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Comparing costs and cost-efficiency of platforms for micronutrient powder (MNP) delivery to children in rural Uganda

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Micronutrient powder (MNP) can reduce iron deficiency in young children, which has been well established in efficacy trials. However, the cost of different delivery platforms has not been determined. We calculated the cost and cost-efficiency of distributed MNP through community-based mechanisms and in health facilities in a primarily rural district in Uganda. An endline survey (*n* = 1072) identified reach and adherence. During the 9-month pilot, 37,458 (community platform) and 12,390 (facility platform) packets of MNP were distributed. Each packet consisted of 30 MNP sachets. In 2016, total costs were $277,082 (community platform, $0.24/sachet) and $221,568 (facility platform, $0.59/sachet). The cost per child reached was lower in the community platform ($53.24) than the facility platform ($65.97). The cost per child adhering to a protocol was $58.08 (community platform) and $72.69 (facility platform). The estimated cost of scaling up the community platform pilot to the district level over 3 years to cover approximately 17,890 children was $1.23 million (scale-up integrated into a partner agency program) to $1.62 million (government scale-up scenario). Unlike previous estimates, these included opportunity costs. Community-based MNP delivery costs were greater, yet more cost-efficient per child reached and adhering to protocol than facility-based delivery. However, total costs for untargeted MNP delivery under program settings are potentially prohibitive.

Keywords: delivery platforms; costing; cost-efficiency; cost-effectiveness; micronutrient powders; infant and young child feeding; development; anemia

Introduction

Undernutrition remains a serious threat to the health and wellbeing of women and children in low- and middle-income countries (LMICs). Malnutrition, including undernutrition and vitamin or mineral deficiencies, is directly or indirectly responsible for almost half of deaths among children under the age of 5.[1] *The Lancet* 2013 series on maternal and child nutrition examined and proposed interventions to improve child nutrition and reduce deaths among infants and children under age 5.[2,3]

Iron deficiency is considered the most prevalent of micronutrient deficiencies[4] and is commonly accepted as the main etiological factor of anemia.[5,6] In infancy and early childhood, iron may be crucial to the development of the brain and central nervous system and hence, for cognitive and behavioral development.[4,7,8] The World Health Organization estimates that 42% of anemia is amendable to iron

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supplementation[9] and the Global Burden of Disease Study found that it was the leading cause of disability years lived among children and adolescents.[10] Iron supply to children can be increased by either changing diets, adding iron to industrially manufactured complementary foods (food fortification), or through supplements, such as micronutrient powder (MNP), which is added to meals for children and infants older than 6 months.[11–13] Efficacy trials in LMICs have shown that MNP can deliver sufficient iron to reduce anemia and the prevalence of iron deficiency in young children[14] and may also increase cognitive performance.[15] While MNP is efficacious when compliance is ensured, adherence to MNP protocols among beneficiaries varies widely.[16]

MNP has been promoted as a low-cost and effective intervention,[12] reportedly costing \$3.60 per child per year,[17] with a cost-effectiveness ratio as high as 37:1 (calculated as the present value of the gain in earnings for each dollar spent on the intervention).[18] However, these estimates were based on the characteristics of fictitious communities in Pakistan and relied on several important assumptions, such as 95% coverage (and missed children eventually reached), 60 sachets consumed over 4 months, and cost of the whole supply of 60 MNP sachets per child of \$1.20.[18] More recently, studies of MNP implementation have found costs to be substantially higher. An MNP intervention in Bangladesh had an estimated total 5-year program cost of 14 million USD.[19]

This study estimates costs based on programmatic elements using two delivery platforms in a single rural site in Uganda: (1) delivery by community health workers (community-based platform) and (2) delivery using facility-based health providers (facility-based platform). The cost, reach, adherence, and cost-efficiency, using reach and adherence as measures of project outcome of this intervention, are relevant for LMICs with similar healthcare infrastructure. We calculated the cost of MNP provision from start-up to the "last mile"—the final leg in product and service delivery when MNP reaches beneficiaries. We compared costs and cost-efficiency across delivery platforms using several indicators of outcomes and estimated the costs of scaling up, extending the pilot program, and integrating MNP delivery activities into existing infant and young child feeding (IYCF) programs.

Materials and methods

Program description

In 2012, the Ugandan Ministry of Health (MOH) established a technical working group to determine the conditions necessary to introduce MNP in Uganda. The Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) project piloted 9 months of MNP distribution in Namutumba, a mostly rural district located in the East Central region, where the prevalence of anemia among young children, in a DHS, was 67.5% in 2011.[20] Namutumba, one of the 111 districts in Uganda, comprises six subcounties and one town council. Each of the subcounties was randomly assigned to either the community delivery platform or the facility platform. In the community delivery platform, volunteer health teams (VHTs) distributed MNP in communities, with health workers playing a limited role in reminding caregivers of children 6–23 months old to pick up MNP packets from their VHT. In the facility delivery platform, health workers at health facilities distributed MNP, with VHTs playing a supporting role in mobilization and sensitization of the community. SPRING provided health workers and VHTs a 2-month supply of MNP for all eligible children in their respective catchment areas. Inventory was refilled every 2 months or as needed. Eligible children were aged 6–23 months, not suffering from any major illnesses. MNP packets were manufactured by DSM Nutritional Products and contained 15 micronutrients (iron, zinc, copper, iodine, selenium, niacinamide, folic acid, and vitamins A, C, D, E, B_1, B_2, B_6, and B_{12}). Caregivers received one packet of 30 sachets, intended for eligible children to receive one sachet every other day. This schedule would meet approximately half the child's daily reference nutrient intake.[21] Activities to support behavior change and encourage adherence to a protocol and a description of caregiver experiences are described elsewhere.[22] The institutional review boards of Makerere University's School of Public Health and John Snow, Inc. provided ethics approval. All participants provided written consent for study participation.

