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Benefit-cost analysis of iron fortification of rice in India: Modelling potential economic gains from improving haemoglobin and averting anaemia

1. Introduction

Anaemia remains one of the most widespread nutritional deficiencies in the world. The causes of anaemia are varied, although iron deficiency is the largest single cause in most settings. For example, Sarna et al.'s recent (2020) analysis for India identifies iron deficiency anaemia as the most common form of anaemia among children 1-19 years old, followed by folate or vitamin B12 deficiency. Infections, including malaria and other parasites, as well as limited diet diversity are proximate causes in some settings, both of which respond to income growth, albeit slowly (Alderman and Linnemayr 2009).

Thus, additional complementary strategies are advocated to reduce the burden of anaemia. (Christian 2021). These approaches fall into three broad categories; promotion of diet diversity through behavioural change communication and improved marketing chains; supplementation; and fortification including biofortification. The first may be the most sustainable but it is seldom possible to implement within a large-scale programme. Supplementation is a pillar of antenatal care and is also advocated for school health programs (Bundy et al. 2018). Its efficacy for improving iron status and reducing anaemia is not in doubt, but the ability to reliably supply intended beneficiaries and to ensure adherence to recommended intake frequency is the weak link in most programs. While few surveys measure coverage for the general population, even prioritized supplementation to pregnant women is often low. For example, Heidkamp et al. (2020) find that the average coverage of iron and folic acid supplementation of pregnant women in 17 Demographic and Health Surveys was a trifle above 30%.

Fortification can have a wider reach at a lower cost. Currently, 85 countries mandate wheat flour fortification with iron or folic acid or both (Olson et al. 2021). Other countries fortify maize flour. More recently, extruded fortified rice and double fortified salt with iron and iodine have also been proposed as vehicles for iron fortification (Hurrell 2021a). Despite the extent of mandated programmes, the evidence on their impact on micronutrient status is mixed (Olson et al. 2021; Keats et al. 2019; Peña-Rosas, 2019). One reason is that in the presence of infection and inflammation, iron fortification is less effective (Hurrell 2021b). The varied evidence on the effectiveness of fortification for improving iron status also reflects the diversity of fortificants used with some fortificants resulting in a greater increase in iron than others. There are also substantial variations by age. Moreover, most large-scale fortification strategies cannot ensure that the vulnerable population consume adequate amounts of the fortified products. Thus, while the meta-analysis in Keats et al. (2019) reports a 34% decline in anaemia prevalence in large scale programmes, there are substantial variations with wide confidence intervals in subgroups. It is worth noting that these studies are not confined to populations with iron deficient anaemia; the reported effect sizes include the response of those with or without iron deficiency and reflect the existing rates of gut inflammation and worm infections.

To assist prioritization among competing anaemia reduction programmes in India, the current study presents ex-ante estimates of the benefit cost ratio of an ambitious plan to fortify extruder rice with iron, folic acid, and vitamin B12. There are a few economic studies of the benefits and cost of fortification (Makkar et al. 2022; Horton, Wesley, and Mannar 2011; Prieto-Patron et al. 2020) and others on cost effectiveness for improving child health (Krämer, Kumar, and Vollmer 2021) but none that we are aware of cover large-scale rice fortification.

One estimate for India places the costs of anaemia at 1.3 percent of GDP for children (Plessow et al. 2015). We focus on estimating the benefits of reducing these costs by improving current productivity for adults and future productivity for school-going children through improved learning. We undertake this estimation within the context of a targeted social protection programme in India that provides monthly quotas of in-kind food distribution to households as well as offers free school meals to primary school children. These distribution channels address some of the regulatory and monitoring issues that challenge mandatory fortification of private trade, relevant not only for India but also for school meal programmes in general, which are estimated to have reached 388 million children in 163 countries in 2020 (WFP 2021). This benefit cost modelling also points to a possible contribution for a range of in-kind assistance programs which exist in many countries despite the expansion of cash transfers (Alderman, Gentilini, and Yemstov 2018).

But there is a broader goal of this inquiry. As is common with ex ante benefit cost analysis, the modelling undertaken in this study requires an array of assumptions. While the channels of the food distribution provide relatively more certainty on the quantities of fortified rice obtained than is common in studies of fortification, we need to address the wide confidence intervals of key parameters that remain despite a history of fortification over decades. This pertains to both the biological response to fortification as well as the economic or behavioural implications of such changes. By highlighting the range of plausible outcomes, we hope to motivate efforts to narrow these uncertainties.

Our base case scenario, which we refer to as our core plausible model, indicates a benefit cost ratio of 8.2 with 69 percent coming from improved learning in school and the remainder though enhanced work productivity. We test alternative assumptions, for example, by substituting the lower bound of the confidence interval reported in a meta-analysis of rice fortification yielding a benefit cost ratio of 1.4. All other assumptions lead to larger ratios.

The paper is structured as follows. Section 2 presents the setting in India. Section 3 briefly discusses the mechanisms underlying the model and presents a framework for the analysis, drawing on relevant literature. This is followed by a discussion of the data in Section 4 and an explanation of the methodology in Section 5 with reference to specific literature used to support the analysis. For a more detailed literature review, refer to World Bank (2022). Section 6 presents the results for the core plausible model and the alternative scenarios. Section 7 provides a concluding discussion with policy implications.

2. Setting

Anaemia, as measured by India's National Family Health Survey (NFHS)-5 conducted between 2019 and 2021, has increased for all ages and gender grouping since 2015 (Indian Institute for Population Sciences and MoHFW 2021). To address this persistent problem India has launched a multi-pronged programme, *Anaemia Mukt Bharat* (AMB) (GoI 2022; Rai et al. 2022). Fortified foods are to be distributed in-kind in the school feeding programme called the *Pradhan Mantri Poshan Shakti Nirman*, formerly the Midday Meal scheme (hereafter referred to as MDM), and the Integrated Child Development Services (ICDS). In parallel, the Department of Food and Public Distribution (DFPD plans to fortify rice through the Public Distribution System (PDS).

The Food Safety and Standards Authority of India (FSSAI), the food regulatory body of India, has taken leadership in promoting fortified foods in the country. They have issued the Food Safety and Standards (Fortification of Foods) Regulations, 2018, under which standards for five food commodities – wheat flour, rice, double fortified salt, milk, and edible oil – have been established. Currently, food fortification is promoted as voluntary for the first three of these foods (DFPD 2019).

If implemented, the programme could potentially reach up to 800 million people with subsidized fortified publicly distributed grain (DFPD 2019) and every public primary school child could benefit as well. As the upper limit of grain drawn from the PDS and the daily provision of grain in the MDM are known, we can estimate the amount of fortified rice available to the population. Given these channels, the government can determine which costs of fortification if any could be passed to consumers, something that is often problematic in private trade.

