Designing programs to improve diets for maternal and child health: estimating costs and potential dietary impacts of nutrition-sensitive programs in Ethiopia, Nigeria, and India

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Abstract

Improving maternal and child nutrition in resource-poor settings requires effective use of limited resources, but priority-setting is constrained by limited information about program costs and impacts, especially for interventions designed to improve diet quality. This study utilized a mixed methods approach to identify, describe and estimate the potential costs and impacts on child dietary intake of 12 nutrition-sensitive programs in Ethiopia, Nigeria and India. These potential interventions included conditional livestock and cash transfers, media and education, complementary...
food processing and sales, household production and food pricing programs. Components and costs of each program were identified through a novel participatory process of expert regional consultation followed by validation and calibration from literature searches and comparison with actual budgets. Impacts on child diets were determined by estimating the magnitude of economic mechanisms for dietary change, comprehensive reviews of evaluations and effectiveness for similar programs, and demographic data on each country. Across the 12 programs, total cost per child reached (net present value, purchasing power parity adjusted) ranged very widely: from 0.58 to 2650 USD/year among five programs in Ethiopia; 2.62 to 1919 USD/year among four programs in Nigeria; and 27 to 586 USD/year among three programs in India. When impacts were assessed, the largest dietary improvements were for iron and zinc intakes from a complementary food production program in Ethiopia (increases of 17.7 mg iron/child/day and 7.4 mg zinc/child/day), vitamin A intake from a household animal and horticulture production program in Nigeria (335 RAE/child/day), and animal protein intake from a complementary food processing program in Nigeria (20.0 g/child/day). These results add substantial value to the limited literature on the costs and dietary impacts of nutrition-sensitive interventions targeting children in resource-limited settings, informing policy discussions and serving as critical inputs to future cost-effectiveness analyses focusing on disease outcomes.

**Key Messages**

- Existing evidence on cost-effectiveness for nutrition improvement focuses on interventions to address specific diseases.
- We provide a novel participatory approach to assembling cost and impact data for 12 nutrition-sensitive interventions to improve diet quality in three countries: Ethiopia, Nigeria and India. Programs designed by stakeholders often use resource transfers to influence diets despite their high cost; programs altering food access have lower cost. Future work using these data will analyse net cost-effectiveness.

**Background and motivation**

Undernutrition among children in low-income settings is among the world’s leading causes of death, disability and inequity (Black et al. 2008; GBD 2016 Risk Factors Collaborators 2017). Governments in low- and middle-income countries around the world increasingly acknowledge child nutrition as a high priority, with specific targets for improvements by 2025 (United Nations 2016). National governments and international agencies declared a ‘Decade of Action for Nutrition’ starting in 2016 (Food and Agriculture Organization of the United Nations and World Health Organization 2016).

To achieve these goals, novel programs are needed that address overall dietary diversity and quality (Haddad et al. 2016). Yet, most available evidence to-date focuses on nutrient supplementation (Bhutta et al. 2013), with far less evidence on relative costs and effectiveness of programs that aim to improve dietary quality through nutrition-sensitive actions such as changes in home production, education or purchasing power (Ruel et al. 2013). Nutrition-sensitive interventions can be defined as strategies that address underlying causes of insufficient or inadequate food such as poor agricultural production, limited food markets, low levels of education or weak purchasing power. Nutrition-sensitive programs frequently involve multiple sectors and more diverse stakeholders than supplementation programs, requiring different kinds of evidence and priority-setting processes (Development Initiatives 2017). While many such programs are now being designed and implemented to improve diet quality in low-income countries (Hoddinott et al. 2013), scare empirical evidence exists on their costs and on their impacts on dietary intake.

The purpose of this study is to fill evidence gaps about the costs and impacts of nutrition-sensitive interventions that could potentially be implemented to improve child nutrition in sub-Saharan Africa (SSA) and South Asia. Through consultation with regional experts, we identified the types of interventions likely to be of greatest interest to development actors, delineated the mechanisms and magnitudes by which those actions might alter diets, compared expert consensus views to previously estimated costs and impacts of similar programs undertaken at other times and places, and summarized the implications of this process for priority-setting. Strengths of this approach include its independence from the interests of parties involved in such interventions, which can introduce bias when analyses of program costs and impacts are undertaken by the implementing agency or program funder; and its participatory nature, drawing on local expertise and incorporating perspectives of diverse stakeholders to maximize regional generalizability and relevance.

