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ABSTRACT

Biofortification, breeding staple food crops to be dense sources of essential micronutrients, is fast emerging as a strategy to fight micronutrient malnutrition. Large-scale biofortification investments are being made in several developing countries, but until recently little rigorous evidence about the impact of these investments has been available. In this paper, we report findings from randomized impact evaluations conducted in both Mozambique and Uganda to study the impact of large-scale pilot projects conducted between 2006 and 2009 to introduce provitamin A–rich orange-fleshed sweet potato (OFSP) as a strategy to reduce vitamin A deficiency. In both countries, projects randomly assigned interventions of different cost and intensity to distribute OFSP vines, train households to grow OFSP, and disseminate the health benefits of vitamin A. We compare the impact of the interventions within and across the two countries on OFSP adoption, knowledge about vitamin A, and dietary intake of vitamin A by children, and use causal mediation analysis (Imai et al. 2011) to examine the impact pathways on vitamin A consumption. After two years of intervention, in both countries the project led to OFSP adoption rates of 61–68 percent among project households, improved household knowledge about vitamin A, and nearly doubled average dietary intake of vitamin A, with no difference between the more and less intense intervention models. Evidence suggests that vine access played the most important role in explaining the impact on vitamin A consumption in both countries. Consequently, future programs can be designed to have similar impacts at even lower costs.

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CONTENTS

1. MOTIVATION

Micronutrient malnutrition continues to be a major health problem affecting developing countries, and Africa south of the Sahara in particular. It is responsible for a significant share of infant mortality (Bryce et al. 2003) and hinders human capital development (Alderman, Hoddinott, and Kinsey 2006). Vitamin A deficiency is one of the leading forms of micronutrient malnutrition and is an important cause of morbidity, impaired night vision, and, in more severe manifestations, blindness and increased mortality in young children. It affects nearly 127 million preschool-aged children worldwide and accounts for 6 percent of all deaths among children younger than five years of age (Beaton, Martorell, and Aronson 1993; Black et al. 2008; Fawzi et al. 1994; Villamor and Fawzi 2000; West 2002). Aguayo and Baker (2005) argue that ". . . effective and sustained control of vitamin A deficiency has the potential to be among the most cost-effective and high-impact child-survival interventions in Sub-Saharan Africa." In Mozambique and Uganda, the countries that are the focus of this study, 69 percent and 28 percent of preschool children are vitamin A deficient, respectively (Aguayo and Baker 2005; UBOS/ORC Macro 2001). Vitamin A deficiency disorders also affect adult women by increasing morbidity and mortality during pregnancy (Christian et al. 2000; West et al. 1999).

The leading strategies for alleviating vitamin A deficiency include supplementation and fortification. These approaches require annual campaigns to be effective, and coverage rates vary substantially across countries (UNICEF 2007). An alternative and possibly complementary approach is biofortification, which seeks to reduce micronutrient deficiencies by breeding staple crops to have improved micronutrient content so that poor consumers can substitute for staples low in nutrients with nutrient-dense varieties of the same or similar crops (Bouis 2002).

As a policy tool, biofortification has several advantages. First, staples are consumed daily and constitute a large proportion of diets of poor households, making biofortification pro-poor. Second, once the biofortified variety has been developed and widely adopted, with good access to planting material, the crop can be grown and consumed for years to come at minimal cost. Third, it has the potential to reach vulnerable populations in remote areas that do not have access to commercially marketed fortified foods. Finally, biofortified varieties are selected for their high yields prior to release.

In this paper, we examine outcomes of the dissemination of provitamin A–rich orange-fleshed sweet potato (OFSP) in Mozambique and Uganda through the HarvestPlus Reaching End Users (REU) project[1], which had the overall goal of increasing vitamin A intakes among children younger than five years old and women of childbearing age. To meet this goal, the REU conducted an integrated program to both improve knowledge of the benefits of vitamin A and encourage the adoption and consumption of OFSP by household members, particularly women and children. A unique feature of the REU is that it ran very similar programs in both countries with broadly common features: (1) a seed systems component, which included vine distribution and agricultural extension; (2) a demand-creation component, which worked through nutrition trainings; and (3) trainings in marketing and product development. The selected regions were areas where white- or yellow-fleshed sweet potato is either the primary staple crop (Uganda) or an important secondary staple (Mozambique).

A second important aspect of the REU is that it incorporated a rigorous, randomized impact evaluation, with baseline and endline surveys in both countries. The baseline and endline surveys were composed of two components: a socioeconomic survey that measured adoption and nutrition knowledge and a nutrition and 24-hour recall dietary intake survey that measured intakes of vitamin A (and other nutrients) among the target groups. The surveys were also coordinated across countries to include measures of many of the same household characteristics and outcomes. To identify impacts, sampled farmer groups or community organizations were randomly assigned into two treatment groups, one more intensive (Model 1) and the other less intensive (Model 2), and a control group[2].

The impact evaluation is unique in several ways. First, it compares key outcomes from very similar interventions implemented simultaneously in two very different countries, therefore speaking to external validity[3]. Second, it takes advantage of the recent literature on causal mechanism

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[1] The HarvestPlus-supported OFSP varieties in both countries are dense sources of beta-carotene, bred locally, and have good agronomic properties.

[2] There were two important differences between the implementation strategies in Mozambique and Uganda. First, the vine distribution policy differed; in Mozambique distributions took place annually, while one distribution took place in Uganda. Second, the extension strategy differed somewhat; in Mozambique, the project used a pair of extensionists in each zone (agriculture and demand creation), whereas based on the higher education levels in Uganda, it was decided to use one extensionist for agriculture, demand creation, and marketing. We consider these differences in our analysis.

[3] Hotz, Loechl, de Brauw, et al. (2012) and Hotz, Loechl, Lubowa, et al. (2012) find that the REU both increased vitamin A intakes and reduced the prevalence of inadequate dietary vitamin A intakes among mothers of childbearing age and children younger than three years old in Mozambique and Uganda.

analysis to try to uncover the key pathways that lead to improved nutritional outcomes. Third, the paper quantifies and compares the cost-effectiveness of two alternative implementation strategies for biofortification. The primary outcome variables are vitamin A intakes by children (and women) and adoption of OFSP; we use indicators of nutrition knowledge gains as secondary impact indicators.

The objectives of this paper are fourfold. First, we compare impacts on nutritional knowledge, crop adoption, and vitamin A intakes between groups of reference children in the two countries. Second, we simultaneously compare the impacts of the two models on the same measures. For the biofortification strategy to succeed it is important to understand whether improvements in vitamin A consumption by children derived primarily from access to the new crop technology and successful adoption or whether information about the health benefits of the crop played a substantial role. Therefore, as the third objective, we quantify the contribution of nutrition knowledge to crop adoption, and of both crop adoption and nutrition knowledge to the impacts on child diets, using causal mechanism analysis (Imai et al. 2011).[4] Finally, we compare costs of the two intervention models and draw implications for the design of cost-effective scaled-up interventions to disseminate OFSP. These results are relevant to the growing literature on constraints to adoption of worthwhile agricultural technologies as well as the role of information in nutrition interventions.

The paper meets its objectives as follows. In the next section, we describe the REU in more detail, including the way it builds upon previous interventions that disseminated OFSP. Section 3 describes the experimental design in more detail, and section 4 lays out the conceptual framework and estimation strategy. Section 5 provides the main impact results and draws out causal mechanisms. Section 6 describes implications of the results both in general and for cost-effectiveness of projects that disseminate OFSP specifically, and biofortified products in general. The final section summarizes our findings.

2. BACKGROUND

Sweet potato is a primary or secondary staple food crop in a number of countries in Africa south of the Sahara. OFSPs that are rich in beta-carotene are excellent sources of provitamin A. In an early efficacy study conducted in South Africa, van Jaarsveld et al. (2005) show that OFSP consumption can improve vitamin A status, and therefore can play a significant role in food-based strategies to overcome vitamin A deficiencies in developing countries. Other studies have shown that OFSP is broadly acceptable to cultivating farmers in both Uganda and Mozambique (Tumwegamire et al. 2007; Masumba et al. 2007). Willingness-to-pay studies demonstrate that consumers like OFSP as much as the traditional white varieties, and when informed about the nutritional value of consuming OFSP, they are willing to pay higher prices, with larger premiums for deeper orange OFSP (Naico and Lusk 2010; Chowdhury et al. 2011).

Prior to the REU, two previous projects introduced OFSP at the farm level. Hagenimana et al. (2001) describe a project that occurred among 10 women's groups in two districts in Kenya between 1995 and 1997. The project was characterized by very high levels of extension supervision—12 monthly visits over the year—and found that the frequency of consumption of vitamin A-rich foods among children aged under 5 increased. A second two-year quasi-experimental project, Towards Sustainable Nutrition Improvement (TSNI), worked to increase intakes of vitamin A and energy among young children through OFSP (Low et al. 2005). Low et al. (2007) show that adoption rates were quite high, with 90 percent of the treatment households producing OFSP in the second year, that OFSP was the major source of vitamin A among treated children, median vitamin A intakes were higher among this group compared to children in the control households, and that there was a substantial reduction in vitamin A deficiency.[5] However, due to small farmer groups and intensive messaging, TSNI was quite expensive on a per beneficiary basis. Given their intensity, scaling up either project would be quite difficult.

Although an ex ante assessment (Meenakshi et al. 2007) suggests that biofortification is highly cost-effective, there is very little other evidence on the ex post cost-effectiveness of OFSP dissemination (Low et al. 2009). The REU was therefore explicitly designed to compare outcomes and costs across different intervention strategies that varied in timing and intensity.

2.1 The REU Project Implementation

The REU project was designed to integrate production, consumption, and exchange of OFSP. These three components were implemented in both countries using two models (Model 1 and Model 2), which differed primarily in timing and intensity of activities, and therefore in average and marginal costs per beneficiary. In the

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[4] The REU's marketing component is not considered a potential contributor to impacts on vitamin A intakes in this paper, as the project report found it did not correlate strongly with increased vitamin A intakes (de Brauw et al. 2010).

[5] TSNI used a control group in a different district than implementation, and results described are based on differences-in-differences estimation. Therefore the results are susceptible to the criticism that treatment groups may be unobservably different than the control group.

first year, the two models were identical in agricultural extension and nutrition education activities, rather than testing the efficacy of dropping certain components of the intervention[6]. The project decided to keep treatments the same in year one because the initial high level of activity was considered necessary for crop adoption and acceptance. Differences between the two models occurred in the second year. In Model 1, the high intensity of extension visits and nutrition messages was maintained in year two. In Model 2, the activities in agriculture and nutrition were scaled back substantially in the second year to provide cost savings.

2.1.1 Seed Systems (Production)

For the seed systems and extension (production) component, the project grew large quantities of OFSP vines for dissemination, distributed multiple varieties of vines to project farmers, and taught farmers growing techniques. A hierarchical management structure was designed in which extensionists working for NGOs hired by the REU project would train selected volunteer extension promoters from among farmer group or community group members. These promoters then assisted in vine distribution and trained group members on how to grow OFSP and maintain the vines between seasons. Farmers therefore had the opportunity to try different varieties and determine which ones they preferred to grow and consume.

2.1.2 Demand Creation (Consumption)

The demand-creation component used multiple strategies to train and inform people about the nutritional benefits of consuming OFSP and other vitamin A sources. Information was conveyed through group trainings with farmer group members, community theater sessions related to the health benefits of OFSP, radio spots, billboards, and other advertising. Nutrition extension had a similar structure to the seed systems component. Communication tools were developed and nutrition promoters were selected from among farmer group or community group members and were trained to deliver nutrition-related messages to their farmer group members.

