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Effect of market production on rural household food consumption: evidence from Uganda

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Abstract

Food access is an important element of food security that has since long been a major concern of rural households. One intervention to improve food access has been increased promotion of market production in the hope that households will get increased income and access to food through the market rather than through self-sufficiency characteristic of subsistence production. We examine the effect of market production on household food consumption using a case of rice in western Uganda, where rice is largely a cash crop. Our analysis is based on propensity score matching and instrumental variable approach using survey data collected from 1137 rural households. We find evidence of negative significant effects of market production on calorie consumption; More commercialized households are more likely to consume less than the required calories per adult equivalent per day. This implies that the substitution effects due to higher shadow prices of food outweigh the income effects of additional crop sales. On the contrary, we find positive significant effects on household dietary diversity. We suggest a mixed approach combining policies targeted at market production as well as production for own consumption, and nutrition sensitization.

Keywords Market-oriented production · Food security · Propensity score matching · Uganda

1 Introduction

Despite widespread economic and agricultural growth during last decades, 13.5% of the population in developing regions remain chronically undernourished (FAO and WFP 2014). In Uganda, for example, over 30% of the total population faced some level of chronic food insecurity in 2015 (Feed The Future 2018). Insufficient food consumption is a public health concern as it increases vulnerability to a range of physical, mental and social health problems (Nord 2014). Children and youth who experience hunger, especially when this occurs repeatedly, are more likely to have poorer health (Kirkpatrick et al. 2010), reach lower levels of education, and have lower incomes at adulthood (Hoddinott et al. 2008).

Agriculture remains the focus of interventions as policy makers seek ways of reducing food insecurity in Africa, which is home to more than one out of four malnourished people (FAO and WFP 2014). Africa's demand for food continues to increase rapidly as a result of urbanization, globalization and especially high population growth. Though impressive, agricultural growth has not been able to meet this rise (Collier and Dercon 2014). In addition, agriculture remains the economic engine of many African countries, contributing an average of 30% of GDP. It is the main source of livelihood for rural households employing over 60% of the work force in Sub-Saharan Africa (Thornton et al. 2011). In Uganda, agriculture contributes 25% of GDP, and it provides the main source of income for all rural households, particularly the poorest 40% (Feed The Future 2018). As such, it is believed to have great potential to influence household food security (Godfray et al. 2010).

Market-oriented agricultural production is considered a viable option to ensure sustainable food security and welfare (Pingali 1997). It has been promoted by policy makers with the expectation that it can raise household income and at the

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same time increase productivity of food crops due to increased input use. However, the market-production strategy in low income areas faces particular challenges; increased income and food productivity may not translate in increased food consumption. For instance, a study by Aromolaran (2004) in Nigeria finds that calorie intake does not get a substantial share of marginal increases in income of low-income households. Similarly, in parts of Eastern Uganda, one of Eastern Africa's major rice producing region, Whyte and Kyaddondo (2006) finds that some rice cultivators starve because they sell all the food. Moreover, market production puts emphasis on specialization in what the producer has comparative advantage in. Considering the fact that food security is not only a problem of food supply but also access, improving productivity of a few selected food crops has limited potential for improving food security if food markets are not better integrated in rural areas.

Food access involves physical access to a place where food is available or economic access through owning the food that is home produced or having the purchasing power to buy it from the market. Whereas accessing food markets is of critical importance for households engaged in market production, rural areas still face the challenge of weak markets characterized by imperfections (Vermeulen et al. 2012). For a majority of people, access to food comes at least partially through the market when they have the income necessary to purchase an adequate diet rather than produce it entirely. However, having sufficient income depends not only on the amount of money one earns but also on the price of food (Staatz et al. 2009). In low income countries such as Uganda where agriculture is dependent on rainfall, households that depend on the market for food face a challenge of food price volatility arising partially from seasonal variation and fluctuations in foreign exchange rate.

Transition from subsistence to market production has had effects specific to each household depending on its resources. The general experience is that, despite their participation in market production, resource-poor households have continued to experience food insecurity due to low supply and limited access (Misselhorn et al. 2012; Shively and Hao 2012). Little has been done to understand how the transition influences food consumption patterns of households engaged in market production. In Rwanda, reduced subsistence orientation was found to reduce household calorie consumption levels, although increased income from the cash crops significantly increased calorie consumption expenditure (Von Braun et al. 1991). Von Braun (1995) recommends that potential food crops should be promoted as cash crops to avoid negative effects of agricultural commercialization on food security. Yet, Kavishe and Mushi (1993) find higher levels of malnutrition in parts of Tanzania where maize, the main food crop is also a cash crop.

Within this context our paper offers a contribution by exploring the relationship between market oriented agricultural production and food security. Unlike in most previous studies which focus on the effect of the traditional cash crops such as coffee (Kuma et al. 2016) and tobacco (Radchenko and Corral 2017), we focus on the commercial production of food crops. While traditional cash crops are mainly grown by large scale farmers, food crops are the main market crops for a great majority of smallholders in rural Africa (Carletto et al. 2017). Previous studies (Von Braun 1995) have recommended commercial production of such food crops as a remedy to food insecurity attributed to cash crops. Our analysis uses two different measures to proxy market-oriented production; share of output marketed and participation in the production of rice. Rice is a food crop that has been highly promoted for the market in part of our study area. Most farmers exposed to this intervention now engage in commercial rice production and, as a result, sell larger shares of their overall produce to the market than farmers in similar neighboring areas. We examine the impact on quantity (caloric intake) and quality (dietary diversity) of food consumed as well as access (food insecurity access scale) to enough quality food. This paper makes the case that promoting market-oriented production may not be effective in improving household food security particularly for small holders in the absence of other sources of income to support non-food consumption.

