The human and economic cost of hidden hunger

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Abstract

Background. *Micronutrient malnutrition is a public health problem in many developing countries. Its negative impact on income growth is recognized in principle, but there are widely varying estimates of the related economic cost.*

Objective. *To discuss available studies that quantify the cost of micronutrient malnutrition, and to develop an alternative framework and apply it to India.*

Methods. *Detailed burden of disease calculations are used to estimate the economic cost of micronutrient malnutrition based on disability-adjusted life years (DALYs) lost.*

Results. *The short-term economic cost of micronutrient malnutrition in India amounts to 0.8% to 2.5% of the gross domestic product.*

Conclusions. *Although the results confirm that micronutrient malnutrition is a huge economic problem, the estimates are lower than those of most previous studies. The differences may be due to differences in underlying assumptions, quality of data, and precision of calculation, but also to dynamic interactions between nutrition, health, and economic productivity, which are difficult to capture. Clear explanation of all calculation details would be desirable for future studies in order to increase credibility and transparency.*

Key words: Burden of disease, DALYs, economic cost, India, micronutrient malnutrition

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Introduction

There are more than 850 million undernourished people worldwide [1, 2], and the huge human and economic costs of hunger are widely acknowledged [3–5]. Yet, many more people are affected by a different, "hidden" kind of hunger, namely, the lack of essential vitamins and minerals. In total, more than two-thirds of the world population—for the most part women and children from resource-poor households—suffer from at least one micronutrient deficiency: as many as 3 billion are at risk for zinc deficiency [6], 2 billion people are anemic, many due to iron deficiency [7], 2 billion are iodine deficient, and about 150 million are deficient in vitamin A [8]. These vitamin and mineral deficiencies impose a considerable disease burden on the affected persons and on the societies in which they live: adverse functional outcomes include stunting, increased susceptibility to infectious diseases, physical impairments, cognitive losses, blindness, and premature mortality.

Given the extent of this nutrition problem, various attempts have been made to quantify its related human and economic costs. The World Bank [9] estimated that the combined economic costs of iron deficiency, iodine deficiency, and vitamin A deficiency in developing countries could waste as much as 5% of gross domestic product (GDP). Subsequently, Murray and Lopez [10] calculated the "global burden of disease," in which iron-deficiency anemia, iodine deficiency, and vitamin A deficiency accounted for 2.4% of the overall disease burden of developing countries. The World Health Organization (WHO) [11] attributed a four-times-higher percentage (i.e., 9% to 10% of the disease burden in developing countries with high mortality) to iron-deficiency anemia, vitamin A deficiency, and zinc deficiency. Looking at one micronutrient deficiency only, Horton and Ross [12] calculated the economic cost of iron-deficiency anemia for 10 developing countries and found an average loss of 4.5% of the GDP, with the median loss being 4.1% and country-specific losses ranging from 2.0% in Honduras to 7.9% in Bangladesh.

Starting from a broader view, the Micronutrient Initiative carried out "National Damage Assessment Reports" for 80 countries where micronutrient deficiencies are prevalent and estimated that, on average, 1% of the GDP is lost to iron-deficiency anemia, iodine deficiency, vitamin A deficiency, and folate deficiency, with the median loss across all countries being 0.8% and country-specific losses ranging from 0.2% in China and Morocco to 2.7% in Mali [13]. The estimates of the economic cost of micronutrient malnutrition are depicted in **figure 1**. Studies that more generally considered protein-energy malnutrition alone or combined with micronutrient deficiencies were not taken into account. Similarly, calculations of the Food and Agriculture Organization [5] that were based on older studies and reported the results of a generation's lifetime loss due to various forms of undernutrition as a percentage of one year's GDP were not considered either.

Although the large cost of hidden hunger is becoming clear, the differences in the estimates are unsatisfactory and call for further research because these estimates form the basis for important policy decisions in the field of nutrition and public health. Also, some of the estimates are not very transparent, but their results are nevertheless taken at face value and perpetuated.