3. THE REU EVALUATION

The impact evaluation was designed as a cluster randomized-controlled prospective evaluation with three intervention arms, comparing two treatments and a control group. In both countries, farmer groups were first stratified by district and then randomly selected into one of two treatment groups (Model 1 or Model 2) or a control group. The baseline survey captures pre-program outcome measures and also control variables in case the contexts differ across intervention arms. The endline survey measures changes in outcomes over time and captures exogenous economic shocks the household has experienced since the baseline[7]. Heckman and Smith (2004) and Heckman, Ichimura, and Todd (1997) show that randomly assigning access to an intervention eliminates selection bias and, in the absence of significant sampling error, it is possible to identify causal impacts of the intervention. Households in the control groups received no intervention for the entire study duration, although they may have been exposed to the media messages, particularly by radio.[8]

3.1 Sample Design

The sample size was based on separate power calculations for the primary outcomes for each of the two countries. In Mozambique, the sample size was based on vitamin A intakes. In Uganda, blood samples were collected for serum retinol for Model 1 households, and vitamin A intakes based on the dietary intake survey were computed for Model 2 households. These outcomes then formed the basis of the sample size determination. The impact of OFSP on serum vitamin A status is addressed elsewhere (Hotz, Loechl, Lubowa, et al. 2012).[9] In both countries, based on the calculated necessary sample sizes, the goal was to interview exactly the same set of households and reference children in the baseline and endline surveys.[10]

3.1.1 Mozambique

The Mozambique sample is composed of 36 community organizations, each in a separate village, from four districts of Zambézia province: 18 of the organizations are located in Milange, 9 in Gurué, and the remaining 9 organizations are split between Nicoadala (5 organizations) and Mopeia

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[6] For example, one option would have been to focus on production in a subset of project areas, dropping the nutrition education component of the intervention. We return to this concept in the empirical work.

[7] In the impact analysis, all households that farmer group members randomly assigned to receive an intervention are considered part of the treatment group even if they decided not to participate. Therefore, impacts can be interpreted as "intent-to-treat" estimates, eliminating potential bias from the household participation decision.

[8] At the end of the study period, control farmer groups were given OFSP vines. The use of a control group is justified in this setting because the long-term net benefits and cost-effectiveness of introducing OFSP in this way are not known, so that it is not clear ex ante whether intervention households will derive a benefit from the interventions, particularly after accounting for their participation cost.

[9] Dietary intake data we also collected on a repeated cross-section of children younger than 36 months in both countries, and on mothers of the reference children. See Hotz, Loechl, de Brauw, et al. (2012) for those results in Mozambique and Hotz, Loechl, Lubowa, et al. (2012) for results in Uganda.

[10] In Mozambique, the study design passed the Internal Review Board for the Ministry of Health. In Uganda, the ethical review boards of the Makerere University Medical School and the Uganda National Council of Science and Technology approved the study.

Table 1. Sample sizes, REU, Mozambique and Uganda, by Baseline/Endline, Group, and Type of Survey

	Household Socioeconomic Survey	Reference Children	Children Aged 6–35 Months
Mozambique			
Baseline	703	441	376
Endline	628	409	173
Uganda			
Baseline	1,176	545	266
Endline	1,116	481	273

Notes: Reference children were chosen to be between the ages of 6 and 35 months in Mozambique and between 3 and 5 years in Uganda. Some children in Mozambique chosen as reference children were older than 35 months; hence the discrepancy between columns 2 and 3.

districts (4 organizations).[11] Power calculations indicated that 12 households per community organization be included in the nutrition survey; given additional returns to collecting socioeconomic data and adoption data indicated by power calculations, the goal was to conduct the socioeconomic survey in 20 households per community organization.

Communities initially selected had to meet four salient requirements: First, they had to have enough families with resident children between the ages of 6 and 35 months at baseline to be able to meet sample size requirements; second, they had to have reasonably high access to lowlands so that vines could be kept between growing seasons; third, other agricultural interventions were not active in selected communities, and selected communities had not been previously targeted for an OFSP project; and fourth, the selected communities could not be adjacent to one another, to limit contamination and jealousy between communities.[12] The 36 villages included in the sample were then randomly selected into one of the two treatment arms or the control group, stratified by district.[13]

A total of 703 households were included in the socioeconomic survey baseline sample (Table 1). In all 36 villages, the teams did 24-hour recalls in 12 households as planned at baseline; the resulting sample was 441 children (column 2). In the endline survey conducted in 2009, 628 households were resurveyed in the socioeconomic survey, whereas 409 of the reference children were found and interviewed in the dietary intake survey. Because attrition was found not to be random, it did not affect impact measurements (de Brauw et al. 2010).

3.1.2 Uganda

The Uganda sample includes 84 farmer groups from three districts: Kamuli, Bukedea, and Mukono. These districts were selected for the REU project because white- and yellow-fleshed sweet potatoes are commonly grown and consumed there, and they are relatively close to potential markets for OFSP. Farmer groups were sampled from a list of active farmer groups in each district obtained from nongovernmental organization (NGO) implementing partners based on consultation with local leaders. Within district strata, farmer groups were randomly assigned into one of two treatment arms (Model 1 and Model 2) or the control group, in proportions 12:4:12. The sample is unbalanced, with fewer farmer groups in Model 2, because it was determined that the large samples required for biochemical assessment were too costly to include in all three intervention arms. The resulting sample includes 36 farmer groups in Model 1, 12 in Model 2, and 36 in the control group.

In contrast to Mozambique, in Uganda reference children were defined as children aged 3 to 5 years of age (36 to 71 months), so that nearly all of these children would age out of the Ugandan government's vitamin A supplementation program a few months before the endline survey. Power calculations suggested that 14 households per cluster in

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[11] Organizations in Nicoadala and Mopeia were selected from a single stratum (the "South").

[12] To implement the REU in Mozambique, farmer groups or community organizations had to be formed by project staff, often from church groups. Before the fieldwork occurred in all communities, staff informed the leaders of that village about the survey and compiled a list of households that were members of the primary community organization that would be used as the organization for the intervention. From that list of households, 25 households with children younger than three years old were randomly selected from the list of community groups, where 5 were meant as replacement households; in general, the enumeration staff found that the community lists did not always accurately indicate households with children younger than three years old.

[13] Randomization took place at a project meeting in Mozambique by selecting papers with village names on them from an urn.

Model 1 and control farmer groups would be needed to detect the minimum effect size desired for serum retinol measured blood samples, so the target sample size per farmer group was 14 households. For the purposes of this paper, then, the baseline sample is 1,176 households that were farmer group members at baseline.[14]

Dietary intakes were collected in households in all farmer groups, but the sampling of reference children for the dietary intake interviews was unbalanced in order to account for the smaller number of clusters in Model 2. In Model 1 and control clusters, eight reference children aged 3 to 5 years were randomly selected from sample farmer group member households, while in Model 2 clusters, 14 reference children were selected for the dietary intake interviews. This created a total of 545 reference children in the baseline.

3.2 Survey Content

3.2.1 Socioeconomic Survey

In both countries, baseline socioeconomic surveys were conducted (in 2006 in Mozambique and in 2007 in Uganda) to elicit information about household demographics and human capital, primary employment, landholdings, production of grains and legumes, detailed production information on sweet potatoes and growing practices, details on OFSP adoption, agricultural input use, sources of information and social networks, food and nonfood consumption and expenditures, food consumed away from home and consumption habits, assets and information about the house, livestock, and shocks. We further asked both the mother and the father of the reference child about their knowledge of child feeding practices, vitamin A and its sources, and the sources of news and information they use. Baseline questionnaires in each country were similar, but modified for relevance to the local context.

The endline surveys conducted in 2009 in both countries largely followed the structure of the baseline surveys, but there were some important differences. The surveys included redesigned modules related to sweet potato production and consumption to learn specific details about the experience households had in growing OFSP. We asked about production since the project began; due to concerns regarding potential recall bias, we asked a more detailed set of questions about the previous 12 months and more limited questions about prior seasons. The endline gathered information on household participation in the REU project, their experience with OFSP adoption and production, and an expanded social networks module. At endline, survey teams made several efforts to contact each household included in the baseline survey.

3.2.2 Nutrition Survey

In both countries, baseline nutrition surveys took place alongside the socioeconomic surveys. In the endline, the nutrition surveys took place in advance of the endline socioeconomic survey so that households would still be growing and consuming OFSP. As with the socioeconomic survey, the endline survey had to identify the correct reference child in each of the panel households.

The most intensive component of the nutrition survey was the dietary intake module, which was designed to capture detailed data on the quantity and composition of all food consumed in the 24-hour period ending on the morning of the interview for targeted individual household members.[15] The dietary intake survey used a quantitative 24-hour recall methodology adapted from an interactive, multiple-pass method developed previously for use in Malawi (Gibson and Ferguson 1999). Standard recipe data were also collected, in advance, from women in communities following the methods of Gibson and Ferguson (2008) to minimize the respondent burden in recalling recipes.

The dietary intake data were used to estimate each individual's consumption of food energy, vitamin A, protein, and other micronutrients in a 24-hour period using the following procedure. A table of conversion factors was compiled from local sources, where possible, to convert food volumes or sizes to weights representative of the food state as consumed. Weights were then converted into energy and nutrient intakes using a food composition table compiled for this project, specific to each country.[16] One complication is that different varieties of OFSP have different beta-carotene content, and in both countries the

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[14] The survey also included five households per farmer group that were neighbors, explicitly to learn about the diffusion of OFSP vines at endline.

[15] See Arimond et al. (2009) for a detailed description of field procedures followed during the dietary intake component of the study. Several other data collection components were also completed during the nutrition survey: anthropometric measures of children and mothers in the dietary intake study and all other panel households were taken when possible; modules on morbidity and young child feeding practices were collected among the households included in the dietary intake study plus four additional households included in the socioeconomic survey; and a food frequency questionnaire was also administered among children.

[16] Where not possible from local sources, weights were derived from the USDA Nutrient Database (USDA Agricultural Research Service 2006). The USDA Nutrient Database was the primary source for conversion factors due to completeness and high-quality analytic and sampling standards. Where nutrient content of raw foods was converted to cooked forms, appropriate water content changes and nutrient retention factors were applied (USDA Agricultural Research Service 2003).

composition of varieties differed. To measure the average beta-carotene content of OFSP being grown in specific districts in each country, we had samples of each OFSP variety analyzed for beta-carotene content. We then used project data to estimate the proportion of each variety being grown by district in each country and the yield per plant (in kilograms), to weight the variety-specific beta-carotene and estimate average vitamin A content.

4. CONCEPTUAL FRAMEWORK & ESTIMATION STRATEGY

Although the primary goal of the REU is to reduce vitamin A deficiency through increased OFSP consumption, the mechanisms by which OFSP can affect the prevalence of vitamin A deficiency can be fairly complex. Farmers must first learn about and decide to grow the new OFSP varieties, initially through interaction with promoters linked to the agricultural extension program. Other members of the community may later gain access to OFSP, by purchasing vines or receiving them as gifts from other households, or by consuming OFSP obtained in the market or as gifts. Once the OFSP roots are available from fields or markets, households must decide how much OFSP to consume, who will consume it, and in what form. The nutrition promotion activities should affect these behaviors and increase demand for OFSP and other sources of vitamin A. The nutrition trainings also teach households how to store and prepare the crop to maintain high levels of beta-carotene in consumption.

The conceptual framework for analyzing how the introduction of OFSP could affect vitamin A intakes derives from the class of agricultural household models (e.g., Singh, Squire, and Strauss 1986) that can be extended to include intra-household allocation issues. (e.g., Chiappori et al. 1993). Consider a household's decision about the consumption of a specific good, *i*. Assuming that functions are well-behaved, according to the agricultural household model, the consumption, *C*, of good *i* will be

$$C_i = f\left(\mathbf{PA}, \mathbf{PB}, M + E\left(\sum_{j=1}^{N} \pi_j^*(\mathbf{PA}, \mathbf{PB} \mid \mathbf{Z}, \mathbf{X})\right) \middle| \gamma, \mathbf{X}\right), \qquad (1)$$

where **pA** and **pB** represent vectors of prices of goods in sets *A* and *B*, respectively; *M* represents exogenous household income outside of farming; **Z** represents household endowments; **X** represents the information set available to the household; and γ represents the households idiosyncratic preferences. Finally, *j* references the *N* crops that the household might grow, and π_j^* represents the expected profits of growing crop *j*, given household endowments and information. The crops are a subset of all goods consumed by the household, so prices in these sets can also affect profits. If markets are complete, then the production and consumption decisions are separable (e.g., Benjamin 1992). In other words, one can assume that the household initially maximizes profits, and then decides upon consumption based on prices and income; household endowments do not affect the household's consumption decision.