The paper is structured as follows; Section 2 contains the theory linking market production and food security, Section 3 presents the methodology used to estimate the effect of market production on household food consumption and outlines a description of the survey data. Section 4 presents the results and discussion. The conclusion forms section 5.

2 Market production and food security

2.1 Diverging views

There are two divergent views on the effect of market production on household food consumption; the first view suggests that market production positively affects household food security as it generates income that empowers the household to purchase a variety of foods it does not produce (Timmer 1997). As income increases, households are expected to adjust their food consumption pattern away from the cheap foods like cereals, tubers and pulses towards balancing their diet by including nutritionally rich foods, especially proteins of animal origin such as meat, fish, milk and other livestock products (Abdulai and Aubert 2004). Moreover, in areas where markets are functional, income from market production stabilizes household food consumption against seasonality (Timmer 1997).

In developing countries such as Uganda where agriculture is mainly rain fed, households experience seasonal variability in food supply and this results in food price fluctuation. Most households therefore, suffer transitory food insecurity during the pre-harvest season, while they are relatively food secure

during harvest and post-harvest periods. However, during pre-harvest period households engaged in market production are expected to have relatively better access to food. As consumers, they are affected by higher prices during pre-harvest season, but as producers they benefit from high food prices that increase their profits from food production. If the positive profit effect outweighs the negative effect the households' food consumption increases (Taylor and Adelman 2003). Thus, they are able to smooth their consumption through the market. Furthermore, Govereh and Jayne (2003) argue that income raised from market production can be used to purchase inputs for food crop production thus increasing productivity and consequently increase food availability.

The other view is that market production negatively affects household food consumption due to reduced food availability as a result of displacement of staples by cash crops or when a big portion of produce is sold (Von Braun and Kennedy 1994). Food markets are located in far-away towns where food comes from different areas. Due to poor infrastructure, transport costs are high. Buyers, therefore, may not be able to access enough food as prices are high, and for sellers real income from produce decreases due to transaction costs (Goetz 1992). Due to low output prices, farmers tend to sell large quantities, not necessarily because they have surpluses but to raise enough cash for taking care of household necessities (Fafchamps and Hill 2005; Key et al. 2000; Rahut et al. 2010). Low prices thus reduce income and physical food available for the household, jointly causing food insecurity (Feleke et al. 2005; Sadoulet and De Janvry 1995). Anderman et al. (2014) show that in Ghana increased production of cash crops lowers food security through food price inflation and increased seasonal price hikes. Relatedly, Kostov and Lingard (2004) argue that under difficult conditions such as inefficient input, output, credit and labor markets, risks and uncertainties characteristic of most developing countries, subsistence agriculture may be the only way for rural people to survive. Households that engage in subsistence farming have access to comparatively cheaper food and to a variety of nutritious foods, especially vegetables and fruits that are rich in micronutrients (Zezza and Tasciotti 2010).

Also, the argument that households engaged in market production have a relatively smooth consumption may not be true in rural areas where food in the market is locally supplied. Due to forces of demand and supply, in post-harvest period staples prices fall and households that purchase food are likely to consume more since acquiring calories is relatively cheap while the opposite is true during pre-harvest period. Thus, households that depend on the market for their food security are equally affected by the agricultural cycle (D'Souza and Jolliffe 2014).

2.2 Theoretical model

The structure of the model in which the household consumption is entrenched is critical in shaping the effects of market production on food security (Chiappori and Donni 2009; Vermeulen 2002). We formalize the relation between market production and food consumption using a farm household model. First, we assume that the household can only produce for own consumption. The household produces and consumes two 'crops': a staple crop and a composite food, which can be thought of as vegetables and pulses, but also animal source foods such as meat, eggs and dairy. Next, we introduce a sales market for the staple crop. The differences between the two models illustrate the impact of the introduction of such a market.

2.2.1 A simple household model without sale of produce

We assume the household maximizes the utility of the consumption of staple food (C_1), a composite category of other food (C_2), non-food products (C_{nf}) and home time (l). Following De Janvry et al. (1991), the utility function is concave, with the exact shape depending on household characteristics z:

$$Max\ u(C_1, C_2, C_{nf}, l_l; z) \tag{1}$$

The household can produce both staple crops ($i = 1$) and other food ($i = 2$) using family labor (l_f):

$$Q_i = q_i(l_{fi}), \forall i \in 1, 2 \tag{2}$$

We begin with a simple model assuming that the household only produces for own consumption. To finance market purchase for consumption of the two types of food (C_{mi}) and other products (C_{nf}), the household engages in off-farm employment (l_o) which is remunerated with a fixed wage rate (w) and has limited availability ($\overline{W}$):

$$C_{nf} + \sum_i p_i C_{mi} = w l_o, \tag{3a}$$

$$l_o \leq \overline{W}, \tag{3b}$$

where p_i is the market price of food i and the price of non-food consumption is the numeraire. Total food consumption (C_i) is the sum of own produce and food purchased in the market:

$$C_i = Q_i + C_{mi}\ , \forall i \in 1, 2 \tag{4a}$$

$$C_{mi} \geq 0, \quad \forall i \in 1, 2 \tag{4b}$$

The time endowment (T) of the household is limited:

$$T = \sum_i l_{fi} + l_o + l_l. \tag{5}$$

Utility is maximized under the following conditions (see appendix for derivations and full Kuhn-Tucker conditions):

$$\frac{\partial u}{\partial l_l} \Big/ \frac{\partial u}{\partial C_{nf}} = w - \lambda \Big/ \frac{\partial u}{\partial C_{nf}} = p_1 \frac{\partial q_1}{\partial l_{1f}} - \mu_1 \frac{\partial q_1}{\partial l_{1f}} \Big/ \frac{\partial u}{\partial C_{nf}} = p_2 \frac{\partial q_2}{\partial l_{2f}} - \mu_2 \frac{\partial q_2}{\partial l_{2f}} \Big/ \frac{\partial u}{\partial C_{nf}},$$

$$\tag{6a}$$

$$\frac{\partial u}{\partial C_1}\frac{\partial q_1}{\partial l_{f1}} = \frac{\partial u}{\partial C_2}\frac{\partial q_2}{\partial l_{fi}}, \tag{6b}$$

where $\lambda > 0$ if $l_0 = \overline{W}$, 0 otherwise; and $\mu_i > 0$ if $C_{mi} = 0$, 0 otherwise. In an interior solution ($\lambda, \mu = 0$), none of the market constraints is binding and the household employs labor in both types of food production until the marginal value of product of crop labor at market prices and the marginal value of home time ($\frac{\partial u}{\partial l_i} / \frac{\partial u}{\partial C_{nf}}$) equals the wage rate. Consumption expenditures are allocated between staples, other food, and non-food consumption according to their relative prices in the market. When the wage employment constraint is binding ($\lambda > 0$, the marginal value of home time and marginal value product of crop labor will be lower than the wage rate. The household will now use more labor in crop production and, as food cannot be sold, consume more food than in the interior solution. The shadow prices for both crops are then below the market price. Labor is allocated between crops so as to equalize the marginal value in consumption of labor in both crops.

2.2.2 Introducing crop sales

Inspired by Key et al. ([2000](#)), we introduce the option to market the staple at a price $p_1 - \tau$, where τ are the proportional transaction costs between selling and buying. To keep the model simple, we ignore fixed transaction costs and assume that excessive transaction costs for other crops inhibit sales. The scale of production is much smaller and they are often perishable. The cash constraint is now as follows:

$$C_{nf} + \sum_i p_i C_{mi} = (p_1 - \tau)M_1 + wl_o, \tag{7a}$$

where $M_1 \geq 0$ is the sales quantity of the staple crop. The associated food balances are:

$$C_1 = Q_1 - M_1 + C_{1m}, \tag{8a}$$

$$C_2 = Q_2 + C_{2m}. \tag{8b}$$

This gives the following extended optimal utility condition (see appendix for derivation and full Kuhn-Tucker conditions):

$$\frac{\partial u}{\partial l_l} / \frac{\partial u}{\partial C_{nf}} = w - \lambda / \frac{\partial u}{\partial C_{nf}} = p_1 \frac{\partial q_1}{\partial l_{f1}} - \mu_1 \frac{\partial q_1}{\partial l_{f1}} / \frac{\partial u}{\partial C_{nf}}$$

$$= (p_1 - \tau)\frac{\partial q_1}{\partial l_{f1}} + \nu \frac{\partial q_1}{\partial l_{f1}} / \frac{\partial u}{\partial C_{nf}}$$

$$= p_2 \frac{\partial q_2}{\partial l_{f2}} - \mu_2 \frac{\partial q_2}{\partial l_{f2}} / \frac{\partial u}{\partial C_{nf}}, \tag{9a}$$

where again $\lambda > 0$ if $l_0 = \overline{W}$, 0 otherwise; and $\mu_i > 0$ if $C_{mi} = 0$, 0 otherwise. In addition, $\nu > 0$ if $S_1 = 0$, 0 otherwise. The key difference with the previous model is that households can now also sell produce to earn cash ($\nu = 0, \mu_i > 0$). In this case, the

price against which crop 1 is valued is the sales price $p_1 - \tau$, which now binds the shadow price of staple from below.

Households that benefit from the sales opportunities face several changes compared to the model without sales. The shadow price of staples increases, which results in higher production of staples and more labor used in staple food production. As a result, the shadow wage increases and labor use in the composite food crop decreases, resulting in lower production. In an extreme case, the labor market constraint will no longer be binding and the shadow wage will equal the wage rate. Income increases which ceteris paribus results in higher consumption of all goods. However, also relative prices change. The price of staples and leisure increase (unless the labor market constraint was not binding) relative to the price of the composite food and nonfood. This means that the substitution effect is negative for staples and leisure and positive for the composite food and nonfood. Hence, the consumption of the composite food and nonfood unambiguously increase, while the effects on staple food consumption and leisure is ambiguous. As the production of the composite food decreases, more of this food will be purchased in the market.

While the model does not explicitly include land, this is obviously the key resource required for crop production besides labour. Households with a larger land/labor ratio will, ceteris paribus, have a higher marginal productivity of labor and a higher production of both crops. The potential to produce for the market is higher, which leads to higher income effects. As the shadow price of the staple without sales market is also lower for larger farms, the substitution effect will also be larger.