The major approaches used for quantifying the cost of micronutrient deficiencies can be divided into two broad categories: cost-of-illness (CoI) studies, which capture the economic costs (and sometimes only the loss in labor productivity); and calculations based on disability-adjusted life years (DALYs), which try to capture the broader welfare losses and focus on the human costs in terms of the disease burden. The results of the two approaches cannot be compared easily, because CoI studies express market losses in monetary terms (or percentage losses of GDP), whereas the number of DALYs lost is a nonmonetary measure

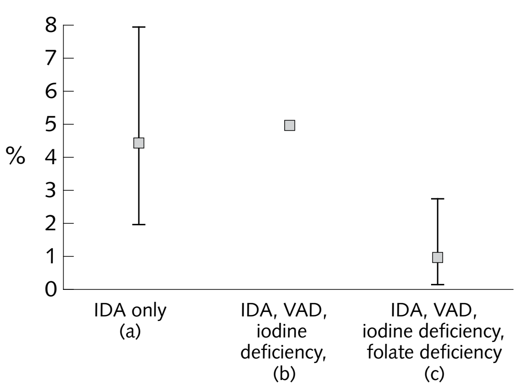

FIG. 1. The economic cost of micronutrient deficiencies in developing countries (loss of GDP). Average costs and, where available, cost ranges are given. IDA, iron-deficiency anemia; VAD, vitamin A deficiency.
Sources: a [12], b [9], c [13].

with a broader scope.

We try to facilitate a better understanding of the different approaches and explain possible sources of differences in the estimates. Moreover, we use recent studies of DALYs lost due to micronutrient deficiencies and suggest a framework for monetizing them. The monetization procedure does not attempt to capture the intrinsic value of life, so that only the economic part of the broader human cost is expressed in dollar terms. In that sense, CoI and monetized DALYs approaches both try to measure the economic cost of micronutrient deficiencies, so that the results should be similar, irrespective of the different methods of calculation. The empirical analysis focuses on India, where micronutrient deficiencies are a public health problem of sizeable proportions [14].

In the next section, we explain the CoI and DALYs approaches in greater detail, before developing a framework in the Methods section of how DALYs can be monetized. Then the empirical results are presented and discussed, and the last section offers conclusions.

Approaches to calculate the cost of micronutrient deficiencies

Cost of illness

In general, CoI calculations use clinical studies of the impact of micronutrient deficiencies on productivity or cognition (due to physical and mental impairments), which they relate to the incomes of different target groups to obtain an absolute loss in monetary terms for each affected individual. If this loss is multiplied by the prevalence rates of the respective micronutrient deficiencies in each target group and added up across all groups, an estimate of the productivity loss is obtained, to which health-care costs can be added to get an estimate of the overall economic loss:

$$CoI = \sum_i \sum_j \left(T_j P_{ij} Y_{ij} R_{ij} + H_{ij} \right) \qquad (1)$$

where T_j is the number of people in target group j, P_{ij} is the prevalence rate of micronutrient deficiency i in target group j, Y_{ij} is the average income in target group j, R_{ij} is the relative reduction in productivity due to micronutrient deficiency i in target group j, and H_{ij} are the health-care costs that are caused by micronutrient deficiency i in target group j. Hence, the different estimates of the economic cost (**fig. 1**) can be explained by the inclusion of different target groups, use of different prevalence rates, choice of different income levels, different estimates of the productivity reductions through micronutrient deficiencies, or different valuations of the related health-care costs. A different approach to quantify the economic dimension of micronutrient deficiencies is to examine their impact on wages by means of regression analyses. To our knowledge this has only been done for individual regions and for single micronutrient deficiencies or proxies thereof [15–17].

Disability-adjusted life years

The DALYs approach to measuring the burden of disease was originated by Murray and Lopez, who have also provided in-depth explanations and replies to criticisms of this concept in their book [10]. A more recent overview of the relevant literature has been compiled by Fox-Rushby [18]. We have refined the approach for applications in a micronutrient deficiency context [19]. The basic idea of the DALYs approach is to determine the number of new cases of adverse functional outcomes that are caused by micronutrient deficiencies in a given year and to weight their severity on a scale between 0 and 1 (where 0 represents a state of complete health and 1 a state equal to death, which is how mortality and morbidity can be combined in a single index). After weighting, the duration of all conditions is added up to result in an estimate of the health loss of micronutrient deficiencies, which is expressed in the annual number of healthy life years (or DALYs) lost:

$$DALYs_{lost} = \sum_j T_j M_j \left(\frac{1-e^{-rL_j}}{r} \right) + \sum_i \sum_j T_j I_{ij} D_{ij} \left(\frac{1-e^{-rd_{ij}}}{r} \right) \qquad (2)$$

where T_j is the total number of people in target group j, M_j is the mortality rate associated with the respective micronutrient deficiency in target group j, L_j is the average remaining life expectancy for target group j, I_{ij} is the incidence rate of health outcome i in target group j, D_{ij} is the disability weight for health outcome i in target group j, d_{ij} is the duration of health outcome i in target group j (for permanent conditions d_{ij} equals L_j), and r is the rate at which future health losses are discounted. Discounting is standard practice in health economics analyses to make values comparable over time, because people value health gains in the near future more highly than more distant health gains [20]. For instance, if a person whose remaining life expectancy is 10 years died prematurely today, a loss of 10 DALYs would be caused without discounting. Discounted at a common rate of 3%, the present value of the loss is reduced to around 8.8 DALYs.

Equation 2 reveals that different estimates of the disease burden of micronutrient deficiencies can mainly be explained by the inclusion of different target groups, different adverse functional outcomes, and use of different incidence rates; disability weights and discount rates are usually used more consistently across studies. In the case of vitamin A deficiency, differences may also be explained by the difficulty of measuring vitamin A deficiency: its prevalence is usually estimated based on the occurrence of Bitot's spots and corneal scars, which are clear signs of vitamin A deficiency but rather rare; that is, extrapolations tend to have a certain margin of error.

Methods

In this article, we mainly focus on estimates of DALYs and their monetization. As explained above, the empirical analysis focuses on the example of India. Previous DALY estimates of the burden of micronutrient deficiencies mostly focus on iron-deficiency anemia and vitamin A deficiency, and different functional outcomes have been included in the calculations. **Table 1**, for instance, shows that Murray and Lopez [10] and the World Health Organization [11] did not include mortality. However, especially for vitamin A deficiency, child mortality is an important problem, so that these results underestimate the true burden. Also, these estimates either are somewhat older or refer to more aggregate geographic areas. We build on more recent estimates for vitamin A deficiency and iron-deficiency anemia in India by Stein et al. [21, 22], which include all functional outcomes for which a causal relationship has been proven in meta-analyses. According to these estimates, in India 4.0 million DALYs are lost annually due to iron-deficiency anemia and 2.3 million due to vitamin A deficiency. Furthermore, we include estimates for zinc deficiency, which causes an annual loss of 2.8 million DALYs [23], and use projections for the loss due to iodine deficiency of 0.2 million DALYs [10]. Adding up these numbers for the four micronutrient deficiencies results in an aggregate annual burden of 9.3 million DALYs lost. In other words, without micronu-

TABLE 1. Estimates of the disease burden of micronutrient deficiencies in India in 2000/01 (millions of DALYs lost)

Micronutrient deficiency	Murray and Lopez [10][a]	WHO [11][b]	Stein et al. [21, 22]
IDA (without mortality)	3.7	3.3	3.7
IDA (including all functional outcomes)[c]	—	—	4.0
VAD (visual problems only)	0.4	0.1	0.3
VAD (including all functional outcomes)[c]	—	—	2.3

DALY, disability-adjusted life year; IDA, iron-deficiency anemia; VAD, vitamin A deficiency

a. Projections for 2000.

b. Derived from the calculations for high-mortality countries in South and Southeast Asia (SEAR-D) by applying India's population weight.

c. "All functional outcomes" means the inclusion of all health outcomes of the respective micronutrient deficiency as defined in Stein et al. [19].

trient deficiencies, 9.3 million healthy life years could be saved in India each year.

Valuing DALYs

We now develop a framework to convert the burden—or the human cost—of micronutrient malnutrition expressed in DALYs lost into a monetary measure. By attributing a monetary value to each DALY lost, we do not attempt to assign an intrinsic value to human life as such, since this is disputed not only on ethical but also on theoretical grounds [24, 25]. Therefore, any practical valuation of life is necessarily only an estimate of the *lower* economic bound of its true value to society or the individual. Here we only approximate the average tangible *economic* cost that can be associated with the loss of a DALY in the short run. This may provide a first idea of the orders of magnitude involved, and it makes results comparable to those of CoI studies, even if it fails to capture the full value of a DALY. (Indeed, one could argue that the use of DALYs to quantify the human cost of micronutrient deficiencies is already an underestimate, because it only includes the disease burden borne by the affected individuals and not, for example, the anxiety experienced by relatives and friends of those who are ill or the loss borne by the family members of those who die.)