Fiedler et al. (2012) studied wheat flour fortification in the PDS in Gujarat, which appeared to address iron deficiency but may be impractical since wheat grain for local small-scale milling, not flour, is the likely product for distribution. There is also a growing evidence base on distribution of double fortified salt with iodine as well as iron distributed through the PDS. Large randomised control trials (RCTs) have been undertaken in the two most populous states, Bihar and Uttar Pradesh (Banerjee, Barnhardt, and Duflo 2018; Cyriac et al. 2020). The former found low take up while the latter observed high take-up but low utilization. There are a few small studies of extruder rice in school meals in India. Both Mahapatra et al. (2021) and Moretti et al. (2006) find evidence of reduced anaemia with the former also observing improved cognition. However, neither study modelled economic impact.

3. Framework of analysis

Iron fortification of rice is expected to address iron deficiency anaemia by increasing the haemoglobin (Hb) levels of beneficiaries. Lower Hb levels reduce the oxygen carrying capacity of blood resulting in lethargy, fatigue, and poor concentration, as well as lower cognitive ability

(Kraemer and Zimmerman 2007). Among adults, low Hb levels result in diminished work capacity and in children the impact is seen in terms of impaired cognitive function, which can impact academic performance.

The economic gains from iron supplementation or fortification among adults come from improved work capacity and the present value of future productivity gains among children from academic improvements reflecting improved cognition (Horton and Ross 2003a; Prieto-Patron 2020).

While the functional consequences of low Hb in terms of reduced work capacity are well established (Kraemer and Zimmerman 2007), quantifying their impact in terms of a decline in productivity is not as well studied. Horton and Ross (2003a) reviewed this literature and extrapolated it to a general population. Studies that inform the basis of quantifying the impact of low Hb levels on current productivity intermediated through an increase in work capacity are discussed further under Section 5.4.

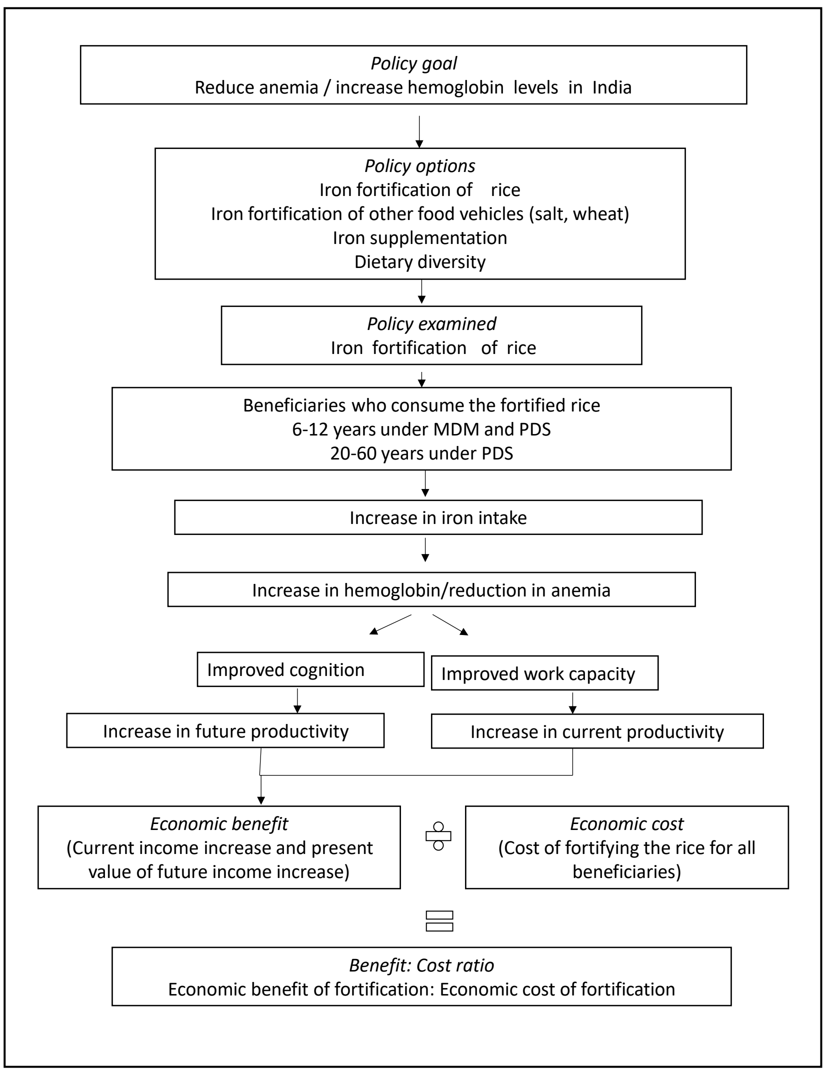
There is encouraging evidence of the impact of iron supplementation and fortification on cognition and academic performance among children older than 5 years although the results are less promising for a younger age group. Britto et al. (2017) identify four micronutrient supplementation trials that positively impacted academic performance in 5-16 year old children susceptible to deficiencies (SMD 0·30, 95% CI 0·01 to 0·58). In a study of elementary school students in China iron supplementation was associated with an increase in math scores (Low et al. 2013). Improvement in both math and language scores attributed to multiple micronutrient fortification of school meals is also reported in India (Mahapatra et al. 2020). Scott et al. (2018) note improved cognitive performance in Indian school going adolescents (12-16 year old) who consumed iron biofortified pearl millet in a 6-month double blind randomized control trial. Chong et al.'s (2015) study on adolescents in a rural secondary school in Peru supports the positive effect of iron supplementation on improved school performance.

This study considers gains from fortification for those who are mild or moderately anaemic and excludes the severely anaemic since it is standard practice to address relatively rare severe anaemia with medical treatment. Reproductive benefits of fortification accruing to pregnant and lactating women are excluded because they should benefit from receiving antenatal iron and folate supplementation through the ICDS. The fortification programme would serve to complement rather than replace antenatal iron supplementation. Additionally, benefits for children under 5 years are excluded because the evidence of long-term gains from anaemia reduction for this age group is inconclusive (Britto et al. 2017). Fortification benefits to individuals 13-19 years old are also not included in the calculations of economic benefits, in part because they are not currently covered in MDM. We also exclude any potential economic gains from work productivity via fortification of PDS rice for these individuals. This stems from the conservative assumption that the labour force consists of individuals 20-60 years old. We evaluate benefits from the PDS in economic quintiles 1, 2 and 3 to capture poorer groups of populations. The costs of fortification for the PDS and MDM grain have not been adjusted downwards for the groups for which the benefits are excluded in this model. By excluding benefits accruing to families in the two upper quintiles that draw PDS grain as well as considering the costs for fortifying all the PDS and MDM grain, we offer a lower estimate. Recall that we only calculate the benefits of the iron component of the combined fortification with iron, B12 and folate, the latter being particularly important in pregnancy. This also contributes to providing a lower estimate of the benefits. Figure 1 presents a framework for the analysis based on the above discussion.