Now, consider that the goods in set *B* lack markets. The resulting consumption level of good *i* is

$$C_i' = f\left(\mathbf{PA}, \mathbf{PB}, M + E\left(\sum_{j=1}^{N} \pi_j^*(\mathbf{PA}, \mathbf{PB} \mid \mathbf{Z}, \mathbf{X})\right) \middle| \gamma, \mathbf{X}\right). \qquad (2)$$

Missing markets can occur for inputs, such as land, labor, credit, or outputs, such as specific crops. There are several implications of missing markets. First, decisions about what crops to grow may now be influenced by household consumer preferences. If the household prefers to consume a crop that is not marketed, then the household must produce that crop. Second, household endowments may now play a role in consumption decisions.

Within this framework, consider the introduction of a new crop such as OFSP. Seasonal markets for sweet potatoes exist in both countries, but prior to the project, markets for OFSP were largely nonexistent. Therefore, the model considering missing markets in Equation 2 is more appropriate than the model of demand in Equation 1 in which markets for all goods exist. The introduction of the new crop can largely be thought of as a change in the household information set, from $\mathbf{X}_0$ to $\mathbf{X}_1$.[17] The information set may continue to increase as well throughout the life of the project, as biofortified varieties are agronomically superior to white or yellow varieties, and farmers may learn about these traits as they experience higher yields with OFSP than they had with white or yellow sweet potatoes; alternatively, nutrition messages about the crop may also resonate further as the project continues.

An increase in available information related to OFSP may therefore influence adoption and consumption decisions. The information works through two channels. First, given that the information relates to growing OFSP and its health benefits, the information should unambiguously lead to more consumption of OFSP. However, if markets do not develop, households must adopt OFSP as a crop to increase their consumption. If households already grow other types of sweet potato, then they must switch part or all of the area under sweet potato cultivation to OFSP to meet desired consumption of OFSP; they may also bring additional area under the cultivation of sweet potato by growing OFSP on newly acquired land or substituting for other crops. If households adopt OFSP, note that there could be positive

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[17] At least in the first year of the project, when planting material is distributed in project villages, the price of OFSP vines simultaneously falls from ∞ to 0.

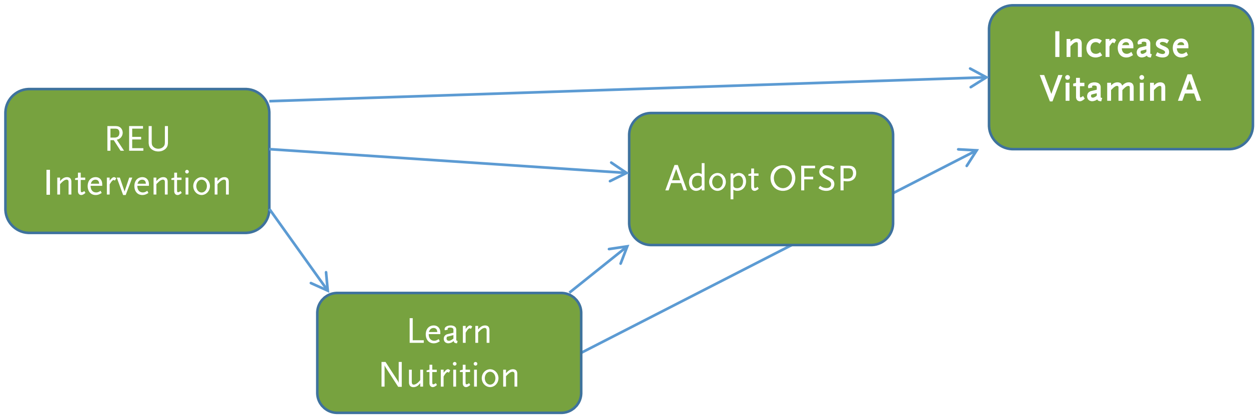

Figure 1. Schematic Representation of Potential Mechanisms to Improve Vitamin A Consumption Among Targeted Children in REU Intervention, Mozambique and Uganda

or negative effects on full income; the decision to adopt may also be influenced by latent household preferences for OFSP over other foods. The consumption decision may, therefore, be enhanced or dampened by the income effect. Furthermore, augmented availability of OFSP within the household does not necessarily translate to enhanced consumption among children and women, even though the REU specifically targeted messages about OFSP to these groups. Although estimation of a formal model of agricultural household decision making, including allocation among family members, is beyond the scope of this paper, the organizing model provides the basis for the choice of outcome and mediation variables.

The primary mechanisms by which the REU can affect consumption are outlined in Figure 1. The intervention may have affected information about the nutritional content of OFSP, or vitamin A in general, which could in turn affect adoption decisions. Second, the increased information on nutritional content might affect OFSP consumption by young children directly, hypothetically either through market purchases or by targeting young children as consumers of OFSP within the household. An alternative mechanism for increased consumption of OFSP is through adoption; farmers simply adopt OFSP and then consume it. We also measure a direct effect of the intervention on consumption, which could occur either because the project affected production or consumption for reasons not explicitly modeled; or the proxy variables we use in estimation do not fully reflect project effects.

For each outcome, the impacts of Model 1 and Model 2 on an outcome Yi1 among household or child i at the endline (period 1) can be estimated as:

$$Y_{i1} = \alpha + \beta_1 T_{1i} + \beta_2 T_{2i} + \gamma X_i + \psi Y_{i0} + \varepsilon_i, \qquad (3)$$

where T_1 represents an indicator variable for households in Model 1 farmer groups, T_2 is an indicator variable for households in Model 2 farmer groups, X_i is a vector of baseline household characteristics, Y_{i0} is the baseline outcome, which is available for nutrition knowledge and vitamin A consumption outcomes, and ε_i is a mean zero error term. Equation 3 is a more flexible functional form than the difference-in-differences estimator and is identical to the difference-in-differences estimator if γ is restricted to 1. Since X_i and Y_{i0} are both theoretically orthogonal to the treatment variable, it should be possible to omit them from models with no consequences for the point estimate of β. However, these variables may also explain some of the variation in the endline outcome Y_{i1}, hence reducing the overall variance of the estimator. As a result, this form of the treatment model has more power than the difference-in-differences estimator when autocorrelation in the outcome variable exists (McKenzie 2011).

The coefficients β_1 and β_2 represent the average intent-to-treat effect on Model 1 and Model 2 households or individuals, respectively. In addition to testing whether the intent-to-treat effect is larger than zero for each group, we can use Equation 3 to test the null hypothesis that $\beta_1 = \beta_2$, which implies that the impacts of Model 1 and Model 2 were no different. If impacts are no different, we can instead estimate a simplified model:

$$Y_{i1} = \alpha + \beta T_i + \gamma X_i + \psi Y_{i0} + \varepsilon_i \qquad (4)$$

where T now indicates a treatment indicator variable. In estimation, we find very few significant differences between impacts among Model 1 and Model 2 farmers, so we conduct the causal mediation analysis using Equation 4 as the primary regression.

4.1 Measuring Outcomes

Following the conceptual model outlined in Figure 1, we choose variables that measure the impacts of nutritional extension (N_i) that logically might lead to adoption (A_i) or consumption (C_i). We therefore measure the impacts of nutritional extension using two variables: the number of facts about vitamin A promoted by the REU that mothers could recite, and conditional on knowing about vitamin A, whether mothers named OFSP as a vitamin A source when asked an open-ended question regarding vitamin A food sources.

We primarily measure adoption as an indicator variable, defined as whether or not farmers kept vines for the following season (Mozambique) or if farmers were growing OFSP at the time of the final survey (Uganda); and the intensity of adoption, by the share of OFSP in the total sweet potato area farmed by the household.[18] The drawback to this variable is that it is undefined for households that do not grow sweet potatoes; yet for those that do grow sweet potatoes, it measures the commitment to OFSP quite well.[19] Finally, we measure consumption using the unadjusted vitamin A intakes (C_i) directly, calculated from the dietary intake studies (Hotz, Loechl, de Brauw, et al. 2012; Hotz, Loechl, Lubowa, et al. 2012).

4.2 Causal Mediation Analysis

We are interested in understanding the contribution of additional nutritional knowledge to adoption, and the contribution of additional nutritional knowledge and adoption to increased vitamin A consumption among children (Figure 1). Because the treatment assignment was randomized, the average treatment effect is identified, but we are also interested in the average causal mediation effect, or the average effect of the treatment that occurs through a mediating variable. Consider that the outcome of interest Y_i for individual i is a function of both the treatment and some mediating variable, $M_i(T_i)$, which is itself affected by the treatment. Following Imai et al. (2011), the causal mediating effect is written as

$$\delta_i(t) \equiv Y_i\,(t, M_i(1)) - Y_i\,(t, M_i(0)) \tag{5}$$

for each treatment status $t = 0, 1$. The quantity $\delta_i(t)$ represents the change in the outcome Y that corresponds to the change in the mediator variable from the control to the treatment condition, while holding the effect of the treatment otherwise constant. Clearly, for observations receiving the treatment, $M_i(0)$ cannot be observed, so this quantity must be estimated.

The direct effect $\zeta_i(t)$ of the treatment is what remains after the indirect effect is estimated, and can be written as

$$\zeta_i(t) \equiv Y_i\,(1, M_i(t)) - Y_i\,(0, M_i(t)) \tag{6}$$

for each treatment status $t = 0, 1$. Averaging across all individuals i, the average causal mediation effect (ACME) is $\bar{\delta}(t)$ and the average direct effect (ADE) is $\bar{\zeta}(t)$. The average treatment effect $\bar{\beta}$ is equal to the sum of the ACME and the ADE, $\bar{\beta} = \bar{\delta}\,(t) + \bar{\zeta}(t)$.

To estimate the ACME and the ADE, we must make a further assumption, that Imai et al. (2010) call the sequential ignorability assumption. First, we assume that given the baseline characteristics, assignment to the treatment is independent of outcomes and mediator variables:

$$\{Y_i(t,m), M_i(t)\} \perp T_i|X_i = x. \tag{7}$$

Equation 8 should hold due to the randomization of the treatment. Second, the sequential ignorability assumption states that

$$Y_i(t,m) \perp M_i(t)|T_i = t, X_i = x. \tag{8}$$

Equation 9 implies that once we control for actual treatment status and observed baseline characteristics, there are no unobservables that confound the relationship between the outcome and the mediator variable. The assumption is clearly quite strong. If any unobservable affects both the mediating variable and the outcome, then estimates of the ACME are likely to be biased. Imai et al. (2010) demonstrate that no further distributional or functional form assumptions must be made to identify the ACME and ADE if the assumption in Equation 8 holds. Therefore, in exchange for making a strong assumption about the relationship between the outcome and the mediator, we can estimate the ACME and the ADE with few additional assumptions. Further, we can test the robustness of our estimates to unobservables that might be correlated with both the mediator and the outcome.

After making the sequential ignorability assumption, an initial way of estimating the ACME is to assume a linear relationship and estimate:

$$Y_i = \alpha + \kappa T_i + \xi M_i + \gamma X_i + \psi Y_{i0} + u_i. \tag{9}$$

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[18] Given that the project distributed vines to farmers in the last year of the REU in Mozambique, we deemed whether or not farmers kept vines as a better indicator of adoption. Follow-up fieldwork conducted by the International Potato Center (CIP) in 2010 indicated that this variable reliably estimated adoption at the community level

[19] Both of the adoption variables are measured at endline only, implying $A_{i0} = 0 \; \forall \; i$.

The ACME can be calculated using M_i as the dependent variable in Equation 4; it is $\hat{\beta}\hat{\xi}$ where β is the effect of the treatment on the mediator and ξ is the effect of the mediator on the outcome. Sequential ignorability implies zero correlation between the error terms ε_i and u_i; however, a finding of no correlation does not necessarily imply that sequential ignorability holds.

