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Agricultural Commercialization and Nutrition in Smallholder Farm Households

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Abstract

Commercialization of smallholder agriculture is widely seen as an essential pathway towards rural economic growth. While previous studies have analyzed effects of commercialization on productivity and income, implications for farm household nutrition have received much less attention. We evaluate the impact of commercialization on household food security and dietary quality, with a special focus on calorie and micronutrient consumption. We also examine transmission channels by looking at the role of income, gender, and possible substitution between the consumption of own-produced and purchased foods. The analysis builds on survey data from 805 farm households in Western Kenya. A control function approach is used to address issues of endogeneity. Generalized propensity scores are employed to estimate continuous treatment effects. Commercialization significantly improves food security and dietary quality in terms of calorie, zinc, and iron consumption. For vitamin A, effects are positive but statistically insignificant. Commercialization contributes to higher incomes and added nutrients from purchased foods. It does not reduce the consumption of nutrients from own-produced foods, even after controlling for farm size, which can be explained by higher productivity on more commercialized farms. Enhancing market access is important not only for rural economic growth, but also for making smallholder agriculture more nutrition-sensitive.

Key words: commercialization, market access, continuous treatment, nutrition, dietary quality, Africa

JEL *codes*: I15, Q12, Q13, Q18

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Introduction

In spite of global efforts to alleviate hunger and improve nutrition, an estimated 800 million people are still chronically undernourished, and at least 2 billion people suffer from micronutrient deficiencies (FAO 2015; IFPRI 2016). A large proportion of these people are smallholder farmers in developing countries who crucially depend on agriculture as a source of food and income (IFPRI 2016). A key question for improving nutrition is therefore how to make smallholder agriculture more nutrition-sensitive (Pingali 2015; Smith and Haddad 2015; Global Panel on Agriculture and Food Systems for Nutrition 2016).

Much of the recent literature on nutrition-sensitive agriculture focuses on the link between on-farm production diversity and farm household diets (Jones, Shrinivas, and Bezner-Kerr 2014; Sibhatu, Krishna, and Qaim 2015; Koppmair, Kassie, and Qaim 2017; Jones 2017). A few of these studies have also pointed at the importance of markets for improving diets, yet capturing farmers' access to markets only in terms of simple proxies such as market distance (Sibhatu et al.2015; Koppmair et al. 2017). Moreover, the dietary indicators that are typically used have limitations. Most studies use household dietary diversity scores, which are suitable for measuring household food security, but not dietary quality (Kennedy, Ballard, and Dop 2013).

Another strand of the literature has analyzed the effects of agricultural commercialization (hereafter referred to as commercialization) on household welfare. But most studies in this direction look at welfare only in terms of income (Tipraqsa and Schreinemachers 2009; Muriithi, and Matz 2015), not nutrition. Commercialization may influence nutrition through various channels, including changes in income, the availability of own-produced foods, and gender roles within the farm household (von Braun and Kennedy 1994; Carletto et al. 2015). Income gains can increase the economic access to food, but a substitution of purchased food for own-produced food may also change dietary quality, possibly increasing the consumption of calories but not necessarily micronutrients (Popkin, Adair, and Ng 2012; Remans et al.

2015). Changes in gender roles may occur because men often take stronger control of farm production and income during the process of commercialization (von Braun and Kennedy 1994). And male-controlled income is often spent less on dietary quality and nutrition than female-controlled income (Fischer and Qaim 2012).

A few recent studies have analyzed the impact of contract farming and certification programs on household food security and nutrition in different countries of Africa (Chege, Andersson, and Qaim 2015; Chiputwa and Qaim; Bellemare and Novak 2017). But these studies compare farm households that sell in different marketing channels; no differentiation is made between more and less commercialized households. Very few studies have explicitly analyzed effects of commercialization on nutrition, and those that did have looked at nutrition primarily in terms of calorie consumption and child anthropometrics (von Braun and Kennedy 1994; Carletto, Corral, and Guelfi 2017), not dietary quality.

We add to this existing literature by analyzing the effects of commercialization on food security and dietary quality, measured in terms of calorie and micronutrient consumption at the household level. We estimate average and continuous treatment effects and also analyze transmission channels that were hardly addressed in previous studies (Carletto et al. 2017). The analysis builds on a survey of smallholder farmers in Western Kenya. In Kenya, smallholder farming accounts for 75% of total agricultural output (Olwande et al. 2015). As in most other countries of Sub-Saharan Africa, issues of poverty and malnutrition are widespread in the small farm sector (Muthayya et al. 2013; KNBS 2015).

The rest of this article is organized as follows. The next section presents a small conceptual framework to explain expected transmission channels for effects of commercialization on farm household nutrition. This is followed by a description of the empirical estimation strategies and the data, before the estimation results are presented and discussed. The last section concludes.

Conceptual Framework

Figure 1 shows a simple conceptual framework that will guide the empirical analysis. Commercialization can affect farm household nutrition through various transmission channels. Market sales can reduce the availability of own-produced foods and thus limit consumption through the subsistence pathway. A fall in total food consumption may be prevented through food purchases from the market that become possible through higher cash earnings. Research shows that commercialization is typically associated with income gains through agricultural intensification and use of better technology (von Braun and Kennedy 1994; Muriithi, and Matz 2015). Commercialization may also influence the types of crops grown or the livestock species kept on the farm. Closer market integration allows farmers to better harness their comparative advantage, so that higher levels of specialization are generally expected. A focus on the production of non-food cash crops could further reduce the availability of own-produced foods. Yet, in specific situations, it is also possible that farmers further diversify production, especially when markets for certain niche products that are not traditionally grown for own consumption emerge (Tipraqsa and Schreinemachers 2009).

Figure 1 (about here)

In an African context, levels of commercialization, types of crops grown, and technologies used can also have important effects on gender roles within the farm household. Subsistence food crops are often produced and controlled by women, whereas crops that are primarily produced to generate cash income are typically controlled by men (von Braun et al. 1994; Fischer and Qaim 2012). Research shows that female-controlled income is often particularly beneficial for household nutrition, as women tend to spend more on food, dietary quality, and healthcare than men (Hoddinott and Haddad 1995; Chege et al. 2015). Hence, commercialization may possibly have a negative partial effect on household nutrition through this gender pathway.

To better understand the role of the different transmission channels and the overall effect of commercialization on farm household nutrition, crucial questions are to what extent own-produced food is replaced by purchased food, and whether this shift makes diets more or less nutritious from a calorie and micronutrient perspective. It is often assumed that the subsistence pathway is particularly important for dietary quality, because purchased food is felt to be more processed and less nutritious, even though the evidence base for this assumption is relatively thin (Remans et al. 2015; Jones 2017). We will analyze these questions explicitly in the empirical analysis below.

Estimation Strategy

Basic Model

We start the analysis by estimating the overall effect of commercialization on nutrition with regression models of the following type:

(1) $$N_i = \alpha_0 + \alpha_1 C_i + \alpha_2 \mathbf{X}_{i1} + \varepsilon_{i1},$$

where N_i is the nutrition indicator for household *i*, C_i is the level of commercialization, $\mathbf{X}_i$ is a vector of control variables, and ε_{i1} is a random error term. We use different nutrition indicators (N_i), such as calorie and micronutrient consumption levels, and estimate separate regressions for all of them. Details of these indicators are described further below. The level of commercialization (C_i) is defined as a continuous variable ranging between zero (complete subsistence) and one (fully commercialized). Control variables ($\mathbf{X}_i$) include age, gender, and education of the household head, as well as other farm, household, and contextual variables that may affect diets and nutrition.

In this model, we are particularly interested in the treatment effect α_1. Positive and significant estimates for α_1 would mean that commercialization contributes to improved nutrition, and vice versa. It is possible that the sign of α_1 differs between the nutrition indicators. For instance, if it is true that households substitute energy-dense purchased foods for more nutritious own-produced foods we would expect a positive coefficient α_1 in the calorie consumption model and possibly negative coefficients in the micronutrient consumption models.

Addressing Possible Issues of Endogeneity

If $\mathbf{X}_i$ in equation (1) includes all the factors that influence commercialization, and there is no correlation between C_i and ε_{i1}, then ordinary least squares (OLS) would produce unbiased estimates of α_1. However, it is certainly possible that there are unobserved factors that jointly influence C_i and N_i, which would lead to endogeneity bias. For instance, unobserved heterogeneity could occur through differences in farmers' ability or entrepreneurial skills, which are difficult to measure in household surveys.

We test for potential endogeneity of the commercialization variable (C_i) through a control function approach (Smith and Blundell 1986; Rivers and Voung 1988). This approach entails predicting residuals from a first-stage model of the determinants of commercialization, and including the predicted residual term as an additional regressor (a control function) in the nutrition outcome model in equation (1). This control function approach requires at least one valid instrument in the first-stage regression. A statistically significant coefficient of the predicted residual term in equation (1) would imply that commercialization is endogenous and would also correct for the resulting bias. An insignificant residual term would fail to reject the null hypothesis of exogeneity of C_i. In that case, OLS would be preferred. Since C_i is bounded between zero and one, we estimate the first-stage regression using a generalized linear model (GLM) with a binomial family and a logit link. This is important to obtain consistent residual predictions for use in the second stage (Papke and Wooldridge 1996).

Choice of Instrument

As mentioned, the control function approach requires at least one instrument for inclusion in the first-stage regression. A valid instrument must be strongly correlated with commercialization (instrument relevance), but uncorrelated with omitted variables that may affect nutrition (instrument exogeneity), except indirectly through commercialization (Imbens and Wooldridge 2009). Finding a good instrument can be quite challenging (Stock, Wright, and Yogo 2002), but we were able to identify one instrument for commercialization that fulfills all the requirements. The instrument used is the average number of motorcycles owned by households living in in the same ward. A ward is an administrative unit in Kenya that is larger than a village, but smaller than a sub-county. As is explained below, our survey covered 26 wards in 2 different counties and 8 sub-counties. The average number of households in each ward is 31. The instrument was constructed by counting the number of motorcycles owned by sample households in each ward and then dividing by the number of households to obtain an average. In the following, we explain why this is a strong and valid instrument for commercialization.

Over 90% of the farmers in our sample do not own any motorized means of transportation (the average number of motorcycles owned by households is 0.08). Nevertheless, the distance to the market is often too far to make sales without a motor vehicle. As most of the local roads are not paved and public transport services hardly exist, owners of motorcycles tend to offer transport services also for other households living in the same area. Farmers themselves often use these services, as well as local traders who buy at the farm gate and sell in the marketplace. Hence, more motorcycles in the ward mean better market access. Indeed, the average number of motorcycles in the ward is significantly correlated with the degree of commercialization (see results below), which is the condition for instrument relevance.

As we use the average number of motorcycles owned by households in the ward, rather than individual ownership, the instrument is not directly correlated with any of the household nutrition variables used in this analysis. Nor is the instrument significant when included as an additional regressor in equation (1). Results of these tests are shown in table A1 in the appendix. Nevertheless, one could imagine that the number of motorcycles could also be a proxy for higher levels of wealth and income in the ward, which could influence nutrition through various hidden channels. To test for this possibility, we correlated the instrument with various indicators of living standard and wealth at the ward level, such as average education, household income, farm size, and other productive assets. All of the correlation coefficients are very small and none of them is statistically significant (table A2 in the appendix). Hence, the condition for instrument exogeneity is also fulfilled.

Analyzing Transmission Channels

As discussed above, important questions to better understand the transmission channels between commercialization and nutrition are to what extent purchased foods are substituted for own-produced foods and how this affects dietary quality. To analyze this in more detail, we re-estimate the models in equation (1), but this time differentiating between calories and micronutrients from purchased and own-produced foods. If households primarily purchase energy-dense foods in the market, we would expect a positive effect of commercialization on calorie consumption, but not necessarily micronutrient consumption from purchased foods. On the other hand, the effects of commercialization on calorie and micronutrient consumption from own-produced foods will depend on possible changes in farm productivity and production diversity. For these models, the control function approach is also employed.

Beyond analyzing possible substitution effects in household food sources, we are also interested in better understanding the role of the income and gender pathways that were discussed above. We model these pathways explicitly with the following equations:

(2) $$N_i = \beta_0 + \beta_1 Y_i + \beta_2 G_i + \beta_3 \mathbf{X}_i + \varepsilon_{i2},$$

(3) $$Y_i = \delta_0 + \delta_1 C_i + \delta_2 \mathbf{X}_i + \varepsilon_{i3},$$

(4) $$G_i = \gamma_0 + \gamma_1 C_i + \gamma_2 \mathbf{X}_i + \varepsilon_{i4}.$$

Equation (2) models nutrition (N_i) as a function of household income (Y_i) and gender roles within the household (G_i), measured in terms of a dummy that takes a value of one if a male household member controls the farm revenues, and zero otherwise. Given the discussion in the conceptual framework section, we would expect a positive coefficient estimate for β_1 and a negative estimate for β_2. In equations (3) and (4), income and gender roles are considered endogenous and modeled as a function of commercialization (C_i). We would expect positive coefficient estimates for δ_1 and γ_1, meaning that commercialization increases household income and the likelihood of male control of farm revenues. In all three equations we control for other socioeconomic variables ($\mathbf{X}_i$). We estimate equations (2) and (3) with OLS, and equation (4) with linear probability and probit estimators. The results of these models will be interpreted cautiously in terms of associations, not causality, because of the endogeneity of Y_i and G_i.