4. Data

The model requires data on current anaemia rates, number of MDM and PDS beneficiaries, quantity of fortified rice consumed by the beneficiaries, the quantity of rice allocated by the government under these programs, and the current wage rates. We draw on a number of different data sources to fulfil these requirements.

Figure 1. Framework of analysis to model the benefit-cost ratio of iron fortification of rice



The data on both MDM and PDS beneficiaries and the quantities of rice served to these beneficiaries are from the Department of Food & Public Distribution (DFPD 2021). The quantities provided at the upper and lower primary levels have been adjusted downward to two million metric tons of rice to exclude wheat consumption. An additional 26 million metric tons are provided under the PDS. The estimate of the programme cost (Section 5.6) is based on these quantities and data on incremental costs of rice fortification provided by the Government of India (DFPD 2020).

PDS beneficiaries by quintile have been derived by applying the age distribution from the Census 2011 data to the Worldometer population projections for 2021 (World Population Prospects 2019) and the National Sample Survey (NSS) 2011-12 data (NSSO 2014). The quantities consumed by PDS households were also calculated using the NSS data (NSSO 2014). About half of the households in Quintiles 1 to 3 purchase PDS rice. Table A1 provides estimates of beneficiaries and Table A2 presents the percentage of PDS rice purchased across quintiles. Rice consumption under the PDS across a typical 5-member household by income quintile is presented in Table A3 (see also Section 5.2). The increase in iron intake was calculated based on rice consumption, explained in Section 5.1.

The baseline values for anaemia prevalence rates by quintiles for ages 15 to 60 years have been calculated from the NFHS 2015-16 raw data (Indian Institute for Population Sciences and MoHFW 2017) (Table A4). For the younger age groups from 6-12 years we use published Comprehensive National Nutrition Survey (CNNS) 2016-18 data (MoHFW, UNICEF and Population Council 2019). These prevalence data by age, gender, and quintile along with the WHO (2011) Hb cut offs for mild, moderate, and severe anaemia were used to arrive at the Hb distribution across different age groups and quintiles following Gera et al. (2012) and is explained in Supplement S1 to this paper. These were used to estimate the number of beneficiaries who avert anaemia due to fortification. We do not employ the alternate estimates of anaemia cut-offs in the Indian context (Sachdev et al. 2021) since this is a contentious issue and beyond the scope of this paper.

The Periodic Labour Force Survey (PLFS) raw data for 2018-19 (Ministry of Statistics and Programme Implementation (MoSPI) 2019) was used to calculate the sector wise wage rates to estimate the economic benefit from productivity gains (Table A5).

5. Methodology

This study applies a set of parameters to map fortified rice consumption to expected Hb response among the MDM and PDS beneficiaries. Additional parameters are employed to derive economic outcomes associated with the projected change in Hb. There is considerable uncertainty involved in choosing parameters for the model, a theme of this research, which is explored with alternative modelling. The modelling is undertaken in seven steps described below from Section 5.1 to 5.7, following the framework outlined in Figure 1. Section 5.8 recapitulates and summarises the model assumptions and Section 5.9 describes the alternative scenarios considered.

5.1. Determining the number of beneficiaries

The MDM beneficiaries fall under two categories – lower primary (6-10 years old) and upper primary (11-12 years old) students. We scaled the total number of MDM beneficiaries reported by DFPD by 83 percent, the proportion of rice grain allocation out of total wheat and rice allocation under the MDM. The number of MDM rice beneficiaries at the lower and upper primary level is a product of the total MDM beneficiaries $Bmdm_a$ for each of the age groups a ($6 \leq a \leq 10$ and $11 \leq a \leq 12$ years) and the proportion of rice in the MDM programme.

We calculate number of PDS beneficiaries by age, a, economic quintile, q, and gender, g ($Bpds_{aqg}$ $6 \leq a \leq 12$ years and $20 \leq a \leq 60$ years, q=1,2,3). We calculate the population by age group for 2021 using the Census 2011 age distribution corresponding to the age groups in our model projected to the 2021 population of 1.392 billion (World Population Prospects 2019). We distribute this population across economic quintiles using the percentage distribution of total households across the quintiles from the NSS raw data for 2011-12 (NSSO 2014). Finally, to get the total PDS rice beneficiaries we multiply the age and quintile-wise population with the percentage of households by quintile that consumed PDS rice to account for current coverage patterns.

5.2. Determining the quantity of fortified rice consumed

Quantities consumed are based on the amount of rice provided though the PDS and MDM. We assume that the primary school going population obtains meals for 230 school days in the year. The quantity of rice served under the MDM ($Qmdm_a$) at the upper primary level is 150 grams (dry weight) and at the lower primary level 100 grams of rice is served (DFPD 2021).

For PDS rice we derive the quantities consumed $Qpds_{aqg}$ by age a (6-12 years and 20-60 years), gender, g, and the lower three economic quintiles, q, using the NSS 2011-12 data on consumption among households that consume PDS rice (NSSO 2014). We assume the PDS ration – about half of total household rice consumption – is shared by a representative family of five with three children, two in primary school, one adult female older than 20 years , and one male older than 20 years (see Table A3). We adjust quantities to account for differences in consumption by age by applying consumption equivalents from Thimmayamma et al. (2016). We further adjust the quantity of PDS rice consumed at home by the MDM group downwards reflecting the number of school days offered. On school days, we assume that these children receive MDM rice and half of their portion of PDS rice and on non-school days they receive the full amount of PDS grain.

5.3. Determining additional iron intake, change in haemoglobin and duration of intake

The *additional iron intake* per day from consumption of fortified rice per beneficiary of age a in the MDM group ($\Delta Femdm_a$ 6≤a≤12 years) and of age a, economic quintile q and of gender g for the PDS consumers ($\Delta Fepds_{aqg}$ 6≤a≤12 years and 20≤a≤60 years, q=1,2,3) is the product of the unit fortificant level added to rice and the amount of rice consumed per day. We assume that the programme runs for seven years to overlap with the total number of elementary school years for the youngest cohort 6 years of age at the start of the programme.

The compound recommended for rice fortification in India by the FSSAI is ferric pyrophosphate (FePP) since it does not change the sensory properties of the grain. Thus, it is easily accepted by the consumer (Hurrell 2018). The FSSAI stipulates a minimum fortificant level of 2.8mg/100g and a maximum of 4.2 mg/100g for rice fortification in India. We assume a mid-range fortificant level of 3.5 mg/100g of rice to limit the risk of causing toxicity or gut inflammation.

The *change in the Hb level* ΔHb_{aqg} as a response to iron intake is assumed to be truncated, based on Thomas et al. (2006), Basta et al. (1979) and Edgerton et al. (1979), who find that Hb levels increase until the individual reaches normal Hb levels, after which the response is muted, eventually reaching a plateau. The Hb response to iron intake is also steeper at lower initial Hb levels in that trial. Our calculations using data presented in Ekström et al. (2000) are consistent with an assumption of achieving 50% of the total Hb response when the first third of the dose is taken, 30% at the next third and 20% at the final third. Thus, as long as the body has a deficit, we expect a response. A plateau, or no response, will occur once the deficit is removed.