This translates into the following hypotheses:

> *Hypothesis 1. Participating in market production increases the shadow price for staple food and depresses staple food consumption at given income levels. This substitution effect outweighs the income effect associated with market production and results in lower consumption of calories, for which the staple is the main source.*
>
> *Hypothesis 2. Participating in market production increases household income and thus increases the consumption of the composite category of non-staple foods, which results in a higher dietary diversity.*
>
> *Hypothesis 3. Participating in market production increases dependence on the market for food consumption and thus decreases food security*
>
> *Hypothesis 4. The effects of market production on food consumption depend on farm size.*

3 Methodology

Our models compare a situation without the possibility to sell crops to a situation where one type of crops -staples, can be

sold at a given price. In reality, virtually all farmers live in locations with some level of market development, which is reflected in the height of the transaction costs. Transaction costs may differ between regions and crops depending on infrastructure, which encompasses roads as well as other facilities but also on the spread of production and market information. Depending on their level, transaction costs may be prohibitive of sales or just limit them. In reality, most smallholder farmers sell part of their crops to the market, which makes the relevant comparison not between pure subsistence farmers and market-oriented farmers but between farmers with less or more market orientation.

3.1 Identification strategy and sample selection

As explained above, regional differences in market development cause differences in the degree of commercialization of smallholder production. In addition, participation in market production is a decision influenced by the characteristics of the household. While any household can decide to specialize in producing what they can easily market, raise income to buy food and be food secure, richer households may be in possession of more adequate resources such as land, labor and capital that give them a comparative advantage to produce for the market (Barrett 2008). Also, transaction costs may be household specific (De Janvry et al. 1991). The decision to what extent a household produces for the market is therefore based partly on self-selection. Hence, a direct comparison between more and less market oriented farm households would produce biased estimates of the impact of market production (Blundell and Costa Dias 2000). This problem can be solved in the presence of a source of exogenous variation in market production.

The study faced the challenge to identify households exposed to such variation. We chose to use the case of rice production in Kanungu district in western Uganda. Rice was first introduced as a commercial staple crop in the district in 2003/2004, as part of a large government program on agricultural modernization, the Area-Based Agricultural Modernization Program (AAMP) (CARD 2014). Unique in the area, the program combined technological training and market support where farmers and marketing associations were trained in modern farming techniques, business development, marketing and value addition. Twelve rice hulling machines were established in the study area, including one that does sorting and packaging. After AAMP, the rice project was taken over by a government program called National Agricultural Advisory Services (NAADS). NAADS continued to support and promote rice production. It is now a priority cash crop in five out of twelve sub counties in the study area and one of priority commodities at national level (MAAIF 2010). Hence, the geographic spread of the project was relatively small, targeting some sub counties but leaving out highly similar ones. As these neglected areas did not receive similar support, we believe that the rice project provides exogenous variation in staple production for the market.

We therefore collected household survey data on food production and consumption from both project (treatment) and non-project (control) sub counties in Kanungu district during the pre-harvest period in March–May 2014. We employed a multi-stage sampling procedure to select respondents. The sample was drawn from seven sub counties; five project sub counties, and two non-project sub counties. The two non-project sub counties were purposively selected to resemble the project sub counties in both socioeconomic and agro-ecological conditions so that the presence of the project was the only exogenous difference. From each of the selected sub counties we made a list of villages for random selection of villages. For each of the selected villages, the village councilor and the extension worker made a list of households. We randomly selected 4 villages with 30 households each from each of the project sub counties and 6 with 50 households each from both of the non-project sub counties. For various reasons such as absence or refusal to respond, a total of 63 households were not interviewed, resulting in a sample of 1137 households of which 592 were from project areas and 545 were from non-project areas. For each respondent household, we collected data on household demographic and socioeconomic characteristics, agricultural production and marketing, and food security. Agricultural production data were collected for the two full seasons before the survey: March–July and August–January 2013/14. We chose to collect data during the pre-harvest period as this is the period in which most households experience food shortages and hence the period interventions should target. Also, farmers do not keep rice stocks until more than a few months after harvesting, which allows us to ignore rice stocks in our calculation of marketed shares.

We observe negligible 'contamination'/spillover effects in the sub counties used as control. While equally suitable for rice cultivation as the project areas, rice cultivation is virtually absent, and there are no alternative market crops not cultivated in the treatment sub counties. From our survey, 73% of the households in the project area and none of the household in the non-project area grew rice (Table 1). Rice is by far the crop with the highest proportion marketed: 57% compared to 13–29% for other crops in the pooled sample. The marketed shares for other crops are also slightly higher in the treatment area, possibly due to spillover effect of project activities such as training in business development and market linkages. Overall, farmers in the project area sell 53% of their produce (individual crops valued at their market price), compared to 41% for control farmers. These proportions are much higher than the national average crop commercialization index of 26.3 (Carletto et al. 2017). Hence, while both groups of farmers engage in food markets, this engagement is substantially higher for farmers who have been exogenously exposed to a project stimulating rice production for the market.