Imai et al. (2011) propose a nonparametric estimator for equations 6 and 7, which relaxes the linearity assumption in Equation 9. They estimate the ACME by estimating regression models as above, then predicting the treatment effect using the value of the mediator variable predicted in the treatment condition, then the control condition, and averaging over those for all values. In estimating regression models predicting the mediator and the outcome of interest, the linearity assumption above can be relaxed; for example, a logit or a probit model can be used to estimate a binary outcome.[20]

Imai et al. (2010) further propose a method of testing the sensitivity of the ACME estimate to the sequential ignorability assumption. Define $\rho = \varepsilon_i u_i$, or the correlation between the two error terms. If $\rho \neq 0$, it implies that a confounding variable (or a set of confounding variables) exists that biases the ACME estimate. Larger values of ρ, in absolute value terms, imply larger bias in the estimate of the ACME. Imai et al. (2010) note that it is possible to demonstrate how much a potentially omitted variable might affect the relationship between the outcome and the mediator through the goodness of fit (R^2). If an unobserved variable, such as the predisposition to participate in programs, was unobserved and was quite important, it would change the goodness of fit in both models. On the other hand, if it does not matter much, it would slightly change the R^2 in both models. Therefore, the relative change in R^2 between the two models can be used as a sensitivity check, simulating over many possible changes in the goodness of fit. We incorporate sensitivity checks into our analysis, in case a confounding variable exists that violates the sequential ignorability assumption and might affect our estimates of the contributions of nutritional knowledge variables to OFSP adoption, or of nutritional knowledge or adoption to vitamin A intakes among children.

5. RESULTS

In this section, we initially present estimates of the impact of the REU on nutritional knowledge indicators, adoption behavior, and vitamin A consumption among children. We then present estimates for adoption behavior using causal mediation analysis to ascertain how much of the adoption behavior can be explained through the knowledge of messages regarding health benefits of vitamin A, including sensitivity analysis. We finally present estimates for vitamin A intakes using causal mediation analysis to understand how much of those results can be explained through either nutritional knowledge or adoption behavior.

5.1 Main Impact Estimates

Table 2 presents descriptive statistics at baseline for Model 1, Model 2, and control households. Although there are some discrepancies between averages for some statistics between groups, in most cases they are not statistically significant.[21] Where they are significant, controlling for these observable characteristics in regressions may slightly affect impact estimates.

Table 3 compares baseline and endline values for several outcome variables. Descriptively, we find substantial evidence of impacts in both countries. In Mozambique, approximately two-thirds of mothers in the two treatment groups name OFSP as a source of vitamin A at endline, whereas only one-third of mothers in the control group do so. Less than 20 percent of mothers did the same prior to the baseline. The pattern of learning was similar in Uganda. We find similar improvements in the number of vitamin A messages that women can recite.

The REU also appears to have affected adoption. In Mozambique, 75 and 79 percent of farmers in Model 1 and Model 2 were growing OFSP at endline, whereas only 9 percent of farmers in the control group were doing so. Among farmers growing OFSP, the share of OFSP in total area devoted to sweet potatoes increased as well, from between 11 and 20 percent at baseline to between 70 and 73 percent at endline, whereas it actually declined among the control group. It is worth noting that only about 50 percent of baseline farmers were growing any sweet potatoes, so many farmers are dropped altogether from the reported proportions at baseline.

Average dietary intakes of vitamin A by reference children also increased substantially in Model 1 and Model 2 households in both countries (Table 3, Panel C). Reference children, aged 6 to 35 months in Mozambique, consumed slightly more than 200 μg RAE of vitamin A at baseline, regardless of group membership. In Uganda, the reference children were older and so it is not surprising that their baseline consumption of vitamin A is higher, at between 430 and 550 μg RAE. In 2009, reference children in both countries assigned to Model 1 and Model 2 consume

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[20] We note that if a logit or probit model is used in estimating the ACME and ADE, alternative assumptions are made about the structure of the error terms. However, such models may be more appropriate.

[21] These slight differences are studied in more detail in project baseline reports (Arimond et al. 2008; Arimond et al. 2009).

Table 2. Baseline household and child characteristics, by model, REU, Mozambique and Uganda

Characteristic	Mozambique Model 1	Model 2	Control	Uganda Model 1	Model 2	Control
Household characteristics						
Female head	0.05	0.07	0.07	0.10	0.18	0.11
Household size	5.82 (1.94)	5.81 (1.81)	5.85 (1.82)	7.55 (2.79)	7.42 (2.68)	7.68 (3.00)
Years of schooling, head	2.74 (2.49)	3.77 (2.62)	2.88 (2.39)	6.65 (3.41)	6.92 (3.76)	7.07 (3.74)
Log, monthly per capita expenditures	0.88 (0.71)	1.05 (0.70)	0.98 (0.79)	9.99 (0.74)	10.04 (0.74)	9.99 (0.71)
Access to lowlands	0.62	0.65	0.66	0.45	0.35	0.43
Grew OFSP prior to baseline	0.11	0.09	0.06	0.07	0.04	0.06
Grew sweet potato in year prior to baseline	0.47	0.55	0.51	0.83	0.79	0.85
Leader or promoter	0.21	0.24	N/A	0.17	0.17	0.20
Reference child characteristics						
Child's age (months)	23.0 (9.2)	22.0 (8.4)	22.3 (8.6)	51.5 (9.9)	51.3 (10.0)	51.5 (9.6)
Gender (1 = male)	0.49	0.52	0.54	0.46	0.48	0.50
Still breastfed?	0.49	0.54	0.53	-	-	-

Notes: Standard deviations in parentheses for continuous variables. Reference children in Uganda were between ages 3 and 5 at baseline, hence they were no longer breastfed.

Source: Baseline and endline surveys, Mozambique and Uganda

Table 3. Average baseline and endline outcomes, by treatment group, REU, Mozambique and Uganda

Characteristic	Mozambique Model 1	Model 2	Control	Uganda Model 1	Model 2	Control
Panel A: Nutritional knowledge indicators						
Knows OFSP has vitamin A						
Baseline	0.12	0.20	0.17	0.08	0.11	0.06
Endline	0.68	0.63	0.35	0.67	0.67	0.24
Number of vitamin A facts known						
Baseline	0.71 (0.63)	0.74 (0.60)	0.73 (0.62)	0.89 (0.70)	0.85 (0.75)	0.89 (0.70)
Endline	1.28 (0.68)	1.47 (0.76)	0.91 (0.66)	1.28 (0.84)	1.39 (0.80)	0.88 (0.70)
Panel B: Adoption indicators						
Growing OFSP						
Endline	0.75	0.79	0.09	0.66	0.62	0.06
Share of OFSP in sweet potato area						
Baseline	0.20	0.11	0.12	0.00	0.00	0.01
Endline	0.73	0.70	0.07	0.47	0.44	0.02
Panel C: Vitamin A intakes, reference children						
Mean intakes						
Baseline	209.9 (192.4)	204.7 (222.9)	187.8 (187.9)	540.2 (913.6)	431.3 (445.6)	549.1 (1076.8)
Endline	646.7 (825.6)	624.6 (726.6)	350.2 (609.6)	863.2 (1110.5)	1104.7 (1562.9)	575.5 (794.6)

Notes: For continuous outcomes, standard deviations in parentheses. Reference children were aged 6–35 months at baseline in Mozambique and 3–5 years at baseline in Uganda.

Source: REU Baseline and Endline Survey Data, Mozambique and Uganda more vitamin A than children in the control groups. In Mozambique, where children are aged 3–5 years at endline, according to unadjusted intakes, children in Model 1 and Model 2 consume more than 600 μg RAE, on average, whereas in the control group, they consume only 350 μg RAE. In Uganda, children consume between 860 and 1,105 μg RAE in the Model 1 and Model 2 groups, whereas the control group consumes 575 μg RAE, on average.

5.1.1 Impacts on Nutritional Knowledge Indicators

We initially estimate Equation 3 using the two nutrition knowledge indicators as the dependent variable (Table 4). For Mozambique, the REU had a significant impact on the proportion of mothers who named OFSP as a source of vitamin A, whether or not we control for household baseline characteristics (columns 1 and 2). We also find that the REU had a significant impact on the number of vitamin A messages known (columns 3 and 4). In Uganda, point estimates for both dependent variables are somewhat higher than in Mozambique, with or without controls for baseline characteristics.[22] Mothers naming OFSP as a source of vitamin A increased by about 45 percentage points in both models (columns 5 and 6), whereas the number of messages known also increased by approximately half a message, on average (columns 7 and 8).

While the coefficient estimates differ somewhat by model for both Mozambique and Uganda, in neither country do we find larger point estimates for Model 1 than Model 2. Moreover, there are no statistically significant differences between models. Had we found a pattern of larger point estimates for Model 1 than Model 2, we might have begun to believe that Model 1 was more effective, and the sample simply lacked power to measure the difference between Model 1 and Model 2. However, we find larger point estimates among Model 2 mothers for the number of vitamin A messages known in both countries, so it does not seem likely that Model 1 had larger impacts overall than Model 2. We report the average treatment effect across Model 1 and Model 2 using the same specifications at the bottom of Table 4 with one variable to indicate households that were assigned to either treatment group. We find that the estimated impacts of the REU on nutritional knowledge were somewhat higher in Uganda than in Mozambique. In Mozambique, mothers naming OFSP as a source of vitamin A increased by 24.4 percentage points (column 2), while the same measure increased by 45.4 percentage points in Uganda (column 6). Mothers knew 0.35 more vitamin A messages as a result of the program in Mozambique (column 4), while they knew an additional 0.57 messages in Uganda (column 8). Therefore, there are some clear, if modest, gains in nutritional knowledge that occurred among mothers during the REU in both countries. There are two important implications. First, for causal mediation analysis, it should not matter that we average impacts between Model 1 and Model 2. Second, Model 2 was explicitly designed to be less costly than Model 1, so these estimates suggest that Model 2 was more cost-effective than Model 1.

5.1.2 Impacts on OFSP Adoption Indicators

Estimating Equation 4 with an indicator for adoption as the dependent variable demonstrates that both Models 1 and 2 had an impact on adopting OFSP in both countries (Table 5). In Mozambique, when additional household characteristics are not included, we find that households in Model 1 were 65.7 percentage points more likely to adopt than the control group, and households in Model 2 were 69.2 percentage points more likely to adopt. When we control for additional household characteristics, coefficient estimates on the model indicators decrease somewhat, to 62.5 and 65 percentage points for Model 1 and Model 2, respectively.

In Uganda, we find remarkably similar results (Table 5, columns 5 and 6). Households in Model 1 and Model 2 are 61.7 and 57.9 percentage points more likely to adopt OFSP than the control, when we do not control for additional household characteristics. When we do so, the coefficients on the treatment indicators change slightly, to 62.4 and 59.5 percentage points, respectively. Therefore, we can generally conclude that in both countries the REU was successful in leading to OFSP adoption among farmers. Furthermore, as point estimates for adoption were similar in both countries, it is clear that combining the two treatment groups is appropriate for causal mediation analysis. We seek to explain the combined impact estimates through causal mediation analysis, which are 63.8 percentage points in Mozambique and 60.2 percentage points in Uganda (Table 5, columns 2 and 6, respectively).

Next, we estimate the impact of Model 1 and Model 2 on the share of sweet potato area devoted to OFSP, to measure the intensity of the intervention (Table 5, columns 3, 4, 7, and 8). Recall that these regressions are conditional on growing any sweet potato, as observations drop when no area is devoted to sweet potatoes. We find that farmers in Mozambique devote 61.5 and 59 percentage points more of their sweet potato area to OFSP when participating in Model 1 and Model 2, respectively. Only about half of the sample in Mozambique grew OFSP prior to the baseline, and so it is not surprising that the coefficient is relatively

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[22] For the Uganda data, due to missing values for a number of control variables, we lose 141 observations. The average characteristics are not systematically different between the whole sample and the sample used in the regression analysis.