The Hb response is parameterized using Peña-Rosas et al. (2019)'s meta-analysis for six studies of iron fortification of rice. These are a subset of a total of 17 studies in the review where the other studies include fortification with a varied combination of iron, zinc, vitamin A, and folic acid. The analysis of the iron group alone estimates an average Hb rise of 0.393g/dL [95% CI 0.124 to 0.662].

The Peña-Rosas et al. (2019) review also finds a relative risk ratio for the impact on anaemia for the iron alone group of 0.63 [CI: 0.36-1.09]. The review is specific to rice as a vehicle but is consistent with broader reviews such as Das et al. (2013) and Keats et al. (2019) as well as Horton, Wesley, and Mannar's (2011) review of double fortified salt efficacy trials, which finds a net median increase in Hb of 0.3 g/dL.

We inferred the *duration of the intake* based on how much total iron intake would be needed to make the FSSAI fortification effective. Most of the studies in Peña-Rosas et al. use FePP for fortification. The average fortificant amount in the six iron only interventions studied by Peña-Rosas et al. for consumption of 150 grams of dry rice over 150 days is about 15 mg a day (three times the FSSAI mid-range) totalling to 2,270 mg. In order to achieve a similar total intake level to make the FSSAI fortification effective in raising Hb levels, while also maintaining the low daily iron dose of 3.5 mg/100g, the programme would need to run for a longer time than the average in trials reviewed by Peña-Rosas et al. or in most supplementation trials. This is in keeping with a study by Kramer et al. (2021) which found an impact of a trial of salt fortification in schools in India that was only significant with higher school attendance; the authors speculate that effects on cognition may need longer time periods to materialize. For this model, the precise duration will depend on the amount of rice consumed, which differs by age and gender. On an average, it will take at least a year to reach the total intake intended for the different beneficiary categories. We calculate the impacts for one year to be conservative.

There are, however, few studies that have assessed whether a low dose of iron over a few years would provide the same benefit as a higher dose given over a shorter time. Ekstorm et al.

(2002) compared two doses of 60 mg iron once weekly to one dose of 60 mg per day for 12 weeks and concluded that the total amount of iron ingested and not the duration predicted the Hb response. Although that reflects a supplementation not a fortification trial, we assume that it is the total intake of iron that contributes to improved Hb. We also assume that continued consumption of the fortified product at low doses will maintain the iron levels in the body for the seven-year period that the programme is in place.

5.4. Determining the increase in productivity and learning

We consider two economic outcomes from the change in Hb, current work productivity and cognition among children. We assume that all adult beneficiaries of the fortification programme who improve their Hb levels will have improved work capacity leading to an increase in productivity. We assume that work capacity increases with a rise in Hb and not just when the level crosses a threshold to avert anaemia (Rajagopalan and Vinodkumar 2000; Edgerton et al. 1979; Li et al. 1994, Basta et al. 1979, Thomas et al. 2006, and Blakstad et al. 2020). This is possibly an underestimation, at least for a portion of the population; there is evidence that iron benefits are greatest for those with the lowest Hb level (Thomas et al 2006; Edgerton et al. 1979). We account for this non-linearity above when we consider the Hb response to iron intake. However, to map the Hb increase to productivity we assume linearity in the productivity increase for the entire domain of Hb values equal to an average increase, rather than a sharper increase for those who have lower Hb levels. We scale the productivity increase (ΔPr_{aqg} $20 \leq a \leq 60$ years, q=1,2,3) for the Hb increases for the fortification for different age groups and gender in our model assuming a linear relation between Hb and productivity. Thus, ΔPr_{aqg} is a product of the percentage change in productivity and the change in haemoglobin.

In keeping with previous work on estimating current productivity gains (Horton and Ross 2003a; Horton, Wesley, and Mannar 2011; and Prieto-Patron 2020), we differentiate between the productivity impacts for heavy manual and light manual work. Basta et al.'s (1979) finding of a 16.5% increase in productivity from increases in Hb is applied for heavy manual labour (such as construction and mining). We apply an estimate of 5% in light manual productivity (such as the service sector and manufacturing) from Li et al. (1994) and Rajagopal and Vinodkumar (2000). The productivity gain is adjusted for the percentage employed in each sector. A 16.5% heavy manual productivity increase is in keeping with a 1.5g/dL increase in Hb (inferred from Basta et al.'s study) and the 5% light manual productivity increase is associated with 1.3 g/dL (inferred from the Li et al. study). Thus, ΔPr_{aqg} for those engaged in heavy manual labour will be: $0.165/1.5\text{g/dL} \times \Delta Hb_{aqg}$ and for those in light manual work, it will be $0.05/1.3\text{g/dL} \times \Delta Hb_{aqg}$.

The increased Hb can be mapped into incremental learning in school or improvements in academic performance (Scott et al. 2018). We assume that cognitive gains are achieved only if anaemia is averted (see Supplement S1 for an explanation of how we model for anaemia cases averted using the change in haemoglobin). This is a stricter assumption than that for work productivity where we consider gains from marginal increases in Hb for all those who are anaemic but is necessary since we did not find any literature that measures cognitive gains from changes in Hb.

Cognitive benefits accrue to all school going children in the MDM programme who also receive one PDS fortified meal at home (ΔCog_a $6 \leq a \leq 12$ years). We do not aim to assign cognitive benefits to any single schooling year; rather, we conservatively assume that the gains in learning from improved cognition only accrue as a part of a total education experience of seven years. We, therefore, assume that the learning effect is cumulative over a seven-year period and model a single incremental gain for the MDM beneficiaries over that period. Students who are one or two years from completing primary education when any fortification program is implemented will possibly benefit less than those who enter the school after its inauguration, but benefits of MDM supplementation are calculated for a long running program rather than for any transitional period.

We apply estimates of Chong et al. (2015) of a 0.45 standard deviation unit improvement in academic performance due to a 34% decline in anaemia from iron supplementation. In the absence of studies of the cumulative impact of fortification on cognition in school aged children, we assume that the impact of seven years receiving fortified meals is the same as the gains observed in short term supplementation. We scale the academic improvement applying Chong et al.'s estimate and assuming a linear relation with anaemia decline. Nguyen et al. (2022) is also consistent with a contribution to learning from reduced anaemia in India.

5.5. Determining the economic benefit as earnings gains

Improvements in productivity increase earnings in the year that the fortified rice is consumed for participating adults. We assign a monetary value to the productivity change to get earnings gains (ΔEpr_{aqg} $20 \leq a \leq 60$ years, q=1,2,3) by multiplying it with the current wage by sector and quintile, which we calculate using PLFS data (MSPI 2020). We multiply the unit change by the number of beneficiaries scaled for the proportion that have mild and moderate anaemia. We consider wages by different subsectors based on labour intensity. For those employed in agriculture, we assume gains similar to heavy manual productivity for men but assume lighter labour tasks for women working in agriculture (Alesina et al. 2013). Nearly three-quarters of the adult women in India are reported not in the workforce. Although their unpaid work is not included in GDP calculations, there will be domestic productivity gains from improved Hb for this segment of the population.

