

Iron supplementation also reduces maternal and neonatal mortality (although the reductions are not quite of the same magnitude as those for vitamin A and zinc for example). Iron supplementation of pregnant women could reduce mortality for as little as $66 to $115 per DALY in high mortality regions of Sub-Saharan Africa and Southeast Asia (Baltussen et al. 2004) – although this particular study suggests caution since "evidence of intervention effectiveness predominantly relates to small-scale efficiency trials, which may not reflect the actual effect under expected conditions". Baltussen et al. (2004) use the cost of supplementation per pregnant woman as $10-$50 per year including distribution and promotion costs, where the cost varies by region and wage cost of the personnel involved in distribution. BAH (2004) cite similar cost estimates for a program in Nepal.

2.1.3 Zinc

Work on zinc has been relatively recent, and many information gaps remain. There is strongest evidence in favour of therapeutic use of zinc for diarrhea, and WHO and UNICEF have incorporated this into the guidelines for treatment of diarrhea. There is no clear consensus on therapeutic use for respiratory and other infections. Efficacy trials of preventive use have shown benefits for mortality, morbidity and growth but many gaps remain: there is little evidence from programs at scale, there is insufficient study of the proposed timing of preventive supplementation (age of child; daily versus weekly dosage), and there needs to be more analysis of effects of zinc as a component of multiple micronutrient supplementation particularly where iron is included, rather than a single supplement. Studies of zinc fortification have not yielded consistent results, but some of this could be attributable to methodological issues This entire paragraph is drawn from a very useful short survey by Brown (undated: 2006?).

There are ongoing large-scale trials which should help to improve knowledge (Nepal, Zanzibar) as well as other trials (Peru, Ecuador, Bangladesh, Mexico) and these should lead to recommendations for provision of zinc both for therapeutic and preventive uses. Although it is known that there are interactions when both iron and zinc are provided together in supplements, it is likely not desirable to provide only one if both are deficient. The adverse interactions are apparently less of an issue for iron and zinc fortification. GAIN is already funding combined zinc and iron (and other micronutrient) fortification of flour in three countries (wheat flour in all three countries, and maize flour in addition in one of the three).

Cost-effectiveness results for zinc supplementation suggest that therapeutic use for diarrhea is highly cost-effective. Robberstad et al. (2004) suggests that the incremental cost of zinc as part of case management is $0.47 per course of treatment, leading to an average cost of $73 per DALY gained, and $2,100 per death-averted. Sharieff et al. (2006) estimate the cost per DALY saved as $12.20 ($8-$97) and the corresponding cost per death averted as $406 ($273-248) for a preventive course of supplements. These results are for administration of a multiple micronutrient supplement including zinc, costing an estimated $1.20 per child (for 60 sachets consumed over a four-month period, between ages 6 and 12 months, in a country with high infant mortality levels and high diarrhea prevalence).

Although there can be effects on growth of preventive zinc supplementation, the effect of adult stature on wages is fairly modest and is unlikely to lead to a very high benefit-cost ratio as a single nutrient. Preventive supplementation aimed at reducing morbidity and mortality is however potentially cost-effective at young ages, in environments where zinc is expected to be deficient and infant mortality rates are high. For example, a study by Sazawal et al. (2001) in India found that daily provision of a supplement including zinc from 30 to 284 days of age of SGA infants was associated with a 68% reduction in mortality as compared to the same supplement without zinc. Further study of cost-effectiveness of this particular effect would be useful. It is too early to provide cost estimates for preventive zinc supplements until appropriate ages and dosage are better understood, as well as the interaction with iron, since it is unlikely that zinc would be provided as a preventive supplement without other micronutrients.

2.1.4 Folate

Interest in folate interventions in developing countries is quite new. Knowledge of the effects of folic acid intervention periconception on birth defects (particularly anencephaly and spina bifida, but also others) is not that new. Figures in Grosse et al. (2005) for the US imply benefit: cost ratios somewhere between 12:1 and 39:1 (the cost of folic acid fortificant for the US was just a little over $0.01 per person per year; note that these are prevalence- rather than incidence-based estimates). These estimates are probably not too relevant for developing countries, which typically do not incur the large hospital costs that were saved by preventing the need for treating these babies. Rather, the consequences for developing countries are likely to be better expressed in terms of the costs of the morbidity and mortality these babies suffer. Data do not currently permit this calculation. Recent evidence for developed countries also links folic acid fortification to reductions in neuroblastoma (French et al. 2003). There are more debated effects on coronary heart disease, but the benefits of either fortification or supplementation on this are not clear.

Data for developing countries are scarce. However, studies for rural India and China find relatively high levels of neural tube defects at birth (Cherian et al., 2005.; Xiao et al., 1990). One possibility is that this is associated with consumption of rice, which when refined has low folate content.

The Flour Fortification Initiative lists only US, Canada and Chile as currently mandating folic acid fortification of flour, although it has been under consideration in some European countries. GAIN currently includes folic acid fortification in some, but not all, of its projects involving wheat and maize flour in developing countries. The Flour Fortification Initiative includes both iron and folic acid as the minimum fortificants it aims to encourage countries to include.

Folate supplementation faces similar issues to iron supplementation in malarial areas. Some antimalarials (such as sulfadoxine and pyrimethamine) work by interfering with folate metabolism which inhibits the parasite. The Pemba study (Sazawal et al., 2006) exhibited adverse mortality consequences for children receiving iron and folic acid supplements in a high malaria environment. A study of pregnant women in western Kenya provided iron and either a placebo, a low dose of folic acid, or the standard (national guidelines) dose (Ouma et al., 2006). The results suggest that use of the national standard (higher) dose of folic acid supplement compromised the efficacy of the antimalarials, as compared to placebo or a low dose, suggesting a need to revisit national guidelines. The levels of folic acid involved in fortification are less likely to be problematic, although this may require further trial.

Since work on folate is relatively new, there has been no international technical/lobby group for folate comparable to those which have done the work on vitamin A, iron, and zinc and iodine (IVACG, INACG, IZINCG, IDD Network). However, folate is explicitly included with the other four in the purview in the new Micronutrient Forum (Micronutrient Forum, 2007). Although there is little cost-effectiveness work, it seems reasonable that folic acid fortification is sufficiently cheap, and sufficiently beneficial, that it should be included in flour fortification programs when iron is used. More work is required: for example a formal international recommendation would be desirable, some examination of the feasibility of folic acid fortification of other foods would be desirable for countries with rice-based diets, and the issue of fortification in high-malaria environments needs to be examined.

2.1.5 Biofortification

BAH (2004) rated the potential for biofortification of staple crops as very high. Breeding efforts are ongoing and there have already been a couple of efficacy studies of feeding trials for crops biofortified with iron and with vitamin A (cited in Meenakshi et al. 2007). The present value of estimated cost per crop, per country, range from $8m to $25m, over a 30-year horizon. Meenakshi et al. (2007) estimate the median cost per DALY saved as about $10/DALY saved (optimistic scenario) and $120/DALY (pessimistic scenario). The corresponding BCR's (Benefit:Cost Ratios) are 50:1 and 4:1 (with $1000/DALY).

2.2 Anthelminths

Infection with soil-transmitted helminths is very high. Hotez et al. (2006) estimate that 1.2 billion people are infected with roundworm, 0.8 billion with whipworm, and 0.7 billion with hookworm. Many individuals have more than one infection, and over 2 billion people are estimated to be infected by some type of soil-transmitted helminths. These infections have adverse effects on nutritional status, and hookworm infections also have adverse effects on iron status.

Most existing treatment efforts are focused on school age children in part because data suggest that worm loads peak during these years – typically around age five for roundworms and whipworms, and in adolescence for hookworms. Additionally, in many countries, school settings provide a cost effective means of reaching children.