As long as its limitations are clearly stated, such a reduction of DALYs into dollar values is justified for two reasons. First, in this study we want to consolidate the results of DALY-based calculations of the human cost of micronutrient deficiencies with the results for the economic cost of micronutrient deficiencies that are expressed only in monetary terms, to be able to assess the robustness of the two underlying methods. And we want to compare this cost to the overall GDP, which is also only expressed in monetary terms. Second, although DALYs may be a more thorough and powerful measure and therefore be more desirable from an academic point of view, they are also more complicated and more difficult to understand for a wider audience. And although policy makers may be more used to base their decisions on arguments that are put in economic terms, health professionals may also appreciate monetary estimates as supplementary information [26–28].

Societal point of view

In some previous studies, DALYs were valued in order to use them as the basis for specific cost-benefit analyses [29–31], in more global health program evaluations [32], or as a health cost component in other calculations [33]. In these studies, the values attached to each DALY lost in developing countries varied widely. In a 2001 report, WHO [32] used values of US$410–563 for low-income countries, assuming that each DALY saved would give an economic benefit of one year's per capita income. Rijsberman [30] used US$500 per DALY to approximate the per capita annual income of the poor, while Collier and Hoeffler [33] worked with US$1,000 to capture the purchasing power parity level of per capita annual income in many of the least developed countries. Zimmermann and Qaim [31] used US$1,030 as the annual per capita income in the Philippines, while Mills and Shillcutt [29] used 3,830 international dollars as the mean gross national income in low- and middle-income countries. When relatively arbitrary "round" numbers like US$500 or US$1,000 were used, this was done to make the results internationally comparable, although the underlying rationale in each case was to base the DALY value on the average per capita income of the countries for which the analyses were carried out.

DALYs can be lost by all individuals, whether engaged in remunerated activities (now or in the future) or not, just as all individuals are considered in the computation of per capita GDP. Hence, average per capita income may indeed be used to assess the economic loss of one DALY. But this reasoning overlooks the fact that participation in remunerated activities (as well as the size of the remuneration itself) may, in turn, depend on the extent of the micronutrient deficiencies that cause the loss of DALYs in the first place: individuals who suffer from micronutrient deficiencies are less productive and their contribution to the GDP is lower than it could be otherwise. Therefore, deriving the average per capita income from the current GDP may introduce a serious downward bias in the economic valuation of DALYs, especially given the vast number of people affected by micronutrient malnutrition. For this reason, we use a DALY value equal to per capita income only to determine the lower bound of the economic cost of micronutrient malnutrition. For the same reason, and to take account of the value of longevity and leisure time, WHO proposes to use the triple per capita income as a less conservative DALY value: "More conventionally, each DALY would be valued at a multiple of annual income, perhaps three times current income" [32] (**table 2**).

TABLE 2. Possible values for a DALY lost in India

Basis for valuation	Value (2004 US dollars)	Use of valuation
Per capita income	620[a]	Lower bound for economic cost to society
Triple per capita income	1,860	Best estimate for economic cost to society
Average value of a statistical life year	2,874[b]	Individual's valuation of a DALY lost

DALY, disability-adjusted life year.
a. World Bank [34].
b. Derived from India-specific value of a statistical life (VSL) estimates of Miller [35].

Individual point of view

Next to capturing the economic loss to society at large due to micronutrient deficiencies, a valuation of DALYs may also be used to quantify their worth in monetary terms to the affected individuals themselves—which is higher if individuals value their own life and health higher than society values the economic productivity of its (anonymous) members. In this context, a possible approach could be to ask for an individual's willingness to pay (WTP) to prevent the loss of a DALY. Although such specific WTP studies are hardly available, there exists a broader body of literature on the "value of a statistical life" (VSL). These VSL studies are ultimately founded in people's WTP for incremental reductions in their risk of dying or, more often, on people's willingness to accept a higher risk of dying if they earn higher wages. Such VSL results may also be used to derive the value of a statistical life year, which may then be used to value a DALY (**table 2**); in this case the assumption is that people value a statistical life based on the premise that it is a healthy life. A similar approach has been used, for instance, by Cutler and Richardson [36] to value "quality-adjusted life years" in their study on the health gains in the United States between 1970 and 1990 and the potential magnitudes of the rate of return to medical care.