Continuous Treatment Effects

The models in equations (1) to (4) help to establish the average treatment effects of commercialization on nutrition and the underlying transmission channels. But commercialization is a continuous treatment variable, and it is possible that the effects vary by level of commercialization. For instance, when a subsistence farm starts to make the first market sales, the marginal effects on calorie and micronutrient consumption may be higher or lower than when a farm that already sells much of its produce further increases the level of commercialization. To account for possible non-linearity, we additionally use the generalized propensity score (GPS) approach to estimate continuous treatment effects of commercialization (Hirano and Imbens 2004; Kluve et al. 2012; Guardabascio and Ventura 2014). As also true for propensity score approaches with binary treatment variables, the GPS method controls for observed heterogeneity between households with different treatment exposure, but not for possible unobserved heterogeneity.

The GPS approach involves three stages (Kassie, Jaleta and Mattei 2014). At the first stage, the generalized propensity scores are generated based on observed covariates. Given the nature of C, we estimate the GPS using GLM with a binomial family and a logit link (fractional logit). The first stage also involves testing covariate balancing properties. At the second stage, the conditional expected values of the outcome variables (nutrition indicators) are estimated as a function of treatment exposure (level of commercialization) and the GPS. For these estimates, we use a flexible function with quadratic approximation. Given that the nutrition indicators are continuous variables, these models are estimated with OLS. At the last stage, the average dose-response function is estimated. The dose-response function depicts for every treatment exposure level the direction and magnitude of the causal relationship between commercialization and nutrition, after controlling for any observed covariate bias (Hirano and Imbens 2004).

We estimate the dose-response function by averaging the expected nutrition outcome at each level of commercialization (C) as follows:

$$(5) \qquad E\left[\hat{N}_i(C)\right] = \frac{1}{n}\sum_{i=1}^{n} \left[\hat{\alpha}_0 + \hat{\alpha}_1 C + \hat{\alpha}_2 C^2 + \hat{\alpha}_3 \hat{r}(C, \mathbf{X}_i) + \hat{\alpha}_4 \hat{r}(C, \mathbf{X}_i)^2 + \hat{\alpha}_5 C \hat{r}(C, \mathbf{X}_i)\right],$$

where n is the number of observations, the $\hat{\alpha}$ values are parameters estimated at the second stage, and $\hat{r}(C, \mathbf{X}_i)$ is the predicted value of the conditional density of treatment at varying levels of commercialization. Results of the dose-response functions are presented graphically.

Data and Variable Measurement

Farm Household Survey

This study builds on data collected from a survey of smallholder farmers conducted in Kisii and Nyamira counties in Western Kenya between October and December 2015. Given the high population density in Western Kenya, farms in the study area are very small with an average farm size of about 1.6 acres. In terms of nutritional indicators, Kisii and Nyamira are similar to the national average in Kenya (KNBS 2015). The prevalence of child stunting, the most common anthropometric measure of child undernutrition, is around 26% in both counties (KNBS 2015).

A recent census of farm households in Kisii and Nyamira is not available. However, many farmers are organized in farmer groups or self-help groups, and these groups are registered with the Ministry of Gender, Children, and Social Development. We therefore decided to cluster our survey by farmer groups. Together with Africa Harvest, a non-governmental organization active in the region, we constructed a list of all existing groups in Kisii and Nyamira, yet deliberately excluding a few that had received specific development support during the last two years. From this list, we randomly selected 48 groups. The groups vary in size, most of them had around 20-30 members. Prior to the survey, we updated group membership lists together with the group leaders. Depending on group size, we randomly selected 15-20 member households from each group, resulting in a total sample size of 824 farm households, distributed over 8 different sub-counties and 26 wards. The sample is representative of farm households that are organized in farmer groups or self-help groups in this part of Kenya.

Data from sample households were collected through face-to-face interviews carried out in the local language with the household head and/or the spouse. A carefully designed and pretested questionnaire was used, capturing details on household demographics, agricultural production and marketing, other economic activities of the household, food and non-food consumption and expenditures, and contextual characteristics. For a few of the sample households, relevant variables are missing. The analysis is carried out with observations from 805 households for which complete data are available.

Measuring Nutrition

To assess the effects of commercialization on household nutrition, we need appropriate nutrition indicators. There are various ways to assess nutrition at individual and household level, including clinical measures, anthropometric measures, and food consumption-based measures, among others (de Haen, Klasen, and Qaim 2011; Masset et al. 2012; IFPRI 2016). Clinical and anthropometric measures are the most precise indicators of individual nutrition status, but they are less suitable to assess details of people's food sources and dietary quality, which is the focus of our study. Hence, we use household food consumption data, based on which we calculate various measures of food security and dietary quality.

The survey questionnaire included a food consumption recall, capturing the quantity of more than 130 different food items consumed by all household members over a period of 7 days. Survey respondents were also asked to specify the source of each food item consumed, including market purchases, own production, gifts, and other sources. To increase data accuracy, this part of the questionnaire was carried out with the person responsible for food preparation in the household. Based on the food quantities consumed by the household, we calculated edible portions, which were then converted to calorie and micronutrient levels using food composition tables for Kenya (Sehmi 1993). For individual food items not included in these tables, we used food composition tables for neighboring Tanzania (Lukmanji et al. 2008). In terms of micronutrients, we focus on vitamin A, zinc, and iron. Deficiencies in vitamin A, zinc, and iron pose serious health challenges in many developing countries, so that consumption levels of these three micronutrients are considered important proxies of healthy diets and nutrition (Chege et al. 2015; IFPRI 2016).

We divided calorie and micronutrient consumption at household level by adult equivalents (AE) to make the values comparable across households of different size (Chiputwa and Qaim 2016). These consumption values per AE are the nutrition indicators (N_i) used as outcome variables in the econometric models. For the descriptive analysis, we calculate a few additional indicators to further illustrate the local nutrition situation. We use minimum consumption thresholds to characterize undersupplied households (FAO, WHO, and UNU 2001; IOM 2006). A household is considered to be undernourished when it consumes less than 2400 kcal per AE and day. A household is deficient in vitamin A when it consumes less than 625 µg of retinol equivalents (RE). For zinc and iron, the thresholds are 15.0 mg and 18.3 mg, respectively.

Using household-level data on food consumption from a single 7-day recall has certain limitations (de Haen et al. 2011). The approach measures food availability, not actual food intake. Furthermore, differences in seasonality and intra-household distribution are not accounted for. However, these limitations equally apply to all households, with higher and lower levels of commercialization, so that we do not expect any systematic bias in the impact analysis.

For the descriptive analysis, we also construct two simpler nutrition-related indicators that were used in the recent literature on linkages between farm production diversity and dietary diversity (Jones et al. 2014; Sibhatu et al. 2015; Koppmair et al. 2017). First, we compute the household dietary diversity score (HDDS), which counts the number of food groups consumed during the 7-day recall period. The maximum number of food groups in the HDDS is 12 (Sibhatu et al. 2015). The higher the value, the better is the household's general access to food (Kennedy, Ballard and Dop 2013). Second, we compute a different dietary diversity score with a maximum of 10 food groups (DDS10). The DDS10 places higher emphasis on food groups that are important from a micronutrient perspective and is therefore a better proxy of dietary quality (FAO and FHI 360 2016).

Measuring Commercialization

Following von Braun and Kennedy (1994) and Carletto et al. (2017), we construct a commercialization index defined as the share of the total value of farm output sold (value of output sold divided by value of total farm output). This includes both crop and livestock products. The commercialization index is a continuous variable ranging between zero and one. As there are only very few farm households that sell zero farm output, this continuous index is considered more appropriate for the analysis than a binary commercialization variable. For the construction of the index, price data are required to value the quantities of farm output. Prices may vary, even for identical commodities, and they are not observed for all households. For better comparison, we use average sales prices reported by sample households to value farm output.

For a robustness check, we also compute three other measures of commercialization. First, we use a maize commercialization index, calculated as the share of total maize production sold (in quantity terms). Maize is the most important staple food in Kenya and is widely grown by sample households primarily for home consumption. Second, we use a crop commercialization index, computed as the share of total crop output sold (in value terms). Third, we use a livestock commercialization index, computed as the share of total livestock products sold (in value terms).

Descriptive Statistics

Socioeconomic Characteristics

Table 1 presents summary statistics for the full sample, as well as differentiating by level of commercialization. For the descriptive part, we subdivide the sample into commercialization quartiles and compare the 25% least commercialized households (LC25%) with the 25% most commercialized households (MC25%).

(Table 1 about here)

The average household sells 44% of its total farm output. This share ranges between 16% for the least commercialized and 70% for the most commercialized households. As one could expect, the level of commercialization is positively associated with farm size, education, household income, and several other socioeconomic variables. More commercialized farms also use more inputs, such as fertilizers and pesticides, and they have significantly higher land productivity. Sample farms are highly diversified, producing around 13 different crop and livestock species on average. Such a high level of farm diversity is typical for many regions in Africa (Sibhatu et al. 2015). Sample farms produce a number of different food crops, such as maize, beans, sweetpotatoes, bananas, and different types of leafy vegetables. Many also keep chicken, sheep, goats, and sometimes cattle. In terms of cash crops, tea, coffee, and sugarcane are grown by many farmers. Strikingly, more commercialized households are more diversified than less commercialized households, suggesting that under the given conditions commercialization does not lead to higher levels of farm specialization.

Nutrition Indicators

Table 2 shows summary statistics for the nutrition indicators. Around 27% of the sample households are undernourished (calorie-deficient). Even higher proportions are deficient in zinc, iron, and vitamin A, pointing at sizeable nutritional problems. More commercialized households consume significantly higher amounts of calories and micronutrients. Thus, they are also less affected by nutritional deficiencies than less commercialized households. Only for vitamin A deficiency, the difference is not statistically significant. The different dietary diversity scores also confirm better access to food and higher dietary quality among more commercialized households.

(Table 2 about here)

Figure 2 shows a breakdown of the sources of household calorie and micronutrient consumption. For calorie, zinc, and iron supply, market purchases are as important as, or even more important than own production. This is true even for the least commercialized households. Interestingly, for more commercialized farms the role of own production for household diets does not decrease. This is a first indication that the cash income generated through output sales may be used to buy additional food, rather than replacing own-produced food. Higher productivity on more commercialized farms means that more market sales do not necessarily entail lower availability of food for home consumption. Only for vitamin A, the situation is somewhat different. Own production plays the dominant role for vitamin A consumption, especially in the least commercialized households. Tables A3-A5 in the appendix show further details of which food groups are particularly important for micronutrient consumption from market and own-produced sources.

(Figure 2 about here)

Econometric Results

Endogeneity Tests

We start the discussion of the estimation results by looking at the tests for endogeneity of commercialization. As explained in the empirical strategy section, we use a control function approach with the average number of motorcycles owned by households in the ward as the instrument. The first-stage results with commercialization as dependent variable are shown in the first column of table 4. The coefficient estimates for the residual terms included in the second-stage equations are shown in table 3, for the total calorie and micronutrient consumption models, as well as for the models that distinguish between the consumption of purchased and own-produced foods. In all models, the residual-terms are statistically insignificant. Hence, we cannot reject the null hypothesis that commercialization is exogenous in the second stage. Based on these test results, we proceed with OLS.

(Table 3 about here)

Basic Model Results

The estimation results of the basic model with total calorie and micronutrient consumption levels as dependent variables are shown in table 4. Commercialization has positive and significant effects on all nutrition indicators, except for vitamin A where the estimated coefficient is positive but not statistically significant. The commercialization index ranges between zero and one. The results suggest that a 10 percentage point increase in the level of commercialization increases the consumption of calories by 69.6 kcal, of zinc by 0.35 mg, and of iron by 0.55 mg per AE and day. These effect sizes imply increases of 23-30% over the mean consumption levels of the least commercialized households. These are sizeable effects, supporting the hypothesis that commercialization improves farm household nutrition.

(Table 4 about here)

Purchased and Own-Produced Foods

Tables 5 and 6 show results where the nutrition indicators are disaggregated by the consumption of calories and micronutrients from purchased and own-produced foods. The results in table 5 suggest that commercialization has positive and significant effects on the consumption of calories and all three micronutrients from purchased foods. A 10 percentage point increase in the level of commercialization increases calorie consumption from purchased foods by 40.0 kcal, vitamin A consumption from purchased foods by 27.0 µg, zinc consumption by 0.25 mg, and iron consumption by 0.34 mg per AE and day. An obvious interpretation is that the additional cash income generated through farm output sales improves households' economic access to food and dietary quality. More commercialized households do not only purchase cheap calories, but also food items that contribute to improved micronutrient consumption, such as vegetables, fruits, and meat. Particularly noteworthy in table 5 is the positive effect of commercialization on vitamin A consumption, which is largely due to more purchases of leafy vegetables and vitamin A-rich fruits (see table A4 in the appendix).