Table 4. Impacts of REU Model 1 & Model 2 on nutritional knowledge indicators at endline, Mozambique and Uganda

	Mozambique				Uganda			
	Knows OFSP a source of vitamin A, 2009		Number of vitamin A facts known, 2009		Knows OFSP a source of vitamin A, 2009		Number of vitamin A facts known, 2009	
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Model 1 versus Model 2								
Model 1	0.325***	0.283***	0.368***	0.256***	0.456***	0.457***	0.554***	0.559***
	(0.083)	(0.050)	(0.110)	(0.087)	(0.040)	(0.030)	(0.063)	(0.062)
Model 2	0.268***	0.206***	0.556***	0.438***	0.441***	0.447***	0.603***	0.613***
	(0.090)	(0.055)	(0.108)	(0.087)	(0.059)	(0.039)	(0.114)	(0.106)
Additional covariates?	No	Yes	No	Yes	No	Yes	No	Yes
Test H_0: Model 1 = Model 2 (p-value)	0.425	0.180	0.028	0.013	0.820	0.811	0.690	0.633
Panel B: Average treatment effect of both interventions								
Treated	0.295***	0.244***	0.467***	0.348***	0.452***	0.454***	0.566***	0.573***
	(0.079)	(0.045)	(0.103)	(0.082)	(0.036)	(0.028)	(0.058)	(0.057)
Additional covariates?	No	Yes	No	Yes	No	Yes	No	Yes
Number of obs.	610	610	610	609	975	975	975	975

Notes: Regressions are ANCOVA models controlling for baseline level of the outcome. Tests of equality of impact of Model 1 and Model 2 are adjusted Wald tests. Average treatment effects reported at the bottom of the table are average impacts over Model 1 and Model 2, using the same specification for that column in a separate regression. Standard errors are clustered at the village level in Mozambique and the farmer group level in Uganda. *** significant at the 1 percent level; ** significant at the 5 percent level; * significant at the 10 percent level.

Source: Mozambique and Uganda baseline and endline surveys, REU project.

Table 5. Impacts of REU Model 1 and Model 2 on measures of adoption at endline, Mozambique and Uganda

	Mozambique				Uganda			
	Adopted OFSP		Share of OFSP in SP area		Adopted OFSP		Share of OFSP in SP area	
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Model 1 versus Model 2								
Model 1	0.657***	0.625***	0.653***	0.615***	0.617***	0.624***	0.438***	0.428***
	(0.050)	(0.047)	(0.043)	(0.041)	(0.040)	(0.030)	(0.027)	(0.023)
Model 2	0.692***	0.650***	0.622***	0.590***	0.579***	0.595***	0.414***	0.410***
	(0.035)	(0.039)	(0.042)	(0.033)	(0.071)	(0.039)	(0.039)	(0.040)
Additional covariates?	No	Yes	No	Yes	No	Yes	No	Yes
Test H_0: Model 1 = Model 2 (p-value)	0.441	0.573	0.533	0.565	0.649	0.542	0.615	0.688
Panel B: Average treatment effect of both interventions								
Treated	0.675***	0.638***	0.637***	0.602***	0.607***	0.617***	0.432***	0.424***
	(0.037)	(0.037)	(0.035)	(0.030)	(0.034)	(0.025)	(0.023)	(0.020)
Additional covariates?	No	Yes	No	Yes	No	Yes	No	Yes
Number of obs.	610	610	551	551	975	975	751	751

Notes: All models are single difference models at endline. Baseline levels of adoption and area planted with OSP were very low, and so were omitted from these models. The share of OFSP in SP area has 59 missing observations in Mozambique and 224 missing observations in Uganda because these households did not grow any sweet potato. Tests of equality of impact of Model 1 and Model 2 are adjusted Wald tests. Average treatment effects reported at the bottom of the table are average impacts over Model 1 and Model 2, using the same specification for that column in a separate regression. Standard errors are clustered at the village level in Mozambique and the farmer group level in Uganda. *** significant at the 1 percent level.

Source: Mozambique and Uganda baseline and endline surveys, REU project.

large. Many farmers actually adopted OFSP as their only sweet potato variety between the baseline and endline. In Uganda, farmers were more likely to grow sweet potatoes prior to the baseline, so it is not surprising that the share of sweet potato area devoted to OFSP only rises by between 41.3 and 42.8 percentage points among the Model 1 and Model 2 farmers relative to the control group. In both countries, there was substantial substitution of OFSP production for conventional white and yellow varieties. However, in Uganda in particular, households demonstrated a preference for variety, keeping more than half of their sweet potato fields devoted to conventional varieties. There are no significant differences in impacts on planted area between Model 1 and Model 2 in both countries, so as with the discrete adoption indicator, we can combine the two estimates into one treatment indicator without much loss of generality (Table 5, columns 3, 4, 7, and 8).

5.1.3 Impacts on Vitamin A Intakes: Reference Children

The REU project led to substantial increases in average dietary intakes of vitamin A for reference children in both countries (Table 6). Average vitamin A intakes of reference children in Mozambique increased by between 198 and 222 μg RAE, with an average impact of 209.1 μg RAE as a result of the program. This impact is substantial, given that the recommended daily intake for children aged 6–35 months is 210 μg RAE. There is no difference in impact between Model 1 and Model 2, suggesting that the more intensive trainings in Model 1 did not contribute to additional improvements in vitamin A intakes. In Uganda, the impact on dietary intakes of vitamin A for reference children was somewhat larger, ranging from 313.0 to 520.4 μg RAE for Model 1 and Model 2, respectively, with an average treatment effect of 391.9 μg RAE. The larger effect in Uganda than in Mozambique may in part reflect the fact that reference children were 6–35 months of age at baseline in Mozambique but 36–83 months of age at baseline in Uganda. The period between baseline and endline was nearly 36 months in Mozambique and was only 24 months in Uganda; however, the somewhat older children in Uganda should have had higher intakes of food energy and many nutrients by virtue of their age. As in Mozambique, this effect size in Uganda is very large, given that the cutoff for adequate dietary intakes of vitamin A in children age 3–5 years is 260 μg RAE. Impacts on dietary intakes in Uganda as measured by the best linear unbiased predictions (BLUPs) are statistically significantly larger for Model 2 than Model 1, again indicating no gain to the additional trainings provided under Model 1.

Table 6. Impacts of REU Model 1 and Model 2 on vitamin A intakes at endline, reference children, Mozambique and Uganda

	Mozambique		Uganda	
	(1)	(2)	(3)	(4)
Panel A: Model 1 versus Model 2				
Model 1	291.1***	221.9**	304.22**	313.02***
	(84.8)	(84.3)	(115.56)	(101.44)
Model 2	241.7**	198.1**	525.42**	520.61***
	(86.4)	(76.8)	(220.44)	(149.10)
Child characteristics?	Yes	Yes	Yes	Yes
Additional covariates?	No	Yes	No	Yes
Test Ho: Model 1 = Model 2 (p-value)	0.472	0.693	0.358	0.178
Panel B: Average treatment effect of both interventions				
Treated	249.3***	209.1***	389.76***	391.90***
	(83.6)	(74.6)	(115.89)	(96.96)
Child characteristics?	Yes	Yes	Yes	Yes
Additional covariates?	No	Yes	No	Yes
Number of obs.	376	376	446	446

Notes: Tests of equality of impact of Model 1 and Model 2 are adjusted Wald tests. Average treatment effects reported at the bottom of the table are average impacts over Model 1 and Model 2, using the same specification for that column in a separate regression. Standard errors are clustered at the village level in Mozambique and the farmer group level in Uganda. *** significant at the 1 percent level; ** significant at the 5 percent level; * significant at the 10 percent level.

Source: Mozambique and Uganda baseline and endline surveys, REU project.

5.2 Causal Mediation Analysis: Estimates

To understand the contributions of additional nutritional knowledge to the adoption decision and the contributions of nutritional knowledge and adoption to the intakes of vitamin A among children, we make the sequential ignorability assumption embedded in equations 7 and 8. After estimating equations 4 and 9, we provide conditional correlations between the error terms of Equation 9 and a version of Equation 4, which uses the mediating variable as the dependent variable, to understand whether bias might exist in our estimates of the ACME, and if so, in which direction the bias might be.

5.2.1 Nutritional Knowledge Mediating Effect in OFSP Adoption

We measure adoption and nutritional knowledge in both countries in two different ways, so there are eight different mediation effects measured in this subsection. For all combinations, we typically make a linearity assumption and estimate Equation 4 with the mediating outcome as the outcome and Equation 9 to learn the ACME and ADE. Where possible, we also estimate Equation 6; however, in practice it is only possible to estimate the ACME this way when at least the mediating variable is specified as a continuous variable. The continuous measure is the increase in knowledge of vitamin A messages, so the nonparametric estimates use that variable as the mediator. In nonparametric estimation, we measure the ACME both directly and by interacting the mediating variable with the treatment variable, to isolate the impacts of the mediating variable for treated households. In both cases, we describe the impacts that correlation between residuals would potentially have on our estimates for the continuous measure of adoption, and provide estimates of correlations from the linear versions of all of our estimates. Since the sequential ignorability assumption is implausibly strong, it is important to think through how unobservables would affect estimates.

We first estimate causal mediation effects making the linearity assumption (Table 7). We find a very limited amount of adoption occurs through nutritional knowledge, irrespective of the mediating variable. We find a positive but insignificant coefficient (0.058) on the OFSP as a vitamin A source mediating variable in Mozambique (Table 7, column 2), and a statistically significant coefficient in Uganda of 0.098 (Table 7, column 6). In Mozambique, controlling for baseline characteristics the point estimate for the effect of the number of vitamin A messages known at endline on the probability of OFSP adoption is 0.049 (column 4); in Uganda, it is 0.040 (column 8). In Panel A of Table 9, we calculate the ACME and the ADE for each of the two mediating variables and countries. Whether or not we condition on baseline characteristics, we find that the mediating effect of the nutrition variables never exceeds 5 percent in Mozambique (in column 3) and 13 percent in Uganda (in column 5). Therefore as mediating variables, increased knowledge had only limited importance for the adoption of OFSP in both countries.

The share of sweet potato area planted in OFSP as the adoption measure, continuing the linearity assumption, yields similar results to those found in Table 7 (Table 8). In Mozambique, we find small, positive coefficient estimates for both mediating variables (columns 1–4); all but one are significantly different from zero. In Uganda, coefficients on

Table 7. Average impacts of REU on discrete measure of OFSP adoption at endline, including nutrition knowledge mediating variables, Mozambique and Uganda

	Mozambique				Uganda			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treated	0.650***	0.625***	0.637***	0.622***	0.531***	0.572***	0.576***	0.594***
	(0.040)	(0.041)	(0.040)	(0.040)	(0.037)	(0.029)	(0.036)	(0.027)
Knows OFSP is source of vitamin A, endline	0.086**	0.058			0.166***	0.098***		
	(0.041)	(0.041)			(0.032)	(0.032)		
Number of vitamin A facts known, endline			0.081***	0.049**			0.056***	0.040**
			(0.022)	(0.022)			(0.017)	(0.015)
Additional covariates?	No	Yes	No	Yes	No	Yes	No	Yes
Number of obs.	610	610	610	609	975	975	975	975
R2	0.418	0.448	0.425	0.450	0.399	0.461	0.383	0.457

Notes: Standard errors are clustered at the village level in Mozambique and the farmer group level in Uganda. *** significant at the 1 percent level; ** significant at the 5 percent level; * significant at the 10 percent level.

Source: Mozambique and Uganda baseline and endline surveys, REU project.

Table 8. Average impacts of REU on share of OFSP in sweet potato area, including nutrition knowledge mediating variables, Mozambique and Uganda, at endline

	Mozambique				Uganda			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treated	0.609***	0.591***	0.609***	0.593***	0.438***	0.414***	0.423***	0.410***
	(0.036)	(0.032)	(0.040)	(0.035)	(0.029)	(0.024)	(0.025)	(0.022)
Knows OFSP is source of vitamin A, endline	0.092***	0.056*			-0.013	0.022		
	(0.031)	(0.033)			(0.026)	(0.024)		
Number of vitamin A messages known, endline			0.051**	0.025			0.014	0.021*
			(0.022)	(0.022)			(0.014)	(0.012)
Additional covariates?	No	Yes	No	Yes	No	Yes	No	Yes
Number of obs.	534	534	534	533	751	751	751	751
R2	0.488	0.514	0.485	0.511	0.396	0.451	0.396	0.452

Notes: Standard errors are clustered at the village level in Mozambique and the farmer group level in Uganda. *** significant at the 1 percent level; ** significant at the 5 percent level; * significant at the 10 percent level.