Costing data and measures

Comprehensive data on financial and opportunity costs for distributors and households obtaining MNP were collected for each delivery platform (Table 1). Values for physical inputs and weights

Table 1. Cost inputs and descriptions for pilot and scale-up costing scenarios

Input	Description
MNP unit cost	Calculated based on what SPRING actually paid for the MNP product, including unit price, customs clearance price, freight cost, and insurance cost
Capital investments	Equipment (laptops, generator for the office, thermometers for temperature-controlled storage, etc.), vehicles, training and office materials, and fixed monthly overhead for office rental
Transportation	Fuel prices were based on actual prices paid in 2016; fuel efficiency is calculated using SPRING's standard fuel efficiency rate. Average round trips (km) were calculated using driving logs and routes
Program staff time	Calculated using self-reported hours per program activity by staff and implementing partner, salary rates, and full benefits for in-country program staff
Per diems	Rates paid to MOH, community leaders, and hired day labor for travel to and attendance at program activities and overnight stays for training outside trainers' district. Source: Uganda standard per diem rates and SPRING's finance and operations records
VHT member time	Calculated using VHT members' reported hours worked and the prevailing market wage. The prevailing market wage was the opportunity cost of VHT time, calculated as the average wage for outside work, weighted by the number of VHT members reporting that type of work. The opportunity cost for 87% of VHT members reporting no outside labor was set at the lowest reported wage rate ($1.93/day). The opportunity cost for 13% reporting outside income was set at $7.60/day, which was the highest average subcounty level reported daily wage rate. Therefore, the weighted market wage used to calculate VHT opportunity costs was set at $2.66/day
Health worker time	Calculated using health worker reported hours worked and the hourly equivalent of government health worker salaries
Outreach and education materials	Included the development and rollout of radio programs, enrollment cards, adherence charts, posters, and stickers
In-kind reimbursements	Included refreshments and meals for training participants

NOTES: Program impact data were taken from the endline survey. The equivalent market wage was used to calculate opportunity costs for VHTs who could be otherwise employed; this rate was calculated by weighting VHTs' reported daily wage estimates—from paid work outside this project—by the number of VHTs who reported having a second job outside of VHT and subsistence agriculture. MNP, micronutrient powder; MOH, Ministry of Health; SPRING, Strengthening Partnerships, Results, and Innovations in Nutrition Globally; VHT, village health team.

(i.e., unit costs) were from records of implementing agencies and brief surveys collected hours of relevant staff for MNP distribution. To estimate the value of health workers' and other individuals' time, we examined opportunity costs or the value of a given worker's time that would have been earned in alternative employment. Opportunity costs for health workers, ministry officials, and VHTs came from government salaries and market wages. These data generated spreadsheet-based models for calculating the marginal cost of adding MNP distribution to the community platforms and the existent facilities. Items were categorized as either start-up or ongoing costs; these were further disaggregated into categories by activity code, type of activity (capacity building, social behavioral change, logistics, operational monitoring and evaluation, and capital investments), and other indicators.[23] Interviews with individuals familiar with both delivery platforms and related programs in rural areas of Uganda informed adjustments to cost models to estimate integrated programming and over four 3-year, district-wide scale-up scenarios.

Cost-efficiency data and measures

An endline survey using a two-stage cluster sample design was conducted from November to December 2016, 9 months after the start of distribution, to obtain data on reach and adherence to a protocol. Households with children 8–23 months of age were included (by 8 months, children were eligible long enough to have received at least one packet). Baseline use of MNP was assumed to be nil. "Reach" refers to a child having consumed at least one sachet of MNP in the past 7 days; "adherence" is a child having consumed one sachet in a meal, three or more times in the past 7 days, as reported by caregivers. We calculated the estimated cost per child reached and the cost per child, adhering to a protocol from the endline survey and cost data.

While the survey sample was intended to be representative of the district, the study team later found the household listing for household selection omitted some households. The team conducted a full census of a district subpopulation to assess potential sample selection bias. This subcensus revealed some bias in the endline survey: endline households had higher wealth index levels, suggesting that they may have been less vulnerable than subcensus households. However, bias was in the same direction for households in both the community and facility platforms in the endline survey when compared with counterparts in the subcensus survey. Thus, sample selection biases were judged to be equivalent in the community and facility platforms, implying negligible bias for any comparisons by the delivery platform in the endline survey.

Scale-up and integration

Using pilot intervention and district population data, we estimated 3-year district-wide scale-up costs and cost-efficiency for each delivery platform. Scale-up scenarios included (1) implementing partner (IP) scale-up (managed by an international nongovernmental organization); (2) MOH takeover (implemented entirely by the MOH); (3) IP scale-up plus payments to VHTs; (4) MOH takeover plus payments to VHTs; and (5) IP "integrated" scale-up—MNP intervention managed by an IP, but with activities integrated into existing IYCF feeding program activities, with shared capital investments. As an example of (5), MNP training activities might be combined with training for IYCF programs, and the cost of these activities split equally between the two programs.