(Table 5 about here)

Table 6 shows that commercialization has positive and significant effects on the consumption of calories from own-produced foods. For the consumption of micronutrients from own-produced foods, no significant effects are observed. This is interesting, because – ceteris paribus – higher sales of farm outputs could mean lower availability of food and nutrients for home consumption. That such a decrease in the consumption of own-produced foods is not observed is due to higher yields on more commercialized farms. As was shown in Table 1, the level of commercialization is positively correlated with input use and land productivity. And, as was also shown in Table 1, commercialization in the study region does not mean that farmers would grow fewer food crops.

(Table 6 about here)

These results imply that commercialization does not lead to a simple substitution of purchased for own-produced foods. More commercialized households rather add purchased foods to their diets, without reducing the consumption of own-produced foods. This may be a risk-coping strategy in the presence of market failures. Maintaining a certain level of subsistence is a typical response of households to reduce vulnerability to market risk.

Income and Gender Pathways

The positive effects of commercialization on the consumption of calories and micronutrients from purchased foods already suggest that the cash income pathway plays an important role. This is now analyzed more explicitly in table 7. The first column in table 7 reveals a significantly positive association between the level of commercialization and household income. Controlling for other factors, a 10 percentage point rise in the level of commercialization is associated with 23.5 thousand Ksh higher income (26% of mean household income of the least commercialized households). And the other columns in table 7 confirm that gains in household income are significantly associated with higher calorie and micronutrient consumption.

(Table 7 about here)

To evaluate possible effects of commercialization on gender roles, we look at who within the household controls the revenues from farm output sales. But most households sell different outputs, and the control of revenues can differ between commodities. Revenues from typical cash crops are often controlled by men, whereas for revenues from food crops the situation is more diverse. Hence, calculation of a single variable that captures gendered revenue control across households and commodities is not straightforward. For this part of the analysis, we decided to focus only on one commodity, namely maize as the main staple food in the study region. Most sample households cultivate maize for home consumption, about one-quarter of the households sell maize in order to generate cash income. For this maize-selling subsample, we constructed a dummy variable that takes a value of one if a male household member controls maize revenues, and zero otherwise.

Table 8 presents estimation results of models with this gender control dummy as dependent variable. Two specifications are shown, a linear probability and a probit model. Both specifications lead to similar results; the level of commercialization is positively and significantly associated with male control of maize revenues. This is consistent with earlier research showing that commercialization can be associated with women losing control of crop revenues (von Braun and Kennedy 1994; Chege et al. 2015). For the same subsample, Table 9 shows that male control of revenues is associated with lower consumption of calorie, vitamin A, and zinc from purchased foods. In other words, women spend more on food and dietary quality than men, which seems to be especially relevant for vitamin A. As the models in table 9 control for total household income, this negative gender pathway is a partial effect, which does not imply that the total effect of commercialization on nutrition is negative. But the analysis clearly suggests that the total nutrition effects of commercialization were even more positive if the loss of female control of revenues could be prevented.

(Table 8 about here)

(Table 9 about here)

Robustness Checks

To test the robustness of the results, we re-estimate all models in tables 4-6 using alternative indicators of commercialization. Full estimation results of these alternative models are shown in tables A6 to A14 in the appendix. The estimated treatment effects are summarized in table 10, in comparison to the originally estimated effects with the overall commercialization index. Regardless of the commercialization indicator used, the effects on total calorie, zinc, and iron consumption are positive and significant. The other results are also similar to the ones obtained with the overall commercialization index; in most cases, higher levels of commercialization increase the consumption of calories and micronutrients from purchased foods in particular, without significantly decreasing the consumption of own-produced foods.

This underlines the robustness of the estimation results to changes in the commercialization indicator.

(Table 10 about here)

Beyond these general patterns, Table 10 also provides a few additional insights. For maize commercialization, the positive effects on calorie, zinc, and iron consumption from own-produced foods are stronger than those from purchased foods. Maize is the main staple food, so it is not surprising that higher maize production also leads to higher consumption of this crop, especially in undernourished households. Another interesting finding is the positive and significant effect of livestock commercialization on vitamin A from own-produced foods. Meat and eggs are important sources of vitamin A, and households that produce and sell more of these products also tend to consume additional quantities. This is noteworthy, because vitamin A consumption is less responsive to income growth than the consumption of most other nutrients, and thus more difficult to control. The estimates suggest that the promotion of livestock production and marketing could be a good entry point for reducing vitamin A malnutrition.

Continuous Treatment Effects

We now estimate continuous treatment effects with the generalized propensity score (GPS) approach. On the one hand, this helps to further test the robustness of the general findings. On the other hand, accounting for the possibility of non-linear effects can also provide additional insights. Results of the GLM model with the level of commercialization as dependent variable are shown in table A15 in the appendix. This model is used to calculate the propensity scores. Table A16 in the appendix shows covariate balancing tests, comparing four different treatment groups that vary in their level of commercialization. Before matching, many of the covariates for these four groups differ significantly. After matching, most of the differences are statistically insignificant. For the GPS analysis, we exclude 21 untreated households to avoid misleading results (Guardabascio and Ventura 2014).

Figures 3-6 present the estimated dose-response functions. The consumption of total calories, zinc, and iron increases continuously with the level of commercialization, which is consistent with the parametric results discussed above. For zinc, a consumption maximum is reached at a commercialization level of about 0.7 (Figure 5). Yet, this maximum is above the recommended minimum consumption of 15.0 mg of zinc per day, so a slight reduction beyond that point is not of nutritional concern. For calories, zinc, and iron, the consumption increases from purchased foods are also continuous, whereas the consumption from own-produced foods follows an inverse U-shape with increasing levels of commercialization. This is plausible: beyond a certain level of commercialization and dietary intake, the risk-coping function of own-produced foods loses in importance, so that the degree of subsistence can be reduced.

(Figures 3-6 about here)

We now turn to the discussion of the vitamin A results, which are different from those for calories, zinc, and iron. The parametric results above did not find a significant effect of commercialization on total vitamin A consumption. The non-parametric results in Figure 4 provide interesting additional insights. The non-linear dose-response function in the left panel of Figure 4 shows that total vitamin A consumption decreases at low levels of treatment exposure (commercialization), whereas for commercialization levels above 0.5 positive treatment effects are observed. The middle and right panels of Figure 4 explain this non-linear effect: at low levels of treatment exposure, the decrease in vitamin A consumption from own-produced foods is stronger than the increase from purchased foods. This comparison is reversed at higher levels of commercialization. These results clearly suggest that vitamin A nutrition receives special attention during the process of commercialization.

Conclusion

Previous studies have shown that commercialization can improve productivity and income for smallholder farmers. Effects of commercialization on smallholder nutrition are less understood. Very few studies have looked at this relationship, and those that did have rendered mixed results (von Braun and Kennedy 1994; Carletto et al. 2017). While von Braun and Kennedy showed positive nutrition effects of commercialization, Carletto et al. (2017) mostly found insignificant effects. None of these existing studies has explicitly looked at dietary quality, as we did here. Furthermore, we have added to the literature by not only looking at the treatment effects, but also analyzing the underlying transmission channels.

Using survey data from smallholder farm households in Western Kenya, we have shown that commercialization has positive effects on food security and dietary quality. Higher levels of commercialization significantly contribute to improved calorie, zinc, and iron consumption. For vitamin A consumption, the effects of commercialization were found to be insignificant. The positive effects for most dietary indicators are primarily due to rising cash incomes, allowing households to purchase more food from the market. However, rather than substituting for own-produced foods, purchased foods are added to the diet with increasing levels of commercialization. Hence, commercialization contributes to higher levels of dietary diversity. That commercialized households continue to also rely on own-produced foods is probably attributable to market risk; maintaining a certain level of subsistence is a typical strategy of smallholders to better cope with unpredictable market developments. Only for highly commercialized farms, the role of own-produced foods in household diets starts to decrease.

We have also analyzed how commercialization may affect gender roles within farm households. As hypothesized, commercialization leads to a higher share of farm revenues being controlled by male household members. And this shift from female to male control has negative partial effects on the consumption of calories and micronutrients, especially vitamin A. These results confirm earlier research showing that women tend to spend more on dietary quality and nutrition than men (Hoddinott and Haddad 1995; Fischer and Qaim 2012).

Overall, we conclude that commercialization can contribute significantly to improved nutrition in the small farm sector. An important policy implication is that enhancing market access is a key strategy to make smallholder agriculture more nutrition-sensitive. The role of women should receive particular attention. The evidence suggests that women may lose decision-making power with increasing levels of commercialization, but this may possibly be prevented through more gender-sensitive approaches and awareness-building initiatives. We also stress that commercialization alone will not suffice to address all types of malnutrition. Commercialization helps to increase cash income, but the consumption of certain micronutrients – such as vitamin A – does not seem to be particularly responsive to income growth. Hence, more specific, complementary interventions may also be needed.

While several tests confirmed the robustness of our findings, a few limitations remain. First, the analysis relies on cross-sectional data, which limits the strength of the identification strategy. Follow-up studies with panel data and observed changes in the level of commercialization over time would be very useful. Second, the 7-day food consumption data provide a reasonable snapshot of dietary quality at the household level, but to analyze issues of seasonality and intra-household distribution would require higher-frequency data collected for individuals within each household. Finally, the results are context-specific and should not be generalized. Further research is needed to provide more insights on the nutrition effects of smallholder commercialization in different settings.

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Table 1. Summary Statistics by Level of Commercialization

Variable	Full sample Mean	LC25% Mean	MC25% Mean	Mean Difference
Socioeconomic characteristics				
Commercialization (share of farm output sold, 0-1)	0.44	0.16	0.70	-0.55***
	(0.21)	(0.09)	(0.09)	
Age of household head (years)	49.27	48.34	48.35	-0.01
	(12.57)	(13.63)	(11.22)	
Male household head (dummy)	0.77	0.67	0.82	-0.14***
	(0.42)	(0.47)	(0.39)	
Education of household head (years)	8.94	7.80	9.69	-1.89***
	(3.77)	(4.09)	(3.19)	
Household size (adult equivalents)	3.99	3.89	3.92	-0.03
	(1.58)	(1.63)	(1.62)	
Farm size (acres)	1.61	1.14	2.04	-0.90***
	(1.27)	(0.95)	(1.55)	
Motorcycles per household in ward (number)	0.08	0.08	0.10	-0.02***
	(0.05)	(0.05)	(0.06)	
Farm productive assets (1,000 Ksh)	19.93	15.54	23.78	-8.24***
	(23.69)	(20.84)	(25.43)	
Household income (1,000 Ksh/year)	180.53	90.69	281.36	-190.67***
	(218.46)	(103.12)	(285.81)	
Off-farm income (dummy)	0.81	0.81	0.78	0.04
	(0.39)	(0.39)	(0.42)	
Access to credit (dummy)	0.78	0.69	0.80	-0.11**
	(0.41)	(0.46)	(0.40)	
Distance to the closest market (km)	4.91	4.97	4.60	0.37
	(7.01)	(7.53)	(5.25)	
Distance to the closest extension agent (km)	4.34	5.52	3.89	1.63***
	(4.93)	(5.40)	(4.67)	
Household head/spouse is a group official (dummy)	0.35	0.28	0.41	-0.13***
	(0.48)	(0.45)	(0.49)	
Farm productivity and input use				
Value of crop output (1,000 Ksh/acre)	87.68	70.32	105.13	-34.80***
	(105.29)	(97.12)	(110.42)	
Seed cost (Ksh/acre)	3184.90	3018.04	3212.07	-194.03
	(3892.72)	(2411.09)	(3792.63)	
Fertilizer cost (Ksh/acre)	6269.29	5383.40	6569.09	-1185.69**
	(5479.26)	(4515.33)	(6338.84)	
Manure cost (Ksh/acre)	708.89	608.87	666.33	-57.46
	(2958.03)	(2171.11)	(2794.36)	
Pesticide cost (Ksh/acre)	659.72	330.46	911.25	-580.79***
	(1626.87)	(1080.75)	(2038.22)	
Farm production diversity				
Production diversity (no. of crop/livestock species)	12.87	11.68	13.12	-1.45***
	(4.66)	(4.40)	(4.94)	
Food crop production diversity (no. of food crop species)	8.01	7.56	7.99	-0.42
	(3.07)	(3.07)	(3.30)	
Livestock production diversity (no. of livestock species)	3.11	2.76	3.22	-0.46
	(2.97	(2.86)	(3.11)	
Farm production diversity (no. of food crop/livestock species)	11.11	10.33	11.21	-0.88**
	(4.39)	(4.06)	(4.72)	
Observations	805	202	201	403

Note: Standard deviations are shown in parentheses. LC25%, 25% least commercialized households; MC25%, 25% most commercialized households; Ksh, Kenyan shillings; 1 US dollar = 96.3 Ksh. Value of farm productive assets excludes motorcycle to avoid possible endogeneity problems in the control function models. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table 2. Summary Statistics of Nutrition Indicators by Level of Commercialization