However, whether the mortality risk some people are willing to accept for higher wages may be used in a meaningful way to approximate the value of a DALY lost is an open question: the empirical basis for using these estimates in applications to specific countries is rather thin, and individual studies often rely on homogeneous subgroups of people—most often workers whose wage-risk trade-off may not be representative [37, 38]. Such estimations are also prone to problems and biases of their own [39]. Hence, using scarce, nonrepresentative, and less robust estimates to reflect the values of whole, more heterogeneous societies could be problematic. Nonetheless, Viscusi [37] points out that the estimates do provide some guidance in determining the orders of magnitude involved. Therefore, although the VSL estimate provided in **table 2** is the best estimate available, we stress that its absolute value should only be seen as such an indication of the order of magnitude of the value individuals attach to a healthy life year they lose. Further research in this direction is clearly warranted.

We build our estimate of the individual valuation of a DALY on Miller [35], who reports "low," "high," and "best" estimates for the VSL in India and expresses these estimates as multiples of the national per capita income. For India his "best" estimate is 158 times greater than the national per capita income; for 2004 this would be US$109,210. In assuming that the estimations are based on the WTP of adults aged 30 to 39 years, we use an average remaining life expectancy of 38 years [40] to derive an average value for an Indian statistical life year of US$2,874. (For the United States, Murphy and Topel [41] have carried out a more sophisticated study to take, for example, life-cycle changes into account, but for India such analyses are not available.)

Losses relative to GDP

As discussed in the Introduction, in many studies the economic cost of micronutrient deficiencies is reported as a percentage loss of GDP. Such a relative measure has the obvious advantage of being comparable across countries (whereas reporting absolute figures would always draw attention to the larger countries, simply because they have absolutely more cases of micronutrient deficiencies). It is also useful for raising awareness of the magnitude of the adverse impact of micronutrient deficiencies on income growth among researchers and policy makers who are interested in economic development.

Building on the calculations of the burden of micronutrient deficiencies and the economic valuation of DALYs, the number of DALYs lost can be multiplied by the respective monetary value to obtain the absolute economic loss of hidden hunger in monetary terms. Dividing this by the overall GDP results in the percentage of GDP that represents the economic cost of micronutrient deficiencies, which can then be compared with other estimates or used as a relative measure of the cost of hidden hunger.

Results

Having described the possibilities of estimating the economic cost of micronutrient malnutrition based on burden of disease calculations, in this section we present results for India, for which recent estimates of the burden of the major micronutrient deficiencies are available, as described above [10, 21–23]. On the basis of these estimates, using the different monetary values per DALY discussed in the previous section (**table 2**) results in an overall economic loss of 0.8% to 2.5% of the Indian GDP, which rises to 3.9% if the affected individuals' valuation of the disease burden is included. The corresponding absolute losses in monetary terms amount to US$5.8–26.8 billion (**table 3**). Among the analyzed micronutrient deficiencies, iron-deficiency anemia is responsible for over 40% of the total loss, while zinc deficiency causes 30% of the loss and vitamin A deficiency 25%; iodine deficiency accounts for only 2% of the overall loss of micronutrient deficiencies. It also becomes clear that the welfare loss experienced by the individuals suffering from micronutrient deficiencies is much higher than the economic loss for society at large (1.5 to 4.6 times greater).