Finally, sensitivity analyses explored variations in the data and assumptions around measurement error. Variations were in major cost drivers, such as MNP per unit price, social behavioral change (SBC) design and rollout costs, and training costs. Other variations included MNP unit price discounts, recall bias from self-reporting time allocation, variation in possible market wages and opportunity costs of time, and spatial heterogeneity within and between districts. We clustered low range costs to create an "optimistic" scenario and a high range of costs to create a "pessimistic" scenario. We used a 95% confidence interval to estimate variance in our measures of success.

Results

The majority of households ($n = 1072$) in the endline survey were rural (93.3%), and most caregivers had primary schooling or less (79.8%) (Table 2). Most caregivers received counseling on MNP use when they first received MNP (88.4%); were given program materials (calendar, 86.3%; sticker, 69.4%); and reported that they typically followed the advice of health workers (93.3%). However, only 36.4% correctly identified the age at which children should start MNP use, stop MNP, and recommended MNP frequency (though 93.8% knew at least one of those items). Beneficiaries in the community platform were more likely to have received counseling on MNP use and program materials (97.1% versus 81.1%, t-tests, $P < 0.05$). Reach was higher in the community platform than in the facility platform (63.6% versus 34.6%) (Table 3), as was adherence (58.3% versus 31.4%).

The total cost of the 9-month pilot interventions, including the opportunity costs of VHTs, health workers, and caregivers' time, was $277,082 for the community platform ($0.24 per sachet, $7.40 per packet) and $221,568 for the facility platform ($0.59 per sachet, $17.83 per packet) (Table 4). The cost per child reached for the pilot study was $53.24 in the community platform and $65.97 in the facility platform. The cost per child adhering to a protocol was $58.08 in the community platform and $72.69 in the facility platform. If all eligible children had received MNP and adhered to a protocol for the entire 9-month pilot, the total cost of the programs (holding all other costs constant) would have been $282,000 for the community and $251,000 for the facility platform pilots.

Figure 1 shows the costs by a platform for the 3-year scaled-up scenarios for IP scale-up. Programmatic capacity building activities represented a significant share of total program costs (23%, both platforms), followed by the opportunity cost of VHTs reaching beneficiaries (community platform: 20%, facility platform: 17%) and social-behavioral change (community platform: 17%; facility platform: 19%). MNP procurement was 24% of total costs in the community platform and 30% in the facility platform.

Table 2. **Child, household, and programmatic characteristics, by delivery platform, the endline survey results**

	Total ($n = 1072$) Percentage/Mean (95% CI)	Community platform ($n = 548$) Percentage/Mean (95% CI)	Facility platform ($n = 524$) Percentage/Mean (95% CI)
Child characteristics			
Female	0.523 (0.487−0.560)	0.531 (0.480−0.581)	0.517 (0.465−0.568)
Age in months*	15.6 (15.33−15.9)	16.3 (15.9−16.7)	15.0 (14.6−15.4)
Age category*			
8−11 months	0.203 (0.172−0.238)	0.143 (0.112−0.181)	0.254 (0.205−0.310)
12−17 months	0.443 (0.408−0.478)	0.442 (0.399−0.487)	0.444 (0.392−0.497)
18−23 months	0.354 (0.322−0.388)	0.414 (0.369−0.461)	0.303 (0.259−0.350)
Minimum dietary diversity	0.266 (0.231−0.305)	0.298 (0.246−0.356)	0.239 (0.192−0.294)
Household characteristics			
Tribe			
Musoga	0.766 (0.727−0.800)	0.797 (0.747−0.839)	0.739 (0.679−0.791)
Muganda	0.019 (0.012−0.029)	0.019 (0.010−0.034)	0.019 (0.011−0.034)
Langi	0.002 (0.000−0.007)	0.001 (0.000−0.008)	0.002 (0.000−0.014)
Other	0.214 (0.181−0.252)	0.183 (0.144−0.230)	0.240 (0.190−0.299)
Mother's education: completed primary or less	0.798 (0.824−0.769)	0.809 (0.842−0.772)	0.788 (0.827−0.743)
Health service and MNP exposure			
Follow advice of a health worker	0.933 (0.913−0.949)	0.922 (0.894−0.944)	0.942 (0.910−0.964)
Counseled first time and received MNP*	0.884 (0.851−0.911)	0.971 (0.949−0.983)	0.811 (0.752−0.858)
Knowledge of MNP (start, stop, and frequency)	0.364 (0.323−0.407)	0.385 (0.332−0.440)	0.346 (0.285−0.413)
Reported receiving the program calendar*	0.863 (0.827−0.892)	0.931 (0.902−0.952)	0.804 (0.741−0.855)
Reported receiving a program sticker	0.694 (0.653−0.732)	0.812 (0.771−0.848)	0.593 (0.528−0.656)

Data source: Endline survey data, the Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) project.
NOTES: This table reports data from the endline sample, which only represents a subset of the population receiving the intervention. Minimum dietary diversity is a binary variable indicating the child received foods from four or more of seven food groups (grains, roots, and tubers; legumes and nuts; dairy products (milk, yogurt, and cheese); flesh foods (meat, fish, poultry, and liver/organ meats); eggs; vitamin A–rich fruits and vegetables; and other fruits and vegetables).
*Indicates difference between platforms at $P < 0.05$.