The Partners for Parasite Control project based at WHO has as a goal to treat regularly at least 75% of school age children at risk of illness from schistosomiasis and soil transmitted helminths by 2010 (http://www.who.org/wormcontrol/about_us/en). The most recent global meeting (WHO 2005) found that of the 73 endemic countries, data on progress towards the goal were available for 22 countries for 2004. Of these, only 3 achieved coverage of more than 75% of the target population, and the median coverage was only 10%.

There are also benefits to treating other groups, particularly preschool children and pregnant women. Although preschool children typically have lower worm loads, one hypothesis is that "helminth infections may stimulate inflammatory immune responses in young children with deleterious effects on protein metabolism and erythropoiesis" (Stotzfus et al., 2004). Hotez et al. (2006) summarize the benefits from anthelmintic treatment. For preschool children, treatment is associated with motor and language development and reduced malnutrition. For school age children, benefits include reduced anemia, and improved physical fitness, appetite, growth, and intellectual development.

For pregnant women, benefits include improved maternal hemoglobin, birth-weight and child survival.

Studies since those surveyed by Hotez et al. include Alderman et al. (2006) which found higher weight gain for children below seven treated during child health days in Uganda, as compared to controls. In this program, a single dose of proprietary albendazole added $0.21 to the cost of child health days (attributing all the existing staff costs to vitamin A distribution and other activities at health days). Thus, the cost per child per year was $0.42 for two rounds of coverage, although bulk purchase of generic drugs could reduce these costs somewhat. Fiedler (2007a) estimates the costs for distribution on anthelmintics in Ethiopia at around $0.32 per child per year, including a share of the distribution costs (when the Child Health Day is used to provide deworming, vitamin A, and nutrition screening under five).

The cost-effectiveness of the school age deworming programs is very high. Miguel and Kremer (2004) estimate that treatment in Kenyan schools at a cost of $0.49 per child generated a net present value of wages of over $30. Deworming was the most cost-effective way to increase school participation in their study (and led to a 7.5 percentage point increase in primary school participation in treatment schools). If one allows for the fact that additional teachers would have to be hired to teach the increased number of children participating, the benefit: cost ratio is still over 3:1.

There are apparently no previous cost-effectiveness or cost-benefit estimates in the literature for deworming for preschool children and for pregnant women, which appears to be a symptom of the neglect of the topic of deworming in the literature. The Alderman et al. study in Uganda looks at weight gain only and not iron status or vitamin A absorption and, thus, can not form the basis of a benefit: cost estimate. Moreover, the comprehensive DCPP project does not include cost-effectiveness estimates although there is a chapter on helminths (Hotez et al., 2006), nor is deworming included in the WHO-CHOICE cost effectiveness estimates, even for school-age children. Deworming is aptly included by WHO under the Department of Control of Neglected Tropical Diseases. In a number of iron intervention studies (e.g. Thomas et al., 2004; Beinner et al., 2005), deworming is included in the intervention (but not the title of the article), and yet a substantial fraction of the outcomes attributed by the study to the iron intervention may in fact be due to the anthelminths.

We provide here estimates of the order of magnitude involved for cost-effectiveness for deworming of preschool children, in areas with endemic hookworm. Although deworming has effects on growth, these are relatively small (Bhutta et al., 2008) and the economic effect is hence very modest. The more important effect economically is the effect on anemia. Bhutta et al. (2008) undertake a literature survey, and estimate that the reduction in anemia in preschool children ranges from 4.4% to 21%. The median of this range is 13%. Using Horton and Ross (2006), the present value of the median cognitive loss attributable to anemia in a group of developing countries was $1 per capita (the present value of the loss per child in the relevant age range ranged from $15 to $25). If we can assume that deworming children five times between age 1 and age 3 can reduce anemia 13% and reduce the cognitive loss by 13%, and hence reduce future wages by 2.5%, then the present value of the loss potentially avertable per person in the population is $0.13. In Southeast Asia, the age group requiring coverage is approximately 4% of the population, and in sub-Saharan Africa 6.5%. Accordingly, if deworming costs $0.50 per child per year, then the benefit:cost ratio is 7.5:1 in Southeast Asia, and 4:1 in sub-Saharan Africa. (The assumption that these are the priority areas are based on de Silva et al., 2003).

Costs at this level are feasible as long as deworming is provided in combination with another intervention (and hence shares distribution costs). Deworming as a single intervention provided to preschool children would likely cost about twice as much and would have a correspondingly lower benefit:cost ratio. These BCR's are a little conservative (if reductions in stunting also provide benefits in terms of adult productivity). These estimates are orders of magnitude only, and require further verification.

2.3 Breastfeeding promotion – baby-friendly hospitals

WHO recommends exclusive breastfeeding during the first six months of life as does UNICEF (http://www.who.int/nutrition/topics/infantfeeding_recommendation/en/). However, only slightly over one-third of infants in developing countries receive this best practice (UNICEF 2006). "The highest rates are currently found in East Asia/Pacific (40%) and Eastern/Southern Africa (41%) and the lowest in West/Central Africa (20%) and CEE/CIS (22%)" (UNICEF 2006). UNICEF (2006) also notes that the rates are improving for sub-Saharan Africa, Middle East/North Africa and South Asia. There has been no further improvement in East Asia/Pacific, and data for the other two major regions are insufficient to detect a trend.

While there is little doubt on the efficacy of proper breastfeeding, the scope of programs to influence breastfeeding practices in low income environments where women typically have to engage in agriculture and other labor intensive activities is mixed. Improvement in breastfeeding (and weaning) practices typically requires decentralized educational support (as well as institutional support e.g. allowing women's work to accommodate their needs to breastfeed) and is included in section 2.4 below with other nutrition education programs. However, breastfeeding promotion at the time of delivery in hospitals can be highly cost-effective. Horton et al. (1996) estimate that averting diarrhea morbidity and mortality costs $2-4 per DALY if hospitals prior to the intervention are still using formula ($12 to $19 if they have already eliminated formula). The corresponding costs per death-averted are $100-200 (formula still used) and $550-800 (formula no longer used). The costs per birth of breastfeeding promotion are $0.30-0.40 (formula still used) to $3-4 (formula no longer used).

Obviously many births in the poorer countries occur outside health institutions, and the baby-friendly initiative has more impact on middle-income countries and urban populations. UNICEF has tracked numbers of baby-friendly hospitals since 1990. By 2002 there were over 16,000 such hospitals in 135 countries, but there does not appear to have been a more recent survey.

Recent emphasis of UNICEF's work on the initiative has focused in Central and Eastern Europe/CIS countries. This region has the most number of references – other than the industrialized countries – for a Google search on the UNICEF site for "baby friendly hospitals" (conducted August 1 2007). Although this region has among the lowest exclusive breastfeeding rates, it also has the lowest number of undernourished children of the developing world.

It may therefore be the case that the baby-friendly hospital initiative will only have limited additional impact on nutrition. However it is so cost-effective that efforts should be redoubled to prevent slippage backwards, and the topic should not fall off the international agenda. Data on coverage of baby-friendly hospitals needs to be updated.

2.4 Nutrition education at the community level

The previous sections have discussed a series of highly cost-effective interventions improving nutrition, with benefit: cost ratios similar to those of key primary health interventions such as immunization, prevention of malaria (using treated bednets, household spraying and preventive drug provision for pregnant women) and treatment of STD's to prevent HIV/AIDS. A key element of all these programs is that little behavior change on the part of beneficiaries is required beyond biannual participation in child health days or the purchase of fortified foods that look and taste identical to those previously consumed. In many cases the gains come from inexpensive technological fixes provided to a population.