**Methods**

This study estimated costs and impacts on dietary intake of priority nutrition-sensitive programs to improve maternal-child health in SSA and South Asia. Our mixed methods approach included regional meetings with expert stakeholders from a variety of
### Table 1. Analytical framework for estimating program costs and impacts

| Component of costing framework | Description |
|-------------------------------|-------------|
| Cost category and item description | Items are grouped into program cost categories, including: personnel (by level of salary range); real estate for office space and other needs; transportation costs; supplies, equipment, other resources; monitoring and evaluation as a percent of other program costs; and other costs or revenue. Separate lines within each category are used for individual items with differing prices or numbers of units. |
| Units of measure | Units of measure are explicitly listed, such as person-years for salaries, kilometres travelled for transport, and workshop days for attendee expenses. |
| Price per unit | Price per unit is calculated by converting local currency amounts to constant US dollars in PPP terms, so that costs are comparable across countries and over time. |
| Start-up costs | Calculated using the number of units and cost per unit (quantity × price) during the first year of the program. |
| Recurring costs | Calculated using the number of units and cost per unit (quantity × price) for each year after the first, using a standard inflation rate in PPP prices of 0.05. |
| NPV | Calculated as the sum of all items across duration of each program, with a discount rate over time of 0.03. |

### Dietary impact framework

- **Resource transfers**: Transfer of resources to shift composition of diet.
- **Access changes**: Changing food prices to alter purchasing behaviour.
- **Preference change**: Changing dietary preferences.
- **Food transfers**: Transfer of food items to increase intake of target nutrients.

| Mechanism for impact | Description of impact mechanism | Main program parameters | Main behavioural parameter |
|----------------------|---------------------------------|-------------------------|---------------------------|
| Resource transfers   | Transfer of resources to shift composition of diet | Number of targeted individuals, and value of resource transfer to them, as a percent of their total income | Income elasticity of demand for the targeted food item |
| Access changes       | Changing food prices to alter purchasing behaviour | Number of consumers affected, and percent change in their cost of acquisition of the targeted food item | Price elasticity of demand for the targeted food item |
| Preference change    | Changing dietary preferences | Number of consumers affected by the program's behaviour-change efforts | Change in quantity of nutrient consumed per recipient per day |
| Food transfers       | Transfer of food items to increase intake of target nutrients | Number of recipients to whom food is transferred | Change in quantity of nutrient consumed per recipient per day |

PPP, purchasing power parity

*Each program may aim to alter intake of more than one food, through more than one mechanism of impact as described by program parameters that describe its reach and delivery, and the resulting alteration of dietary intake depends on behavioural parameters obtained from the best available studies of similar changes in similar contexts, as specified in Table 5.

### Selection of programs aiming to improve diet quality

To identify a set of programs most likely to be high priorities for government or donor funding, we organized and held in-person meetings with a range of regional nutrition and program experts on South Asia (hosted in Nepal in December 2015) and SSA (hosted in Ethiopia in February 2016). The goal of these meetings was to identify nutrition-sensitive programs that local experts consider to be of greatest relevance to child nutrition in eight countries with high burdens of undernutrition: India, Nepal, Bangladesh, Ethiopia, Nigeria, Ghana, Tanzania and Uganda. For this analysis we retained the 12 programs for which a full set of cost and impact data could be calculated, which limits coverage to India, Ethiopia and Nigeria.

Our participatory approach ensured that interested parties could not pre-determine which programs should be considered or how their cost-effectiveness should be calculated. At these meetings, a total of 48 specific nutrition-sensitive programs were considered, identified based on interventions that were currently being implemented, under debate as potential additions to existing activities, or new programs with high promise for efficacy. For each proposed program, the following information was discussed: (1) the description of the program; (2) the mechanisms for impact on dietary behaviours; (3) the target foods and nutrients to be increased; (4) the location and demographic characteristics of the target population; (5) the lead authority and implementing organization for the program; (6) the types and costs of resources required for program implementation, using an ingredients approach (unit needs and costs) and separately considering start-up, recurring costs and evaluation; and (7) the additional regional expert contacts relevant to that program. Additional details on the methods and results of these two regional meetings are documented elsewhere (Masters et al. 2017).

From the 48 programs identified at our regional expert meetings, we focused on 12 for analysis in this paper (Table 2) based on the following three criteria: First, we included only programs that participants described as relevant for India, Ethiopia or Nigeria, or for the South Asian or African contexts more generally, so as to align results with country priorities of the Bill & Melinda Gates Foundation which supported this project. Next, we included only programs that targeted children under 5, relevant to linking changes in dietary intake to disease outcomes for maternal-child health. Finally, we excluded programs for which required resources for implementation were not sufficiently documented to compute program costs.