District-wide 3-year scale-up using the IP scenario and community platform was estimated at approximately $1.8 million ($554,000 for the first year and $622,000 for each subsequent year, Table 4). MOH scale-up was estimated at $1.62 million ($530,000 first year and $544,000 subsequent years). Adding monetary payments to VHTs increased costs in scenarios, but total costs for the MOH community platform scale-up decreased from $1.68 million to $1.51 million.[a] Integrating selected MNP activities into ongoing IYCF programs (IP scale-up scenario) was the least expensive scenario, reducing costs by 32% and 30% for community and facility platforms, respectively. Under those scenarios, MNP procurement reached 43% of total costs for the community platform.

The cost per child reached was lower in the community platform ($37.99 per child reached) than in the facility platform ($41.44 per child reached) due to higher coverage. The community platform was more efficient than the facility platform regardless of the outcome considered (the cost per packet delivered, reach, or adherence). The community platform distributed three times more MNP packets in the pilot study than did the facility platform, despite having a slightly smaller target population base. The IP scenario was the most cost-efficient scale-up scenario. Although the total programmatic cost was higher for the commu-

[a]Lower costs resulted from lower VHT payments by MOH compared with alternative payments from other work. Alternative employment could have a higher wage rate than VHT work, though such employment alternatives are not always readily available.

Table 3. Program impact measures, the endline survey data

	Total Percentage (95% CI) ($n = 1072$)	Community platform Percentage (95% CI) ($n = 548$)	Facility platform Percentage (95% CI) ($n = 524$)
Ever heard of MNP	0.988 (0.979−0.993)	0.991 (0.978−0.996)	0.985 (0.970−0.993)
Child consumed MNP yesterday or today*	0.385 (0.351−0.421)	0.526 (0.475−0.577)	0.265 (0.218−0.317)
Consumed in the past 7 days[a]*	0.480 (0.438−0.522)	0.636 (0.582−0.687)	0.346 (0.286−0.412)
Appropriate use in the past week			
Consumed one sachet last time*	0.862 (0.825−0.892)	0.951 (0.920−0.970)	0.785 (0.722−0.838)
Consumed MNP in meal	0.888 (0.853−0.915)	0.966 (0.945−0.980)	0.821 (0.759−0.869)
Consumed MNP 3+ days in the past week*	0.465 (0.425−0.506)	0.611 (0.558−0.662)	0.340 (0.282−0.403)
All three practices above combined[b]*	0.438 (0.398−0.478)	0.583 (0.529−0.635)	0.314 (0.257−0.376)
At least two packets of MNP received*	0.642 (0.608−0.675)	0.875 (0.838−0.904)	0.444 (0.389−0.500)

Data source: Endline survey, the Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) project.
NOTES: Endline survey includes a sample of the population who received the intervention.
*Indicates difference between platforms at $P < 0.05$.
[a] Represents our measure of "reach" presented in the text.
[b] Represents our measure of "adherence" presented in the text.

nity platform compared with the facility platform, the efficiency of the community platform was greater.

Table 5 shows the range of values used in sensitivity analyses, allowing for optimistic and pessimistic scenarios for costs of selected inputs. The lowest cost scenario for the pilot was $6.12 per packet delivered and $40.78 per child reached in the community platform (Table S1, online only); these costs were $15.02 and $46.65 for the facility platform, respectively. The highest cost scenario for the pilot was $11.79 per packet delivered and $92.77 per child reached (community platform), and $25.28 per packet delivered and $113.15 per child reached (facility platform).

Sensitivity analysis for scale-up scenarios showed the "optimistic" cost of scaling up the lowest cost scenario (integrated IP) using the most cost-effective delivery method (community platform) was $3.51 per packet delivered ($26.39 per child reached). The pessimistic cost estimate for the equivalent scenario was $7.89 per packet ($31.23 per child reached).

Discussion

The international community has called for increased efforts to reduce early childhood undernutrition, and that includes the prevention of micronutrient deficiencies. However, costs associated with the delivery of nutrition interventions are not well documented, particularly for "last-mile" costs (activities and investments in the final step of product and service delivery). To inform policy discussions, we used field-based data on reported consumption and measured costs for two MNP delivery platforms for young children in rural Uganda.

Although the total costs of planning and managing the facility platform were lower than those of the community platform, the latter had better outcomes, and it was more cost-efficient (Fig. 1). This was true regardless of the outcome measure chosen (the cost per packet delivered, reach, or adherence to a consumption protocol). Therefore, total intervention costs are not a sufficient criterion for distribution platform selection.

Second, the cost-efficiency of MNP delivery platforms depended heavily on the definition of successful outcomes. For example, in the IP-managed scale-up scenario for the community platform with IYCF program integration, the cost per sachet delivered was $0.15, the cost per child reached was $36.05, and the cost per child adhered was $39.33. Bottlenecks on the way to consumption

Table 4. Costs of the MNP pilot and scale-up costs, the total cost over 3 years

	Total cost	% budgetary	Cost/packet distributed (2-month supply)	Cost/child reached (taken MNP in the past 7 days)	Cost/child adhered to protocol
Community platform pilot	$277,082	72	$7.40	$53.24	$58.08
Facility platform pilot	$221,568	74	$17.83	$65.97	$72.69
Community platform scale-up					
Implementing partner scale-up	$1,797,517	66	$6.48	$52.66	$57.45
Implementing partner scale-up with paid VHTs	$1,680,226	82	$6.06	$49.22	$53.70
MOH scale-up	$1,617,804	65	$5.83	$47.40	$51.70
MOH scale-up with paid VHTs	$1,508,228	83	$5.44	$44.19	$48.20
Implementing partner-integrated scale-up	$1,230,510	71	$4.44	$36.05	$39.33
Facility platform scale-up					
Implementing partner scale-up	$1,225,133	63	$14.00	$65.97	$72.70
Implementing partner scale-up with paid VHTs	$1,407,345	68	$16.08	$75.79	$83.51
MOH scale-up	$1,041,198	60	$11.89	$56.07	$61.78
MOH scale-up with paid VHTs	$1,231,020	66	$14.06	$66.29	$73.05
Implementing partner-integrated scale-up	$852,618	68	$9.74	$45.91	$50.59