Therefore, we use light manual work to estimate gains from domestic productivity for this segment of the population.

We map the changes in learning (rather than years of schooling) to changes in earnings (Evans and Yuan 2019) since learning is the real outcome for productivity (Hanushek and Woessman 2010). Evans and Yuan find that a one standard deviation improvement in a measure of learning in six country studies averaged to an increase of 36.5% in earnings. In our core model, we scale this by the change in assumed improvement in cognition over all child beneficiaries who avert anaemia. We discount the earnings stream at an annual rate of 3 percent, standard in health studies (Robinson et al. 2019), over the adult working life of the children spanning 40 years from the age of 20 until 60 years to get the present value of an increase in future earnings from cognitive gains for the MDM age group ($PV\Delta Ecog_a$ $6 \leq a \leq 12$ years).

5.6. Determining the cost of fortification

We assume that the costs of the provision of grains to the PDS and MDM programme are determined by existing programs and there will be an incremental increase in the cost resulting from the fortification of the rice grains. This is the incremental cost of the fortification programme considered in this model and the benefits from the fortification are, therefore, evaluated against this incremental cost.

The cost of fortified rice kernels and its blending with regular rice in a ratio of 1:100 is estimated to be Rs. 0.73/kg or US$ 0.01/kg (DFPD 2020). This includes the cost of fortificant production (using three micronutrients: iron, folic acid and B12 in a prescribed proportion), blending, and depreciation. However, this estimate does not include the cost of programme monitoring and evaluation.

The total cost (TC) is calculated as the product of the cost per kilogram of rice fortified and the quantity of rice supplied under the two programmes. Although we consider the benefits from fortifying rice restricted to the MDM and PDS for economic quintiles 1-3 we apply the costs for fortifying the entire PDS and MDM distributions. Following Harberger (1997) we assume an additional 25% deadweight loss as an opportunity cost of raising revenue for financing the fortification. The incremental cost of fortification is estimated at US$ 437 million for each year of fortification. To b. e conservative, we assume that these costs rise faster than inflation by one percent annually.

5.7. Benefit cost ratio

Finally, the benefit cost ratio is calculated as the ratio of the total benefits (earnings increase) to the total costs: ($\sum \Delta Epr_{aqg} + \sum PV\Delta Ecog_{a} + \sum PV\Delta Ecog_{aqg}$)/TC. The earnings increase include those from the current productivity increase among adults 20-49 years old and the future earnings rise from increased learning from cognition gains among children.

5.8. Summary of model assumptions

The assumptions used in the model are recapitulated in Table 1. Table 2 presents the variables used in the model—number of beneficiaries, quantities consumed, additional iron intake, Hb response, productivity change, cognitive change, change in earnings, and the cost—with summary statistics.

To summarize, the parameters employed in our core, plausible scenario are: an Hb response of 0.393 g/dL, scaled down to adjust for iron intake in this model across different age groups and economic quintiles, return to heavy manual labour of 16.5% and light manual labour of 5%, wage rate of US$ 889/year, earnings return to cognition of 36.5 percent and a discount rate of 3% for

Table 1. Model assumptions

Haemoglobin (Hb) response

1- Level of iron fortificant, Ferric Pyrophosphate (FePP), is assumed at 35 mg/kg.

2- Hb response is the same for all mild and moderately anaemic; severe anaemia is not included.

3 -Hb response assumed is 0.393 g/dL (Peña-Rosas et al. 2019).

4-Hb response to iron intake is non-linear with a higher response for lower Hb levels and is truncated, with no response once Hb levels to avert anaemia are achieved.

Productivity

1 - All adults who improve Hb levels have improved work capacity leading to increased productivity.

2- Productivity is linearly related to Hb level and any increase in Hb for anaemic individuals increases productivity, whether or not anaemia is averted.

3- Heavy manual labour productivity increase assumed is 16.5% for Hb increase of 1.5g/dL (Basta et al. 1979).

4- Light manual labour productivity increase assumed at 5% for Hb increase of 1.3 g/dL (Li et al. 1994; Rajagopal and Vinodkumar (2000).

Cognition

1- All children who avert anaemia have improved cognition that translates into incremental earning in school measured as improvement in academic performance.

2- Academic performance improves by 0.45 standard deviation unit for a 34% decline in anaemia (Chong et al. 2015).

3- Total cognitive gains in terms of improved academic performance occur over seven years of receiving fortified meals in primary school and the gain is for life.

Earnings

1- Current productivity increases from improved work capacity translate to increased earnings in a linear relation (Horton and Ross 2003a; Horton et al. 2011; Prieto-Patron 2020).

2- Cognitive gains translate to future earnings over the working life of current school-going children.

3- Economic benefit from cognition is calculated as the present value of future earnings using a discount rate of 3%.

4- Earnings used are current wage rates by sector for men and women calculated from the PLFS 2018-2019 data.

5- The agriculture sector, construction, and mining employ heavy manual labour; manufacturing and service sectors use light manual work and women's work in agriculture is treated as light manual work.

6- We include gains for women not in the workforce and their contribution to domestic productivity is treated as light manual work.

Table 2. Variables used to calculate the economic benefit with summary statistics

Variable	*Definition*	*Data source*	*Values*
$Qmdm_a$ and $Qpds_{aqg}$	Quantity of rice consumed by MDM beneficiaries in age group a (6-10 years and 11-12 years) and quantity of PDS rice in age group a (6≤a≤60 years), quintile q (q=1,2,3) and gender, g	Authors' calculations	100 grams rice in MDM at lower primary level (6-10 years) and 150 grams at upper primary level (11-12 years): Quantity of PDS rice ranges from 97g-127g
$Bmdm_a$ and $Bpds_{aqg}$	Number of MDM beneficiaries in age group a (6-10 years and 11-12 years) and number of PDS beneficiaries by age, quintile and gender (6≤a≤60 years)	DFPD (2021) and Authors' calculations	MDM beneficiaries 6-10 years old are 200 million, 11-12 years old are 115 million. Total PDS beneficiaries estimated is 290 million
ΔFe_{aqg}	Amount of additional iron intake	Authors' calculations	Based on a unit fortificant level of 3.5 mg/100 g of rice. Additional intake ranges from 3.9 mg for 50-60 years to 8 mg for 11-12 years
ΔHb_{aqg}	Change in haemoglobin (and resulting anaemia where relevant) as a result of iron fortification of rice	Authors' calculations	Ranges from 0.301 g/dL to 0.393 g/dL
ΔPr_{aqg}	Change in productivity resulting from improved work capacity due to increased haemoglobin for beneficiaries currently working in age group a (20≤a≤60 years), quintile q (q=1,2,3) and gender, g	Authors' calculations	Ranges from 3.3-3.8% for heavy manual work and 1.2-1.3% for light manual work.
ΔC_{aqg}	Change in cognition measured as academic performance from averting anaemia among beneficiaries in age group a (6≤a≤12years), quintile q (q=1,2,3) and gender g.	Authors' calculations	Ranges between 0.157 to 0.283 standard deviation units of academic performance improvement
ΔE_{aqg}	Change in earnings for beneficiaries in age group a (20≤a≤60 years), quintile q (q=1,2,3) and gender, g	Authors' calculations	Ranges from US$20 million annually for women 50-60 years in Quintile 1 to US$ 197 million for men 29-40 years in Quintile 3
$PV\Delta E_{aqg}$	Present value of future earnings stream for beneficiaries in age group a (20≤a≤60 years), quintile q (q=1,2,3) and gender, g	Authors' calculations	Ranges from US$8 billion for 6--10 year olds getting MDM and PDS in Quintile 1 to US$10 billion for 11-12 years receiving both MDM and PDS