Variable	Full sample Mean	LC25% Mean	MC25% Mean	Mean difference
Total calorie consumption (kcal/day/AE)	3286.06	2973.07	3584.42	-611.35***
	(1273.73)	(1065.46)	(1294.94)	
Prevalence of undernourishment (%)	26.58	33.66	17.91	15.75***
	(44.21)	(47.37)	(38.44)	
Total vitamin A consumption (μg RE/day/AE)	1242.55	1140.09	1406.09	-266.01*
	(1393.24)	(1231.14)	(1542.6)	
Prevalence of vitamin A deficiency (%)	36.65	37.62	33.33	4.29
	(48.21)	(48.56)	(47.26)	
Total zinc consumption (mg/day/AE)	19.67	18.25	21.07	-2.82***
	(8.70)	(7.67)	(8.72)	
Prevalence of zinc deficiency (%)	32.42	40.10	24.38	15.72***
	(46.84)	(49.13)	(43.04)	
Total iron consumption (mg/day/AE)	22.10	18.61	25.04	-6.43***
	(13.31)	(9.76)	(15.21)	
Prevalence of iron deficiency (%)	47.20	56.93	40.30	16.63***
	(49.95)	(49.64)	(49.17)	
Household dietary diversity score (HDDS)	9.42	9.03	9.57	-0.54***
	(1.44)	(1.58)	(1.34)	
Dietary diversity score, 10 food groups (DDS10)	7.00	6.76	7.24	-0.48***
	(1.54)	(1.67)	(1.35)	
Observations	805	202	201	403

Note: Standard deviations are shown in parentheses. LC25%, 25% least commercialized households; MC25%, 25% most commercialized households; AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table 3. Testing for Endogeneity of Commercialization Using Control Function Approach

Nutrition indicators	Coefficient	*p*-value	Conclusion
Total calories consumed (kcal/day/AE)	26.784 (481.880)	0.956	Exogenous
Calories from purchased food (kcal/day/AE)	-41.071 (397.564)	0.918	Exogenous
Calories from own-produced food (kcal/day/AE)	58.605 (419.217)	0.889	Exogenous
Total vitamin A consumed (μg RE/day/AE)	-571.580 (779.305)	0.464	Exogenous
Vitamin A from purchased food (μg RE/day/AE)	139.391 (223.592)	0.533	Exogenous
Vitamin A from own-produced food (μg RE/day/AE)	-355.944 (523.982)	0.497	Exogenous
Total zinc consumed (mg/day/AE)	-3.615 (3.648)	0.322	Exogenous
Zinc from purchased food (mg/day/AE)	-2.752 (2.705)	0.309	Exogenous
Zinc from own-produced food (mg/day/AE)	0.169 (3.091)	0.956	Exogenous
Total iron consumed (mg/day/AE)	6.637 (6.112)	0.278	Exogenous
Iron from purchased food (mg/day/AE)	1.760 (4.419)	0.690	Exogenous
Iron from own-produced food (mg/day/AE)	4.891 (4.379)	0.264	Exogenous

Note: Coefficients of the residual terms included in the model in equation (1) are shown with robust standard errors in parentheses.

Table 4. Determinants of Commercialization and Commercialization Effects on Total Calorie and Nutrient Consumption

Variable	GLM Commer-cialization	OLS Calories (kcal/day/AE)	OLS Vitamin A (µg RE/day/AE)	OLS Zinc (mg/day/AE)	OLS Iron (mg/day/AE)
Commercialization		696.278***	134.149	3.505**	5.506**
		(199.724)	(263.351)	(1.400)	(2.285)
Motorcycles per household in ward	1.681**				
	(0.711)				
Age of household head (years)	0.004	5.797	4.869	-0.020	-0.003
	(0.003)	(3.552)	(4.364)	(0.028)	(0.043)
Age squared (years)	-0.001***	0.267	-0.236	0.001	-0.001
	(0.000)	(0.237)	(0.271)	(0.002)	(0.003)
Male household head (dummy)	0.107	-57.890	112.687	-3.188***	0.801
	(0.078)	(106.080)	(107.580)	(0.831)	(1.117)
Education of household head (years)	0.021**	39.666***	15.314	0.211**	0.486***
	(0.009)	(11.814)	(14.745)	(0.095)	(0.143)
Household size (AE)	-0.057***	-363.127***	-100.187***	-1.770***	-1.851***
	(0.019)	(32.222)	(28.455)	(0.213)	(0.371)
Farm size (acres)	0.152***	118.637***	59.015	0.566**	0.888**
	(0.023)	(37.968)	(50.153)	(0.251)	(0.424)
Farm productive assets (1,000 Ksh)	0.002	4.300**	0.816	0.026**	0.001
	(0.001)	(1.896)	(2.228)	(0.012)	(0.019)
Access to credit (dummy)	0.184**	195.685**	131.445	1.253*	1.722
	(0.073)	(93.312)	(110.167)	(0.711)	(1.071)
Distance to closest market (km)	-0.004	13.729**	16.143*	0.138**	0.163*
	(0.004)	(6.342)	(8.970)	(0.055)	(0.093)
Group official (dummy)	0.083	122.755	102.086	0.691	1.218
	(0.061)	(82.621)	(111.086)	(0.630)	(0.948)
Constant	-0.899***	3428.266***	877.488***	24.030***	21.044***
	(0.221)	(279.035)	(314.009)	(2.085)	(3.259)
Sub-county dummies	Yes	Yes	Yes	Yes	Yes
Observations	805	805	805	805	805
Log pseudo-likelihood	-382.628	-	-	-	-
R-squared	-	0.29	0.04	0.18	0.13

Note: Coefficient estimates are shown with robust standard errors in parentheses. GLM, generalized linear model; OLS, ordinary least squares; AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table 5. Commercialization Effects on Purchased Calorie and Nutrient Consumption

Variable	Calories (kcal/day/AE)	Vitamin A (µg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Commercialization	400.052**	269.931**	2.533**	3.448**
	(180.023)	(121.332)	(1.281)	(1.746)
Age of household head (years)	-2.344	-2.312	-0.057**	-0.063*
	(3.457)	(2.101)	(0.024)	(0.032)
Age squared (years)	0.227	0.264*	0.001	0.002
	(0.224)	(0.160)	(0.001)	(0.002)
Male household head (dummy)	-39.893	-4.055	-1.399**	0.014
	(94.907)	(49.932)	(0.651)	(0.798)
Education of household head (years)	7.077	3.347	0.008	0.153
	(10.805)	(6.122)	(0.074)	(0.105)
Household size (AE)	-208.605***	-13.864	-0.761***	-0.956***
	(23.251)	(13.988)	(0.148)	(0.233)
Farm size (acres)	-10.247	-14.468	-0.314	-0.398
	(29.848)	(16.137)	(0.195)	(0.245)
Farm productive assets (1,000 Ksh)	1.860	-0.061	0.002	0.010
	(1.481)	(0.849)	(0.009)	(0.012)
Access to credit (dummy)	-21.068	-18.899	-0.098	0.601
	(85.261)	(51.588)	(0.620)	(0.788)
Distance to closest market (km)	12.332**	2.294	0.099**	0.109
	(5.610)	(3.611)	(0.042)	(0.093)
Group official (dummy)	70.172	91.364**	0.412	0.327
	(74.304)	(44.588)	(0.524)	(0.665)
Constant	2459.166***	271.910*	14.577***	13.657***
	(270.580)	(144.505)	(1.901)	(2.708)
Sub-county dummies	Yes	Yes	Yes	Yes
Observations	805	805	805	805
R-squared	0.14	0.04	0.10	0.07

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table 6. Commercialization Effects on Own-Produced Calorie and Nutrient Consumption

Variables	Calories (kcal/day/AE)	Vitamin A (μg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Commercialization	317.051*	-187.895	1.065	1.295
	(169.210)	(185.829)	(1.256)	(1.595)
Age of household head (years)	8.472***	4.497	0.030	0.054*
	(2.954)	(3.269)	(0.023)	(0.032)
Age squared (years)	-0.016	-0.582***	-0.001	-0.004*
	(0.206)	(0.177)	(0.002)	(0.002)
Male household head (dummy)	5.802	166.441**	-1.615**	0.918
	(86.117)	(73.599)	(0.732)	(0.806)
Education of household head (years)	30.940***	12.680	0.204**	0.306***
	(10.057)	(11.353)	(0.082)	(0.106)
Household size (AE)	-142.046***	-66.864***	-0.901***	-0.713**
	(25.494)	(22.483)	(0.197)	(0.299)
Farm size (acres)	136.148***	72.173**	0.881***	1.311***
	(31.104)	(35.644)	(0.235)	(0.338)
Farm productive assets (1,000 Ksh)	3.028**	0.669	0.027**	-0.004
	(1.520)	(1.999)	(0.011)	(0.015)
Access to credit (dummy)	206.063**	161.173**	1.404**	1.314*
	(76.084)	(78.759)	(0.591)	(0.771)
Distance to closest market (km)	-1.044	11.468*	0.032	0.036
	(3.972)	(6.534)	(0.041)	(0.052)
Group official (dummy)	54.831	2.771	0.267	0.865
	(70.927)	(89.795)	(0.554)	(0.749)
Constant	798.290***	595.821**	8.620***	6.076***
	(239.590)	(250.016)	(1.822)	(2.220)
Sub-county dummies	Yes	Yes	Yes	Yes
Observations	805	805	805	805
R-squared	0.21	0.04	0.16	0.09

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table 7. Commercialization, Household Income, and Calorie and Nutrient Consumption

Variable	Household income	Calories (kcal/day/AE)	Vitamin A (µg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Commercialization	234.899***				
	(39.289)				
Household income (1,000 Ksh)		0.977***	0.464*	0.006***	0.012***
		(0.237)	(0.276)	(0.001)	(0.003)
Off-farm income dummy	92.421***				
	(14.679)				
Age of household head (years)	-0.377	6.772*	5.016	-0.016	0.006
	(0.484)	(3.521)	(4.173)	(0.027)	(0.042)
Age squared (years)	0.034	0.125	-0.283	0.000	-0.002
	(0.036)	(0.223)	(0.259)	(0.002)	(0.003)
Male household head (dummy)	29.327**	-77.191	96.325	-3.330***	0.494
	(12.532)	(105.849)	(110.363)	(0.852)	(1.128)
Education of household head (years)	6.205***	37.168***	13.123	0.188**	0.433***
	(1.817)	(11.579)	(13.731)	(0.091)	(0.139)
Household size (AE)	6.747	-371.902***	-99.263***	-1.798***	-1.919***
	(4.192)	(31.589)	(28.381)	(0.210)	(0.364)
Farm size (acres)	27.979***	113.959***	50.092	0.525**	0.720*
	(9.485)	(35.063)	(50.209)	(0.238)	(0.399)
Farm productive assets (1,000 Ksh)	3.133***	1.384	-0.694	0.009	-0.036*
	(0.525)	(1.902)	(2.257)	(0.013)	(0.020)
Access to credit (dummy)	20.655	193.306**	122.887	1.216*	1.567
	(13.214)	(92.939)	(110.401)	(0.706)	(1.051)
Constant	-233.161***	3797.379***	1046.071***	26.327***	24.575***
	(44.034)	(280.248)	(305.292)	(2.085)	(3.149)
Sub-county dummies	Yes	Yes	Yes	Yes	Yes
Observations	805	805	805	805	805
R-squared	0.37	0.29	0.04	0.18	0.14

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent; Ksh, Kenyan shillings. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table 8. Association between Maize Commercialization and Male Control of Maize Revenue

Variable	Linear probability model Male controls maize revenue Coefficients	Probit model Male controls maize revenue Coefficients	 Marginal effects
Maize commercialization	0.326**	1.312**	0.365**
	(0.141)	(0.551)	(0.149)
Age of household head (years)	-0.002	-0.009	-0.002
	(0.003)	(0.011)	(0.003)
Male household head (dummy)	0.720***	6.861***	0.684***
	(0.130)	(0.467)	(0.040)
Education of household head (years)	-0.012	-0.066*	-0.018*
	(0.010)	(0.038)	(0.010)
Household head married (dummy)	-0.679***	-6.587***	-0.988***
	(0.109)	(0.309)	(0.005)
Constant	0.240	-5.164***	-
	(0.196)	(0.716)	-
Sub-county dummies	Yes	Yes	Yes
Observations	191	191	191
R-squared	0.17	-	-
Log pseudo likelihood	-	-81.729	-
Pseudo R-squared	-	0.177	-

Note: Standard errors are shown in parentheses. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table 9. Household Income, Gender Roles, and Consumption of Purchased Calories and Nutrients