Source: Mozambique and Uganda baseline and endline surveys, REU project.

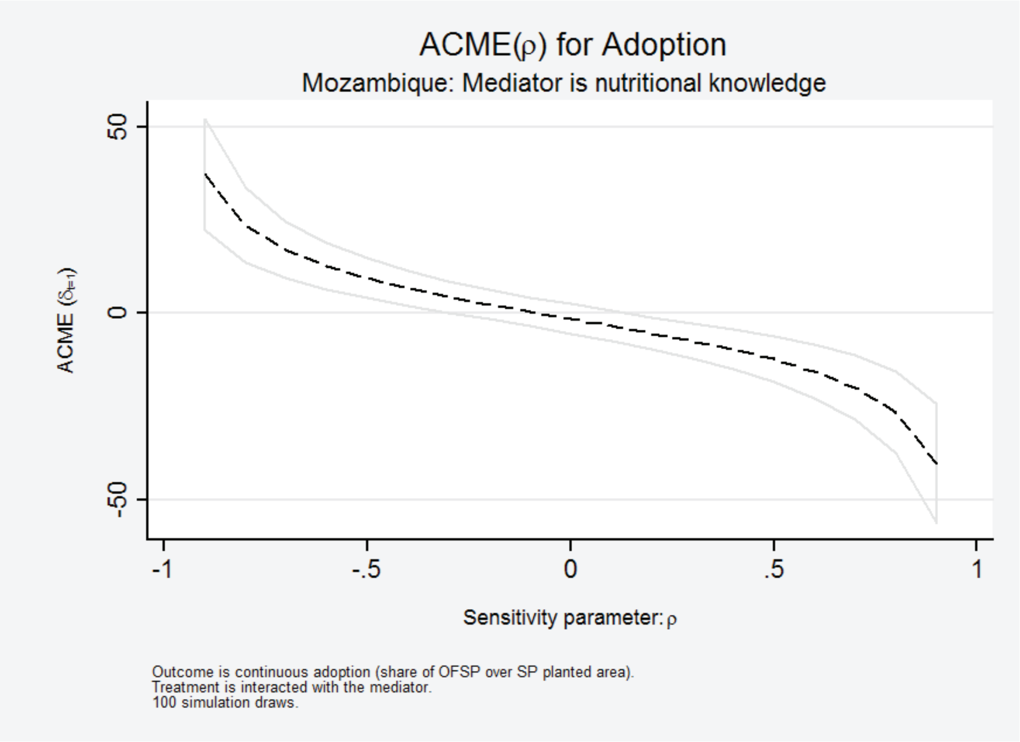
Table 9. Estimates of ACME and ADE for the role of nutrition knowledge in OFSP adoption and share of OFSP in sweet potato area at endline, including nutrition knowledge mediating variables, REU, Mozambique and Uganda

	Mozambique				Uganda			
	Knows OFSP a source of vitamin A, 2009		Number of messages known, 2009		Knows OFSP a source of vitamin A, 2009		Number of messages known, 2009	
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: OFSP adoption								
Conditioning variables	No	Yes	No	Yes	No	Yes	No	Yes
Treatment effect on knowledge	0.295	0.244	0.467	0.348	0.460	0.454	0.567	0.573
Knowledge effect on adoption	0.086	0.058	0.081	0.049	0.166	0.098	0.056	0.040
ACME	0.025**	0.014	0.035**	0.017*	0.076***	0.044***	0.031***	0.023**
	(0.012)	(0.009)	(0.013)	(0.009)	(0.016)	(0.015)	(0.010)	(0.009)
ADE	0.650***	0.623***	0.639***	0.620**	0.531***	0.563***	0.576***	0.584***
	(0.041)	(0.040)	(0.041)	(0.040)	(0.037)	(0.036)	(0.036)	(0.035)
Correlation, residuals	<0.0001	<0.0001	<0.0001	<0.0001	0.024	0.0007	-0.0110	-0.0005
Number of obs.	609	609	609	609	975	975	975	975
Panel B: Share of OFSP in SP area								
Conditioning variables	No	Yes	No	Yes	No	Yes	No	Yes
Treatment effect on knowledge	0.295	0.244	0.467	0.348	0.460	0.454	0.567	0.573
Knowledge effect on adoption	0.092	0.056	0.051	0.025	-0.013	0.020	0.014	0.020
ACME	0.027***	0.014**	0.022*	0.009	-0.006	0.009	0.008	0.012*
	(0.009)	(0.007)	(0.012)	(0.008)	(0.012)	(0.011)	(0.008)	(0.007)
ADE	0.610***	0.589***	0.614***	0.594***	0.438***	0.423***	0.424***	0.420***
	(0.035)	(0.032)	(0.038)	(0.034)	(0.028)	(0.026)	(0.025)	(0.024)
Correlation, residuals	<0.0001	<0.0001	<0.0001	<0.0001	0.072	0.0039	0.0243	0.0012
Number of obs.	609	609	609	609	975	975	975	975

Notes: Standard errors on ACME and ADE generated using seemingly unrelated regressions. The ACME is generated by multiplying the treatment effect on knowledge by the knowledge effect on adoption. Standard errors are clustered at the village level in Mozambique and the farmer group level in Uganda. *** significant at the 1 percent level; ** significant at the 5 percent level; * significant at the 10 percent level.

Source: Mozambique and Uganda baseline and endline surveys, REU project.

Panel A. Mozambique



Panel B. Uganda

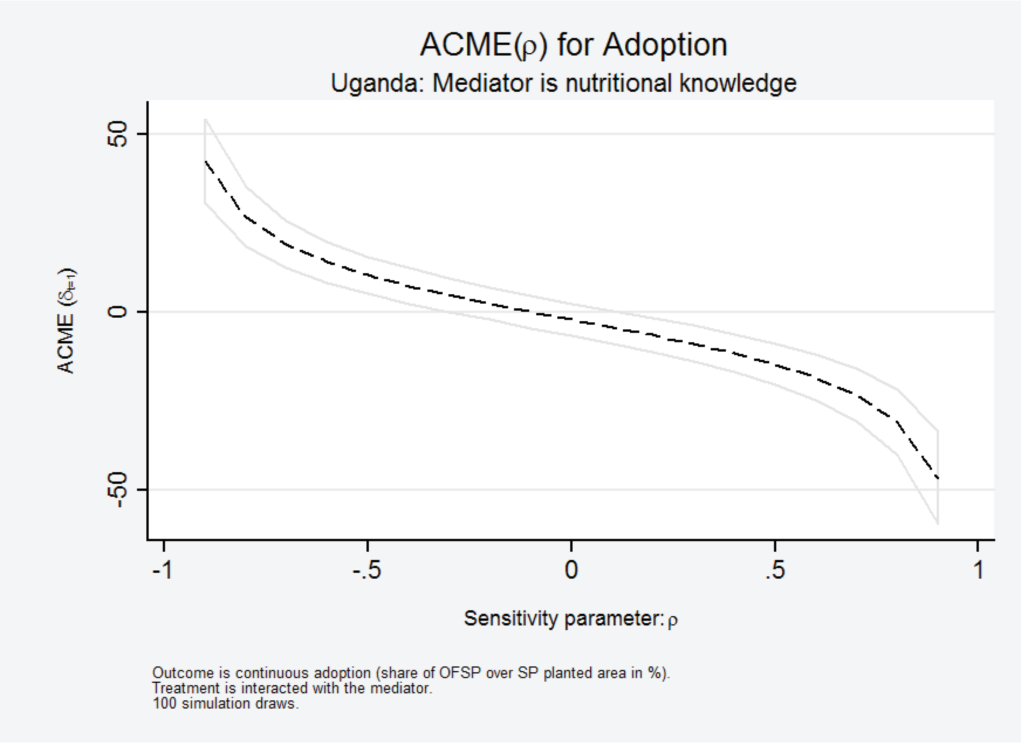


Figure 2. Sensitivity analysis, using number of vitamin A messages as mediator variable, for and share of OFSP in SP area as the outcome variable, including interaction terms, Mozambique and Uganda

both the mediating variables are small and not significantly different from zero (columns 5–8). Therefore, there appears to be only a small amount of mediation through nutritional knowledge on the intensity of adoption. Not surprisingly, when we compute the ACME in both countries, we find that it is very small relative to the ADE (Table 9, Panel B). In fact the ACME is only significant at better than the 5 percent level when we use the OFSP as a source of vitamin A variable as a mediator in Mozambique, and the point estimates suggest an ACME of 5 percent or less. The ACME is only significantly different from zero in Uganda at the 10 percent level in one regression (column 8). Nonparametric estimates using the number of vitamin A facts known as the mediating variable are consistent with the linear estimates; neither mediation effect is statistically different from zero (not shown).

Before we make conclusions based on estimates of mediation effects on adoption through nutritional knowledge, we consider how the sequential ignorability assumptions may affect our estimates. We use the nonparametric estimates to plot ACME estimates while relaxing the assumption of a zero conditional correlation between error terms (Figure 2). In both countries, the graphs suggest that if there is a negative correlation between error terms, then we are underestimating the ACME. Even if the correlation between error terms were substantial and negative in Mozambique (e.g., -0.5), little adoption would be explained by the mediating variable (Panel A). More adoption would be explained by the mediating variable in Uganda if there were substantial negative correlation between error terms. In both cases, if the conditional correlation is positive, then the ACME is actually overestimated.

Therefore, it is worth considering the most plausible direction of correlation between the error terms. Recall that the REU provided households both with OFSP vines and nutritional knowledge. The residuals in explaining nutritional knowledge, then, are the amount of increased nutritional knowledge we cannot explain after controlling for the treatment effect and baseline household characteristics, and the residuals in explaining adoption are the amount of adoption we cannot explain after controlling for the same variables and the mediating variable. It seems likely that, if anything, the residuals would be positively correlated, since a negative correlation would imply that households with additional unexplained nutritional knowledge are actually less likely to have unexplained adoption behavior. We would therefore expect positive correlations between residuals, if any correlation exists.

In fact, we estimated correlations between residuals between the regressions explaining mediating variable and the equations estimated in tables 7 and 8 including baseline characteristics, and find small positive correlations in Uganda, and no correlations at all in Mozambique (Table 9, Panels A and B). These conditional correlations suggest that, if anything, we overestimate the ACME in Uganda, but not in Mozambique. In Uganda, the correlations are slightly higher for the variable measuring knowledge that OFSP is a source of vitamin A, suggesting that the conclusion that as much as 13 percent of adoption in Uganda can be explained through this increase in knowledge is an upper bound.

In summary, using the available measures, we find the demand-creation component of the intervention had little impact on adoption of OFSP. It could be that other aspects of the project, such as the initial price of vines (zero), the vines' other traits such as resistance to pests, characteristics, or consumer acceptance of OFSP were simply important enough to catalyze strong adoption of OFSP. Further, it could be that enhancing nutritional knowledge was not necessary for project success. Alternatively, it could be that the variables representing project messages available to us are not broad enough to reflect project impacts; the general message that OFSP is healthy might have been an important part of adoption. That message, however, is not simple to measure quantitatively given the available data. We return to this concept as we discuss the cost-effectiveness implications of our results.

5.2.2 Nutritional Knowledge, OFSP Adoption, and Vitamin A Intakes

Our next goal is to understand the role of both adoption and nutritional knowledge in explaining vitamin A intakes in the target population. We limit ourselves to examining the mediation effects of OFSP adoption and nutritional knowledge among the reference children; that is, children who were aged 6 to 35 months at baseline in Mozambique and children who were aged 3 to 5 years in Uganda. We initially estimate a version of Equation 4 with two potential mediating variables, one measuring adoption and one measuring nutritional knowledge.[23] We build up estimates in both countries by first estimating models with each mediating variable alone, then testing each possible nutritional knowledge indicator. We focus on the binary measure of adoption and test both possible measures of nutritional knowledge; given that we are primarily using binary mediating variables, we continue to make the linearity assumption in these estimates as well as the strong sequential ignorability assumption. All results on causal mechanisms are, of course, conditional on those assumptions.