### Determination of program impacts

To estimate the impacts of each intervention on diet quality, we began by identifying the potential economic mechanism(s) by which each program might alter children’s food intake. These included (1) transfer of resources or cash to alter the purchase or use of home-
grown foods (hereafter referred to as resource transfers); (2) changing food prices to alter purchasing behaviour (hereafter referred to as access changes); (3) changing dietary preferences to alter the purchase or use of home-grown foods (hereafter referred to as preference changes); and (4) transfer of food items to increase intake (hereafter referred to as food transfers). We then used previous studies of each mechanism to quantify the intervention’s likely effect on dietary components involved in five diet–disease relationships for which we had identified evidence for etiologic effects and significant disease burdens in these regions, namely iron and anaemia, vitamin A and mortality, zinc and diarrhoea, zinc and stunting, and animal protein and stunting.

For each program’s impact on any or all four of these dietary components (iron, vitamin A, zinc and animal protein) we then conducted a comprehensive review of the program evaluation literature to identify published studies of similar interventions. This process began with literature searches using the following search terms alone and in combination: impact, diet, diet diversity, iron, zinc, vitamin A, animal protein, fruit, vegetable, dark green leafy vegetable, cash transfer, conditional, poultry production, small livestock production, animal household, home gardens, complementary food production, complementary feeding, mass media campaign, radio campaign, nutrition education, community education, community demonstrations, peer videos, micronutrient sachets, community

### Table 2. Program elements by country

| Country       | Program name                  | Program description                                      | Target population                                      | Dietary risk factor targeted |
|---------------|--------------------------------|----------------------------------------------------------|--------------------------------------------------------|-----------------------------|
| Ethiopia      | Conditional livestock transfer | Provides one dairy cow per target household, conditional on pregnant mother’s ANC attendance | Children under 5 in the PSNP with pregnant mothers | Cow’s milk, zinc, vitamin A, animal protein |
|               | Conditional poultry transfer  | Provides 2 hens and 1 cock to recipient households, conditional on men engaging in public works programs and women/children attending ANC/child vaccination and health visits | Children under 5 in the PSNP | Eggs, vitamin A, animal protein, zinc, iron |
| Media & education campaign | A radio and education campaign that focuses on increasing intake of animal and plant-based protein, as well as meal frequency using radio segments, nutrition messages delivered by religious leaders. | Children under 5 living in rural areas | Meat, milk, eggs, fish, plant protein sources, iron |
| Educational entertainment | Peer-to-peer videos delivering nutrition messages, coupled with community discussions of prenatal nutrition | National children under 5 | Eggs, vitamin A, animal protein, zinc, iron |
| Complementary food production | Education to women on how to wash, dry, mill, and fortify grains with a micronutrient powder to produce complementary foods for their own use or to sell. | Children under 5 living in semi-urban areas | Grains, maize, sorghum, teff, wheat, barley, pulses, legumes, zinc, iron |
| Nigeria       | Conditional cash transfer      | Cash transfers to pregnant women conditional on ANC attendance by mother and family member, and delivery in health facility | Children under 5 living in rural areas with pregnant mothers | Iron |
| Food pricing program | A flat 10% tax on SSBs to fund FV subsidies for mothers and children | National children under 5 | Fruits, vegetables, vitamin A |
| Complementary food processing and sales | Teaching women to produce and sell affordable cereal-based CF mixed with powdered pulses and dried animal-based foods; coupled with nutrition education on complementary food. | Children 6–24 months in two low-income regions of Nigeria | Cereals, pulses, soy, fish, chicken, lentils, cowpeas, zinc, iron, animal protein, vitamin A |
| Household animal & horticulture production | Provides seedlings, seeds, and chickens, as well as training on food and poultry production, to targeted households with an able body and plot of land with | Children under 5 living in households in the poorest 40% of population | Fruits, vegetables, chicken, zinc, iron, animal protein, vitamin A |
| India         | Complementary food processing  | Provides a monthly ration of locally produced micronutrient sachets, coupled with education on how to add the sachets to complementary food | Children 6–24 months in the poorest 50% of population | Zinc, iron |
| Diet diversity media campaign | Mass media radio campaign focusing on raising consumption of vitamin A-rich foods; coupled with community cooking demonstrations | Children under 5 living in one district | Carrots, pumpkin, mango, vitamin A |
| Home gardens  | Establishes home gardens for households with agricultural or homestead land; provides seeds, supplies, and tools; coupled with education and resources for small livestock/poultry production | Children under 5 living in rural households | Yellow/orange vegetables, dark green leafy vegetables, animal source foods, zinc, vitamin A, iron, animal protein |

PSNP, productive safety net program; ANC, antenatal care; ND, no data; SSB, sugar-sweetened beverage; FV, fruit and vegetable

*Program descriptions are based on consensus formed by stakeholders at regional meetings in Nepal and Ethiopia

**The target population is the population that each program’s impact will be assessed in. Impact estimates are restricted to children under 5 to complement the current version of the model

In cases where regional experts did not specify the target population size, regional data sources such as census data, Demographic Health Surveys, and UN Population Division estimates, were used to approximate target population sizes

Targeted risk factors may be foods, or specific nutrients within foods (in bold text)
mills, income elasticity and price elasticity. Those online searches were complemented by direct contacts with the expert participants from our regional meetings.