Variable	Calories (kcal/day/AE)	Vitamin A (µg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Household income (1,000 Ksh)	1.062***	0.635***	0.005***	0.007***
	(0.230)	(0.187)	(0.001)	(0.003)
Male control of maize revenue (dummy)	-296.957*	-226.349**	-1.813*	-0.096
	(153.684)	(99.672)	(1.014)	(1.961)
Age of household head (years)	1.061	-7.024	-0.067	-0.082
	(6.934)	(6.699)	(0.049)	(0.093)
Male household head (dummy)	-31.396	240.755**	-1.026	-1.008
	(169.603)	(105.857)	(1.190)	(1.663)
Education of household head (years)	-16.801	-20.090	-0.350**	-0.160
	(21.740)	(18.683)	(0.165)	(0.279)
Household size (AE)	-236.862***	-39.612	-0.919 ***	-1.417**
	(44.171)	(32.261)	(0.272)	(0.648)
Farm size (acres)	41.451	-3.444	0.162	0.022
	(56.357)	(34.301)	(0.354)	(0.495)
Farm productive assets (1,000 Ksh)	-1.216	-3.407**	-0.005	-0.001
	(2.859)	(1.676)	(0.019)	(0.032)
Access to credit (dummy)	-192.659	161.623	-1.352	0.947
	(162.014)	(102.004)	(1.148)	(1.967)
Distance to closest market (km)	18.469	-7.907	0.102	-0.091
	(17.653)	(9.020)	(0.130)	(0.203)
Group official (dummy)	175.081	38.931	0.919	0.247
	(136.485)	(90.029)	(0.903)	(1.541)
Constant	2549.336 ***	570.052	18.497***	20.697**
	(435.380)	(455.463)	(3.356)	(8.064)
Sub-county dummies	Yes	Yes	Yes	Yes
Observations	191	191	191	191
R-squared	0.25	0.15	0.19	0.12

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table 10. Commercialization Effects on Calorie and Nutrient Consumption with Alternative Commercialization Indicators

Variable	Total calories (kcal/day/AE)	Purchased calories (kcal/day/AE)	Own-prod. calories (kcal/day/AE)	Total vitamin A (µg RE/day/AE)	Purchased vitamin A (µg RE/day/AE)	Own-prod. vit. A (µg RE/day/AE)
Overall commercialization	696.278***	400.052**	317.051*	134.149	269.931**	-187.895
	(199.724)	(180.023)	(169.210)	(263.351)	(121.332)	(185.829)
Crop commercialization	614.017***	297.156*	330.691**	53.658	209.199**	-199.302
	(179.837)	(157.783)	(151.112)	(237.905)	(105.930)	(171.203)
Livestock commercialization	375.614**	309.521**	107.309	347.840*	117.321	281.310**
	(154.302)	(141.844)	(130.511)	(188.270)	(94.311)	(142.490)
Maize commercialization	1020.883***	103.466	897.857***	130.396	136.684	-2.572
	(229.868)	(181.107)	(170.203)	(283.912)	(144.646)	(215.224)

	Total zinc (mg/day/AE)	Purchased zinc (mg/day/AE)	Own-prod. zinc (mg/day/AE)	Total iron (mg/day/AE)	Purchased iron (mg/day/AE)	Own-prod. iron (mg/day/AE)
Overall commercialization	3.505**	2.533**	1.065	5.506**	3.448**	1.295
	(1.400)	(1.281)	(1.256)	(2.285)	(1.746)	(1.595)
Crop commercialization	3.181**	2.288**	0.986	4.210**	2.642*	0.859
	(1.307)	(1.148)	(1.146)	(2.038)	(1.527)	(1.429)
Livestock commercialization	2.129**	0.904	1.419	4.472***	3.011**	2.065
	(1.079)	(0.976)	(0.939)	(1.715)	(1.335)	(1.331)
Maize commercialization	5.132***	0.305	4.861***	12.625***	4.128*	8.051***
	(1.681)	(1.260)	(1.281)	(2.893)	(2.155)	(2.088)

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. Only commercialization effects are shown. Full model results are provided in tables A6-A14 in the appendix. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

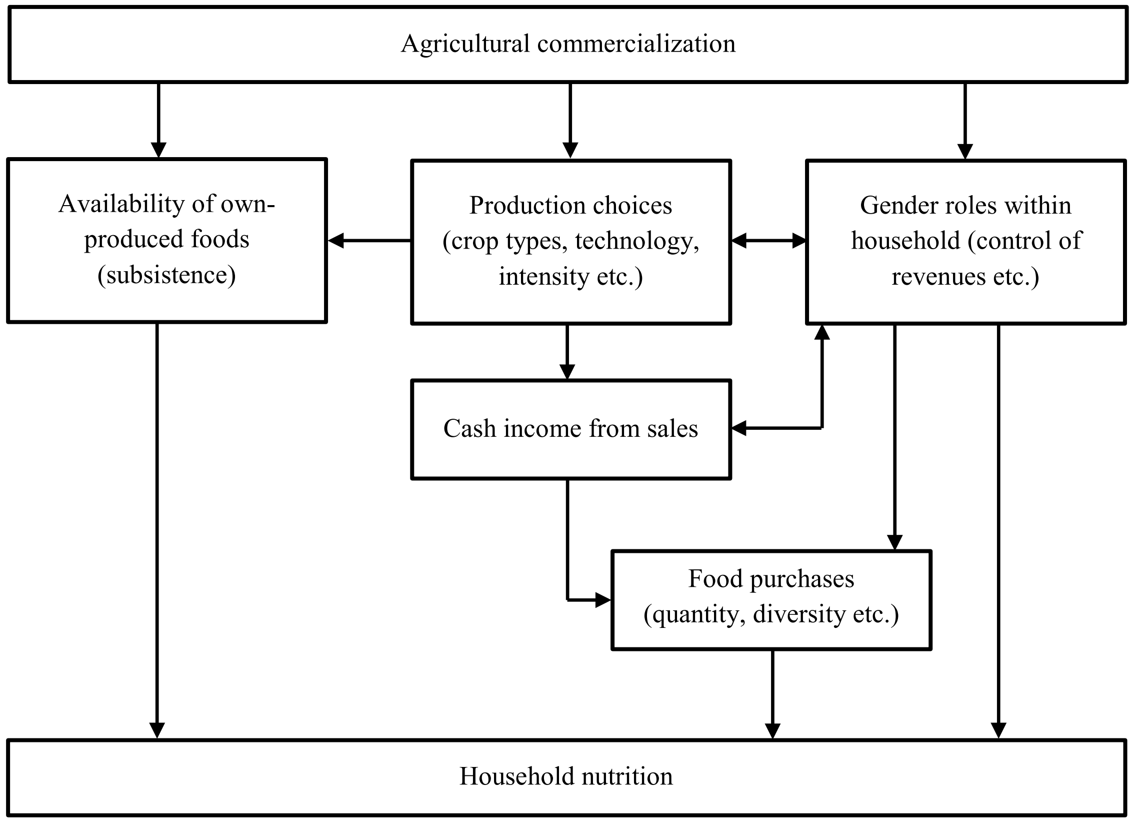

Figure 1. Agricultural Commercialization and Household Nutrition Status

Source: Adapted from von Braun and Kennedy (1994) and Chege et al. (2015).

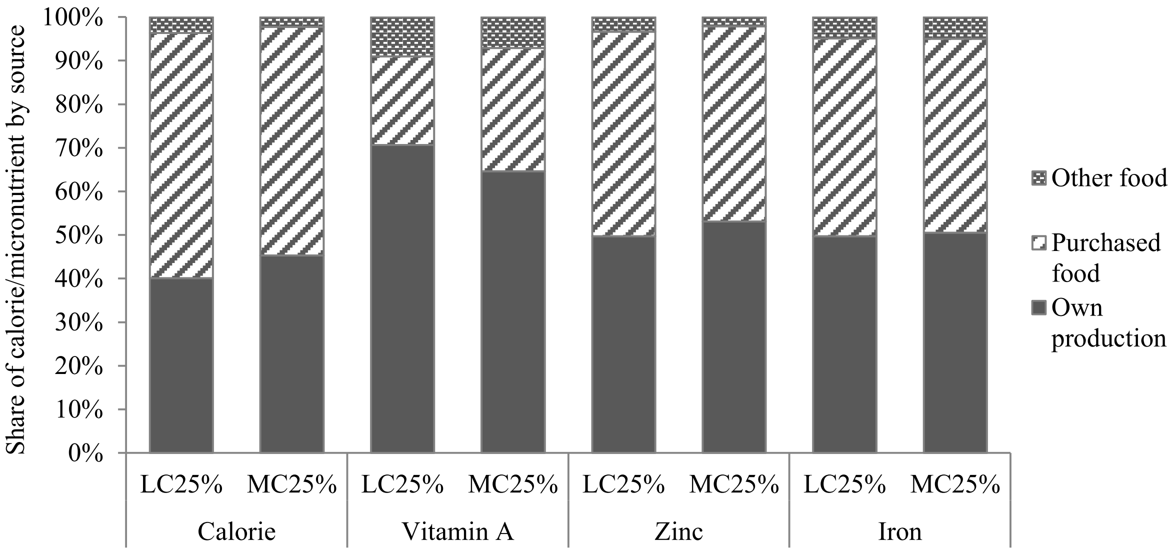

Figure 2. Share of Calorie and Nutrient Consumption from Different Sources

Note: LC25%, 25% least commercialized households; MC25%, 25% most commercialized households.

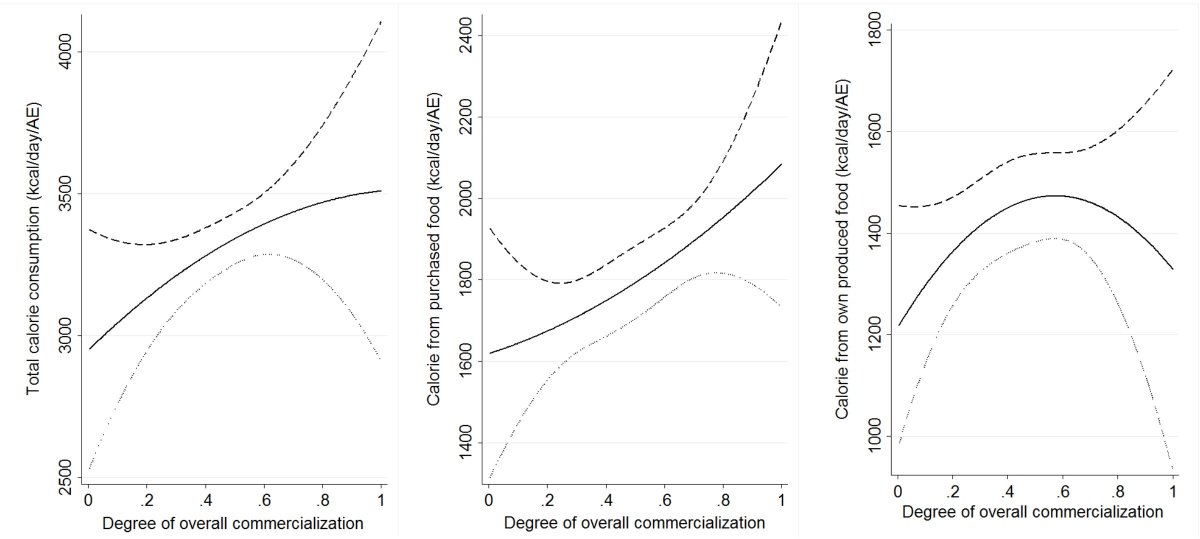

Figure 3. Dose-Response Functions for Commercialization Effects on Calorie Consumption

Note: Solid lines, estimated dose-response functions; dashed lines, 95 % confidence upper bound and tight dotted lines, 95% confidence lower bound intervals obtained through bootstrapping with 10 replications.

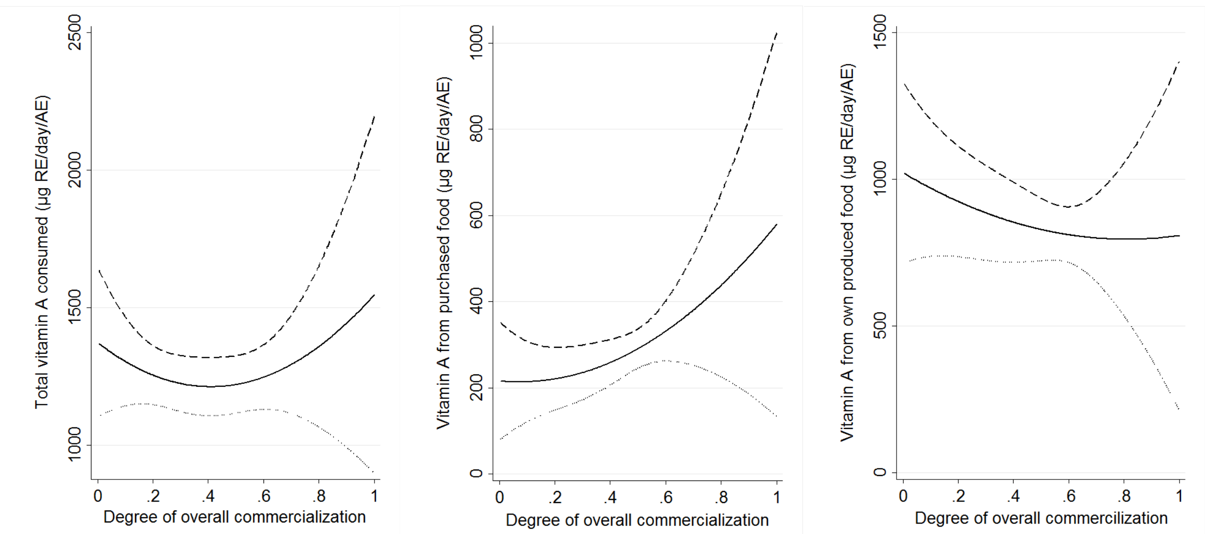

Figure 4. Dose-Response Functions for Commercialization Effects on Vitamin A Consumption

Note: Solid lines, estimated dose-response functions; dashed lines, 95 % confidence upper bound and tight dotted lines, 95% confidence lower bound intervals obtained through bootstrapping with 10 replications.