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[23] Given that in the previous subsection we found that nutritional knowledge only has a small impact, if any, on adoption, we ignore the possibility that the effect of adoption on intakes flows through increased nutritional knowledge.

Table 10. Causal mediation analysis, vitamin A intakes in 2009, reference children, REU, Mozambique and Uganda

	Mozambique					Uganda				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Treated	33.231	203.890**	215.328***	29.513	33.519	193.5*	377.9***	321.4***	186.1	141.2
	(100.762)	(79.587)	(82.911)	(101.894)	(100.197)	(114.021)	(104.463)	(102.080)	(116.085)	(121.669)
Plans to conserve vines or planted OFSP this season	262.233***			269.432***	269.753***	324.0**			323.0**	305.0**
Knows OFSP is source of vitamin A, endline		44.263 (70.486)		26.127 (66.393)				31.3 (116.745)		18.0 (117.877)
Number of vitamin A facts known, endline			28.951 (71.676)		6.997 (72.196)			129.7 (88.970)		117.6 (88.578)
Number of observations	376	372	372	372	372	446	446	446	446	446
R2	0.102	0.085	0.088	0.105	0.104	0.155	0.145	0.151	0.155	0.160

Notes: Models in both countries include district (strata) dummy variables. Standard errors are clustered at the village level in Mozambique and the farmer group level in Uganda. Baseline value of vitamin A consumption and additional covariates included in all regressions. *** significant at the 1 percent level; ** significant at the 5 percent level; * significant at the 10 percent level.

Source: Mozambique and Uganda baseline and endline surveys, REU project.

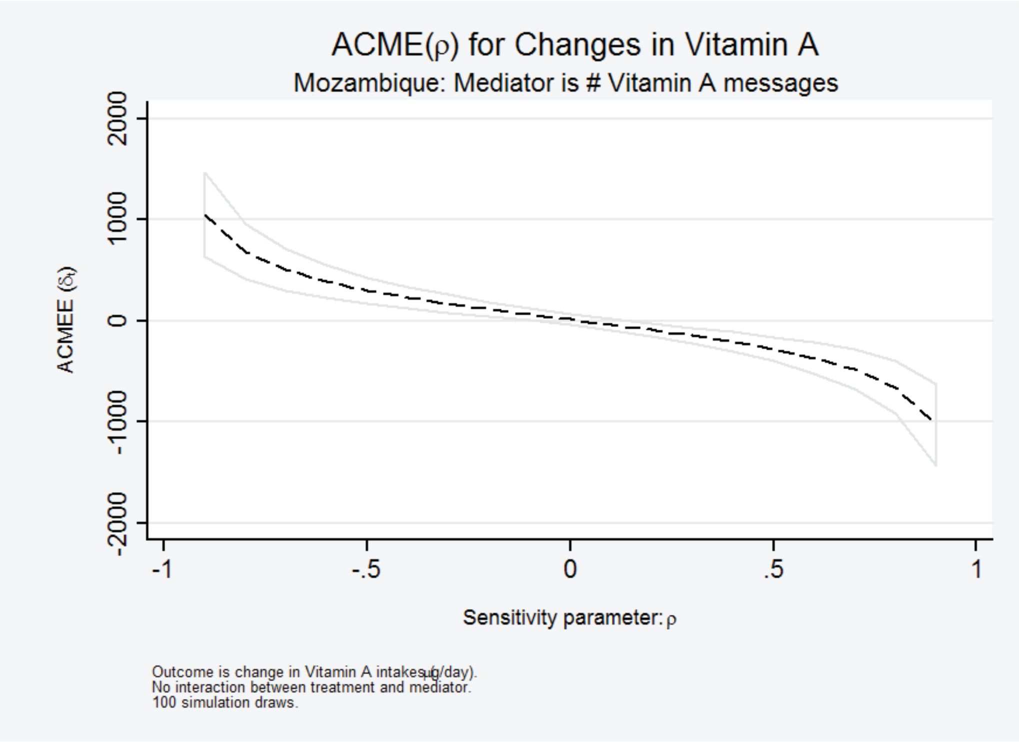
In Mozambique, when we add the adoption variable as a mediator in a regression explaining vitamin A intakes, we find that it usurps nearly the whole treatment effect (Table 10, column 1). When we instead use one of the two nutrition knowledge indicators as a mediating variable (columns 2 and 3), we find that the coefficient estimates on the mediating variables are relatively small and imprecisely estimated, both with t ratios below 1. As with adoption, the sensitivity analysis using the number of vitamin A facts known as the mediator demonstrates that there would have to be a very strong negative correlation between error terms to generate a large mediation effect through nutritional knowledge (Figure 3, Panel A). Therefore, it seems like the demand creation component had little to do with consumption behavior in Mozambique.

To confirm this hypothesis, we use the discrete adoption variable and the two nutrition knowledge variables sequentially as multiple mediation variables (Table 10, columns 4 and 5). We find that the coefficient estimate on the adoption variable is nearly the same in both specifications as it was when it appeared alone. The estimated coefficients on the nutrition knowledge variables remain relatively small and are not statistically different from zero. These results appear quite consistent with the results from the previous subsection, which suggested that nutritional knowledge only had a small impact on adoption, if any. These results combine to suggest nutritional knowledge did not have much of an effect on vitamin A intakes among the reference children, at least in Mozambique.

We next explore the mediation effects among reference children in Uganda (Table 10, columns 6–10). As in Mozambique, we find a large, statistically significant coefficient estimate on the adoption variable (column 6). However, the point estimate on the treatment effect remains reasonably large, suggesting unexplained variation in vitamin A intakes. Using the nutritional knowledge variables as the mediators (columns 7 and 8), the point estimate for the coefficient on the variable measuring whether the mother names OFSP as a food source of vitamin A is actually negative. The coefficient estimate on the number of vitamin A facts known is positive, but not significantly different from zero. Graphing the average causal mediation effect and the average direct effect, not surprisingly we find that the number of vitamin A facts known does not appear to be a mediator (Figure 3, Panel B). Similar to Mozambique, the error terms would have to have a strong negative correlation before the mediation effect through nutritional knowledge would explain a large amount of the average treatment effect for dietary intakes of vitamin A.

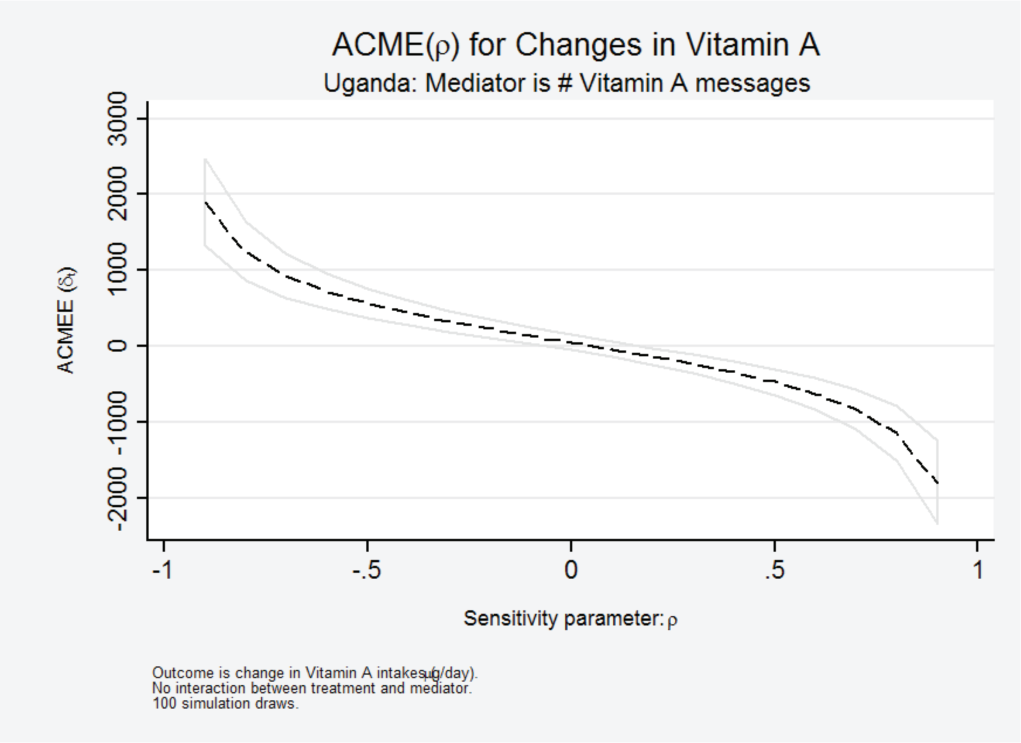
When we estimate models with two mediating variables in Uganda (Table 10, columns 9 and 10), coefficient estimates on the mediating variables do not change much from the regressions in which they entered alone. Because we estimate a negative mediating effect on the

Panel A. Mozambique



Outcome is change in Vitamin A intake (μg/day).
No interaction between treatment and mediator.
100 simulation draws.

Panel B. Uganda



Outcome is change in Vitamin A intake (μg/day).
No interaction between treatment and mediator.
100 simulation draws.

Figure 3. Sensitivity analysis, using number of vitamin A messages as mediator variable, for vitamin A intakes among reference children as the outcome variable, including interaction terms, Mozambique and Uganda.

Table 11. Estimates of average causal mediation effect and average direct effect, increase in vitamin A consumption, REU, Mozambique and Uganda

	Mozambique		Uganda	
	(1)	(2)	(3)	(4)
Linearity assumption				
ACME, adoption	175.5*** (61.2)	180.8*** (62.3)	198.4** (78.4)	186.7** (75.4)
ACME, number of vitamin A facts known		2.42 (25.8)		64.1 (51.9)
ADE	33.6 (100.6)	25.9 (101.2)	193.5* (114.0)	141.1 (121.8)
Share of treatment effect, adoption (%)	83.9	86.5	50.6	47.6
Share of treatment effect, vitamin A messages (%)		0.5		16.4
Number of observations	372	372	446	446

Notes: Standard errors on ACME and ADE generated using seemingly unrelated regressions. Regressions underlying the mediation effects include all explanatory variables. The ACME for adoption is generated by multiplying the treatment effect on adoption by the adoption effect on vitamin A intakes, and the ACME for the number of vitamin A messages is generated by multiplying the treatment effect on knowledge by the knowledge effect on vitamin A intakes.

OFSP as a source of vitamin A indicator variable, we focus interpretation on the number of vitamin A facts known as a mediating variable. An interesting aspect of this regression is that the residual effect of the treatment, contained in the direct effect, drops somewhat in magnitude with both mediating variables used, relative to just using the adoption variable. Compared with the results for Mozambique, there still appears to be a reasonable amount of the treatment effect that remains unexplained by the two mediating variables.

We use the coefficient estimates above to estimate each ACME and the remaining ADE of the treatment on vitamin A intakes among the reference children (Table 11). Specifically, we use the results in column 1 of Table 10 in Mozambique and column 6 in Uganda to estimate the ACME through adoption without the nutritional knowledge variables, and columns 5 and 10 for Mozambique and Uganda, respectively, when we add the number of vitamin A messages known as a mediating variable.

In Mozambique, we find that the increase in vitamin A intakes among the treatment group can fully be explained through the adoption of OFSP, regardless of whether we control for nutritional knowledge indicators (columns 1 and 2). Between 83 and 86 percent of vitamin A intake can be explained through adoption. Meanwhile, when we estimate the ACME for the number of vitamin A messages known, we estimate a small effect (2.4 µg RAE) that is not precisely estimated. The point estimate represents 0.5 percent of the average treatment effect. At least among reference children in Mozambique, these results suggest the impact pathway runs almost directly through adoption. If households adopt OFSP, OFSP finds its way into the diets of younger children.