To identify the most suitable published studies, we searched for outcome and/or impact evaluations that matched the proposed programs on the following criteria: (1) country of interest, (2) target population of interest, (3) mechanism used to alter dietary intake, and (4) target foods and nutrients. In cases where criteria (1) and (2) could not be met, evaluations in other countries and/or target populations in the same region that met the remaining criteria were chosen. Our main countries of interest were India, Ethiopia, and Nigeria, while the larger regions of interest included SSA and South Asia. The target population of interest included children under 5 years of age. Target nutrients of interest included vitamin A, animal protein, iron and zinc. Studies were included if they either reported changes in intakes of these target nutrients or changes in intakes of foods that are major sources of these nutrients.

Studies were excluded if they did not meet any of the aforementioned criteria, if they did not report changes in dietary intake, if they were not experimental in nature, or if they were published before 1995. We also excluded studies from high-income countries [World Bank Classification (The World Bank 2017a)]. In one instance (Educational Entertainment in Ethiopia; see Table 2), the proposed program had only been implemented to change agricultural practices, rather than dietary intake. For this program, we used the existing program’s reported change in uptake of targeted practices as a proxy for changes in dietary behaviours.

From these searches, titles and abstracts were reviewed for relevance using criteria outlined above. The full texts of potentially relevant studies were retrieved. For studies meeting inclusion and exclusion criteria, key data were extracted including country, study design, target population, description of intervention and control groups, intervention components, duration of the intervention, target foods and/or nutrients of intervention, method for assessing dietary intake and intervention effects on diet for the target population. In cases where multiple studies met inclusion criteria for a given program, the closest match was chosen based on our pre-specified criteria outlined above. For each dietary factor of interest, we utilized primary survey data (Global Nutrition and Policy Consortium 2017) to estimate intake by demographic strata within countries (Smith et al. 2016). For programs with multiple nutrient targets, multiple impact sources were chosen as necessary to produce impact estimates for all target nutrients. For studies that reported the effects of programs or interventions on food intake rather than nutrient intake, local food composition tables were used to convert food intakes into nutrient intakes.

### Estimating the targeted population for each program

For each of the 12 programs, information on priority target populations was collected at the regional meetings. This information was used in combination with census data or population estimates and demographic data for each country (United Nations 2017) to estimate the total target population for each program. Whenever possible, published reports on potential impact of each program were used to adjust the target population to estimate actual reach, whenever possible. Data on differences between targeted and reached populations were available for three of programs listed in Table 2 from the sources in Table 3; for other programs, costs and impacts were estimated on the basis of reaching the full target population.

### Calibration and validation of program costs

For the 12 selected programs, resources and costs determined from the regional meetings were reviewed for completeness and face validity. Missing or outlier costs were researched in the scientific literature for relevant matches or, if necessary, derived from similar items priced for other interventions within the same region. Costs were distributed across different budget item categories for specificity. Resource needs and costs were calibrated and validated against published reports from similar program interventions identified using the search process described above. Resources and costs were also calibrated and validated across all of the 12 programs so that costs for a given type of resource could easily be compared across the 12 interventions.

Total costs for each program were computed in net present value (NPV) terms to combine start-up and recurring costs, using purchasing power parity (PPP) adjusted prices to facilitate comparisons across countries and over time. PPP adjustment accounts for differences in both currencies and purchasing power in each country. All costs were reported in USD using 2015 PPP exchange rates (The World Bank 2017b). Start-up costs corresponded to the first 12 months of each program, and recurring costs to each subsequent year of intervention. A standard inflation rate of 0.03 per year was applied for costs arising from 2 through the end of the program, and NPVs were calculated using a discount rate of 0.05.

### Results

#### Characteristics of selected programs

The descriptions, target populations and target foods or nutrients for each of the 12 identified programs are detailed in Table 2. In Ethiopia, these included two conditional transfer programs designed to be nutrition-sensitive extensions of the existing Productive Safety Net Program (PSNP), which focused on providing households with either livestock or poultry conditional on household members meeting specific conditions. Two other programs in Ethiopia focused on nutrition education, and one on assisting women to produce complementary infant foods. All five of the Ethiopian programs targeted increased consumption of zinc and iron; four also focused on increasing animal source foods, and one also focused on increasing grains and legumes.

In Nigeria, the programs included a conditional cash transfer program for pregnant women conditional on antenatal care attendance, a food pricing program that taxed sugar-sweetened beverages and subsidized fruits and vegetables, a complementary food program that taught women to produce and sell complementary food, and a program that increased household animal and horticulture production (Table 2). Among these, iron and vitamin A were the most commonly targeted nutrients; two programs were especially comprehensive and targeted iron, vitamin A, zinc and animal protein.