Data source: Authors' calculations from costing data, the Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) intervention.[36]

NOTES: $, U.S. dollars. One packet contains 30 sachets (2-month supply), from monitoring and evaluation inventory flows; adhered to protocol=child consumed one sachet MNP, with food, at least three times in the past week, based on the endline survey data. First-year costs included start-up costs plus 9 months of MNP delivery, while the next 2 years have a 12-month delivery period.

in the home can reduce the number of children adhering to a protocol and hamper the intended nutritional benefits of the intervention.[24]

Third, costs reflected the opportunity cost for volunteers delivering MNP to resource-poor households rather than cash outlays. The continued participation of these individuals is essential to the performance and sustainability of MNP programs, especially in the community-based program, which was more cost-efficient. We demonstrated that if VHTs were paid, government outlays could increase, and cost-efficiency fall. However, establishing a cadre of paid community health workers might provide additional opportunities to integrate and scale up multiple nutrition-related activities, potentially improving program outcomes and cost-efficiency in the long run.

Fourth, total last mile opportunity costs were substantial. In the pilot study, the last mile opportunity costs accounted for 20% of total costs in the community platform and 17% of total costs in the facility platform. These costs account for a smaller percentage of the total costs in the 3-year IP integrated scale-up scenarios (10% and 11% for community and facility platforms, respectively). Studies that focus only on product procurement costs may underestimate the costs of delivering MNP, especially in rural settings.

Fifth, program costs can always be reduced, but doing so carelessly, such as eliminating expensive components like SBC, can undermine positive program outcomes and potentially reduce cost-efficiency. We compared the scale-up of MNP by an international IP (such as a nongovernmental

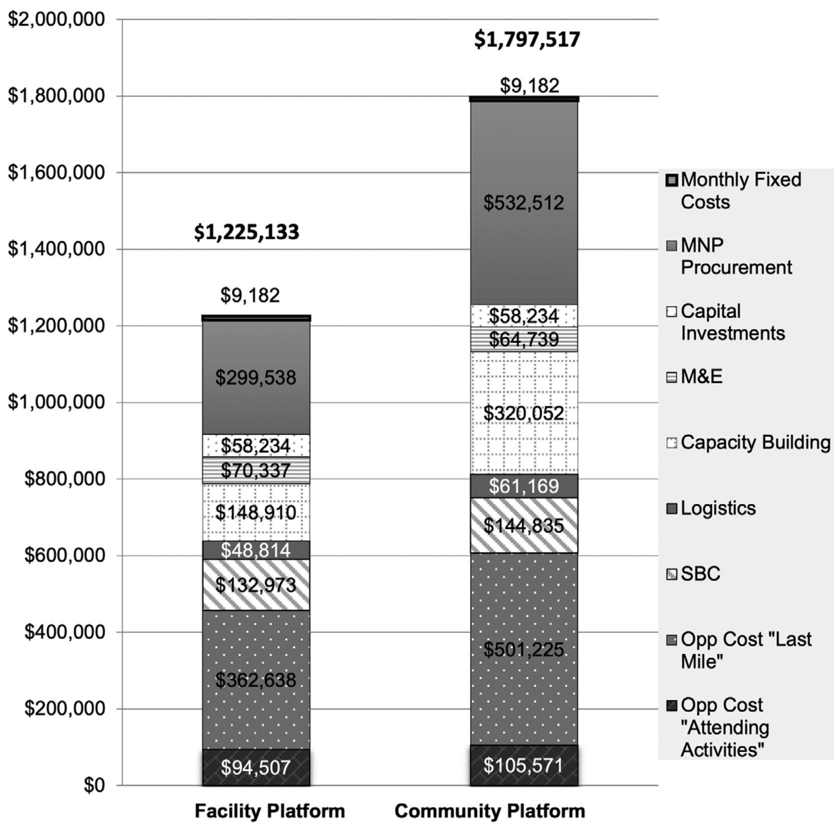

Figure 1. Three-year scaled-up costs and cost categories, by the delivery platform. Data were obtained from authors' calculations from the costing study.[36] The opportunity cost of the "last mile" is the opportunity cost of VHTs, health workers, and households for MNP distribution. The opportunity cost of "attending activities" is the opportunity cost to VHTs and community members' time for attending any training associated with MNP. Costs are in 2016 U.S. dollars. MNP, micronutrient powder; M&E, monitoring and evaluation; Opp Cost, opportunity cost; SBC, social behavioral change.

organization) and the MOH. Under the assumptions of equivalent program quality, a government-run system would be slightly more cost-efficient. Integrating MNP products and services into existing IYCP programs for a 3-year district-wide scale-up resulted in a 32% reduction in total costs. However, the integration of delivery services, training, and personnel has implications for both program sustainability and success in reaching children.