The limitation of the nutrition interventions discussed above is that they address only a modest component of overall undernutrition. To make further progress households may have to change their food practices. The key periods for such changes are during pregnancy, lactation and weaning. Growth and cognitive deficits related to undernutrition prior to age two are extremely difficult, if not impossible, to reverse.

The key messages involve diet of pregnant and lactating women, breastfeeding, complementary feeding of infants and young children particularly between six and twenty-four months, and identifying inadequate growth and weight gain particularly below age two. Delivering these messages effectively requires one-on-one discussion, typically with the mother. Weighing the mother-to-be, and weighing and measuring the baby, are very important tools with which to frame the educational messages, as long as it is recognized that the weighing is not an end in itself. The sessions can also be used to provide micronutrient supplements and anthelminths.

Program experience suggests that such nutrition education can be provided cost-effectively on par with many other attractive health investments, albeit at an order of magnitude more costly than nutrition interventions covered in sections 2.1 through 2.3.

We discuss below interventions grouped into three different types, which depend on the level of development of the country and the current level of development of health services. Cost-effectiveness is typically higher when interventions are "packaged" with other interventions and the costs of personnel time are spread over multiple interventions.

The three intervention types are: incorporation of nutrition education into Child Health Days; community nutrition promotion using volunteers; and nutrition education as part of the lowest tier of the health care system. Another way of thinking of this is as an integrated program of outreach and family-community care, where the relative weight of outreach and family-community care depends on the institutional background in individual countries (Darmstadt et al., 2005). Interestingly, Darmstadt et al. comment that for neonatal survival "Most of this benefit is derived from family-community care", which is consistent with our expectation for nutrition. The "package" of family-community care initiatives combined with nutrition education could be for example neonatal survival, or safe motherhood, or integrated management of child illness.

2.4.1 Outreach initiatives

Outreach initiatives play the greatest role in countries with the most limited coverage of primary health care services and are part of the legacy of vertical programs. Fiedler (2007) cites UNICEF statistics that more than 60 countries have at least one Child Health Day, with the vast majority having more than one. According to a Google search of the UNICEF website (August 1 2007), the highest number of hits are for Africa, followed by Asia, with India running third. (Interestingly, there are also many references to the US Child Health Day in October). Most days include vitamin A, immunizations and – increasingly - deworming, with growth monitoring in about a quarter of the countries, and occasionally other interventions. Goodman et al. (2000) discuss the advantages of including vitamin A in immunization days.

Fiedler's (2007) estimates for Ethiopia are that each round (of the two per year) costs $0.56 per child, excluding measles vaccination, $1.04 including measles. The cost by component was 25% (vitamin A), 29% (deworming), 15% (screening) and 31% (intensive education/other), in the model without measles immunization. His cost-effectiveness estimates (only attributing benefits to the vitamin A component) were given in section 2.1 above; if one redid the calculations to include benefits from deworming, this would be an even more attractive investment. Ethiopia is an example of a country towards the lower extreme of the distribution of availability of primary health care facilities, where the outreach format is likely to be particularly appropriate.

2.4.2 Community nutrition interventions

Community nutrition interventions incorporating growth promotion have a long history, and there are a number of surveys (see for example Allen and Gillespie, 2001; World Bank, 2006). Older success stories include Tamil Nadu state in India, Indonesia and Thailand (see World Bank, 2006 for references, and short descriptions for Tamil Nadu and Thailand), as well as Iringa, Tanzania (Pelletier and Jonsson, 1994). Lessons from earlier programs have been synthesized by aid agencies (e.g. the BASICS program funded by USAID, with its six-component essential nutrition actions in health services). Many of these programs use community volunteers to mobilize the necessary large volume of personnel without concomitantly large personnel costs. However, successful programs need to maintain motivation of volunteers to maintain success, and to avoid high training costs associated with high turnover.

Mason et al. (2001) describe Thailand's success in reducing underweight prevalence by about 3 percentage points per year in the 1980's (as compared to the usual 0.1 to 1.0 percentage point reduction per year in Asia in the absence of nationwide programs). The Tamil Nadu program was estimated to have a cost per death-averted of $1492 (this program included highly-targeted supplementary feeding: Ho, 1985).

More recent programs include Bangladesh (BINP), Honduras, Madagascar and Senegal (World Bank 2006 contains brief descriptions for three of these excluding Senegal). World Vision (2006) describes programs with impacts in four African countries (Ethiopia, Ghana, Malawi and Tanzania) and is currently undertaking cost-effectiveness analysis (Siekmans, pers. comm.). Recent examples of careful impact studies include Galasso and Umapathi, 2007: Madagascar - SEECALINE), Alderman et al (2007a: Senegal), Alderman (2007: Uganda).

For Senegal, being in the treatment area reduced the probability of underweight by 17% as compared to the control (Alderman et al., 2007a). For Madagascar (Galasso and Umapathi, 2007) the program improved the average weight-for-age z-score by 7.6 percentage points as compared to the control, and height-for-age by 3.1 percentage points. For Uganda (Alderman, 2007) the only consistent impacts were seen in the under-12 months age group, where the change in z-scores of weight for age were 0.22 standard deviations higher in the treatment than the control area (recumbent length was not measured for these youngest children, hence the effect on height-for-age is not known). For Bangladesh, there is no consistent evidence of differences in child nutritional status, maternal weight gain during pregnancy, or birth weight between project and non-project areas, although in project areas there was greater use of vitamin A and iron supplementation. There were also positive effects on weight in subgroups such as among pregnant women who reported eating more (a key message from the nutrition education component), particularly destitute women (World Bank, 2005).

Recent carefully-done cost studies include Fiedler (2007b: RACHNA: CARE/India), and Fiedler (2003: Honduras: AINC). World Bank's (2006) survey suggests the additional recurrent cost per recipient is about $1.60 to $10 ($11-18 per person if food is included). This cost would be similar to the $5-$15 range recommended for such programs by Mason et al. (1999) without food (about double if food is also provided); Mason et al. argue that the programs below $5 in cost per person tend to have insufficient impact. The Honduras program fits into this same range (Fiedler, 2003, estimates the long-term, annual, recurrent cost per child participating as $6.82, and $4.0 as the incremental budget requirements per child participating, net of some shared costs such as personnel).

Cost-effectiveness data still tend to be scarce. An older study for the Dominican Republic cost $493 per case of malnutrition averted (USAID: 1988 this could be converted to cost per death averted, but the numbers would be relatively high; the cost per beneficiary at $23 is definitely in the higher range). Fiedler (2007b) estimates the cost per death averted from the RACHNA program as $1098, and the cost per DALY gained as $39. RACHNA is an add-on to the nationwide government interventions (in nutrition – ICDS and in reproductive health) and focuses on capacity-building and outreach to encourage women in particular to use available services. It is a somewhat unusual intervention (since it focuses on encouraging greater use of services, rather than providing a service), but the findings are interesting nonetheless.

The literature suggests that good program design is essential in programs relying on behavior change. Immunization and fortification programs can fail – but this would be the exception rather than the rule. However, there are various behavior-change programs showing little or even no effect, and hence very poor cost-effectiveness. Country implementation capacity and program design are key. Thus, with the available data the cost effectiveness of community nutrition programs is not well established. The measured benefits are often in terms of incremental growth; if these programs also enhance cognitive development then the benefits might appear higher. Moreover, if the community growth promotion also increases the utilization of micronutrients or anthelmintics then these benefits would also be used in the estimation of the benefit: cost ratio.