MDM: Mid-day meal; PDS: Public distribution system
Source: DFPD 2020 and Authors' calculations

future earnings with no real income growth. The productivity benefits are calculated as an increase in current earnings and the cognitive benefits result in increased earnings in the future. Both benefits and costs are calculated over a seven-year period to accommodate a cohort of the youngest MDM beneficiaries of the programme who will complete primary school in seven years and the oldest MDM age group of 12 years who will finish high school in this period assuming that the benefits of the cognitive gain will be realized as learning over these seven years.

5.9. Alternative scenarios

We consider two sets of alternative scenarios to the core plausible scenario, one set representing the lower bound and the other set the upper bound value for two alternatives of each of seven parameter values employed in our model. We vary these values one at a time, resulting in 14 scenarios (seven under each set). For Hb response, our lower bound alternative is 0.124 g/dL, which is the lower bound of the confidence interval for the meta-analysis by Peña-Rosas et al. (2019). We stress that this outcome is not as probable as the base case which uses the point estimate of 0.383 g/dL from that study. Moreover, we do not balance the lower bound with the equally probable upper bound of the confidence interval. As a second alternative scenario we use a value of 0.183 g/dL that falls between the lower bound and the average from Peña-Rosas et al. (2019. The two alternative parameter values for returns to cognition explored are: a higher return estimated by Evans and Yuan (2019) from a trial intervention in India at 51% and a lower one of 8% following Horton and Ross (2003a). We also consider halving the productivity estimates reported in the literature, halving the wage rate, doubling the discount rate, and increasing the real income growth rate (see Supplement Table S2 for scenario details).

6. Results

Our base case scenario, referred to as the core plausible model, applies a set of relatively conservative assumptions based on available literature. Table A6 provides baseline and post-fortification anaemia prevalence for this scenario.

Core plausible scenario: The total benefit from fortification of MDM and PDS for the three lower income quintiles is valued at US$26.7 billion (Table 3). The incremental cost for the fortification over seven years is estimated at US$3.3 billion with a benefit-cost ratio of 8.2. The productivity benefits over the seven years, estimated at $8.4 billion, form a third of the total benefit from the combined programme whereas the cognitive benefits at a present value of US$ 18.3 billion contribute 69% of the benefits. The MDM benefit contributes US$10.4 billion with a BC ratio of 11.7. The present value of gains per beneficiary is on an average US$49. The BC ratio for the PDS without MDM is also positive at 3.7.

Alternative scenarios. The benefit-cost range for all the alternative scenarios is shown in the tornado diagram in Figure 2. To illustrate, consider income growth. The core scenario does not include income growth, but if the economy grows by 1% (under set 1 of alternative scenarios), future labour productivity and returns to cognition would be higher, bringing the BC ratio up to 9.4 compared to 8.2 under the core scenario. With a higher annual growth rate of 3% (the upper bound set 2 of alternative scenarios), the benefit cost ratio rises to 12. For economy of space, we do not present BC ratios for every scenario and use the two colours to represent the two alternative ranges of parameter values considered. See Supplement Table S2 for details.

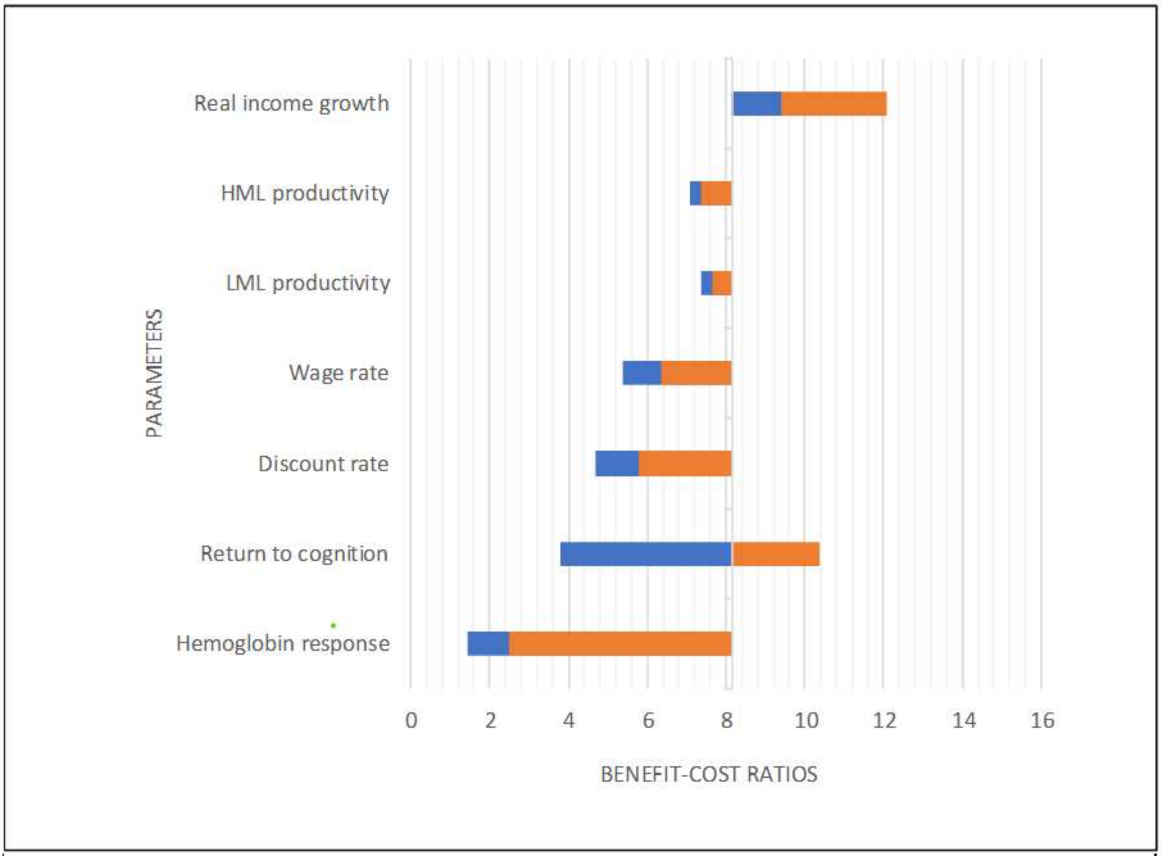
The lower bound Hb response of 0.124 g/dL returns a BC ratio of 1.4 while the alternative higher value of 0.183 g/dL corresponds with a BC ratio of 2.5, relative to the base case of 8.2.