The estimated cost of scaling up to country level for Uganda would likely surpass scale-up estimates for Bangladesh estimated in Ahmed *et al.*:[19] the total cost in our study was $600,000–$800,000 for one of the 111 districts, likely exceeding the 14 million USD implementation cost estimated for Bangladesh. Methods do vary across studies, which may lead to varying estimates. For example, the Bangladesh study estimated opportunity costs for services provided by voluntary staff based on consultation with program personnel, and these costs may vary substantially by country or even district. Also, it is important to note that nutrition interventions requiring behavioral change also tend to be expensive. For instance, behavioral change interventions providing a community nutrition program promoting breastfeeding, appropriate and timely complementary feeding, and handwashing was estimated to cost $5–15 per participant per year;[17] and a breastfeeding promotion program was estimated to cost $16–85 per supported month of exclusive breastfeeding in South Africa and $139 per mother counseled in Uganda.[25] While such interventions are markedly different from MNP supplementation, they similarly aim to achieve social and behavioral change and may establish expectations around upper and lower boundaries to cost parameters.

Table 5. Ranges of values used in sensitivity analyses

Parameter	Base estimate parameter costs	Optimistic estimate	Pessimistic estimate
MNP unit cost[a]	$1.14/packet	$0.99/packet	$1.47/packet
Average hours per month (opportunity cost—“last mile”)	CP: 46.6 (VHTs); 5.66 (HWs); and 1 (HH) FP: 1.6 (VHTs); 109 (HWs); and 3 (HH)	CP: 39 (VHTs); 3.66 (HWs); and 5 (HHs) FP: 1 (VHTs); 80 (HWs); and 3 (HHs)	CP: 54.1 (VHTs); 7.66 (HWs); 1.5 (HHs) FP: 2 (VHTs); 120 (HWs); 7 (HHs)
Prevailing market wage for VHTs/household opportunity costs	$2.66/day–VHTs and HHs; $3.66/day–HW	$1.92/day–VHTs and HHs; $2.75/day–HWs	$7.59/day VHTs and HHs; $4.58/day HWs
Reimbursement rate for fuel	$0.15/km	$0.14/km	$0.17/km
Distance of average road trip (SPRING staff)	88.7 km/trip	48 km/trip	114 km/trip
Salaries for program staff	Standard salary rates, plus 38%[b]	Standard salary rates	Standard salary rates, plus 38%, plus max U2SC salary for a public health officer
Reach: consumed MNP in the past 7 days	CP: 63.6% FP: 34.6%	CP: 68.7% FP: 41.2%	CP: 58.2% FP: 28.6%
Adherence: consumed one sachet of MNP with food at least three times over the past 7 days	CP: 58.3% FP: 31.4%	63.5% 37.6%	52.9% 25.7%

Data source: Authors’ calculations from the costing study.[36]

Notes: Program impact data were taken from the endline survey. *Reach* is defined as a child who took MNP in the past 7 days. *Adherence* is defined as a child taking one sachet of MNP with food at least three times in the past 7 days. CP, community platform; FP, facility platform; HW, health worker; HH, household; MNP, micronutrient powder; VHT, village health team; SPRING, Strengthening Partnerships, Results, and Innovations in Nutrition Globally.

[a] MNP unit costs (cost/packet) include a standard $0.78 per packet, plus variable customs clearance tax, shipping, and insurance. For example, in the actual pilot, MNP was shipped by freight into Uganda at $0.20/packet, so the pessimistic scenario assumes the rate to ship by air ($0.30/packet).

[b] The additional 38% accounts for staff benefits.

Reach and adherence were higher in the community platform, which also had higher levels of counseling. Higher reach and adherence were also associated with knowledge of correct MNP use (adherence was 57.9% for individuals correctly identifying start age, stop age, and frequency of use, compared with 35.7% answering at least one of those questions incorrectly). Thus, it is possible that improved counseling skills among VHTs could increase the cost-efficiency of the intervention but reaching greater than 60% adherence would be challenging and expensive. It is certainly possible that novel, low-cost investments, such as daily text messages to caregivers,[26] could increase reach and adherence, but recent studies suggest that counseling and contact with frontline workers were important drivers of adherence.[27–29]

This study had limitations. The pilot was for just one of more than 100 districts in Uganda. Differences across districts could imply differential costs for personnel, transportation, and/or materials; these could vary by population density, the heterogeneity of geography, demographics, education levels, and social norms, among other characteristics. These same district-level characteristics may also affect the expected outcomes. Nevertheless, our estimates are a starting point for estimating the cost per child of scale-up.

Variations between countries, and even within Uganda, make it challenging to generalize results. For example, unit costs are estimated to be higher in Africa than in Asia due to increased travel time to reach beneficiaries; also, Africa tends to have higher labor costs.[3] However, the relatively high cost of going the last mile is likely to be similar in LMICs with similar health infrastructure and health-seeking behaviors among caregivers.

Ideally, we would want to know the values of all the life-long benefits of improved child nutrition that could be attributed to particular programs and to set these alongside intervention program costs. Unfortunately, we do not have such information. For example, it would be helpful to account for the value of cases of averted anemia or cognitive/developmental outcomes that could potentially be attributed to MNP intervention. Indeed, there may be longer-term effects on children, school performance, and even job performance. These impacts could potentially be large for some children, though we were not able to observe such impacts over the course of this brief study. Ultimately, it is unclear how cost and cost-effectiveness might change or how MNP programs would perform relative to other investments known to enhance school performances. For the purposes of the present study, we recognize that we are not assessing such potential long-term impacts.