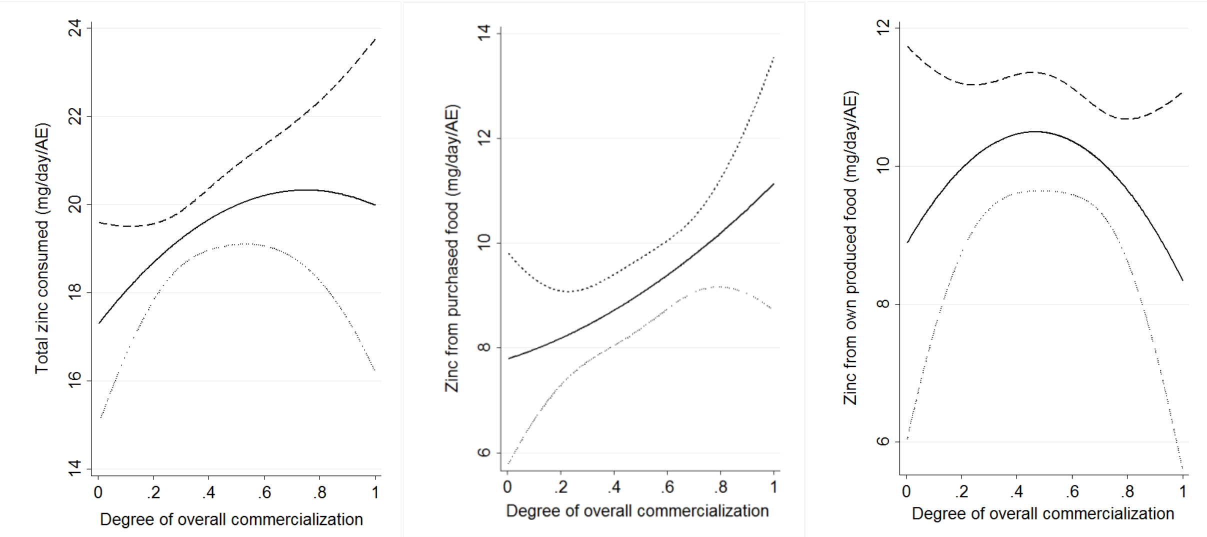

Figure 5. Dose-Response Functions for Commercialization Effects on Zinc Consumption

Note: Solid lines, estimated dose-response functions; dashed lines, 95 % confidence upper bound and tight dotted lines, 95% confidence lower bound intervals obtained through bootstrapping with 10 replications.

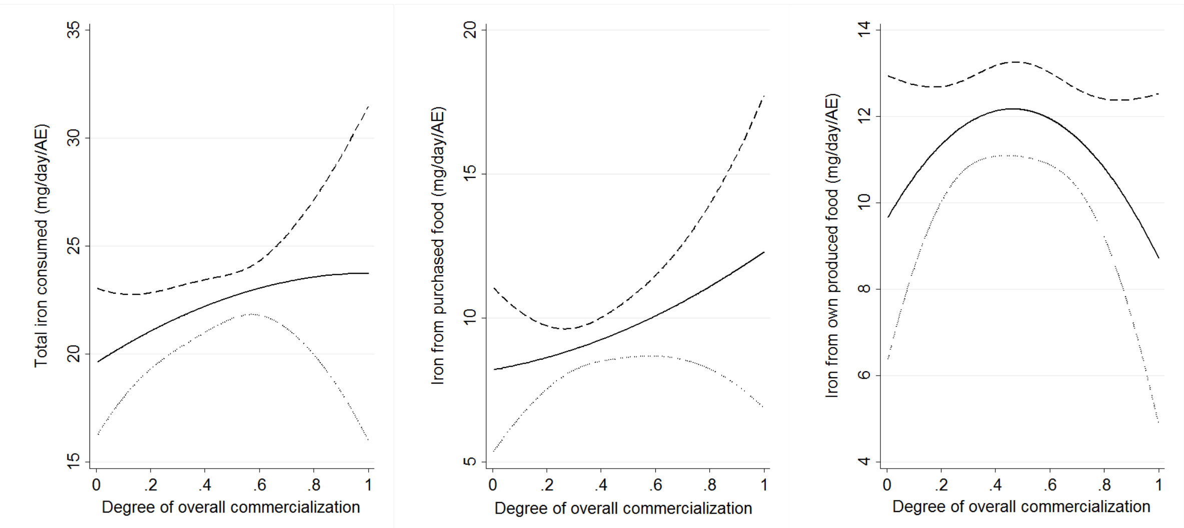

Figure 6. Dose-Response Functions for Commercialization Effects on Iron Consumption

Note: Solid lines, estimated dose-response functions; dashed lines, 95 % confidence upper bound and tight dotted lines, 95% confidence lower bound intervals obtained through bootstrapping with 10 replications.

APPENDIX

Table A1. Association between Instrument and Nutrition Indicators

Nutrition indicators	Correlation coefficient	Regression coefficient
Total calorie consumed (kcal/day/AE)	0.014 (0.695)	-45.020 (0.956)
Calorie from purchased food (kcal/day/AE)	-0.007 (0.834)	69.033 (0.918)
Calorie from own-produced food (kcal/day/AE)	0.024 (0.498)	-98.506 (0.889)
Total vitamin A consumed (µg RE/day/AE)	0.030 (0.403)	960.737 (0.464)
Vitamin A from purchased food (µg RE/day/AE)	0.014 (0.692)	-234.294 (0.533)
Vitamin A from own-produced food (µg RE/day/AE)	0.011 (0.759)	598.286 (0.497)
Total zinc consumed (mg/day/AE)	0.056 (0.111)	6.077 (0.322)
Zinc from purchased food (mg/day/AE)	0.021 (0.551)	4.626 (0.309)
Zinc from own-produced food (mg/day/AE)	0.038 (0.283)	-0.286 (0.956)
Total iron consumed (mg/day/AE)	-0.015 (0.680)	-11.156 (0.278)
Iron from purchased food (mg/day/AE)	0.020 (0.564)	-2.959 (0.690)
Iron from own-produced food (mg/day/AE)	-0.040 (0.256)	-8.221 (0.264)

Note: The average number of motorcycles per household in the ward is used as an instrument for commercialization. *p*-values are shown in parentheses. The regression coefficients were estimated with models that include the instrument plus all other explanatory variables as those in Table 4.

Table A2. Correlation between Instrument and Mean Socioeconomic Characteristics at Ward Levels

	Correlation coefficients	*p*-value
Mean education of household head (years)	0.054	0.794
Mean household income (1,000 Ksh)	0.038	0.852
Mean farm productive assets (1,000 Ksh)	-0.039	0.851
Mean farm size (acres)	0.036	0.860

Note: The average number of motorcycles per household in the ward is used as an instrument for commercialization. Socioeconomic characteristics were computed by averaging across all sample households in the ward.

Table A3. Overall Consumption of Micronutrients from Different Food Group by Level of Commercialization

Food group	Total vitamin A (µg RE/day/AE)		Total zinc (mg/day/AE)		Total iron (mg/day/AE)	
	LC25%	MC25%	LC25%	MC25%	LC25%	MC25%
Starchy staple foods	9.17	33.88	11.37	13.12^{***}	8.16	11.03^{***}
	(49.88)	(220.47)	(5.11)	(6.03)	(5.58)	(8.47)
Pulses (beans, peas, lentils)	0.59	0.75^{*}	0.53	0.63	0.47	0.63^{**}
	(0.81)	(0.89)	(0.67)	(0.69)	(0.66)	(0.84)
Nuts and seeds	0.00	0.01	0.04	0.04	0.01	0.01
	(0.03)	(0.11)	(0.24)	(0.22)	(0.08)	(0.06)
Dairy	125.49	146.56	1.69	1.97	0.13	0.17^{*}
	(284.29)	(373.69)	(1.82)	(1.96)	(0.14)	(0.24)
Meat, poultry, and fish	1.27	0.76	0.82	1.18^{**}	0.23	0.36^{***}
	(14.64)	(5.84)	(1.68)	(1.77)	(0.46)	(0.52)
Eggs	2.24	3.33^{**}	0.07	0.10^{**}	0.06	0.09^{**}
	(3.80)	(5.23)	(0.11)	(0.16)	(0.12)	(0.15)
Vitamin A-rich dark green leafy vegetables	759.40	807.77	2.02	1.96	4.29	5.68^{**}
	(1176.77)	(1238.49)	(3.20)	(2.66)	(4.96)	(8.20)
Other vitamin A-rich fruits and vegetables	110.37	238.07^{**}	0.14	0.20^{*}	0.52	0.77^{**}
	(267.44)	(773.09)	(0.31)	(0.31)	(1.01)	(1.25)
Other vegetables	81.77	103.14^{*}	0.91	1.05	3.62	4.81^{**}
	(118.93)	(127.83)	(1.53)	(1.28)	(4.08)	(5.45)
Other fruits	48.39	71.09^{**}	0.59	0.79^{**}	0.88	1.05
	(60.36)	(113.71)	(0.76)	(1.18)	(1.49)	(1.49)
Total micronutrients	1140.09	1406.09^{*}	18.25	21.07^{***}	18.61	25.04^{***}
	(1231.14)	(1542.60)	(7.67)	(8.72)	(9.76)	(15.21)
Observations	202	201	202	201	202	201

Note: Mean values are shown with standard deviations in parentheses. The food groups disaggregation is the one also used for the dietary diversity score with 10 food groups (DDS10) in the main paper. LC25%, 25% least commercialized households; MC25%, 25% most commercialized households; RE, retinol equivalent; AE, adult equivalent. *, **, and *** differences between LC25% and MC25% are significant at 10%, 5%, and 1% level, respectively.

Table A4. Consumption of Purchased Micronutrients from Different Food Groups by Level of Commercialization

Food group	Purchased vitamin A (µg RE/day/AE)		Purchased zinc (mg/day/AE)		Purchased iron (mg/day/AE)	
	LC25%	MC25%	LC25%	MC25%	LC25%	MC25%
Starchy staple foods	1.40	2.29^{**}	6.30	6.66	4.81	6.34^{***}
	(2.94)	(4.00)	(5.59)	(5.43)	(4.97)	(6.73)
Pulses (beans, peas, lentils)	0.25	0.20	0.21	0.15	0.20	0.16
	(0.69)	(0.55)	(0.53)	(0.36)	(0.56)	(0.46)
Nuts and seeds	0.00	0.00	0.01	0.02	0.00	0.01
	(0.03)	(0.00)	(0.09)	(0.13)	(0.02)	(0.03)
Dairy	31.61	36.90	0.49	0.51	0.04	0.05
	(56.51)	(67.69)	(0.88)	(0.93)	(0.09)	(0.11)
Meat, poultry, and fish	1.28	1.67	0.71	0.99^{*}	0.20	0.30^{**}
	(14.68)	(14.55)	(1.54)	(1.64)	(0.41)	(0.47)
Eggs	0.74	0.78	0.02	0.02	0.02	0.02
	(2.35)	(2.61)	(0.07)	(0.07)	(0.07)	(0.09)
Vitamin A-rich dark green leafy vegetables	110.55	222.85^{**}	0.38	0.48	1.47	2.03
	(341.06)	(717.80)	(1.15)	(1.54)	(3.61)	(6.29)
Other vitamin A-rich fruits and vegetables	54.99	94.35^{*}	0.06	0.06	0.24	0.27
	(150.66)	(302.53)	(0.14)	(0.13)	(0.53)	(0.49)
Other vegetables	20.54	20.80	0.23	0.30	1.22	1.58^{*}
	(67.03)	(41.72)	(0.45)	(0.52)	(1.84)	(2.43)
Other fruits	10.30	17.60	0.13	0.22	0.15	0.24
	(24.74)	(70.59)	(0.30)	(0.92)	(0.36)	(0.85)
Total micronutrients	231.65	397.31^{***}	8.53	9.41	8.34	11.00^{***}
	(394.53)	(788.89)	(6.85)	(6.71)	(7.65)	(10.98)
Observations	202	201	202	201	202	201

Note: Mean values are shown with standard deviations in parentheses. The food groups disaggregation is the one also used for the dietary diversity score with 10 food groups (DDS10) in the main paper. LC25%, 25% least commercialized households; MC25%, 25% most commercialized households; RE, retinol equivalent; AE, adult equivalent. *, **, and *** differences between LC25% and MC25% are significant at 10%, 5%, and 1% level, respectively.