The findings in Uganda are substantially different (Table 11, columns 3 and 4). The ACME for adoption is 198.4 µg RAE, explaining slightly more than half of the average treatment effect of 391.9 µg RAE on its own (column 3). It drops slightly when the number of vitamin A messages is added to the regression, which explains about 15 percent of the average treatment effect; the coefficient estimate is 64.1 µg RAE, but it is not significantly different from zero. Whereas the ACME for adoption continues to explain the largest share of the average treatment effect, about 35 percent of the treatment effect is left unexplained by the mediating variables. Since the direct pathway from the program to consumption is unlikely to be substantial, these results suggest that some variable is missing that might help explain adoption and intakes by reference children.[24]

As we have discussed throughout the paper, the nutritional knowledge variables are inherently narrow; they measure whether mothers grasp specific knowledge disseminated as part of the project. It seems plausible that the general health message of the project—that is, that OFSP is healthy for younger children to consume—may help explain some of the remaining increase in intakes by younger children.[25] Conditional on the assumptions we

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[24] The estimated ADE could, in part, reflect unmodeled correlations between the residuals in error terms between the two mediating variables and the outcome variable.

[25] This message comes across both in the overall project report (Har-

made to generate estimates of the mediation effects, at least in Uganda the nutritional knowledge component of the project may have had an important role in increasing vitamin A intakes, though its role appears small based on the narrow measures of nutritional knowledge. Given that the correlation between error terms in the mediation regressions is likely to be positive, if anything, these estimated impacts are likely upper bounds.

6. COST-EFFECTIVENESS IMPLICATIONS

To examine the implications of our results for the cost-effectiveness of future, similar interventions to the REU, we focus first on the average costs per beneficiary, since the marginal costs are a difficult concept to define in this case (see de Brauw et al. 2010, for an extended discussion). We consider costs only for Model 2, since Model 1 and Model 2 clearly had similar impacts, and Model 2 was less expensive.

We measure beneficiaries in four ways. First, we define direct beneficiaries as the number of households who received vines from the project at some point in time. In both countries, organization or farmer group membership was fluid, so estimating the actual number of REU beneficiaries is not trivial. We use aggregates from initial vine distribution lists to construct estimates of the number of direct beneficiaries by this definition across the two models. Second, other households also benefited from the project through vines given to them by direct beneficiaries.[26] In both countries, we measured such beneficiaries in the endline survey, and we call them indirect beneficiaries. Diffusion rates were 0.32 in Mozambique and 1.00 in Uganda among Model 2 households (Table 12).

The third and fourth definitions of beneficiaries are at the individual level since the target beneficiaries of the REU are mothers and children, for whom increased vitamin A consumption is most important; we estimate their number in the intervention households (Table 12, rows 2–4). Ugandan households are somewhat larger than Mozambican households; in Uganda there are 1.73 children younger than 5 per household, whereas in Mozambique there are 1.25 children. Based on the average of 0.97 mothers per household in Mozambique and 0.99 in Uganda, we assume there are approximately 2.22 beneficiaries per household in Mozambique and 2.69 beneficiaries per household in Uganda. Finally, since not all beneficiaries actually adopt OFSP, we also estimate the benefits per adopting household, based on our single difference estimates of adoption impacts.

On a per household or per beneficiary basis (Table 13, Panel A), Model 2 was slightly more expensive in Mozambique than in Uganda ($146 versus $132 per household). On per individual beneficiary basis and accounting for diffusion, costs drop to $52 in Mozambique and $26 in Uganda. The intervention appears less expensive, in relative terms, in Uganda because the number of direct beneficiaries per household was higher, as was diffusion. Clearly, increasing diffusion can help make the costs per beneficiary lower. Once we account for the fact that not all households that benefit from the project actually adopt vines (Panel B), the cost per individual beneficiary increases to $67 in Mozambique and $36 in Uganda. About 70 percent of the disparity between countries is due to the difference in diffusion rates.

That said, these results also suggest some modifications to the implementation design that would not materially affect overall adoption or dietary intakes. For example, as noted earlier (see de Brauw et al. 2010), the marketing component of the REU did not influence household adoption or dietary intakes, so it could hypothetically be dropped from a future intervention focused on distribution, adoption, and increasing intakes (Table 13, Panel C). We show the budget proportions of each component in Figure 4; dropping marketing would save 11 percent of the budget in Mozambique and 21 percent in Uganda, where extensionists applied more effort to marketing. The results in section 6.2 suggest that the bulk of the demand-creation messages did not have a large effect on the adoption of OFSP by REU participants, nor dietary intakes. However, as our measures are somewhat narrow and focus on detailed messages, it could be that the broader message that OFSP is healthier than white or yellow sweet potatoes is the important one leading to adoption. If so, then the project messages and therefore expenditures on demand creation can be scaled back substantially. We consider the implications of cutting the demand-creation budget by 25, 50, and 75 percent in both countries, on top of removing the marketing component.[27]

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vestPlus 2010) and in qualitative research that was done as part of the project.

[26] We base our estimates of indirect beneficiaries on the vine diffusion modules included in both endline surveys. Therefore, we may underestimate diffusion somewhat if there was a great deal of OFSP consumption by households purchasing OFSP in markets or receiving OFSP from direct-beneficiary households. However, given that most households in the intervention in both countries grew OFSP for home consumption, the magnitude of our underestimate is likely to be quite minimal.

[27] The latter two reductions are based on the notion of heavily cutting back the nutrition extension messages in both countries, but retaining some basic messages, or alternatively just using mass marketing, such as radio and billboards, to promote the nutrition messages of the project. In the longer term, if adoption was successful and an organic market for OFSP did not appear, one might consider a follow-up marketing intervention.

We find that average costs per adopting household drop to between $127 and $170 in Mozambique and $120 and $157 in Uganda, depending upon the reduction in the demand-creation budget. A 50 percent reduction is probably the largest feasible reduction if any contact with households related to demand-creation messages is to be maintained, so we believe that costs per adopting household could be reasonably reduced to $141 in Mozambique and $132 in Uganda. In both countries, an increased emphasis on promoting diffusion would help decrease average cost estimates even further.

Table 12. Parameters for diffusion and primary beneficiaries per household, REU, Model 2, Mozambique and Uganda

Parameter	**Mozambique**	**Uganda**
OSP diffusion rate	0.32	1.00
Targeted beneficiaries		
Mothers per household	0.97	0.99
Children aged 6–59 months per household	1.25	1.73
Total beneficiaries per household	2.22	2.72

Notes: Diffusion rate is measured as the number of individuals with whom the household reported sharing OSP vines; figures based only on Model 2 households in both countries. Targeted beneficiaries are the total number of mothers and children between the ages of 6–59 months living in each household.

Table 13. Average costs per beneficiary household and individual, REU and hypothetical reduced REU programs, all based on Model 2, Mozambique and Uganda

Variable	Mozambique	Uganda
Panel A: Targeted household		
Direct household beneficiary	$146	$132
Direct individual beneficiary	$65	$49
Direct + indirect household beneficiary	$117	$66
Direct + indirect individual beneficiary	$52	$26
Panel B: Households adopting OSP		
Direct household beneficiary	$191	$199
Direct individual beneficiary	$85	$74
Direct + indirect household beneficiary	$153	$100
Direct + indirect individual beneficiary	$68	$36
Panel C: Households adopting OSP		
Direct household beneficiary, dropping marketing component	$170	$157
Direct household beneficiary, dropping 25 percent of demand creation and marketing	$156	$145
Direct household beneficiary, dropping 50 percent of demand creation and marketing	$141	$132
Direct household beneficiary, dropping 75 percent of demand creation and marketing	$127	$120

Notes: Standard errors on ACME and ADE generated using seemingly unrelated regressions. The ACME is generated by multiplying the treatment effect on knowledge by the knowledge effect on adoption. Standard errors are clustered at the village level in Mozambique and the farmer group level in Uganda. *** significant at the 1 percent level; ** significant at the 5 percent level; * significant at the 10 percent level.

Source: Mozambique and Uganda baseline and endline surveys, REU project.

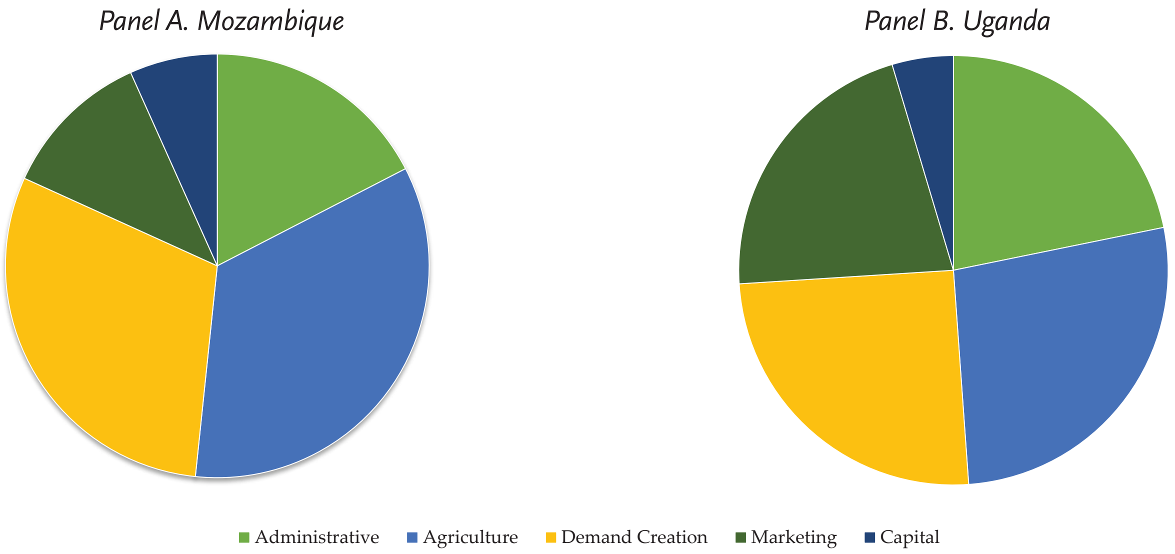

Figure 4. Budget shares of REU project components, Mozambique and Uganda

7. CONCLUSION

In this paper, we have quantified the impacts of a biofortification program from a randomized control trial conducted in both Mozambique and Uganda. The integrated program was delivered using two models, which differed in intensity. Our results suggest that in both countries, biofortified crops were adopted and vitamin A intakes increased among targeted children, and that the less intense program worked just as well as the more intense program. The average treatment effect on increases in vitamin A consumption was larger in Uganda than Mozambique; this difference is related to the age difference among reference children at baseline, as they were older (3 to 5 years) in Uganda than Mozambique (6 to 35 months) and therefore consume more food in general at endline. Nonetheless, in both countries the increase in consumption meets or exceeds the US recommended daily allowance of vitamin A, suggesting the integrated program had a strong impact on the nutritional content of diet among children in treated households.

We used causal mediation analysis to shed light on how the program worked. In both countries, knowledge of the project's primary nutritional messages appears to have had little direct effect on OFSP adoption. Adoption is therefore likely due to a combination of factors: OFSP are not that agronomically different from white sweet potatoes, and people liked to consume them, so it was not difficult to convince producers to produce them for their own consumption in most cases. Since some work is necessary to maintain the vines over time, one lingering question is whether farmers will be able to sustain them over longer periods. Further work is being conducted to study how well farmers were able to maintain vines in the medium term.

We further used causal mediation analysis to understand the role that adoption and increased nutritional knowledge play in explaining increased vitamin A intakes among reference children. Here, the results vary significantly between the two countries. In Mozambique, the increase in vitamin A consumption can be explained almost exclusively through the adoption of OFSP, as defined by households planning to keep vines for the next growing season (in 2010). Nutritional knowledge appears to have played a limited role in promoting vitamin A intakes. In Uganda, adoption was the largest factor in explaining increased vitamin A consumption, but greater nutritional knowledge also played a role in increasing intakes, and a relatively large amount was not explained by either mediation variable. The most plausible explanation is that broader project messages, related to the fact that OFSP is healthy to consume, played an important role in catalyzing consumption by younger children.

Finally, we discussed the implications of our results for the cost-effectiveness of future OFSP promotion programs. Model 2 was clearly more cost-effective than Model 1, and we make suggestions about how future projects might reduce the cost structure by focusing the messages in demand creation and eliminating the marketing component of the intervention. Costs could be further reduced, at least in the short term, if farmers could be more actively induced to share OFSP planting material with non-project members, since the project would then have more beneficiaries. Future research will focus on designing effective mechanisms to induce farmers to share OFSP planting material with others.

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