Table 1 Percentage share of food crops marketed

Crop	Pooled sample (N = 1137)		Treated (N = 592)		Control (N = 545)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Rice	57.1	24.3	57.1	24.3	–	–
Millet	28.7	25.9	35.0	28.0	21.5	21.5
Beans	29.1	25.6	32.0	27.8	26.8	23.4
Ground nuts	28.0	26.1	28.3	27.1	27.7	25.4
Maize	21.7	26.8	27.0	28.6	15.7	23.3
Banana	24.6	27.6	28.7	31.1	23.0	26.1
Sweet potatoes	15.7	25.0	19.8	28.5	13.0	22.0
Solanum potato	17.7	28.3	26.0	26.6	16.6	28.5
Cassava	22.3	31.2	22.7	30.5	22.0	31.7
Market production Index[1]	46.4	22.1	53.4	18.7	40.8	23..0

Household survey data. [1] Value of total household sales divided by total production value. All production, including the share retained for home consumption, is valued at farm gate prices

The absence of rice in the control areas is likely due to an information and services gap. Information creates awareness and may shape attitude which are important factors in framing outlooks and expectations of farmers towards technology choice (Doss 2006). Unless farmers are given information with regard to a new technology, they are likely not to adopt it. Market information in particular plays a significant role in farmers' decision to participate in market production (Goetz 1992; Omiti et al. 2009). Most farmers lack the capacity and enthusiasm to search for information by themselves. Moreover, in Uganda farmers have developed an attitude of relying on 'hand outs' such that they always wait for support from government or non-governmental organization to adopt a new technology. Other than information provision, the project established a strong infrastructure for rice trade in the treatment area, including hulling machines and farmer-trades linkages. No such infrastructure was developed in the control areas. We therefore believe that if a similar program would have been introduced in the non-rice growing area, households would equally participate in market production.

3.2 Indicators

Linked to our hypotheses, we use three types of indicators of food security; daily calorie consumption per adult male equivalent (AME), household dietary diversity, and household food insecurity access scale (HFIAS). By using calorie consumption per day per adult male equivalent (AME = number of adults + (number of children <18 years) × 0.5) rather than per capita, we control roughly for variation that arises due to different food requirements by age groups. This allows direct comparison of energy intake by households of different size and composition (Weisell and Dop 2012). We use conversion factors (West et al. 1988) and the nutri-survey program to compute the energy (calories) intake per adult equivalent per

day based on quantities and frequency a given food stuff was consumed by the household in a recall period of 7 days. The survey uses a 7-day recall period instead of the traditional 24-h period to control for daily consumption fluctuations. Depending on the number of meals a household consumes in a day, most households are not expected to consume a variety of food stuffs within 24 h. As households do not keep consumption records, we relied on the memory of female respondents for quantities and frequency of foods consumed since women are usually in charge of food preparations (Beegle et al. 2012).

Food wastage, food given to guests and food eaten away from home present potential biases, but we expect these to be small. Since the survey is conducted during pre-harvest period, we expect minimal wastage as food is rather scarce. Similarly, in rural areas it is not common that people eat away from home except on functions or when they travel to far distances, and we do not expect many of such occasions. However, respondents may have difficulties remembering all the foods their household consumed over the recall period. Moreover, it may also be difficult for respondents to accurately estimate quantities consumed, especially of home-produced foods such as tubers. These are harvested as piece meal, and there are various containers used during harvest such that we relied on the good estimation skills of the women who harvest and cook such foods. As such, there is potential of measurement error associated with recall (Beegle et al. 2012). However, we have no reason to believe that this error would be associated with market production and therefore do not expect it to affect our estimates.

Dietary diversity is a qualitative measure of food consumption that reflects household access to a variety of foods, and it is a proxy for (micro) nutrient adequacy of the diet (Hoddinott and Yohannes 2002; Kennedy et al. 2011). Dietary diversity captures the number of different types of food or food groups

consumed in a specific period (Zezza and Tasciotti 2010). Following FAO but ignoring spices, condiments and beverages, we grouped the various foods into eleven categories; cereals, root and stem tubers, vegetables, fruits, meat, eggs, fish, milk and milk products, pulses, cooking oil, and sweets. If a household consumed any one of the foods in a given category in the period of 7 days before the interview, it scores 1 and 0 otherwise. The sum of all categories is the household dietary diversity score (HDDS).

The HFIAS score is conventionally used as a continuous measure of the degree of food insecurity in terms of access for a period of four weeks (Coates et al. 2007). The HFIAS covers a set of nine questions related to three different domains of food insecurity (access): anxiety and uncertainty, insufficient quality, and insufficient intake. Each question asks for the frequency of occurrence of a certain condition and scores from 0 (never) to 3 (often), with an overall score ranging from 0 to 27. The higher the score, the more food insecure in terms of access the household is. In our study, we extend the period from four weeks to twelve months to control for seasonality in the agricultural cycle, keeping the rest the same.

3.3 Descriptive statistics

Most survey households were male headed (84%) with farming as their main occupation (92%) (Table 2). Farming was slightly more dominant in the treatment than in the control area: 95% mentioned farming as their main occupation compared to 89% (Table 7). The average household had 6 members, of which 4 are adults, and owned 4 acres of land. Control households were slightly larger with 6.4 members on average compared to 5.7 for controls. They also owned larger farms on average: 5.4 acres compared to 3.9. Almost half owned livestock. The distance to the market ranged from 0.2 to 18 km, with an average of 2.8 km.

Food insecurity is prevalent in the area. The scores for the HFIAS covered the entire range from 0 to 27, with an average of 4.6. While on average survey households are food secure with a mean calorie consumption of 3580 kcal per adult male equivalent per day, caloric consumption for 26.5% is less than the minimum requirement of 2780 kcal per adult male equivalent per day (FAO and WHO 1985). This proportion is below what has been reported in a previous study, which indicates that 46% of the population in the western region was energy deficient in 2009–2010 (World Food Program and UBOS 2013). Moreover, 36% of households asserted that they sometimes or often do not have enough to eat, and 33.3% of households reported eating less than three meals per day. This situation was mainly reported for the months of March, April and September (this is the growing period for most of the crops). The reasons households give for not always having enough to eat include; harvesting too little (70%), selling most of what is harvested (14%), and lack of money (12%).