2.4.3 Nutrition components of primary health care system

In middle income countries and urban areas, coverage by existing primary health facilities tends to be better. One evaluation (Waters et al., 2006) estimates the cost-effectiveness of adding a health facility-based nutrition education program, including complementary feeding demonstrations, growth monitoring sessions and nutrition messages, and motivation for the personnel using an accreditation process combined with training. They report that the marginal cost of the intervention was $6.12 per child reached, $55.16 per case of stunting prevented, and $1952 per death averted. If one however costs out the staff time costs, this would increase costs to $15.37 per child reached, $138.50 per case of stunting prevented, and $4900 per death averted. These cost levels indicate why poorer countries try to incorporate volunteers where possible.

Table 1 summarizes the basic cost-effectiveness and/or benefit-cost data for the solutions advocated. All the proposed solutions have very attractive benefit:cost ratios/cost-effectiveness. The following section then undertakes a more detailed economic analysis and modeling.

3 Detailed economic analysis

This section presents the sensitivity analysis of the solutions, varying parameters such as the discount rate and the monetary equivalent of the DALY, and highlights some of the methodological issues. As per the Copenhagen Consensus guidelines, two different discount rates are used: the 3% social discount rate often used by international organizations such as the World Bank in social projects, and a higher rate of 6% closer to (although still far from equal to) the rate used on commercial projects. Secondly, the DALY is assigned a monetary value in order to allow comparability with other investments, and the two alternatives used are $1000/DALY and $5000/DALY. There is no particular theoretical rationale for these numbers (other than a "rule of thumb" that health investments are good value if the cost is less than three times per capita GDP – and the $1000 and $5000 numbers would be reasonable for a poor country and a lower middle income country respectively) (Stokley, 2004; Mill and Shillcut, 2004). We first discuss some methodological issues (section 3.1), then undertake some simulations (section 3.2). The reader is referred to BAH (2004) for more detailed consideration of methodology.

3.1. Methodological issues.

In this section we discuss five issues regarding methodology, which affect the ranking of results and hence their policy implications. These issues are:

- the discount rate used, and how this changes the relative ranking of interventions which avert death as compared to those which improve future productivity;
- how cost-effectiveness or benefit: cost ratios change across regions as costs and disease patterns vary;
- the difference between incidence- and prevalence-based calculations;
- the ethical concerns surrounding attaching a dollar value to the DALY; and
- the ethical concern as to whether a year of life saved is equally valuable at all ages.

Undertaking the calculations with different discount rates is not a trivial exercise. The effect depends on the time path of benefits, and may require going back to the original study data. Changing the discount rate for nutrition interventions has different effects on interventions which save lives and where benefits start to accrue immediately (DALY's saved), than where the outcome is cognitive improvement and where benefits accrue in the form of future productivity.

For example, an intervention which saves an infant life in a country where life expectancy is 60 years (assume for simplicity zero disability) saves 60 DALY's (undiscounted) or 28.5 DALY's (present value, discounted at 3%). If the DALY is valued at $1000, this corresponds to $60,000 (undiscounted) or $28,505 (discounted). Similarly, an intervention which increases cognitive development in the first year of life, which increases productivity by an absolute amount of $2000/year between ages 21 and 50 inclusive, also generates benefits of $60,000 (undiscounted), but only $22,356 (when discounted at 3%).

If we make the same comparison at a 6% discount rate, the present value of the DALY's saved for the life-saving intervention is $17,131, but the present value of the benefits from the cognitive intervention drops to only $9,207. With no discounting, the two projects yield the same outcome. Discounted at 3%, the cognitive project yields 78% of the value of the life-saving project; discounted at 6%, this drops to 54%. As discount rates increase, obviously interventions with returns farther in the future become relatively less and less attractive.

Differences in costs and epidemiological profiles across countries matter. The cost-effectiveness/benefit: cost data in table 1 are typically from individual studies in individual countries, and do not hold for all contexts. Even within countries, the average cost-effectiveness is not likely to remain the same as more and more of the population is covered. It is typically much more costly per person to cover the last 30% of the population than the first 70%.

Whereas data on epidemiological profiles across countries are readily available, data on health costs are less so. The relative price structures for different types of interventions differ across countries. In poor countries interventions using tradables (such as higher-technology interventions in hospitals) are relatively more costly than interventions using non-tradables (such as nutrition education interventions intensive in salaries). Mulligan et al. (2005) provide carefully-calculated templates of costs of selected health items in six different WHO regions. We use here the relative cost of a visit to a health center as an indicator of the kinds of nutrition interventions occurring at the community level. Their estimates are that the visit cost is approximately similar in South Asia and Sub-Saharan Africa, about 10% lower in East Asia, about 30% higher in Eastern Europe/Central Asia, 112% higher in Middle East/North Africa, and 150% higher in Latin America. Given also the epidemiological differences, this suggests that cost-effectiveness and benefit: cost results for nutrition interventions in the low income countries (many of these in South Asia and sub-Saharan Africa) are likely to be substantially different from those in the middle income countries.

The difference between incidence- and prevalence-based estimates is another methodological issue. Incidence estimates compare the current cost of an intervention with the downstream benefits, all discounted to the present. These are preferred to prevalence estimates that simply compare the current costs of an intervention (for example, what it would cost to iodize salt throughout the developing world), with the current cost of the deficiency (e.g. the current losses attributable to IQ losses based on current patterns of goiter in mothers), using estimates as to what proportion of the costs could be averted by the intervention. Incidence-based calculations however are more effort to undertake. Prevalence estimates should be regarded as rough estimates of the orders of magnitude involved, and they are less accurate as a measure of the incremental effect of a new intervention. In table 1, prevalence-based estimates from the literature have been recalculated as incidence-based, for comparability.

The conversion of DALY's to dollars raises ethical/conceptual issues. At the core, this requires assigning a monetary value to human life, a calculation that many find uncomfortable. Assigning different values to human life in different countries may be distasteful: nevertheless, this is implicit in the "rule of thumb" statement that health spending to save one DALY is reasonable up to three times per capita GDP. Note that the values assigned in the Copenhagen Consensus project are as follows: with a life expectancy of 60 years, a 3% discount rate, and a DALY value of $1000, a life saved (in infancy) is worth around $28,505; the same life saved is worth just $17,131 with a 6% discount rate. The same calculation at a DALY value of $5000 implicitly values a human life saved at birth at $142,525 with a 3% discount rate, and $85,655 at a 6% discount rate.

Another related conceptual issue is the value of a year of human life at different ages. Current practice (in Jamison et al., 2006) is not to weight DALY's differentially at different ages, such that a healthy year of an infant's life is currently worth the same as a year of a prime-age adult's life and as a year of an elderly person's life. (This is of course different from the practice of discounting future benefits; for any individual, a future life-year saved is worth less than an immediate life-year saved).

Thus saving an infant life in a country with life expectancy of 60, saves 60 years of life (which when discounted amounts to 28.5 life years saved if discounted at 3%). By contrast, saving a life at age 59 saves only 1 life year (no discounting is necessary). This assigns a much greater weight to interventions which save infant lives than those which save lives of older adults. In the previous version of the Disease Control Priorities project (Jamison et al., 1993) this led to differential weighting of life years according to age, whereby life years saved of prime-age working adults were weighted more highly than life years saved of either children or the elderly. However, in the most recent version of the Disease Control Priorities project (Jamison et al., 2006) the differential weightings were not used. Obviously the relative weighting used changes the relative ranking of interventions, and hence has policy implications.

There are no easy solutions to these methodological issues. One needs to be aware of them when interpreting the results, and to treat the results as orders of magnitude rather than precise estimates.