Our study also had several strengths. In contrast to previous work, we calculated cost-efficiency using actual program inventory flows and field-based estimates of program reach and adherence outcomes. We found that cost-efficiency was substantially higher when defined by the amount of MNP distributed (inventory flows), compared with beneficiaries' reported consumption or adherence to a protocol. Previous cost studies have not measured actual program reach or adherence[11,30] and, therefore, may have overestimated the cost-efficiency and the cost-effectiveness of MNP interventions. Further, while our cost estimates exceed previous estimates,[16,30] these differences can be attributed to the use of actual program costs, measured reach and adherence, and importantly, accounting for the opportunity cost of workers' time. Data were collected prospectively to accurately assess the total costs, including repeat interviews with program staff regarding their time allocation. As a result, these findings represent more realistic estimates of "going the last mile" to reach beneficiaries.

We provide comprehensive and current MNP cost composition data, which can be used to inform global calculations with reasonable adjustments and assumptions. The World Bank recently estimated the cost to provide MNP to 34 million children 6–23 months of age,[17] assuming the cost of MNP distribution accounted for 50% of the overall costs. We found MNP distribution accounted for 43% of total costs in the most cost-efficient scaled-up scenario (and less in other scenarios), suggesting that costs other than MNP distribution might be underestimated with the World Bank assumptions.

Current investments in health meet only 1% of the total amount required to scale up evidence-based nutrition-specific interventions.[31] There is an urgent need to identify cost-efficient and effective interventions to reduce micronutrient deficiencies and fill funding gaps for nutritional interventions. Future studies could improve unit cost and cost-efficiency comparability across settings and between interventions to inform decision making. They could also test differing dosages of MNP because there is no agreed-to level of MNP consumption required for nutritional impact, and a higher number of sachets are now being proposed.[32] The dosage factor might affect estimates of cost-efficiency.[16]

Many LMICs have ongoing programs that distribute MNP to families with young children; most of these programs receive substantial financial and other support from the international community.[33] The same is true for most vitamin A supplementation programs in sub-Saharan Africa. If national governments are called upon to cover more of the costs of MNP programs, then hard choices may have to be made regarding the program's scale and geographic foci. One way to potentially improve cost-efficiency would be targeting—geographically or otherwise—MNP to children at the greatest risk of micronutrient deficiencies and/or selecting more cost-efficient delivery platforms and strengthening them to improve reach and adherence. However, such a strategy must be weighed against equity issues.[34]

Ultimately, MNP is just one of several interventions available to address micronutrient deficiencies among young children. The results of recent nutrition modeling research suggest that industrial food fortification, biofortification, and other interventions (individually and jointly) may be cost-efficient options for reducing the prevalence of vitamin A deficiencies in Cameroon, in some macroregions to below levels that would trigger public health concern.[35] Field-level confirmation of modeled results is needed. The challenge for the international community is to assemble data, refine tools, and develop political commitments to identify site-specific micronutrient deficiencies and to design cost-efficient combinations of national and subnational programs, perhaps including MNP programs, to address them.

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Author contributions

B.R., A.D., S.N., and S.V. contributed to the study design; W.S., B.R., A.D., S.V., E.B. and S.N. contributed to data analysis and interpretation; and W.S. wrote the manuscript with input and revisions from B.R., A.D., S.V., E.B. and S.N.

Supporting information

Additional supporting information may be found in the online version of this article.

Table S1. Sensitivity analysis calculations for pilot and integrated IP scale-up.

Competing interests

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References

1. World Health Organization. Malnutrition. Fact Sheet 2020. Accessed March 29, 2021. https://www.who.int/news-room/fact-sheets/detail/malnutrition.
2. Black, R.E., C.G. Victora, S.P. Walker, *et al.* 2013. Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet North Am. Ed.* **382:** 427–451.
3. Bhutta, Z.A., J.K. Das, A. Rizvi, *et al.* 2013. Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? *Lancet* **382:** 452–477.
4. Krebs, N.F., B. Lozoff & M.K. Georgieff. 2017. Neurodevelopment: the impact of nutrition and inflammation during infancy in low-resource settings. *Pediatrics* **139**(Suppl. 1): S50–S58.
5. Engle-Stone, R., G.J. Aaron, J. Huang, *et al.* 2017. Predictors of anemia in preschool children: Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia (BRINDA) project. *Am. J. Clin. Nutr.* **106**(Suppl 1): 402S–415S.
6. Kassebaum, N.J. 2016. The global burden of anemia. *Hematol. Oncol. Clin. North Am.* **30:** 247–308.
7. Jáuregui-Lobera, I. 2014. Iron deficiency and cognitive functions. *Neuropsychiatr. Dis. Treat*. **10:** 2087.
8. Larson, L.M., K.S. Phiri & S.-R. Pasricha. 2017. Iron and cognitive development: what is the evidence? *Ann. Nutr. Metab.* **71**(Suppl. 3): 25–38.
9. Kyu, H.H., C. Pinho, J.A. Wagner, *et al.* 2016. Global and National Burden of Diseases and Injuries among children and adolescents between 1990 and 2013: findings from the Global Burden of Disease 2013 Study. *JAMA Pediatr*. **170**(3): 267–287.
10. World Health Organization. Iron deficiency anaemia: assessment, prevention and control: a guide for programme managers. 2001.
11. Armstrong, A.L. 2009. Anemia in Central-Asia pre-school children: definition, risk factors and evaluation of home fortification intervention.
12. Horton, S. 2006. The economics of food fortification. *J. Nutr.* **136:** 1068–1071.
13. Olney, D.K., R. Rawat & M.T. Ruel. 2012. Identifying potential programs and platforms to deliver multiple micronutrient interventions. *J. Nutr.* **142:** 178S–185S.
14. Suchdev, P.S., M.E.D. Jefferds, E. Ota, *et al.* 2020. Home fortification of foods with multiple micronutrient powders for health and nutrition in children under two years of age. *Cochrane Database Syst. Rev*. **2**: CD008959.
15. Black, M.M., S. Fernandez-Rao, K.M. Nair, *et al.* 2021. A randomized multiple micronutrient powder point-of-use fortification trial implemented in Indian preschools