Table 2 Descriptive statistics

	Mean	St Dev	Min	Max
Calorie consumption per adult equivalent	3580	1177	448.6	5896
Household Dietary Diversity Score	6.6	1.7	2.0	10
Household Food Insecurity Access Score	4.6	6.0	0	27
Market production Index[1]	46.4	22.1	0	97.0
Education of husband (years)	6.7	3.8	0	20
Education of wife (years)	5.0	3.2	0	17
Household size	6.1	2.6	1	24
Dependency ratio (all members/members>18)	1.5	1.0	0	6
Wealth (thousands Ug Sh)	10,300	7,279	165	29,500
Size of land owned (acres)	4.3	5.4	0	35
Distance to the market (km)	2.8	2.3	0.2	18
Gender of household head: male =1; otherwise = 0	83.7			
Married = 1; otherwise = 0	78.7			
Household own livestock =1, 0 otherwise	47.8			
Depends on family labor =1; 0 = otherwise	60.7			
Main occupation; farming =1; otherwise =0	91.9			
No secondary occupation =1; otherwise =0	52.5			
Member of farmer group =1; otherwise =0	53.1			
Member of saving & credit group =1; otherwise =0	81.3			
Member of marketing group =1; otherwise =0	3.8			
N = 897				

[1] The Market Production Index equals the value of total household sales divided by the value of total production. All production, including the share retained for home consumption, is valued at farm gate prices

3.4 Estimation strategy

We use two different strategies to determine the effect of market production on household food consumption, both starting from the exogenous variation in market production caused by the rice project. The results from the two approaches provide complementary information on causal effects since they rely on different assumptions (Blundell and Costa Dias 2000; DiPrete and Gangl 2004).

First, we compare the food security indicators for rice producers and non-rice producers. Remember that rice is an exogenously promoted marketable crop and that rice producers are more market oriented than otherwise similar farmers. As explained above, rice was promoted as a commercial staple crop with associated market support in a number of subcounties, where it was widely adopted, while it was not promoted and therefore not produced in similar subcounties. Hence, we assume that there are no systematic unobserved differences between rice growing and non-rice growing farmers. To increase the efficiency of the estimates and control for potentially remaining differences in observable characteristics, we use propensity score matching (Blundell and Costa Dias 2000). Propensity score matching has the advantage that it does not require a parametric model linking outcome to the treatment, and it allows estimation of mean impacts without arbitrary assumption about functional forms and error distribution (Ravallion 2007) thus improving the accuracy of the causal estimates (DiPrete and Gangl 2004). We used a logit model to estimate the propensity score -the conditional probability of a household participating in rice production given its observable characteristics (Rosenbaum and Rubin 1983); and then calculated the average treatment effect on the treated (ATT) (Caliendo and Kopeinig 2008). Given the right observations X, the observations of the non-rice growing households (the comparison group) are statistically what the observations of the rice growing households would be had they not participated. We impose the common support condition in the estimation of propensity scores by matching in the region of common support. This allows households with the same values of confounding factors to have a positive probability of being among rice growing households and the control group (Heckman et al. 1997). To assess the robustness of the estimates, we use different matching methods (nearest neighbor matching, kernel matching and radius matching) (Caliendo and Kopeinig 2008; Heckman et al. 1997). In addition, we carry out sensitivity analyses using Rosenbaum's bounds to establish the sensitivity of the estimated treatment effects to a potential unobserved covariate that is highly correlated with both treatment and potential outcomes.

Second, we use exposure to (information from) the rice project as an instrument for the market production index. This is based on the premise that access to information on commercial rice production through agricultural extension pushed households into more market-oriented production. As argued before, exposure to the project can be considered exogenous, and we see no reason to expect a direct effect of the project activities on food security. A similar instrument has been used in previous studies such as in Dontsop Nguezet et al. (2011). Instrumental variable (IV) regression gives the local average treatment effect (LATE), which is the average treatment effect for those induced into the treatment by assignment (Angrist and Imbens 1995). IV comes at the cost of reduced precision of the estimates and may produce biased estimates if the underlying assumptions are not valid. Test results indicate that the estimates are reliable and the instrument is strong (Stock and Yogo 2005) see appendix Tables 11, 12, 13, 14, and 15).

3.5 Propensity score estimates

Table 3 presents the logit regression results. As independent variables, we used information on household characteristics as well as on individual education and demographic characteristics which could reasonably be treated as exogenous to participation in market-oriented production. The variable membership in farmer groups may seem to be endogenous as it could be affected by market production itself. However, in Uganda most groups are externally initiated, and forming farmer groups has become a common approach that is used to provide services and inputs both by government and development agencies in rural areas. Thus, it is reasonable to assume that membership in farmer groups is not influenced by participation in market-oriented production. Farmers who live closer to the market will probably be able to get higher prices, though this effect may not be linear. We therefore included both distance to the market and distance to the market squared as explanatory variables in our regression.

Households producing rice are more likely to be married, with young household heads, they own relatively more land and agriculture is more likely to be their main occupation. They are also more likely to be members of farmer groups and savings and credit associations. The distribution of propensity scores using Kernel and Radius matching are shown in Appendix Fig. 2.