3.2. Policy simulations

In this section, we undertake simulations to show the effect of varying the discount rate, and the dollar value assigned to a DALY. To simplify exposition, we group those interventions with outcomes expressed in DALY's into two groups, using the cost-effectiveness magnitudes suggested from the literature and summarized in Table 1. In one group the cost is approximately $20 (or less) per DALY saved, and in the other the cost-effectiveness is approximately $100 (or less) per DALY saved (calculated at a 3% discount rate). We also undertake simulations for a few interventions where the outcome is calculated in dollars rather than DALYs.

We assume that the intervention costs and benefits are relevant for South Asia or sub-Saharan Africa, where the large majority of undernourished people live. Costs in other regions would be higher, and health benefits would be smaller (since the incidence of undernutrition is lower and mortality rates are usually higher, lower additional costs of targeting or screening would be necessary).

Table 2 then provides the sensitivity analysis, showing the effect of increasing the discount rate from 3% to 6%, as well as assigning the DALY a value of $1000 or $5000. For the countries in South Asia and sub-Saharan Africa, the calculations with the DALY valued at $5000 probably are less relevant. If per capita GNP is below $1000, it likely does not make sense to value a DALY at $5000. The higher DALY value is arguably more appropriate for middle income countries.

The results show that all the nutrition interventions described have very attractive benefit: cost ratios both at 3% and 6% discount rates. Obviously, however, strong assumptions have been required to make these calculations. The higher discount rate makes interventions benefitting children's cognitive development relatively less attractive, since the benefits are further in the future.

Table 3 provides very rough estimates of the total costs and total benefits involved in implementing these solutions at scale. A number of assumptions have been made, and the numbers should be regarded as orders of magnitude, rather than precise. The estimates include scaling up in sub-Saharan Africa and South and Asia only (unless otherwise indicated). This is where the majority of undernourished children live, and from where the cost data are derived. It would likely be disproportionately more costly to scale up to address undernutrition elsewhere. Moreover, the estimates are for scaling up most interventions to cover 80% of the population. We do not have good estimates as yet of the costs for scaling up to reach the last 20%, although we can surmise that the costs are higher as are the benefits, on average.

Table 3 shows that investing about $120 million in micronutrient interventions in South Asia and sub-Saharan Africa (zinc, vitamin A and biofortification) could reduce DALY losses attributable to micronutrient malnutrition by 2 million DALY's (or about 5% of the total such losses attributable to micronutrient deficiencies according to Bhutta et al., 2008). Investing about $800 million in nutrition education (focused on breastfeeding and complementary feeding) could reduce DALY losses attributable to stunting/wasting by amount 10 million DALY's (or about 12.5% of the losses attributable to stunting/wasting, again using Bhutta et al., 2008). These interventions would by no means eliminate undernutrition, but Bhutta et al. (2008) estimate that only about a third of stunting and a quarter of the mortality and morbidity associated with undernutrition can be eliminated by these solutions. To eliminate the rest likely requires significant transfer of food and/or income, and longer-term changes in the status of women.

Additional investments in iron fortification and salt iodization would cost $286 million, with only small DALY gains but large returns in dollar terms. Although the resource cost is $286 million, the cost to governments could be considerably smaller, if consumers absorbed the modest per-person cost of the fortificant. Deworming preschoolers would cost $26.5 million, yielding $159 million in benefits.

Overall, implementing these solutions would cost $1.2 billion, yield benefits valued at $15.3 billion (using the $1000/DALY value), and save 12.0 million DALY's. These DALY's saved represent about 3% of all DALY's lost in children below 5. The cost to governments and donors could be reduced to $0.9 billion, if the costs of extending iron fortification and salt iodization were assumed by households. There is also the possibility of redirecting some existing spending intended to improve nutrition, to these highly cost-effective solutions. Bhutta et al (2008) comment that "supplementary feeding interventions beyond 36 months of age would probably not reduce stunting and might be inadvisable, since rapid weight gain in later childhood is associated with adverse long-term outcomes".

It should be noted that some of the benefits calculations rely heavily on the implicit value assigned to human life. Specifically, the calculations of the benefits for micronutrient supplements (vitamin A and zinc), for biofortification (new agricultural technology), and for nutrition education rely on the implicit assumption that saving an infant life is worth about $30,000 (if the DALY is worth $1000, and the discount rate is 3%). The calculations for fortification (iodized salt, and iron fortification of cereals), and the calculations for deworming, do not rely on this assumption and are robust to it.

4. Discussion

This chapter has revisited and updated previous estimates (BAH 2004) from the previous round of the Copenhagen Consensus. In the previous study, micronutrient interventions were found to have among the highest benefit:cost ratios of any development intervention. More recent research underscores this, and provides further guidance as to the type of interventions, as well as areas where additional work is needed. The current priorities are completing the coverage of under-twos with vitamin A capsules; extending vitamin A capsules to neonates; zinc supplementation (with the 6-12 months group being likely the priority: economic analysis is so far restricted to therapeutic use for diarrhea); completion of Universal Salt iodization, and iron and folate fortification of staples. We have divided the solutions analyzed into supplementation and fortification. Biofortification (plant breeding for high micronutrient content) remains promising but not yet with widespread results.

Breastfeeding promotion in hospitals (also considered in BAH 2004) likewise remains highly attractive as an intervention. Even though large strides have been made in removing formula use in hospitals (with the baby-friendly hospital initiative), the benefit: cost of promoting optimal breastfeeding is high. Impetus for baby-friendly hospitals has slowed and data are not available on the remaining number of hospitals which are not baby-friendly. Hence economic analysis of the overall cost of this possible solution cannot be presented.

Anthelminths (deworming) have been examined in more detail than in the previous estimates. These are as attractive as some micronutrient interventions. Whereas current international goals generally focus on school-age children, these should likely be extended to preschool children in high-prevalence areas. We have not undertaken calculations for pregnant women in second or third trimester, but this may also be cost-effective.

Nutrition education in the community, particularly focused on supporting breastfeeding and weaning practices, is also an attractive intervention when the program is implemented well. In sub-Saharan Africa and South Asia this is likely to take the form of a community nutrition program, since few countries in these regions have good coverage of primary health care systems in which nutrition education can be included.

Finally, all these interventions address only a modest proportion of the overall undernutrition problem. Bhutta et al. (2008) estimate that micronutrient interventions can reduce DALY's lost due to undernutrition by 17% (reducing mortality prior to age 3 by 12% and stunting by 17%). Bhutta et al. (2008) estimate that a package (breastfeeding promotion and support, and promotion of complementary feeding and other support) could achieve a further reduction of 13% of DALY's lost due to undernutrition (13% reduction in mortality, 16% reduction in stunting). To achieve a further reduction beyond this, one would have to consider broader programs such as food or cash transfers, enhancing the status of women, etc. It is not surprising that only a quarter to a third of undernutrition can be removed by micronutrient interventions and nutrition education; the rest requires reduction of poverty which is the major cause of children not having a diet adequate in quality and quantity.

The focus of interventions throughout this chapter has been on interventions in South Asia and sub-Saharan Africa. These are the regions for which the cost-effectiveness and benefit: cost data are drawn (benefit: cost ratios are lower for other regions); and these are the regions where between 75% and 80% of the world's undernourished children live (75% of the stunted and 80% of the wasted).

The discussion has focused on nutritional outcomes; however clearly nutritional improvements also have impacts on health and on educational achievement and hence other development outcomes, which have not been quantified here.