Table 3. Estimated economic benefit, cost, benefit-cost ratio, and unit benefit of fortification under the core, plausible scenario

Type of benefit and programme	*Value*
MDM and PDS combined	
Present value of cognitive benefit (US$ billion)	18.3
Current value of productivity benefit (US$ billion)	8.4
Total benefit	26.7
Total cost (US$ billion)	3.3
Benefit-Cost ratio	8.2
Number of MDM beneficiaries	316,005,363
Number of PDS rice beneficiaries	232,853,719
Total beneficiaries	548,859,082
Benefit per beneficiary (US$)	49
PDS only	
Current value of productivity benefit (US$ billion)	8.4
Present value of cognitive benefit (US$ billion)	3.8
Total benefit (US$ billion)	10.2
Total cost (US$ billion)	2.7
Benefit-Cost ratio	3.7
MDM only	
Present value of cognitive benefit (US$ billion)	10.4
Total cost (US$ billion)	0.89
Benefit-Cost ratio	11.7

Even though the Horton and Ross (2003a) return to cognition of 8% applied to our model is not directly comparable to the other approaches since Horton and Ross consider returns to grade attainment rather than cognition the BC ratio is still 3.8. Lowering the productivity estimates to half the value of those reported in the literature also does not return a BC ratio lower than one. Note that doubling the discount rate to 6% or to an even higher 10% still yields a positive benefit-cost ratio. Varying the discount rate does not impact the current productivity gains but lowers the future gains from cognitive improvements. This increases the weight of current productivity gains in the total gains compared to the core plausible scenario.

Figure 2. Tornado diagram showing range of Benefit-Cost ratios for rice fortification under different scenarios.



Parameter values used under the scenarios shown

	Hemoglobin response	Return to cognition	Discount rate	Wage rate (US$/year)	Real income growth	HML productivity	LML productivity
Core, plausible scenario (BC ratio 8.2)	0.393	37%	3%	889	0%	16.5%	5%
Alternative scenarios set 1	0.124	8%	6%	444	1%	5%	1%
Alternative scenarios set 2	0.183	51%	10%	600	3%	8%	2.5%

BC ratio: Benefict-cost ratio; HML: Heavy manual labor; LML: Light manual labor

Overall, the results are in keeping with previous research. For example, Horton and Ross (2003a,b) estimate a loss of US$3.64 per capita or 0.81% of the GDP at the time in 10 developing countries based on lower physical productivity and cognitive impairment and estimated a benefit-cost ratio of 8.7. Horton, Alderman, and Rivera (2009) also calculate favourable BC ratios for iron fortification.

7. Discussion

The modelling exercise indicates large potential gains from fortification in the context of Indian food security programs. This would come through a combination of participation in MDM as well as the PDS programme. However, as this analysis focuses only on national averages there is a need for caution in implementation in the absence of rigorous impact evaluations that also consider differences across states. Moreover, currently, roughly half of the three poorest quintiles draw PDS rice (Authors' calculations from NSS 2011-12 data (NSSO 2014)). Any improvements in coverage would increase the benefits of fortification.

As modelled, the returns to fortification are particularly high for cognition even assuming conservatively that learning gains from cognitive improvement are spread over seven years of schooling rather than a single year. This may suggest prioritization of fortification in the MDM. As with our assumptions on labour force productivity, the modelling is based on plausible assumptions for both the effect sizes of the impact on Hb and on the implications of these changes for economic activity. While we offer illustrations of the sensitivity of the base case to alternative assumptions, we recognize that there is no consensus on these parameters. Nor is it likely that these uncertainties will be reconciled in the foreseeable future.

The current estimates do not include a range of plausible benefits. Economic gains to the beneficiaries could reduce expenditures on targeted social programs as well as increase tax revenues. We also do not consider savings in medical costs or overall health gains. Many of these are centred around safe pregnancies and are best addressed in other programs. We also do not include the benefits of folic acid fortification although it is highly efficacious in reducing neural tube defects (Keats et al. 2019). These benefits, although real, are difficult to include without adding yet additional assumptions, including the value of a death averted. However, as they are clearly positive and add nothing to the costs in these estimates, the omission biases our estimates downward.

The study does not address the full range of approaches to reducing anaemia including deworming and malaria control although the literature reviewed usually reports the impacts of programmes without selecting for a sample free of other possible contributors to anaemia. Moreover, the study does not address the range of possible iron fortification programmes and their relative effectiveness on a range of outcomes. Double fortified salt with both iron and iodine is currently available in India. Indeed, Makkar et al. (2022) estimate a benefit cost for double fortified salt based on labour productivity that is similar to the results from that component of the current study, although the methodology is distinct. Similarly, Kramer, Kumar, and Vollmer (2021) find fortified salt in schools to be highly effective for improving Hb and averting anaemia in the short run, which they view as a conservative estimate, but they did not find significant improvement on test scores. Wheat flour is another potential vehicle for fortification, particularly in the MDM programme. However, distribution in the PDS incurs second round costs for millers which may add a challenge to widespread implementation.

Rice fortification as well as other possible programs, especially those embedded in an overall strategy that includes supplementation, needs to consider Tolerable Upper Limits (TULs), the level of daily intake that poses no risks of adverse health effects to almost all individuals in the general population (Pachón et al. 2021; see World Bank (2022) for a note on the risk of toxicity). Simulations indicate that this risk is low in most situations unless the entirety of the diet is fortified. However, population monitoring is advised (Pachón et al. 2021, Engle-Stone et al. 2019). This is particularly relevant where there is a possibility of a simultaneous roll out of other programs aimed at increasing iron intake such as through supplementation or through the fortification of additional food vehicles like wheat and salt (Swaminathan et al. 2019; see also Kurpad et al. 2021). However, there is little evidence of public health issues from excess daily intake in countries with a history of fortification (sometimes mandatory) or a wide range of processed foods so the risk of exceeding TULs is likely low. This said, any existing debate on this risk reinforces the call to fill gaps in the public health and economic implications of scaled fortification programmes.