The actual economic and human loss from micronutrient malnutrition may be higher than the sum of the

TABLE 3. The disease burden of micronutrient deficiencies in India and the related economic cost

Cost	IDA	ZnD	VAD	Iodine deficiency	IDA, VAD, and iodine deficiency	IDA, ZnD, VAD, and iodine deficiency
No. of DALYs lost (millions)	4.0[a]	2.8[b]	2.3[c]	0.2[d]	6.5	9.3
Lower bound of economic cost[e]						
Absolute loss (2004 US$, billions)	2.48	1.74	1.43	0.12	4.03	5.77
Relative loss (%GDP)[f]	0.36	0.25	0.21	0.02	0.58	0.83
Best estimate of economic cost[e]						
Absolute loss (2004 US$, billions)	7.44	5.21	4.28	0.37	12.09	17.30
Relative loss (%GDP)[f]	1.08	0.75	0.62	0.05	1.75	2.50
Aggregated costs from the perspective of the affected individuals[e]						
Absolute cost (2004 US$, billions)	11.50	8.05	6.61	0.58	18.68	26.73
Relative loss (%GDP)[f]	1.66	1.16	0.96	0.08	2.70	3.87

IDA, iron-deficiency anemia; ZnD, zinc deficiency; VAD, vitamin A deficiency; GDP, gross domestic product
a. Stein et al. [22].
b. Stein et al. [23].
c. Stein et al. [21].
d. Projection for 2000 by Murray and Lopez [10].
e. See **table 2** for source.
f. GDP of US$691.2 billion from World Bank [34].

individual deficiencies if these occur simultaneously or overlap partially. Here the DALYs calculations were only based on adverse functional outcomes of individual micronutrient deficiencies for which causality was clearly proven. However, the underlying clinical studies only investigated the health limitations imposed by deficiency of a single micronutrient. Therefore, if individuals are deficient in two or more micronutrients, alleviating one deficiency may only improve the health of the individuals to the level the other micronutrient deficiency permits; or deficiency in one micronutrient may even limit the bioavailability of another [42–44]. Hence, estimating the burden of each micronutrient deficiency separately may result in an underestimate of the overall burden of micronutrient malnutrition, and the bias may be substantial. For instance, recent estimates indicate that 27% to 36% of pre-schoolchildren in South Asia suffer from vitamin A deficiency, iodine deficiency, anemia, and undernutrition at the same time [44].

Discussion

We have used an alternative approach to previous studies to quantify the economic cost of micronutrient malnutrition, in order to test the robustness of available estimates and examine possible sources of differences (**fig. 1**). In doing so, we used India as a case study. Our results are significantly lower than what most other studies indicate for India (**fig. 2**). For example, Horton and Ross [12] put the cost of iron-deficiency anemia in India at 6% of the GDP, whereas our best estimate corresponds to a loss of 1.1%. Horton and Ross [12] point out that the impact of iron-deficiency anemia would be considerably lower if cognitive effects were disregarded, but our calculations include these effects. Similarly, the World Bank [9] estimate of a 5% loss of GDP from iron-deficiency anemia, vitamin A deficiency, and iodine deficiency is considerably higher than our estimate of 1.75% for the same set of micronutrient deficiencies. Part of the divergence might be due to intercountry differences, since the World Bank study is based on developing countries in general. Furthermore, the World Bank estimate is more than 10 years old, and the prevalence of micronutrient deficiencies may have declined since then. The more recent estimate of the Micronutrient Initiative amounts

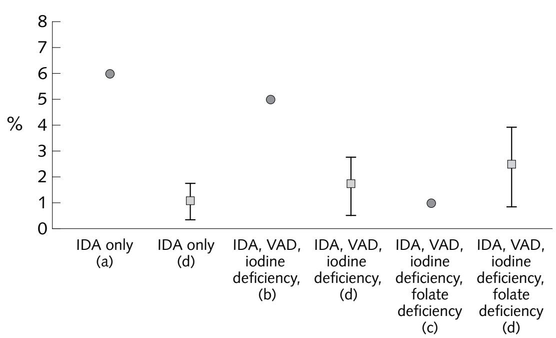

FIG. 2. The economic cost of micronutrient deficiencies in India (loss of GDP). IDA, iron-deficiency anemia; ZnD, zinc deficiency; VAD, vitamin A deficiency.
Sources: a [12]; b [9] (for developing countries in general); c [13]; d, table 3 (best estimate and range between lower bound and individual costs).

to only 1% of the GDP, in spite of the fact that the cost of folate deficiency is additionally included [13]. Unfortunately, what method and data were used—either by the World Bank or by the Micronutrient Initiative—to arrive at these estimates is not explained in the studies and remains unclear. Therefore, additional reasons for the diverging results may be differences in data quality, calculation precision, and assumptions made. We only include adverse functional outcomes of each micronutrient deficiency for which there is a clear consensus in the literature confirmed by meta-analyses. This may result in an underestimate of the true costs, because it disregards potential negative effects of as yet unproven health outcomes or of multiple micronutrient deficiencies. Yet, the requirements for data to analyze the effect of simultaneous and interacting deficiencies are high, and the scientific basis for quantifying their health impact is still thin. Hence, we were conservative, refraining from speculations about the impact of unproven or contestable outcomes and mechanisms. Still, even the lower bound estimate of 0.8% GDP loss indicates the severity of the micronutrient malnutrition problem in India.