Table 1. Summary cost-effectiveness/benefit: cost estimates from the literature

Intervention	**Cost/person/ Year**[a]	**Cost-effectiveness**	**Benefit:cost Ratio**	**Source**
Micronutrient Supplementation				
Vitamin A Supplementation	$0.20	$3-16/DALY		Chung et al 2000 Fiedler 2000 Horton 1999
Zinc supplement (diarrhea therapy)	$0.47 (10 days)	$73/DALY		Robberstad et al. 2004
Iron supplementation Pregnant women	$10-50	$66-115/DALY		Baltussen et al. 2004
Micronutrient Fortification				
Salt iodization	$0.05		30:1	Authors' estimate[a]
Iron fortification	$0.10-12		7.8:1	Horton and Ross 2003
Folate fortification	$0.01		12:1 to 39:1	Grosse et al. 2005 for USA
Home fortification				
Iron home fortification	$1.20 (4 mths)		37:1	Sharieff et al. 2006
Zinc home fortification	$1.20 (4 mths)	$12.20/DALY		Sharieff et al. 2006
Biofortification	$0.5-$1m / country/yr	$10-120/DALY	4:1 to 50:1	Meenakshi et al 2007
Anthelminths, School age	$0.49 $0.32		3: 1 to 60:1	Miguel & Kremer 2004 Fiedler 2007 (cost)
Anthelminths, Preschoolers	$0.50		6:1	Authors' estimates
Breastfeeding promotion Baby-friendly hospital	$0.30-40 to $3-4/birth	$2-4/DALY to $12-19/DALY		Horton et al. 1996
Community nutrition Education				
Community nutrition	$5-10 no food			Mason et al.

	$10-20 w' food			1999 World Bank 2006 (both are surveys)
Community nutrition		$53/DALY[b]		Tamil Nadu, Ho 1985
Community nutrition add-on		$39/DALY		India, Fiedler 2007
Community Nutrition		$61-153/DALY[c]		Peru, Waters et al. 2006

[a] Authors' calculation; recalculates prevalence estimate using data and references from Horton (2006), to obtain incidence-based estimate. See also Appendix 1.
[b] Assumes 28 DALY equivalent to one death averted, using Fiedler (2007) number for India
[c] Assumes 32 DALY equivalent to one death averted, for Peru

Table 2. Sensitivity analysis: benefit: cost ratios for nutrition interventions

Intervention	**Discount rate 3% Value of DALY $1000**	**Discount rate 6% Value of DALY $1000**	**Discount rate 3% Value of DALY $5000**	**Discount rate 6% Value of DALY $5000**
Highly effective versus mortality(<$20/DALY)	50:1	30:1	250:1	150:1
Effective versus mortality(<$100/DALY)	10:1	6:1	50:1	30:1
Salt iodization	30:1	12:1	Same as $1000 DALY	Same as $1000 DALY
Iron fortification	8:1	7:1	Same as $1000 DALY	Same as $1000 DALY
Anthelminths, preschool	6:1	2.4:1	Same as $1000 DALY	Same as $1000 DALY

Calculations for interventions averting mortality by present authors, using discount factors in Section 3.1. For sources and methods of calculation for salt iodization and iron fortification see Appendix 1. Estimates for provision of anthelminths to school-age children at 6% discount rate were made by present authors, based on Miguel and Kremer, 2004 (who use a 3% discount rate). The “highly effective versus mortality” group includes vitamin A supplementation, and breastfeeding promotion (baby-friendly hospitals). The “effective versus mortality” group includes iron supplementation for pregnant women, therapeutic use of zinc for diarrhea, biofortification and community-based nutrition education.

Table 3. Ballpark estimates of annual costs and benefits of scaling up interventions

Intervention	Numbers Affected (millions)	Solution cost per person Per year	Cost-effect - iveness/ BCR used	DALY's Saved/year (millions)	Total cost/ Year (millions)	Total benefit/ Year (millions) At $1000/DALY	BCR of Solutions $1000 per DALY
Solution 1: Micronutrient Supplementation							**17.3**
Vitamin A Capsules <age 2	11.8	$0.20	$10/DALY	0.24	$2.4	$240	
Therapeutic zinc supplements, courses, infants 6-12 months	58	$1.00	$73/DALY	0.8	$58	$800	
Solution 2: Micronutrient Fortification							**9.5**
Salt iodization	380	$0.05	30:1	Small	$19	$570	
Iron fortification	2,223	$0.12	8:1	Small	$267	$2,136	
Solution 3: Biofortification (Plant breeding)	**36 countries**	**$0.75m/ country**	**$55/DALY**	**1.0**	**$60**	**$1000**	**16.7**
Solution 4 Deworming Preschoolers	**53**	**$0.50**	**6:1**	**-**	**$26.5**	**$159**	**6.0**
Solution 5 Community-based nutrition Promotion	**114**	**$7**	**$80/DALY**	**10.0**	**$798**	**$10,000**	**12.5**
TOTAL all Solutions	-	-	-	**12.0**	**$1,171.5**	**$15,276**	

Salt iodization: assumes scale up in the 3 more lagging regions (South Asia: current coverage 64%, Sub-Saharan Africa: current coverage 64% and CEE/CIS: current coverage 50%), to 80% of households consuming iodized salt. Other developing regions have current coverage 84-85%. Data on coverage from UNICEF (2008).

Vitamin A: assumes scale up to full coverage (two doses) to 80% of children age 2 and below, in Sub-Saharan Africa (where coverage is currently 73%) and South Asia (where current coverage is 71%). For comparison, current coverage in East Asia is 82%. Data on coverage from UNICEF (2008).

Zinc supplements: assumes 2 courses of supplements per year for treatment of diarrhea OR a course of "Sprinkles" for children 6-12 months for approximately 3 months, reaching 80% of children in 6-18 month age group, in South Asia and Sub-Saharan Africa. Assumes current coverage is essentially zero.

Iron fortification: assumes fortification reaching 80% of the population of sub-Saharan Africa and South Asia, assuming negligible current coverage.

Biofortification: assumes spending on average on two staples per country for about 40 countries in South Asia and sub-Saharan Africa.

Anthelminths: assumes two treatments annually for 80% of children below between ages 1 and 3, in Africa and Southeast Asia, assuming negligible current coverage.

Community nutrition: assumes program targeted to rural and poorer urban children in sub-Saharan Africa, South Asia, reaching 80% of children below 2.

References

Alderman, H., 2007. Longitudinal Study of the Nutrition and Early Child Development Program in Uganda. *World Development*, 35(8), 1376-1389.

Alderman, H., B. Nidiaye, S. Linnemayr, A. Ka, C. Rokx, K. Dieng, M. Mulder-Sibanda, 2007a. Effectiveness of a Community-based intervention to improve nutrition in young children in Senegal: a difference in difference analysis. *Public Health Nutrition*, forthcoming.

Alderman, H., J. Konde-Lule, I. Sebuliba, D. Bundy, A. Hall, 2006. Effect on weight gain of routinely giving albendazole to preschool children during child health days in Uganda: cluster randomized controlled trial. *BMJ*, 333:122-126.

Allen, L and S. Gillespie, 2001. What works? A review of the efficacy and effectiveness of nutrition interventions. Geneva, WHO ACC/SCN Nutrition Policy Paper no. 19.

Beinner M.A., J.A. Lamounier, C. Tomaz, 2005. Effect of Iron-Fortified Drinking Water of Daycare Facilities on the Hemoglobin Status of Young Children. *J Am Coll Nut* 24(2), 107-114.

Behrman, J., H. Alderman, and J. Hoddinott. 2004. "Hunger and Malnutrition". In B. Lomborg (ed.) *Global Crises, Global Solutions.* Cambridge (UK): Cambridge University Press.

Bhutta, Z.A., T. Ahmed, R.E. Black, S. Cousens, K. Dewey, E. Giugliani, B.A. Haider, B. Kirkwood, S.S.Morris, H.P.S. Sachdev, M. Shekar. 2008. What works? Interventions for maternal and child undernutrition and survival. *Lancet* (371): 417-440.