Three priority programs were identified for India, including one focused on complementary infant food processing for low-income families with children, one utilizing a mass media education campaign to increase consumption of vitamin A-rich foods among children under 5, and one establishing home horticulture for rural households with children under 5 (Table 2). Vitamin A, zinc and iron were the most commonly targeted nutrients among these programs, while animal protein would be targeted by one of them.

### Estimated program impacts

The most commonly identified economic mechanism of impact was direct changes in dietary consumption via food transfers (N = 7 programs) (Table 3). Other mechanisms included changes in dietary...
preferences (N = 3), resource transfers for household purchases (N = 1) and access improvement (N = 1).

Among nutrients targeted, iron was estimated to be the most improved by complementary food production in Ethiopia, with an increase in consumption of 17.7 mg/recipient/day. This program was also estimated to produce the largest increase in zinc intake (7.4 mg/child/day). For vitamin A, the largest estimated increase in intake was associated with the household animal and horticulture production program in Nigeria (335 RAE/child/day); and for animal protein, the largest estimated increase was associated with the complementary food processing program in Nigeria (20.00 g/child/day).

When evaluated by mechanisms of impact, programs involving direct changes in intake via food transfers were generally estimated to produce larger changes in intakes of target nutrients than programs utilizing other mechanisms of impact.

### Estimated program costs

The program costing structures, outlined by budget item, are detailed in Table 4. When comparing individual budget items shared across programs, in Ethiopia the most expensive items were personnel salaries for senior professionals (mean = 45,000 USD/year), skilled personnel (tier 2; mean = 14,600 USD/year), and professionals (mean = 7800 USD/year). The least expensive items shared across programs included transportation (mean = 0.46 USD/km or 1708 USD/year) and support for volunteers (mean = 140 USD). Budget items that only appeared for one program in Ethiopia, and therefore could not be compared across programs, ranged from 100,000 USD for a consulting contract for radio production and distribution to 12.98 USD/kg of micronutrient powder.

For shared budget items across Nigeria programs, the most expensive included senior professionals (mean = 24,000 USD/year),...
skilled personnel (mean = 8300 USD/year) and vehicles (9093 USD/unit). In comparison, the least expensive included support for volunteers (306 USD), unskilled personnel (mean = 1000 USD/year), and office space (mean = 3000 USD/year). Additional items that were not shared across budgets in Nigeria included chickens, cash transfers, tree seedlings and vegetable seeds.

In India, senior professionals were the most expensive shared budget item (mean = 45 031 USD/year), while unskilled personnel were the least expensive (3637 USD/year). Among items that only appeared in one program budget, the cost of a consulting contract to produce television announcements was most expensive (200 000 USD/contract), while micronutrient sachets were the least (0.02 USD/sachet).

Among the 12 programs, 11 had a specified duration of 5 years, and one had a duration of 3 years (Table 5). Total discounted cost per child reached, shown in Table 5, ranged from USD 2650 for a livestock transfer program to 0.58 for a media and education campaign, both in Ethiopia. In other countries total cost per child ranged from USD 1919 for a cash transfer program to 2.62 for a food pricing program in Nigeria, and from USD 586 for home gardens to 27 for a media campaign in India. The most expensive programs per child used transfers of valuable assets such as livestock, garden supplies and cash, while the least costly programs used outreach and food pricing or market access such as for complementary foods in Ethiopia.

Table 4. Price per unit for selected resources used in multiple programs

| Country   | Item                     | Unit       | Mean<sup>a</sup> (USD) | Minimum<sup>b</sup> (USD) | Maximum<sup>c</sup> (USD) |
|-----------|--------------------------|------------|-------------------------|---------------------------|--------------------------|
| Ethiopia  | Senior professional      | Per year   | 45 000                  | 40 000                    | 60 000                   |
| Ethiopia  | Support for volunteers   |            | 140                     | 20                        | 200                      |
| Nigeria   | Senior professional      | Per year   | 24 000                  | 18 000                    | 30 000                   |
| Nigeria   | Support for volunteers   |            | 306                     | NA                        | NA                       |
| India     | Senior professional      | Per year   | 45 031                  | 40 000                    | 46 729                   |
| India     | Office space             | Per year   | 3000                    | 1000                      | 5000                     |

Source: Costs for each program estimated by workshop participants and project staff were subsequently cross-validated against actual program budgets in the field and against program costing literature.

<sup>a</sup>For items that were only reported once within each country across multiple programs, mean costs are equivalent to the single reported cost. In cases where items were reported multiple times across program budgets within a given country, mean costs are the average cost for that item.