If we disregard the very low estimate of the Micronutrient Initiative, one possible explanation for the relatively low result of our calculations could also be that we used DALYs estimates of the *human* cost to approximate the *economic* cost. Possibly, the limitations imposed by micronutrient deficiencies on the functioning of individuals are less severe—from a health perspective—than their consequences for the individuals' productivity. That is, the disability weights in equation 2 may not accurately reflect the economic dimension of the adverse functional outcomes of micronutrient deficiencies. However, it could as well be that CoI studies overestimate the economic cost, because well-nourished individuals might not use all their additional productive capacity to pursue remunerated activities but choose to engage in social or leisure activities instead [45]. Or, simply, institutional, social, or technological factors (such as fixed hourly wages, peer pressure, or assembly-line work) may limit the incentives to increase production [46]. Other factors (such as alternative employment opportunities during the off season or in sluggish economies) may also influence work output [47]. However, these are all rather short-term considerations. Dynamic interactions between hidden hunger and economic development may be a more important factor in determining the cost of micronutrient deficiencies.

Micronutrient deficiencies and income growth in the long run

In his seminal historical work, Fogel [45, 48] has shown how better nutrition contributes to economic growth, both by immediately increasing work output (thermodynamic effect) and enlarging health endowments over time from one birth cohort to another (physiological effect). This is also how he explains 30% of the British growth in per capita income over the past two centuries. And, although Fogel focuses on the impact of energy malnutrition (i.e., a shortfall in calorie intake), he also mentions micronutrient deficiencies (of iodine, iron, and folate), and he points to the health effects of improved consumption of vitamins and other trace elements through dietary diversity and dietary supplements [45]. Moreover, some of the indicators he uses to measure the impact of malnutrition in general (such as stunting) also capture the more specific impact of micronutrient deficiencies. Hence, it is probably justified to interpret his results as covering the impact of better nutrition in general and indicating the potential impact of improved micronutrient intakes in particular; the more global perspective of his work also takes account of possible micronutrient interactions that are not captured by the other studies. Therefore, the relatively low results of our calculations, which are based on the current economic performance of India, may also reflect the fact that India is stuck in a poverty–malnutrition trap [49, 50].

Conclusions

In this study we used an alternative approach to quantify the *economic* cost of hidden hunger, building on studies that measured its *human* cost (expressed in DALYs lost) rather than the more common CoI calculations. In our example for India, we found that a reasonable estimate of the combined economic cost of iron-deficiency anemia, zinc deficiency, vitamin A deficiency, and iodine deficiency amounts to a loss of 2.5% of the Indian GDP—compared with 6.9% economic growth in 2004. This finding illustrates clearly the limitations that micronutrient malnutrition can impose on economic development. Nonetheless, our results are lower than most other estimates of the economic cost of hidden hunger. The differences may be due to differences in underlying assumptions, quality of data, and precision of calculation. Another possible explanation is the time it may take to realize the theoretical productivity gains, which are quantified in CoI studies. As historical analyses show, controlling malnutrition may help to increase economic output tremendously, but this may take generations. Therefore, a sensible approach could be to determine the economic cost of micronutrient malnutrition for a given time frame only. In this context, we found that even in the very short term, the economic cost of micronutrient malnutrition in India equals 0.8% of the GDP. Although further research is needed to incorporate the dynamics of reduced micronutrient malnutrition and possible feedbacks between malnutrition and economic growth into projections of the future economic cost, our findings for the short-term cost of hidden hunger should be disquieting enough to further sensitize the academic community to this issue and to convince policy makers of the severity of the problem. To increase the credibility of related estimates, high-quality nutrition and health data are needed, but we also argue for a transparent explanation of details of calculation and assumptions, which has not always been the case in previous studies.

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