Yet the need to address anaemia is readily apparent and policy will be debated with the information on hand. Thus, our main recommendation is that any country fortification programme, such as the one under consideration for India, include a plan for rigorous assessment of the programme to ascertain intakes of sources of iron, not only for fortified rice alone but of its impact in the context of other fortificants and supplements. Ideally such an assessment would track coverage and intakes among various ages and economic strata as well as any changes in Hb and other biological markers as well as determine the cumulative impacts, if any, over relatively long periods of coverage. Additionally, future benefit cost models would gain confidence if these assessments included sub-studies that could shed light on any associated changes in measures of cognition and labour productivity. Any discomfort with the assumptions employed here should be a welcomed spur to undertake such studies.

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Table A1. Number of beneficiaries by age and quintile

Programme and age group	*Number of beneficiaries*		
Midday Meal Programme (MDM)			
6-10 years	200,578,930		
11-12 years	115,426,434		
Public Distribution System (PDS)	*Quintile 1*	*Quintile 2*	*Quintile 3*
6-10 years	13,461,123	12,645,387	12,578,167
11-12 years	5,389,350	5,062,759	5,035,846
13-14 years girls	2,438,700	2,290,917	2,278,739
13-14 years boys	2,635,247	2,475,552	2,462,393
15-19 girls	5,791,445	5,440,487	5,411,566
15-19 boys	6,553,307	6,156,180	6,123,455
20-49 women	24,051,780	22,594,258	22,474,151
20-49 men	27,264,387	25,612,182	25,476,033
50-60 women	5,331,114	5,008,052	4,981,430
50-60 men	5,528,449	5,193,428	5,165,821

Source: Authors' calculations using DFPD (2020) data for MDM and Census 2011, World Population Prospects (2019) and NSSO (2014) for PDS.

Table A2. Percentage of households that purchase PDS rice by quintile

	Percentage of households that purchase PDS rice
Quintile 1	55%
Quintile 2	47%
Quintile 3	44%
Quintile 4	37%
Quintile 5	21%

PDS: Public Distribution System

Table A3. Public Distribution System (PDS) rice consumption across a typical 5-member household by income quintile

	Rice consumption in grams/capita/day		
Age group	*Quintile 1*	*Quintile 2*	*Quintile 3*
6-12 years girls and boys[a]	79	79	79
13-14 years girls and boys	140	133	134
15-19 years girls and boys	153	145	146
1 adult male	127	121	122
1 adult female	102	97	98
Total	637	604	610

[a] This is the Midday Meal (MDM) age group. The quantity of rice consumed is scaled down to 79 grams from an average consumption of 115 grams per day after adjusting for school-going days. Under the MDM the 6-10 year old group receives 100 grams and the 11-12 year old group receives 150 grams of rice
Source: Authors' calculations using the NSS 2011-12 raw data (NSSO 2014)

Table A4. Baseline anaemia prevalence by age, gender and income quintile

PDS[a] Quintile 1		PDS Quintile 2		PDS Quintile 3		MDM[b]	
Age group	Anaemia rate	Age group	Anaemia rate	Age group	Anaemia rate	Age group	Anaemia rate
20-49 women	58.8%	20-49 women	55.2%	20-49 women	53.3%	6-10	26.4%
20-49 men	30.6%	20-49 men	24.7%	20-49 men	21.3%	11-12	24.3%
50-60 women	59.2%	50-60 women	55.1%	50-60 women	53.3%		
50-60 men	38.6%	50-60 men	36.2%	50-60 men	31.0%		

[a]PDS: Public Distribution System; [b]MDM: Midday Meal programme

Table A5. Annual wage by sector, income quintile, gender, and age group

	Women	Men	Women	Men
	20-49 years		50-60 years	
Quintile 1				
Industry				
Construction, Mining, Quarrying (HML)	1,428	1,436	721	1,436
Manufacturing and Utilities (LML)	631	836	604	836
Agriculture	723	1,347	516	1,347
Service	843	1,288	614	1,288
Quintile 2				
Industry				
Construction, Mining and Quarrying (HML)	781	1,568	802	2,573
Manufacturing and Utilities (LML)	601	948	675	1,474
Agriculture	909	1,557	1,041	2,207
Service	827	1,436	801	2,005
Quintile 3				
Industry				
Construction, Mining and Quarrying (HML)	845	1,850	1,168	2,516
Manufacturing and Utilities (LML)	695	1,250	591	937
Agriculture	1,070	1,822	970	2,232
Service	1,258	1,676	1,045	2,140

HML: Heavy manual labour; LML: light manual labour

Table A6. Current (baseline) and endline (post-fortification) anaemia rates and cases, number of total recipients of fortified rice, number of beneficiaries who are anaemic and number of anaemia cases averted

Age in years and type of programme	Baseline anaemia prevalence	Endline anaemia	Anaemia reduction % point	Anaemia reduction %	Total beneficiaries (anaemic and non-anaemic)	Baseline mild & moderate anaemic beneficiaries	Endline anaemic beneficiaries	Anaemic cases averted
MDM, PDS								
6-10	26.4%	22.5%	4.0%	15.0%	200,578,930	40,418,116	45,078,528	7,954,833
11-12	24.3%	19.1%	5.2%	21.4%	115,426,434	23,928,453	22,020,161	5,988,336
PDS Quintile 1								
20-49 women	58.8%	52.7%	6.1%	10.4%	24,051,780	12,502,115	12,672,157	1,472,695
20-49 men	30.6%	25.8%	4.8%	15.7%	27,264,387	5,553,756	7,021,841	1,310,156
50-60 women	59.2%	53.0%	6.2%	10.4%	5,331,114	2,733,262	2,827,950	328,602
50-60 men	38.6%	32.8%	5.8%	15.0%	5,528,449	1,568,974	1,812,856	318,914
PDS Quintile 2								
20-49 women	55.2%	49.5%	5.7%	10.4%	22,594,258	11,744,495	11,184,534	1,294,275
20-49 men	24.7%	20.8%	3.9%	16.0%	25,612,182	5,217,202	5,320,186	1,011,145
50-60 women	55.1%	49.4%	5.7%	10.3%	5,008,052	2,567,628	2,472,056	284,877
50-60 men	36.2%	29.5%	6.7%	18.4%	5,193,428	1,473,895	1,532,690	346,293
PDS Quintile 3								
20-49 women	53.3%	47.6%	5.7%	10.6%	22,474,151	11,682,064	10,697,917	1,274,063
20-49 men	21.3%	17.8%	3.4%	16.2%	25,476,033	5,189,468	4,541,422	877,330
50-60 women	53.3%	47.8%	5.5%	10.3%	4,981,430	2,553,979	2,381,365	272,741
50-60 men	31.0%	27.0%	4.0%	12.8%	5,165,821	1,466,060	1,394,731	204,607

MDM: Midday meal; PDS: Public Distribution System

Source: NFHS 4 (2015-16) and CNNS 2016-18 for current anaemia rates (baseline) and authors' calculations for anaemia rates post fortification (endline anaemia rates).