Balancing tests show that -while before matching there are differences between the treated and the control group in the means of many covariates, after matching these differences are very small and statistically not significantly different from zero. The chi^2 test results show very low pseudo R^2s for the matched sample, and these are statistically not significant ($p > 0.05$). The absolute standardized difference of the means of the linear index of the propensity score in the treated and matched control group (B) and the ratio of treated to matched control group variances of the propensity score index(R) conform to Rubins' recommendation (B is less than 25% and R is within the range 0.5–2) (Rubin 2001). These results suggest

Table 3 Logistic regression estimates

Participation in rice market production	Coefficient	Std. Err.
Age of household head	−0.0274***	0.0073
Education of household head	0.03288	0.0241
Education of spouse	−0.0318	0.0483
Education of spouse x secondary occupation	−0.0407***	0.0145
Number of persons in the household	0.0636**	0.0327
Land owned (Acres)	0.2765***	0.0414
Land owned squared	−0.0077***	0.0014
Distance from home to the road (km)	0.0468	0.0339
Distance to the road squared	−0.0001	0.0001
Access to extension services	0.0273	0.0493
Married = 1; otherwise = 0	1.2799***	0.2488
Main occupation; agriculture =1; otherwise =0	1.3104***	0.3331
No secondary occupation =1; otherwise =0	−0.0309	0.2020
Member in farmer group =1; otherwise =0	0.7365***	0.1796
Member of saving & credit group =1; otherwise =0	−0.7313***	0.1952
Number of obs	933	
Prob > chi^2	0.0000	
Pseudo R^2	0.1504	

*Significant at 10%; **Significant at 5%; *** Significant at 1%

that all covariates used to generate propensity scores are well balanced after matching. Details on propensity score estimates and balancing tests are presented in Appendix Table 7.

4 Results

4.1 Does market production affect household food consumption?

In line with hypothesis 1, our PSM results indicate that market production reduces household caloric consumption. Compared to non-rice households, rice households consume on average 343–359 less calories per male adult equivalent per day depending on the matching method used (Table 4). These results are fairly robust to hidden selection bias: doubts on the statistical significance of estimated results occur only if confounding factors cause the odds ratio of participating in rice production to differ by a factor above 3.0 (DiPrete and Gangl 2004). The LATE gives qualitatively similar results: we find a negative significant effect of market production on household calorie consumption (Table 5). The LATE of households induced into market production is significantly lower than the ATT. This can be explained by the different nature of the two estimators, while ATT gives an overall average effect, 2SLS gives a weighted average of unit causal effects and the weights are determined by how the compliers are distributed.

The negative effect of market production on calorie consumption thus confirms our hypothesis that the negative substitution effect outweighs the positive income effect.

Consistent with previous studies, in rural Uganda food energy sufficiency is more closely associated with home production (World Food Program and UBOS 2013). Due to the increased market opportunities for staples, their relative price has increased, making them a less attractive consumption good compared to other food and nonfood. Income also increases, but as hypothesized, the substitution effect outweighs the income effect. A substantial share of the rice harvested is sold. Since such income usually comes in lump sum, a large part is likely to be spent on non-food consumption that are one-time purchases or seasonal payments such as education fees. However, this is outside the scope of this paper.

In conformity to hypothesis 2, we find that market production has a significant positive effect on dietary diversity. Households engaged in market-oriented rice production on average have a dietary diversity score of 0.3 above that of non-rice households (Table 4). Again, these results are reasonably robust to hidden selection bias; only confounding factors that cause odds ratio of participating in rice production to differ by a factor above 1.4 cast doubts on the statistical significance of estimated results. Like for calorie consumption, The LATE results are qualitatively similar but smaller (Table 5).

We therefore find that more market-oriented households are better able to purchase different types of foods and thus have a slightly more diverse diet. Overall, households derive a big proportion of their nutrition from cereals, tubers, and pulses, which are consumed almost on a daily basis (Fig. 1). Vegetables and fruits are commonly consumed in the rainy season, when the survey was taken, but much less in the dry season due to limited availability. The rest of the food

Table 4 Average treatment effect and sensitivity analysis for food access

Outcome	Matching algorithm	Number of treated	Number of control	Mean outcome treated	ATT (SE)	Critical level of hidden bias (Γ)
Calorie consumption (per adult equivalent /day)	Nearest neighbour (NN = 4)	416	517	3358	−357.21*** (114.01)	Above 3
	Kernel matching (band width = 0.06)	416	517	3358	−359.47*** (101.57)	Above 3
	Radius matching (caliper =0.02)	402	517	3363	−342.31*** (101.5)	Above 3
Household Food Insecurity Access score	Nearest neighbour (NN =4)	416	517	4.89	0.68 (0.49)	
	Kernel matching (band width = 0.04)	416	517	4.89	0.58 (0.48)	
	Radius matching (caliper =0.03)	412	517	4.93	0.68 (0.42)	
Household Dietary Diversity Score	Nearest neighbour (NN = 5)	411	517	6.92	0.339** (0.16)	1.3–1.4
	Kernel matching (band width = 0.05)	411	517	6.92	0.320** (0.13)	1.3–1.4
	Radius matching (caliper =0.02)	397	514	6.92	0.330** (0.12)	1.3–1.4

*Significant at 10%; **Significant at 5%; *** Significant at 1%

categories are consumed less frequently. Animal proteins are costly, not always available in sufficient quantities, and there is limited knowledge of their importance. The higher dietary diversity of more market-oriented households results from a larger likelihood that these households purchase food. Hence, they are exposed to a variety of foods including meat, eggs, fish, and cooking oil, which are typically bought in the market.