<sup>b</sup>The minimum cost of a single item within each category as specified by workshop participants; reported only if an item appears in multiple program budgets within each country.

<sup>c</sup>The maximum cost of a single item within each category as specified by the workshop participants; reported only if an item appears in multiple program budgets within each country.

<sup>d</sup>Item reported more than once across program budgets, but the cost was the same in each budget for the given country.

<sup>e</sup>This item was only present in one program budget for the given country, and therefore a minimum and maximum cost are not reported; however, items that appeared once were cross-validated with other existing program budgets, costing literature, and expert project staff.
**Table 5.** Duration, size of target population and total costs per child targeted by each program*

| Country       | Program name                                | Length of program (years) | Number of children targetedd | Start-up cost per child targeted (USD) | Recurring cost per child targeted (USD/year) | Discounted NPV per child targeted (USD)f |
|---------------|---------------------------------------------|---------------------------|------------------------------|----------------------------------------|---------------------------------------------|------------------------------------------|
| Ethiopia      | Conditional livestock transfer              | 5                         | 941 200                      | 522                                    | 552                                         | 2650                                     |
|               | Conditional poultry transfer                | 5                         | 1 568 600c                   | 141                                    | 147                                         | 709                                      |
|               | Media & education campaign                  | 3                         | 7 848 700                    | 0.2                                    | 0.2                                         | 0.6                                      |
|               | Educational entertainment                   | 5                         | 14 600 000                   | 6.48                                   | 5.59                                        | 28                                       |
|               | Complementary food production               | 5                         | 1 449 000                    | 1.8                                    | 1.9                                         | 9.1                                      |
| Nigeria       | Conditional cash transfer                   | 5                         | 21 953 300                   | 380                                    | 399                                         | 1919                                     |
|               | Food pricing program                        | 5                         | 18 043 200c                  | 0.92                                   | 0.95                                        | 2.62                                     |
|               | Complementary food processing and sales     | 5                         | 360 000                      | 34                                     | 35                                          | 169                                      |
|               | Household animal & horticulture production  | 5                         | 6 500 000                    | 203                                    | 214                                         | 1026                                     |
| India         | Complementary food processing               | 5                         | 114 123 000                  | 7.75                                   | 7.67                                        | 37                                       |
|               | Diet diversity media campaign               | 5                         | 129 600                      | 9.06                                   | 4.7                                         | 27                                       |
|               | Home gardens                                | 5                         | 83 95 600                    | 118                                    | 121                                         | 386                                      |

NPV, net present value; SSBE, sugar sweetened beverage

*All past values are adjusted to USD using 2015 PPP exchange rates for each year from World Bank, World Development Indicators

**Discussion**

**Main findings**

This study provides novel estimates of estimated budgetary costs and potential impact on child dietary quality of 12 nutrition-sensitive interventions in Ethiopia, Nigeria and India, using a mixed methods participatory approach including regional stakeholders from diverse sectoral, institutional and disciplinary backgrounds to identify programs of interest with their key components and mechanisms, followed by literature reviews to produce a calibrated and validated set of budgets and impact estimates. This methodology offers a promising approach to estimating the costs and dietary impacts of nutrition-sensitive programs in resource-limited settings.

A principal finding is that stakeholder-designed interventions achieved the largest potential changes in child nutrient intake via food and resource transfers, rather than via market prices or other mechanisms. Such programs included transfers of poultry and other livestock, assistance with complementary food production, and resources necessary for homestead gardens. This finding is consistent with prior literature highlighting the benefits of similar programs on dietary quality. For example, livestock production programs have been found to improve dietary intakes among the poor by providing a regular supply of animal-source foods that are rich in nutrients such as zinc, iron and animal protein, with less susceptibility to seasonal fluctuations (Randolph et al. 2007). In addition, home gardens and homestead food production programs have been found to improve maternal and child intakes of target foods and nutrients and to increase dietary diversity (Ruel and Alderman 2013, Webb and Kennedy 2014). Finally, a systematic review of complementary feeding interventions found that those involving education alone for mothers on appropriate complementary feeding have a modest impact on recommended micronutrient intakes, while fortification strategies for complementary foods such as prioritized in our programs have a larger impact on micronutrient intakes (Dewey and Adu-Afarwuah 2008). Our results align with these findings by showing a larger impact on iron and zinc intakes of the proposed complementary food fortification and production program in Ethiopia when compared with the complementary food processing program in Nigeria that focused on education but not direct fortification.