Table A5. Consumption of Own-Produced Micronutrients from Different Food Groups by Level of Commercialization

Food group	Own-produced vitamin A (µg RE/day/AE)		Own-produced zinc (mg/day/AE)		Own-produced iron (mg/day/AE)	
	LC25%	MC25%	LC25%	MC25%	LC25%	MC25%
Starchy staple foods	7.75	31.44	4.95	6.35**	3.22	4.35**
	(49.99)	(220.28)	(5.25)	(5.99)	(4.29)	(6.29)
Pulses (beans, peas, lentils)	0.34	0.55***	0.31	0.47**	0.27	0.46***
	(0.54)	(0.80)	(0.53)	(0.68)	(0.44)	(0.79)
Nuts and seeds	0.00	0.01	0.02	0.02	0.01	0.01
	(0.00)	(0.11)	(0.23)	(0.19)	(0.08)	(0.05)
Dairy	87.54	108.95	1.07	1.41*	0.08	0.12
	(288.44)	(378.35)	(1.84)	(2.10)	(0.14)	(0.23)
Meat, poultry, and fish	0.00	0.00	0.08	0.19	0.03	0.06*
	(0.03)	(0.00)	(0.64)	(0.73)	(0.19)	(0.22)
Eggs	1.47	2.55***	0.04	0.08***	0.04	0.07**
	(3.29)	(4.89)	(0.10)	(0.15)	(0.10)	(0.13)
Vitamin A-rich dark green leafy vegetables	554.37	528.70	1.48	1.37	2.55	3.30*
	(943.04)	(796.66)	(2.62)	(1.97)	(3.40)	(5.18)
Other vitamin A-rich fruits and vegetables	51.36	104.81	0.08	0.12*	0.27	0.45**
	(181.40)	(493.06)	(0.25)	(0.25)	(0.75)	(1.02)
Other vegetables	53.02	81.63***	0.64	0.69	2.13	3.04**
	(92.12)	(125.95)	(1.50)	(1.05)	(3.61)	(4.59)
Other fruits	31.00	42.97*	0.37	0.49	0.61	0.66
	(51.87)	(84.37)	(0.61)	(0.86)	(1.46)	(1.22)
Total micronutrients	786.85	901	9.06	11.19***	9.20	12.52***
	(1000.91)	(1136.97)	(6.86)	(8.04)	(7.17)	(11.44)
Observations	202	201	202	201	202	201

Note: Mean values are shown with standard deviations in parentheses. The food groups disaggregation is the one also used for the dietary diversity score with 10 food groups (DDS10) in the main paper. LC25%, 25% least commercialized households; MC25%, 25% most commercialized households; RE, retinol equivalent; AE, adult equivalent. *, **, and *** differences between LC25% and MC25% are significant at 10%, 5%, and 1% level, respectively.

Table A6. Determinants of Crop Commercialization and Commercialization Effects on Total Calorie and Nutrient Consumption

Variable	GLM Crop commer-cialization	OLS Calories (kcal/day/AE)	OLS Vitamin A (µg RE/day/AE)	OLS Zinc (mg/day/AE)	OLS Iron (mg/day/AE)
Crop commercialization		614.017***	53.658	3.181**	4.210**
		(179.837)	(237.905)	(1.307)	(2.038)
Motorcycles per household in ward	2.089***				
	(0.773)				
Age of household head (years)	0.004	5.824	4.935	-0.020	-0.002
	(0.003)	(3.546)	(4.369)	(0.028)	(0.043)
Age squared (years)	-0.001***	0.270	-0.247	0.001	-0.001
	(0.000)	(0.236)	(0.269)	(0.002)	(0.003)
Male household head (dummy)	0.067	-49.995	115.031	-3.150***	0.872
	(0.086)	(105.708)	(107.467)	(0.831)	(1.121)
Education of household head (years)	0.020*	40.224***	15.726	0.214**	0.494***
	(0.010)	(11.788)	(14.722)	(0.095)	(0.143)
Household size (AE)	-0.054**	-364.644***	-101.276***	-1.776***	-1.871***
	(0.021)	(31.901)	(28.438)	(0.213)	(0.371)
Farm size (acres)	0.164***	119.915***	61.836	0.569**	0.924**
	(0.028)	(37.377)	(51.012)	(0.249)	(0.422)
Farm productive assets (1,000 Ksh)	-0.000	4.608**	0.876	0.028**	0.003
	(0.002)	(1.922)	(2.218)	(0.012)	(0.019)
Access to credit (dummy)	0.220***	194.227**	134.215	1.241*	1.741
	(0.081)	(93.607)	(110.490)	(0.713)	(1.068)
Distance to closest market (km)	-0.009*	14.318**	16.134*	0.141**	0.166*
	(0.004)	(6.474)	(9.023)	(0.055)	(0.094)
Group official (dummy)	0.104	121.189	103.332	0.681	1.221
	(0.069)	(82.704)	(110.879)	(0.630)	(0.949)
Constant	-0.906***	3449.627***	902.802***	24.108***	21.425***
	(0.248)	(278.924)	(309.572)	(2.085)	(3.280)
Sub-county dummies	Yes	Yes	Yes	Yes	Yes
Observations	805	805	805	805	805
Log pseudo-likelihood	-388.713	-	-	-	-
R-squared	-	0.29	0.04	0.18	0.13

Note: Coefficient estimates are shown with robust standard errors in parentheses. GLM, generalized linear model; OLS, ordinary least squares (the predicted residuals from the first stage were insignificant in the second stage); AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table A7. Crop Commercialization Effects on Purchased Calorie and Nutrient Consumption

Variable	Calories (kcal/day/AE)	Vitamin A (μg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Crop commercialization	297.156*	209.199**	2.288**	2.642*
	(157.783)	(105.930)	(1.148)	(1.527)
Age of household head (years)	-2.276	-2.275	-0.056**	-0.062*
	(3.454)	(2.106)	(0.024)	(0.032)
Age squared (years)	0.219	0.261	0.001	0.002
	(0.224)	(0.160)	(0.001)	(0.002)
Male household head (dummy)	-34.650	-0.628	-1.371**	0.058
	(94.692)	(50.001)	(0.651)	(0.801)
Education of household head (years)	7.660	3.699	0.009	0.158
	(10.849)	(6.106)	(0.074)	(0.105)
Household size (AE)	-210.163***	-14.807	-0.766***	-0.968***
	(23.189)	(14.041)	(0.148)	(0.234)
Farm size (acres)	-7.296	-12.824	-0.312	-0.376
	(29.911)	(16.254)	(0.196)	(0.243)
Farm productive assets (1,000 Ksh)	2.038	0.059	0.003	0.012
	(1.490)	(0.839)	(0.009)	(0.012)
Access to credit (dummy)	-19.281	-18.103	-0.106	0.613
	(85.438)	(51.627)	(0.621)	(0.790)
Distance to closest market (km)	12.565**	2.467	0.102**	0.111
	(5.710)	(3.651)	(0.042)	(0.093)
Group official (dummy)	70.605	91.448**	0.405	0.329
	(74.342)	(44.637)	(0.523)	(0.666)
Constant	2489.682	289.649	14.637	13.893
	(269.801)	(145.735)	(1.897)	(2.730)
Sub-county dummies	Yes	Yes	Yes	Yes
Observations	805	805	805	805
R-squared	0.14	0.04	0.10	0.07

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table A8. Crop Commercialization Effects on Own-Produced Calorie and Nutrient Consumption

Variables	Calories (kcal/day/AE)	Vitamin A (µg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Crop commercialization	330.691**	-199.302	0.986	0.859
	(151.112)	(171.203)	(1.146)	(1.429)
Age of household head (years)	8.436***	4.522	0.030	0.055*
	(2.949)	(3.269)	(0.023)	(0.032)
Age squared (years)	-0.006	-0.589***	-0.001	-0.004*
	(0.206)	(0.176)	(0.002)	(0.002)
Male household head (dummy)	8.747	164.738**	-1.603**	0.936
	(86.078)	(73.578)	(0.733)	(0.807)
Education of household head (years)	30.953***	12.689	0.204**	0.308***
	(10.031)	(11.378)	(0.082)	(0.106)
Household size (AE)	-142.106***	-66.869***	-0.902***	-0.720**
	(25.354)	(22.567)	(0.197)	(0.300)
Farm size (acres)	134.695***	73.167**	0.881***	1.325***
	(30.875)	(36.074)	(0.234)	(0.337)
Farm productive assets (1,000 Ksh)	3.168**	0.586	0.027**	-0.003
	(1.524)	(1.998)	(0.011)	(0.015)
Access to credit (dummy)	202.987***	163.153**	1.400**	1.324*
	(76.366)	(78.745)	(0.593)	(0.770)
Distance to closest market (km)	-0.678	11.245*	0.033	0.037
	(3.990)	(6.541)	(0.041)	(0.052)
Group official (dummy)	52.894	3.999	0.264	0.868
	(70.948)	(89.651)	(0.555)	(0.749)
Constant	791.260***	601.077**	8.637***	6.208***
	(238.470)	(246.578)	(1.826)	(2.214)
Sub-county dummies	Yes	Yes	Yes	Yes
Observations	805	805	805	805
R-squared	0.21	0.04	0.16	0.09

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table A9. Determinants of Maize Commercialization and Commercialization Effects on Total Calorie and Nutrient Consumption

Variable	GLM Maize commer-cialization	OLS Calories (kcal/day/AE)	OLS Vitamin A (µg RE/day/AE)	OLS Zinc (mg/day/AE)	OLS Iron (mg/day/AE)
Maize commercialization		1020.883***	130.396	5.132***	12.625***
		(229.868)	(283.912)	(1.681)	(2.893)
Motorcycles per household in ward	3.486**				
	(1.477)				
Age of household head (years)	-0.003	6.099	4.576	-0.024	-0.011
	(0.007)	(3.551)	(4.543)	(0.028)	(0.043)
Age squared (years)	-0.000	0.246	-0.226	0.001	-0.001
	(0.001)	(0.236)	(0.279)	(0.002)	(0.003)
Male household head (dummy)	-0.201	-48.852	112.100	-3.108***	1.206
	(0.203)	(108.660)	(114.385)	(0.878)	(1.161)
Education of household head (years)	0.066***	42.372***	14.155	0.225**	0.466***
	(0.023)	(11.712)	(15.913)	(0.099)	(0.146)
Household size (AE)	-0.154***	-350.640***	-95.745***	-1.723***	-1.689***
	(0.058)	(32.468)	(30.142)	(0.221)	(0.374)
Farm size (acres)	0.213***	114.291**	57.448	0.539**	0.793**
	(0.056)	(35.643)	(50.274)	(0.247)	(0.404)
Farm productive assets (1,000 Ksh)	0.008**	3.845*	0.962	0.024*	-0.005
	(0.003)	(1.880)	(2.253)	(0.013)	(0.019)
Access to credit (dummy)	0.228	227.981*	123.324	1.327*	2.038*
	(0.188)	(93.564)	(117.808)	(0.733)	(1.063)
Distance to closest market (km)	-0.041**	15.818*	19.207*	0.161***	0.211**
	(0.020)	(7.318)	(10.329)	(0.061)	(0.106)
Distance to extension agent (km)	-0.092***	-3.165	-10.108	-0.070	-0.031
	(0.029)	(8.516)	(10.078)	(0.057)	(0.094)
Group official (dummy)	0.258	98.507	99.900	0.523	0.987
	(0.161)	(86.505)	(120.504)	(0.657)	(0.978)
Constant	-2.269***	3528.696***	952.619***	25.041***	21.513***
	(0.603)	(288.912)	(323.025)	(2.205)	(3.420)
Sub-county dummies	Yes	Yes	Yes	Yes	Yes
Observations	755	755	755	755	755
Log pseudo-likelihood	-196.132	-	-	-	-
R-squared	-	0.31	0.04	0.20	0.17

Note: Coefficient estimates are shown with robust standard errors in parentheses. GLM, generalized linear model; OLS, ordinary least squares (the predicted residuals from the first stage were insignificant in the second stage); AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table A10. Maize Commercialization Effects on Purchased Calorie and Nutrient Consumption