Black, R.E.,L.H. Allen, Z.A. Bhutta, L.E.Caulfield, M. de Onis, M. Essati, C. Mathers, J. Rivera. 2008. Maternal and child undernutrition: global and regional exposures and health consequences. *Lancet* (371): 243-260.

Bobonis, G., E. Miguel, and C. Puri-Sharma, 2006. Anemia and school participation. *Journal of Human Resources* 41(4), 692-721.

Brown, K, 2006? Information gaps for scaling-up programs to improve zinc nutrition. A2Z Technical Paper, http://www.a2zproject.org/resources.cfm downloaded July 29, 2007.

Cherian, A., S. Seena, R.K. Bullock and A.C. Antony, 2005. Incidence of neural tube defects in the least-developed area of India: a population-based study. *Lancet* (366): 930-931.

Ching, P., M. Birmingham, T. Goodman, R. Sutter and B. Loevinsohn, 2000. Childhood mortality impact and costs of integrating vitamin A supplementation into immunization campaigns. *Am J Pub Health* 90(10), 1526-1529.

Darmstadt, G.L., Z.A. Butta, S. Cousens, T.Adam, N. Walker, L. de Bernis, 2005. Neonatal Survival 2: Evidence-based, cost-effective interventions: how many newborn babies can we save? *Lancet* 365(March 12) 977-988

De Benoist, B., 2007. Control of iodine deficiency in pregnant and lactating women, and in children less than 2 years: report of a WHO Technical Consultation. Presentation at Micronutrient Forum, Istanbul, 16-18 April.

De Silva, N.R., S. Brooker, P.J. Hotez, A. Montresor, D. Engels and L. Savioli, 2003. Soil-transmitted helminth infections: updating the global picture. *Trends in Parasitology* 19, 547-551.

Fiedler, J.L., 2007a. The cost of child health days: a case study of Ethiopia's enhanced outreach strategy. Social Sectors Development Strategies, Washington DC, draft (mimeo).

Fiedler, J.L., 2007b. A cost analysis of the CARE/India RACHNA program. Washington DC, Social Sectors Development Strategies, draft (mimeo.)

Fiedler, J.L. 2003. A cost analysis of the Honduras community-based integrated child care program. Washington DC, World Bank HNP Discussion Paper.

Fiedler, J.L. 2000. The Nepal national vitamin A program: prototype to emulate or donor enclave? *Health Policy and Planning* 15(2), 145-156.

French, A., R. Grant, S. Weitzman, J.G. Ray, M.J. Vermeulen, L. Sung, M. Greenberg and G. Koren, 2003. Folic acid food fortification is associated with a decline in neuroblastoma. *Clinical pharmacology & therapeutics* 74(3): 288-294.

Galasso, E. and J. Yau, 2006. Learning through monitoring: lessons from a large-scale nutrition program in Madagascar. World Bank Policy Research Working Paper No. 4058 Available at SSRN: http://ssrn.com/abstract=943915.

Gera, T., H.P.S. Sachdev, P. Nestel and S.S. Sachdev, 2007. Effect of iron supplementation on haemoglobin response in children: systematic review of randomised controlled trials. *Journal of Pediatric Gastroenterology and Nutrition* 44, 468-486.

Goodman, T., N. Dalmiya, B. de Benoist and W. Schultink, 2000. Polio as a platform: using national immunization days to deliver vitamin A supplements. *Bulletin of the World Health Organization* 78(3), 305-314.

Grosse, S.D., N.J. Waitzman, P.S. Romano and J. Mulinare, 2005. Reevaluating the benefits of folic acid fortification in the United States: economic analysis, regulation, and public health. *Am J Pub Health* 95(11), 1917-1922.

Gulani, A., J. Nagpal, C. Osmond, H.P.S. Sachdev, 2007. Effect of administration of intestinal anthelmintic drugs on haemoglobin: systematic review of randomized controlled trials. *BMJ*, doi:10.1136/bmj.39150.510475.AE.

Ho, T.J. Economic issues in assessing nutrition projects: costs, affordability and cost-effectiveness, 1985. Washington DC: World Bank PHN Technical Note 84-14.

Hoddinott, J., J.R. Behrman, J.A. Maluccio, R. Flores and R. Martorell, 2008. Effect of a nutrition intervention during early childhood on economic productivity in Guatemalan adults. *Lancet* 371, 411-416.

Horton, S., 2006. The economics of food fortification. *Journal of Nutrition*, 136, 1068-1071.

Horton S., 2004. The economic impact of micronutrient deficiencies. In Pettifor J.M, S. Zlotkin (eds) *Micronutrient Deficiencies during the Weaning Period and the First Years of Life. Nestle Nutrition Workshop Series Pediatric Program*, 54, 187-202, Basel: Karger AG.

Horton, S. and J. Ross, 2003. The economics of iron deficiency. *Food Policy*, 28(1), 51-75. See also Horton, S. and J. Ross, 2006. Corrigendum. http://dx.doi.org/10.1016/j.foodpol.2006.08.002.

Horton, S., 1999. Opportunities for investments in nutrition in low-income Asia. *Asian Development Review*, 17, 246-273.

Horton, S., T. Sanghvi, M. Phillips, J. Fiedler, R. Perez-Escamilla, C. Lutter, A. Rivera and A.M. Segall-Correa, 1996. Breastfeeding promotion and priority setting in health. *Health Policy and Planning,* 11(2), 156-168.

Hotez, P.J., D.A.P. Bundy, K. Beegle, S. Brooker, L. Drake, N. de Silva, A. Montresor, D. Engels, M. Jukes, L. Chitsulo, J. Chow, R. Lazminarayan, C.M. Michaud, J. Bethony, R. Correa-Oliveira, S.H. Xiao, A. Fenwick and L. Savioli, 2006. Helminth Infections: Soil-transmitted helminth infections and schistosomiasis. In Jamison, D.T., J.G. Breman, A.R. Measham, G. Alleyne, M. Claeson, D.B. Evans, P. Jhan, A. Mills and P. Musgrove, *Disease control priorities in developing countries, second edition.* World Bank and Oxford University Press, Washington DC and New York.

IZINCG, 2004. Assessment of the risk of zinc deficiency in populations and options for its control. C. Hotz and K.H. Brown (eds.). *Food and Nutrition Bulletin*, 25, S94-204.

Jamison, D.T., W.H. Mosley, A.R. Measham and J.L. Bobadilla (eds.). 1993. *Disease control priorities in developing countries.* Oxford University Press, New York.

Jamison, D.T., J.G. Breman, A.R. Measham, G. Alleyne, M. Claeson, D.B. Evans, P. Jha, A. Mills and P. Musgrove, 2006. *Disease control priorities in developing countries, second edition.* World Bank and Oxford University Press, Washington DC and New York.

Lozoff, B., E. Jimenez and J.B. Smith, 2006. Double burden of iron deficiency in infancy and low socio-economic status: a longitudinal analysis of cognitive test scores to 19 years. *Arch Pediatr Adolesc Med* 160(11), 1108-13.

Maluccio, J.A., J. Hoddinott, J.R. Behrman, A.Quisumbing, R. Martorell and A.D. Stein, 2006. The impact of nutrition during early childhood on education among Guatemalan adults. Philadelphia-Washington-Atlanta: University of Pennsylvania-IFPRI-Emory draft (mimeo.)

Mason, J., J. Hunt, D. Parker and U. Jonsson, 2001. Improving child nutrition in Asia. *Food and Nutrition Bulletin* 22(3: supplement), 3-85.

Mason, J., J. Hunt, D. Parker and U. Jonsson, 1999. Investing in child nutrition in Asia. *Asian Development Review* 17(1,2), 1-32.