A second important finding is that food and resource transfers are the costliest programs per child targeted. Programs that aimed to alter preferences, change market prices or otherwise improve access to healthy foods tended to be less costly per child, even though some of these achieved comparable estimated levels of changes in dietary intake. These findings highlight the need for future formal cost-effectiveness analyses and comparisons of these very different programs for each target population. Indeed, our results provide a foundation of methods, costs, and impacts for the development of appropriate modelling approaches, parameters and sensitivity analyses to assess cost-effectiveness. For instance, it may be that beneficiaries in more remote areas are best reached via transfers, while households closer to markets may be reached more cost-effectively via programs to alter prices and promote behaviour change. The overall cost-effectiveness of either kind of program will also depend on the numbers of beneficiaries and their relative risks for various disease outcomes associated with changes in dietary intake.

**Strengths**

An important feature of this analysis is that interventions considered were selected and defined through a participatory process including a diverse group of regional experts in SSA and South Asia. These
stakeholder consultations ensured that the interventions described in the study incorporated local knowledge and expertise from a range of sectoral, disciplinary and institutional backgrounds, which also helps ensure accuracy and relevance for policymaking in each country setting (Victora et al. 2012; Holdsworth et al. 2015). Importantly, these methods also limited the opportunity for any single interested party to influence results in their favour, a challenge for prior program evaluations often performed by the implementing agency, funding sponsor or other interested party (Every-Palmer and Howick 2014). We identified and focused upon specific diet–disease relationships with evidence for etiologic effects and relevant burdens for maternal-child health in these regions. A mixed methods approach allowed us to incorporate calibration and validation of program resources, costs, and impacts based on existing evidence.

Limitations
While our mixed methods approach and stakeholder engagement increase the potential relevance of the results to local decision-making, such methods preclude comprehensive assessment of every possible program iteration. The data presented here should be considered central estimates for costs and impacts of 12 specific programs for these countries. Future analyses should formally consider scientific and sampling uncertainty, for example incorporated as part of sensitivity analyses in subsequent cost-effectiveness analyses. Our methods focused on SSA and South Asia, and subsequently on Ethiopia, Nigeria and India as major representative countries; and our findings may be less generalizable to other countries or regions. On the other hand, the approach described here provides a roadmap for similar assessments of nutrition-sensitive interventions to improve diet quality in other countries.

Conclusions
We identified and characterized 12 specific programs to improve diet quality and child health in Ethiopia, Nigeria and India, along with estimated resource costs and dietary impacts. These methods and results can help address crucial knowledge gaps relating to nutrition-sensitive interventions targeting maternal-child health in low- and middle-income countries. The findings may inform ongoing policy discussions to meet national and international nutrition goals, and can also serve as critical inputs to future cost-effectiveness analyses of programs to improve the well-being of children in resource-limited settings.