Variables	Calories (kcal/day/AE)	Vitamin A (μg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Maize commercialization	103.466	136.684	0.305	4.128*
	(181.107)	(144.646)	(1.260)	(2.155)
Age of household head (years)	-2.018	-1.860	-0.057**	-0.065**
	(3.488)	(2.174)	(0.025)	(0.033)
Age squared (years)	0.142	0.245	0.001	0.002
	(0.228)	(0.166)	(0.002)	(0.002)
Male household head (dummy)	-42.890	3.029	-1.311*	0.016
	(97.426)	(54.575)	(0.680)	(0.849)
Education of household head (years)	15.210	3.571	0.050	0.158
	(10.570)	(6.825)	(0.077)	(0.108)
Household size (AE)	-210.389***	-14.272	-0.805***	-0.897***
	(24.416)	(14.890)	(0.156)	(0.244)
Farm size (acres)	6.087	-6.719	-0.173	-0.306
	(30.112)	(15.392)	(0.195)	(0.244)
Farm productive assets (1,000 Ksh)	1.626	-0.142	-0.000	0.009
	(1.532)	(0.876)	(0.009)	(0.012)
Access to credit (dummy)	5.541	-19.414	-0.000	0.711
	(87.098)	(53.817)	(0.643)	(0.813)
Distance to closest market (km)	13.157**	2.814	0.106**	0.128
	(5.954)	(4.053)	(0.044)	(0.106)
Distance to extension agent (km)	-7.835	0.207	-0.051	-0.044
	(6.629)	(4.353)	(0.049)	(0.080)
Group official (dummy)	26.748	81.944*	0.145	-0.012
	(76.566)	(47.351)	(0.531)	(0.670)
Constant	2534.046***	323.378**	15.268***	14.289***
	(272.834)	(155.151)	(1.993)	(2.764)
Sub-county dummies	Yes	Yes	Yes	Yes
Observations	755	755	755	755
R-squared	0.14	0.04	0.10	0.08

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table A11. Maize Commercialization Effects on Own-Produced Calorie and Nutrient Consumption

Variables	Calories (kcal/day/AE)	Vitamin A (μg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Maize commercialization	897.857***	-2.572	4.861***	8.051***
	(170.203)	(215.224)	(1.281)	(2.088)
Age of household head (years)	8.320***	3.772	0.026	0.048
	(3.008)	(3.427)	(0.023)	(0.034)
Age squared (years)	0.029	-0.554***	-0.000	-0.004*
	(0.211)	(0.186)	(0.002)	(0.002)
Male household head (dummy)	20.911	156.901**	-1.596**	1.345
	(88.400)	(77.339)	(0.771)	(0.838)
Education of household head (years)	25.053**	11.780	0.170**	0.260**
	(10.361)	(12.312)	(0.086)	(0.110)
Household size (AE)	-127.421***	-61.510***	-0.805***	-0.600**
	(25.269)	(23.588)	(0.198)	(0.302)
Farm size (acres)	118.387***	62.786*	0.714***	1.088***
	(30.333)	(37.078)	(0.237)	(0.335)
Farm productive assets (1,000 Ksh)	2.822*	0.876	0.027**	-0.008
	(1.474)	(2.045)	(0.011)	(0.016)
Access to credit (dummy)	216.445***	152.441*	1.396**	1.466*
	(78.042)	(83.924)	(0.614)	(0.769)
Distance to closest market (km)	-0.820	12.634*	0.045	0.052
	(4.330)	(7.434)	(0.046)	(0.060)
Distance to extension agent (km)	6.780	-5.678	-0.017	0.032
	(8.282)	(7.444)	(0.053)	(0.071)
Group official (dummy)	70.976	5.287	0.341	0.911
	(73.776)	(96.729)	(0.582)	(0.787)
Constant	831.462***	579.400**	9.041***	5.874**
	(242.093)	(257.632)	(1.810)	(2.315)
Sub-county dummies	Yes	Yes	Yes	Yes
Observations	755	755	755	755
R-squared	0.23	0.04	0.17	0.13

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table A12. Livestock Commercialization Effects on Total Calorie and Nutrient Consumption

Variables	Calories (kcal/day/AE)	Vitamin A (µg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Livestock commercialization	375.614**	347.840*	2.129**	4.472***
	(154.302)	(188.270)	(1.079)	(1.715)
Age of household head (years)	4.880	3.804	-0.017	0.005
	(3.944)	(4.779)	(0.031)	(0.045)
Age squared (years)	0.235	-0.258	0.001	-0.002
	(0.268)	(0.285)	(0.002)	(0.003)
Male household head (dummy)	-113.109	181.089*	-3.093***	0.918
	(118.271)	(109.455)	(0.950)	(1.174)
Education of household head (years)	35.261***	10.156	0.180*	0.378**
	(12.408)	(15.227)	(0.101)	(0.151)
Household size (AE)	-367.595***	-100.242***	-1.840***	-1.712***
	(35.759)	(30.906)	(0.238)	(0.391)
Farm size (acres)	118.698***	48.770	0.527**	0.851**
	(38.552)	(50.316)	(0.253)	(0.432)
Farm productive assets (1,000 Ksh)	4.706**	0.836	0.025*	0.006
	(2.021)	(2.398)	(0.013)	(0.020)
Access to credit (dummy)	150.138	145.078	0.956	2.149*
	(104.960)	(116.733)	(0.793)	(1.140)
Distance to closest market (km)	9.742	15.844*	0.116**	0.157
	(6.406)	(9.231)	(0.055)	(0.097)
Group official (dummy)	102.414	37.031	0.433	0.852
	(87.229)	(116.306)	(0.652)	(0.977)
Constant	3869.169***	915.836**	26.003***	22.067***
	(307.936)	(341.163)	(2.309)	(3.481)
Sub-county dummies	Yes	Yes	Yes	Yes
Observations	712	712	712	712
R-squared	0.27	0.05	0.17	0.11

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table A13. Livestock Commercialization Effects on Purchased Calorie and Nutrient Consumption

Variables	Calorie (kcal/day/AE)	Vitamin A (µg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Livestock commercialization	309.521**	117.321	0.904	3.011**
	(141.844)	(94.311)	(0.976)	(1.335)
Age of household head (years)	-2.767	-2.299	-0.054**	-0.055
	(3.808)	(2.305)	(0.027)	(0.033)
Age squared (years)	0.013	0.241	0.000	0.001
	(0.249)	(0.177)	(0.002)	(0.002)
Male household head (dummy)	-149.392	23.739	-1.606**	-0.525
	(106.682)	(40.034)	(0.733)	(0.873)
Education of household head (years)	7.276	2.759	0.002	0.105
	(11.668)	(5.988)	(0.081)	(0.113)
Household size (AE)	-211.908***	-15.361	-0.810***	-0.873***
	(26.221)	(11.721)	(0.162)	(0.238)
Farm size (acres)	-8.987	-4.866	-0.292	-0.420
	(29.961)	(16.123)	(0.195)	(0.250)
Farm productive assets (1,000 Ksh)	1.636	0.269	0.001	0.014
	(1.591)	(0.902)	(0.010)	(0.013)
Access to credit (dummy)	21.644	47.339	0.252	1.465*
	(96.151)	(45.397)	(0.704)	(0.765)
Distance to closest market (km)	10.571*	2.774	0.093**	0.110
	(5.776)	(3.748)	(0.044)	(0.097)
Group official (dummy)	81.198	78.891*	0.471	0.586
	(79.723)	(41.729)	(0.557)	(0.685)
Constant	2675.738***	231.118	15.551***	13.654***
	(303.996)	(155.831)	(2.176)	(2.916)
Sub-county dummies	Yes	Yes	Yes	Yes
Observations	712	712	712	712
R-squared	0.14	0.05	0.10	0.07

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table A14. Livestock Commercialization Effects on Own-Produced Calorie and Nutrient Consumption

Variables	Calories (kcal/day/AE)	Vitamin A (μg RE/day/AE)	Zinc (mg/day/AE)	Iron (mg/day/AE)
Livestock commercialization	107.309	281.310**	1.419	2.065
	(130.511)	(142.490)	(0.939)	(1.331)
Age of household head (years)	8.344***	4.427	0.034	0.057
	(2.996)	(3.611)	(0.024)	(0.035)
Age squared (years)	0.153	-0.477**	0.001	-0.003
	(0.208)	(0.203)	(0.002)	(0.002)
Male household head (dummy)	57.276	186.674**	-1.400*	1.443*
	(93.192)	(82.451)	(0.833)	(0.817)
Education of household head (years)	24.781**	4.810	0.166*	0.240**
	(10.467)	(12.234)	(0.088)	(0.111)
Household size (AE)	-143.866***	-66.519**	-0.928***	-0.662**
	(27.122)	(26.073)	(0.218)	(0.316)
Farm size (acres)	135.775***	48.019	0.808***	1.258***
	(30.176)	(36.184)	(0.233)	(0.344)
Farm productive assets (1,000 Ksh)	3.519**	0.339	0.026**	-0.004
	(1.526)	(2.170)	(0.012)	(0.016)
Access to credit (dummy)	119.422	119.493	0.802	0.726
	(81.470)	(87.420)	(0.644)	(0.847)
Distance to closest market (km)	-3.400	10.836	0.016	0.026
	(3.939)	(6.668)	(0.041)	(0.052)
Group official (dummy)	18.441	-54.080	-0.080	0.206
	(73.183)	(97.244)	(0.574)	(0.771)
Constant	1020.326***	609.973**	9.642***	6.818***
	(248.674)	(274.705)	(1.915)	(2.249)
Sub-county dummies	Yes	Yes	Yes	Yes
Observations	712	712	712	712
R-squared	0.22	0.04	0.16	0.09

Note: Coefficient estimates are shown with robust standard errors in parentheses. All models were estimated with ordinary least squares. AE, adult equivalents; RE, retinol equivalent. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table A15. GLM (Fractional Logit) Regression for Estimating Propensity Scores

Variables	GLM Overall commercialization
Age of household head (years)	0.001
	(0.003)
Male household head (dummy)	0.056
	(0.075)
Education of household head (years)	0.025***
	(0.009)
Household size (AE)	-0.042**
	(0.018)
Farm size (acres)	0.140***
	(0.023)
Farm productive assets (1,000 Ksh)	0.002
	(0.001)
Access to credit (dummy)	0.124*
	(0.070)
Distance to closest market (km)	-0.003
	(0.004)
Group official (dummy)	0.068
	(0.059)
Sub-county dummies	
Sameta	-0.095
	(0.098)
Gucha	0.081
	(0.103
Kisii Central	-0.282**
	(0.124)
Nyamache	0.044
	(0.097)
Nyamira South	0.028
	(0.114)
Manga	-0.314***
	(0.094)
Masaba North	0.168*
	(0.099)
Constant	0.578***
	(0.208)
Observations	784
Pseudo R-squared	-1.452
Log pseudo-likelihood	-373.823

Note: Coefficient estimates are shown with robust standard errors in parentheses. Kenyenya used as reference sub-county. GLM, generalized linear model. *, **, and *** significant at 10%, 5%, and 1% level, respectively.

Table A16. Covariate Balancing Tests for Generalized Propensity Score Matching (*t*-Statistics for Mean Differences Across Four Treatment Groups)

Covariate	Before matching				After matching			
	TG1[>0,0.30]	TG2 [0.31,0.46]	TG3 [0.47,0.58]	TG4 [0.59,1]	TG1 [>0,0.30]	TG2 [0.31,0.46]	TG3 [0.47,0.58]	TG4 [0.59,1]
Farm and household characteristics								
Age of household head (years)	0.36	-0.07	-1.74*	1.45	0.45	-0.38	-1.61	1.11
Male household head (dummy)	3.35***	0.20	-1.77*	-1.77*	0.28	0.01	-0.71	0.27
Education of household head (years)	5.54***	0.57	-2.76***	-3.27***	0.74	0.09	-1.39	-0.22
Household size (AE)	0.51	-2.32**	1.01	0.80	0.62	-2.22**	0.59	0.57
Farm size (acres)	6.16***	1.62	-2.28**	-5.45***	1.59	0.04	-0.77	-0.89
Farm productive assets (1,000 Ksh)	2.91***	0.77	-1.22	-2.45**	-0.24	-0.33	-0.07	-0.59
Access to credit (dummy)	2.47**	-1.36	-0.35	-0.75	0.29	-1.65*	0.18	0.17
Distance to main market (km)	-0.18	-1.01	0.49	0.69	1.21	-0.91	0.10	0.41
Group official (dummy)	1.85*	0.82	-0.56	-2.11**	-0.57	0.70	0.14	-0.49
Sub-county dummies								
Sameta	0.74	-0.74	-0.25	0.25	0.12	-0.88	-0.61	0.52
Gucha	0.93	1.18	0.43	-2.55***	-1.09	1.13	1.27	-1.43
Kisii Central	-1.27	-0.26	-0.26	1.79*	0.42	0.06	-1.02	0.34
Nyamache	1.10	0.86	-1.10	-0.86	-0.68	0.72	-0.84	0.49
Nyamira South	2.23**	-3.05***	0.20	0.61	1.84*	-2.75***	0.28	1.18
Manga	-5.77***	0.51	1.96**	3.20***	-0.88	0.79	0.76	-0.05
Masaba North	2.63***	0.07	-1.06	-1.63	-0.37	-0.83	-0.12	0.59

Note: TG, treatment group. The treatment groups (TG1-TG4) are of equal size, based on the households' level of overall commercialization; levels of commercialization are shown in brackets. Mean values of each TG are compared with means of all others TGs combined. *, **, and *** denote significant difference at the 10%, 5%, and 1% level, respectively.