Meenakshi, J.V., N. Johnson, V.M. Manyong, H.De Groote, J. Javelosa, D. Yanggen, F. Naher, C. Gonzalez, J. Garcia and E. Meng. 2007. How cost-effective is biofortification in combating micronutrient malnutrition? An *ex-ante* assessment. HarvestPlus Working Paper No. 2.,c/o IFPRI, Washington DC.

Micronutrient Forum, 2007. News Release. Downloaded from http://www.micronutrientforum.org/newsRelease.pdf July 29, 2007. Conference dated April 16-18, 2007.

Miguel, E. and M. Kremer, 2004: Worms: Identifying Impacts on Health and Education in the Presence of Treatment Externalities, *Econometrica VOL PAGES*

Mill, A. and S. Shillcut, 2004. Communicable Disease. In B. Lomborg (ed.) *Global crises, global solutions.* Cambridge University Press, Cambridge.

Mulligan, J.-A., J. A. Fox-Rushby, T. Adam, B. Johns and A. Mills (2005). Unit costs of health care inputs in low and middle income regions. Disease Control Priorities Project Working Paper no. 9, available from http://www.dcpp.org

Neidecker-Gonzales, O., H. Bouis and P. Nestel, 2007. Estimating the global costs of Vitamin A capsule distribution – a review of the literature and development of a country –level model. *Food and Nutrition Bulletin* 28(3): 307-316.

Ouma, P., M.E. Parise, M.J. Hamel, F.O. ter Kuile, K. Otieno, J.G. Ayisi, P.A.Kager, R.W. Steketee, L. Slutsker and A. M. van Eijk, 2006. A randomized controlled trial of folate supplementation when treating malaria in pregnancy with sulfadexine-pyrimethamine. PLoS Clinical Trials 1(6) e28.

Pelletier, D.L. and U. Jonsson, 1994. The use of information in the Iringa Nutrition Program: Some global lessons for nutrition surveillance. Food Policy 19(3), 301-313.

Rahmathullah, L., J.M. Tielsch, R.D. Thulasiraj, J.Katz, C.Coles, S.Devi, R.John, K. Prakash, A.V. Sadanand, N. Edwin, C. Karamaraj, 2003. Impact of supplementing newborn infants with vitamin A on early infant mortality: community based randomized trial in southern India. *BMJ* 327(7409), 254.

Robberstad, B., T. Strand., R.E. Black and H. Sommerfelt, 2004. Cost-effectiveness of zinc as adjunct therapy for acute childhood diarrhea in developing countries. *Bull WHO* 82(7), 523-31.

Sachdev, H.P.S., T. Gera and P. Nestel, 2006. Effect of iron supplementation on physical growth in children: systematic review of randomized controlled trials. *Public Health Nutrition* 9(7), 904-920.

Sachdev, H.P.S., T. Gera and P. Nestel, 2005. Effect of iron supplementation on mental and motor development in children: systematic review of randomized controlled trials. *Public Health Nutrition*, 8(2), 117-132.

Sazawal, S., R.E. Black, M.Ramsan, H.M. Chwaya, R.J. Stoltzfus, A. Dutta, U. Dhinga, I. Kabole, S. Deb, M.K. Othman, F.M. Kabole, 2006. Effects of routine prophylactic supplementation with iron and folic acid on admission to hospital and mortality in preschool children in a high malaria transmission setting: community-based, randomized, placebo-controlled trial. *Lancet* 367 (Jan 14) 133-143.

Sharieff, W., S. Horton and S. Zlotkin, 2006. Economic Gains of a home fortification program: evaluation of "Sprinkles" from provider's perspective. *Canadian Journal of Public Health*, 97(1), 20-23.

Stokley, N., 2004. Expert Comments. In Bjorn Lomborg (ed.) *Global crises, global solutions.* Cambridge University Press, Cambridge.

Stoltzfus, R.J., 2007. Taking stock: iron. Presentation at Istanbul, Turkey: Micronutrient Forum, April 16-18.

Stoltzfus R.J., H.M. Chway, A. Montresor, J.M. Tielsch, J.K. Jape, M. Albonico and L. Savioli, 2004 Low dose daily iron supplementation improves iron status and appetite but not anemia, whereas quarterly anthelminthic treatment improves growth, appetite and anemia in Zanzibari preschool children. *J Nutr*. 134, 348-356.

Thomas D., E. Frankenberg, J.-P. Habicht et al., 2004. Causal effect of health on labor market outcomes: evidence from a random assignment iron supplementation intervention. Presented at Population Association of America Annual Meetings, Boston, April.

UNICEF, 2006: Progress for children: A report card on nutrition. UNICEF, New York.

UNICEF, 2007. State of the World's Children 2008. UNICEF, New York.

USAID, 1988. Growth monitoring and nutrition education: impact evaluation of an effective applied nutrition program in the Dominican Republic. CRS/CARITAS, 1983-86. Washington DC: USAID of Nutrition.

Waters, H.R., M.E. Penny, H.M. Creed-Kanashiro, R.C. Robert, R.Narro, J. Willis, L.E. Caulfield and R.E. Black, 2006. The cost-effectiveness of a child nutrition education program in Peru. *Health Policy and Planning* 21(4), 257-264.

World Bank, 2006: Repositioning nutrition as central to development: a strategy for large-scale action. World Bank, Washington DC.

World Vision, 2006. Improving nutrition of women and children: the MICAH program, final program report: 2005. World Vision, Mississauga.

Xiao, K.Z., Z.Y. Zhang, Y.M. Su et al., (1990). Central nervous system congenital malformations, especially neural tube defects in 29 provinces, metropolitan cities and autonomous regions of China: Chinese Birth Defects Monitoring Program. *Int J Epidemiology* 19: 978-982.

Appendix 1: Methods/Sources for calculations in Table 2.

Salt iodization
Uses basic data described in Horton (2004). Assumes:
- cost of salt iodization $0.05/person/year; iodization is sufficient to remove threat of goiter
- goiter prevalence in pregnant women 10%
- economic loss per birth to a woman with goiter averages 15%
- future earnings accrue between ages 21 and 50, and their present value at birth, per capita average, is 11.18 times GDP/capita (3% discount rate) or $4.61 (6% discount rate)
- life expectancy 60 years, no disability, and no mortality during working years 21 to 50
- birth rate of 24 per 1000 (similar to India)
- no real GDP growth
- GNI/capita is $370 (similar to India in 2000, when costs obtained)
- Hence present value of benefits per capita is $1.47 (at 3% discount rate), and benefit: cost is approximately 30:1
- Present value of benefits per capita is $0.60 (at 6% discount rate) and benefit: cost is approximately 12:1

Iron fortification
Uses data and methods from Horton and Ross (2003). Assumes:
- cost of iron fortification of flour is $0.12/capita
- prevalence of anemia is about 60%
- iron fortification reduces anemia by 9 percentage points, or approximately 20%
- productivity losses in manual labour are 5%; in heavy manual labour 17%; and in other work (cognitive effect) 4%
- future earnings accrue between ages 21 and 50, and their present value at birth, per capita average is 11.18 times GDP/capita (3% discount rate) or $4.61 (6% discount rate); but iron fortification must be maintained until adolescence to obtain future cognitive benefits (15 years of fortification)
- life expectancy is 60 years, no disability, and no mortality during working years 21 to 50
- no real GDP growth
- GNI/capita is $370 (India in 2000 at time of Horton and Ross, 2003, calculation)
- Benefits in terms of immediate impact on GDP is $3.78 (Horton and Ross 2003) (physical productivity)
- Benefits in terms of future GDP (cognitive gains) are $1.03 (at 3% discount rate) and $0.38 (at 6% discount rate), based on labour share of GDP at 40%
- Benefit: cost ratio is 8:1 (3% discount rate) and 7:1 (6% discount rate)