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References
Ayele Z, Peacock C. 2003. Improving access to and consumption of animal source foods in rural households: the experiences of a women-focused goat development program in the highlands of Ethiopia. Journal of Nutrition 133: 3983s–6s.
Bhutta ZA, Das JK, Rizvi A, Lancet Nutrition Interventions Review Group, Maternal and Child Nutrition Study Group et al. 2013. Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? Lancet 382: 452–77.
Black RE, Allen LJ, Bhutta ZA, Maternal, Group, C.U.S., others et al. 2008. Maternal and child undernutrition: global and regional exposures and health consequences. The Lancet 371: 243–60.
Chakravary I. 2000. Food-based strategies to control vitamin A deficiency. Food and Nutrition Bulletin 21: 135–43.
De Pee S, Bloom MW, Satoto Yip R et al. 1998. Impact of a social marketing campaign promoting dark-green leafy vegetables and eggs in Central Java, Indonesia. International Journal for Vitamin and Nutrition Research 68: 389–98.
Development Initiatives, 2017. Global Nutrition Report 2017: Nourishing the SDGs. Bristol, UK: Development Initiatives.
Dewey KG, Adu-Afarwuah S. 2008. Systematic review of the efficacy and effectiveness of complementary feeding interventions in developing countries. Maternal & Child Nutrition 4: 24–85.
Ecker O, Weinberger K, Quam M. 2010. Patterns and determinants of dietary micronutrient deficiencies in rural areas of East Africa. African Journal of Agricultural and Resource Economics 4: 175–94.
Every-Palmer S, Howick J. 2014. How evidence-based medicine is failing due to biased trials and selective publication: EBM fails due to biased trials and selective publication. Journal of Evaluation in Clinical Practice 20: 908–14.
Faber M, Phungula MA, Venter SL, Dhansay MA, Benade AS. 2002. Home gardens focusing on the production of yellow and dark-green leafy vegetables increase the serum retinol concentrations of 2–5-y-old children in South Africa. American Journal of Clinical Nutrition 76: 1048–54.
Food and Agriculture Organization, World Health Organization, 2016. United Nations Decade of Action on Nutrition: 2016–2025.
Gandhi R, Veeraraghavan R, Toyama K, Ramprasad V. 2009. Digital green: Participatory video for agricultural extension. Information Technologies and International Development 5: 1–15.
Ghana Ministry of Food and Agriculture. 2016. Agriculture in Ghana: Facts and Figures. Accra: Ministry of Food and Agriculture (MoFA).
GBD 2016 Risk Factors Collaborators. 2017. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet 390: 1345–422.
Global Nutrition and Policy Consortium, n.d. The Global Dietary Database.
Haddad L, Hawkes C, Webb P et al. 2016. A new global research agenda for food. Nature 540: 30–2.
Hirve S, Martini E, Juvekar SK et al. 2013. Delivering Sprinkles Plus through the Integrated Child Development Services (ICDS) to reduce anaemia in pre-school children in India. Indian Journal of Pediatrics 80: 990–5.
Hoddinott J, Alderman H, Behrman JR, Haddad L, Horton S. 2013. The economic rationale for investing in stunting reduction. Maternal & Child Nutrition 9: 69–82.
Holdsworth M, Kruger A, Nago E et al. 2015. African stakeholders’ views of research options to improve nutritional status in sub-Saharan Africa. Health Policy and Planning 30: 863–74.
Lartey A, Manu A, Brown KH, Peerson JM, Dewey KG. 1999. A randomized, community-based trial of the effects of improved, centrally processed complementary foods on growth and micronutrient status of Ghanaian infants from 6 to 12 mo of age. American Journal of Clinical Nutrition 70: 391–404.
Masters WA, Rossette KL, Kranz S et al. on behalf of the Global Nutrition and Policy Consortium, 2018. Priority interventions to improve maternal and child diets in sub-Saharan Africa and South Asia. Maternal & Child Nutrition 14: e12526.
Monterrosa EC, Frongillo EA, González de Cossío T et al. 2013. Scripted Messages Delivered by Nurses and Radio Changed Beliefs, Attitudes, Intentions, and Behaviors Regarding Infant and Young Child Feeding in Mexico. Journal of Nutrition 143: 915–22.
Ouidaradou GHZ, Traoré T, Zeba A et al. 2009. Development of an improved local-ingredient-based complementary food and technology transfer to rural households. Food and Nutrition Bulletin 30: 153–60.
Randolph TF, Schelling E, Grace D et al. 2007. Role of livestock in human nutrition and health for poverty reduction in developing countries. Journal of Animal Science 85: 2788–800.
Rawlins R, Pimkina S, Barrett CB, Pedersen S, Wydick B. 2014. Got milk? The impact of Heifer International’s livestock donation programs in Rwanda on nutritional outcomes. Food Policy 44: 202–13.
Ruel MT, Alderman H. 2013. Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? The Lancet 382: 536–51.

Ruel MT, Alderman H. Maternal and Child Nutrition Study Group, 2013. Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? The Lancet (London, England) 382: 536–51.

Smith MR, Micha R, Golden CD, Mozaffarian D, Myers SS. 2016. Global Expanded Nutrient Supply (GENuS) model: a new method for estimating the global dietary supply of nutrients. PLoS One 11: e0146976.

Sonaya EB. 2009. Some technical and socioeconomic factors affecting productivity and profitability of smallholder family poultry. World’s Poultry Science Journal 65: 201–6.

Taher A, Talukder A, Sarkar NR et al. 2004. Homestead gardening for combating vitamin A deficiency. In: Roos N, Bouis HE, Hassan N and Kabir KA (eds). Alleviating malnutrition through agriculture in Bangladesh: biofortification and diversification as sustainable solutions. Washington, DC: IFPRI.

Talukder A, Haselow NJ, Osei AK et al. 2010. Homestead food production model contributes to improved household food security and nutrition status of young children and women in poor populations. Field Actions Science Reports 15, http://factsreports.revues.org/404.

The World Bank, 2017a. World Bank Country and Lending Groups. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

The World Bank, 2017b. World DataBank: World Development Indicators.

Ulimwengu JM, Roberts C, Randriamamonjy J. 2012. Resource-Rich Yet Malnourished: Analysis of the demand for food nutrients in the Democratic Republic of Congo. International Food Policy Research Institute (IFPRI) Discussion Paper 1154. Washington, DC: IFPRI.

United Nations, 2017. United Nations Population Division. United Nations, 2016. The Sustainable Development Goals. http://www.sustainabledevelopment2015.org.

USDA. 2016. USDA National Nutrient Database for Standard Reference, Release 28. Beltsville, MD: U.S. Department of Agriculture (USDA).

Victora CG, Barros FC, Assunção MC et al. 2012. Scaling up maternal nutrition programs to improve birth outcomes: a review of implementation issues. Food and Nutrition Bulletin 33: S6–S26.

Webb P, Kennedy E. 2014. Impacts of agriculture on nutrition: nature of the evidence and research gaps. Food and Nutrition Bulletin 35: 126–33.