increases expressive language and reduces anemia and iron deficiency. *J. Nutr.* https://doi.org/10.1093/jn/nxab066
16. Reerink, I., S.M. Namaste, A. Poonawala, *et al.* 2017. Experiences and lessons learned for delivery of micronutrient powders interventions. *Matern. Child Nutr*. **13**. e12495.
17. Horton, S., M. Shekar, C. McDonald, *et al.* 2010. *Scaling Up Nutrition: What Will It Cost?* Washington, DC: World Bank.
18. Sharieff, W., S.E. Horton & S. Zlotkin. 2006. Economic gains of a home fortification program: evaluation of "Sprinkles" from the provider's perspective. *Can. J. Public Health* **97**: 20–23.
19. Ahmed, S., H. Sarma, Z. Hasan, *et al.* 2020. Cost-effectiveness of a market-based home fortification of food with micronutrient powder programme in Bangladesh. *Public Health Nutr.* **24**(S1): s59–s70.
20. Uganda Bureau of Statistics and ICF International. 2012. *Uganda Demographic and Health Survey 2011*. Kampala and Claverton: Uganda Bureau of Statistics and ICF International Inc.
21. Home Fortification Technical Advisory Group (HF-TAG). 2013. Manual on micronutrient powder (MNP) composition: guidelines and specifications for defining the micronutrient composition of single serve sachets for specified target. *Populations in Low- and Middle-Income Countries with High Prevalence of Anaemia and Micronutrient Deficiencies*. Geneva, Switzerland.
22. D'Agostino, A., F. Ssebiryo, H. Murphy, *et al.* 2019. Facility- and community-based delivery of micronutrient powders in Uganda: opening the black box of implementation using mixed methods. *Matern. Child Nutr*. **15**. e12798.
23. Richardson, B.E.B. 2017. Findings from SPRING's Micronutrient Powder (MNP) Distribution Program in Uganda. Accessed March 24, 2020. https://www.advancingnutrition.org/sites/default/files/2020-02/spring-cost-efficiency-mnp-dist-brief.pdf.
24. Tumilowicz, A., C.H. Schnefke, L.M. Neufeld & G.H. Pelto. 2017. Toward a better understanding of adherence to micronutrient powders: generating theories to guide program design and evaluation based on a review of published results. *Curr. Dev. Nutr*. **1**. e001123.
25. Batura, N., Z. Hill, H. Haghparast-Bidgoli, *et al.* 2015. Highlighting the evidence gap: how cost-effective are interventions to improve early childhood nutrition and development? *Health Policy Plan* **30:** 813–821.
26. Wang, X., R. Luo, C. Liu, *et al.* 2018. Using daily text messages to improve adherence to infant micronutrient powder (MNP) packets in rural Western China: a cluster-randomized controlled trial. *PLoS One* **13**. e0191549.
27. Samuel, A., I.D. Brouwer, N.P. Pamungkas, *et al.* 2020. Determinants of adherence to micronutrient powder use among young children in Ethiopia. *Matern. Child Nutr*. **17**: e13111.
28. Tumilowicz, A., J.P. Habicht, M.N. Mbuya, *et al.* 2019. Bottlenecks and predictors of coverage and adherence outcomes for a micronutrient powder program in Ethiopia. *Matern. Child Nutr*. **15**. e12807.
29. Brewer, J.D., M.P. Santos, K. Román, *et al.* 2020. Micronutrient powder use in Arequipa, Peru: barriers and enablers across multiple levels. *Matern. Child Nutr*. **16**. e12915.
30. Jefferds, M.E., K.R. Mirkovic, G.R. Subedi, *et al.* 2015. Predictors of micronutrient powder sachet coverage in Nepal. *Matern. Child Nutr*. **11**(Suppl. 4): 77–89.
31. Action Against Hunger/ACF International. 2012. Aid for nutrition can investments to scale up nutrition actions be adequately tracked.
32. World Health Organization. 2016. WHO guideline: use of multiple micronutrient powders for point-of-use fortification of foods consumed by infants and young children aged 6–23 months and children aged 2–12 years. World Health Organization.
33. UNICEF Supply Division. *Multiple micronutrient powder: supply and market update 2020*. Accessed April 4, 2021. https://www.unicef.org/supply/media/566/file/Multiple%20micronutrient%20powder%20(MNP)%20supply%20and%20market%20outlook.pdfx.
34. Mulligan, J.-A., J.A. Fox-Rushby, T. Adam, *et al.* 2003. *Unit Costs of Health Care Inputs in Low and Middle Income Regions*. Washington, DC: World Bank.
35. Vosti, S.A., J. Kagin, R. Engle-Stone, *et al.* 2020. Strategies to achieve adequate vitamin A intake for young children: options for Cameroon. *Ann. N.Y. Acad. Sci.* **1465:** 161.
36. Richardson, B.E.B. 2017. *Cost and Cost-Effectiveness of Micronutrient Powder Distribution Pilot, Namutumba District, Uganda*. Arlington, VA: SPRING.