We find less support for our third hypothesis. The ATT for exposure to commercial rice production on HFIAS is not significantly different from 0, but we do find a significant positive LATE for the market production index on HFIAS. The latter conform to our hypothesis that market production increases dependence on the market for food and thus decreases food security.

4.2 Heterogeneous effects

Since land is a major resource for market production (Barrett 2008) we analyze the market production effect on households disaggregated according to land holdings. We chose 3 acres of land as the boundary, because this divides the sample in half. We first test for covariate balancing using disaggregated data, and the results show that all covariates are well balanced (Appendix

Table 10). The pseudo R^2 after matching are very low and not statistically significant. The absolute standardized difference of the means of the linear index of the propensity score in the treated and matched control group (B) and the ratio of treated to matched control group variances of the propensity score index(R) conform to Rubins' recommendation (Rubin 2001); B is less than 25% and R within the range 0.5–2.

Table 6 shows that market-oriented rice production has a larger impact on food security for households with smaller farms. The associated decrease in calorie consumption is significant for both the lower and upper half of the sample households, yet the effect is largest for households with less than three acres. For such households, the income effect of the little produce they can sell is low, while the substitution effect can be substantial. The differences for dietary diversity are even more striking: market-oriented rice production significantly increases dietary diversity for households with small land holdings only. It is clearly more difficult to grow a variety of crops for a diversified diet on a very small farm, so purchased foods have more potential to increase dietary diversity for households with little land. Alternatively, the cash income without additional crops sales may already have been sufficient to reach the desired dietary diversity for the larger farmers. Again, we find limited effects of market production on HFIAS. Overall, these results

Table 5 Local average treatment effect of market production on food consumption

Outcome variable	Late	Standard error	F statistic
Calorie consumption	−157.56***	37.36	23.6
Household Food Insecurity Access score	0.106*	0.053	
Dietary diversity score	0.030**	0.015	

*Significant at 10%; **Significant at 5%; *** Significant at 1%

Fig. 1 Proportion of households consuming food from different food groups in a 7-day recall period
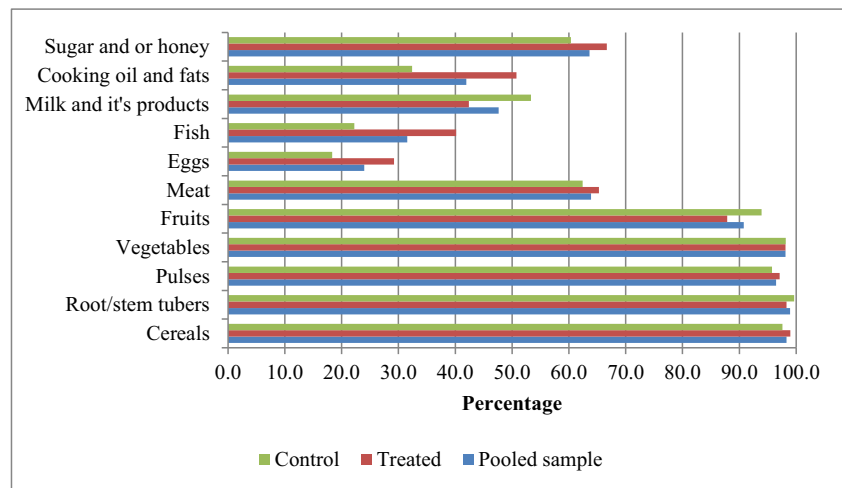
confirm our hypothesis of differences between households based on the size of their farm.

5 Conclusion

This paper examines the effect of market production on rural household food consumption using the case of commercial rice production in western Uganda. We use primary data from rural households that were stratified randomly selected from areas where market-oriented rice production has been actively promoted and areas with similar conditions where this has not been done. We apply a propensity score matching approach to estimate the average treatment effect of market production and test for robustness of our results by estimating the local average treatment effects using instrumental variable approach.

The results of both approaches are consistent and indicate that households engaged in market-oriented rice production are more likely to experience low caloric consumption. We argue that this is due to displacement of food crops for own consumption by the marketable crop and limited allocation of the money earned from crop sales to food purchases. We also find limited evidence of a positive significant effect of market production on the household food insecurity access score. On the contrary, we find evidence that market production increases dietary diversity. Smallholder households engaged in market production tend to purchase a bigger portion of their food and thus have access to different food stuffs. Finally, we find that market production effects on food

Table 6 The effects of market production disaggregated by land holding

Outcome	Matching algorithm	Land owned < 3 acres			Land owned > = 3 acres		
		No. treated (control)	ATT (Std. Err.)	Critical level of hidden bias (Γ)	No. treated (control)	ATT (Std. Err.)	Critical level of hidden bias (Γ)
Calorie consumption (per adult equivalent /day)	Nearest neighbor (NN = 8)	136 (321)	−539.0*** (168.9)	1.8–1.9	279 (220)	−344.5*** (−124.9)	1.9–2.0
	Kernel matching (band width = 0.04)	136 (321)	−518.3*** (−122.7)	1.9–2	279 (220)	−322.9** (−110.4)	1.7–1.8
	Radius matching (caliper =0.03)	136 (321)	−520.7*** (−162.8)	1.9–2	271 (220)	−307.5** (−123.3)	1.7–1.8
Household Food Insecurity Access score	Nearest neighbor (NN = 10)	133 (318)	1.81* (0.76)		273 (219)	1.19 (0.73)	
	Kernel matching (band width = 0.05)	133 (318)	1.50 (0.98)		273 (219)	1.42 (0.93)	
	Radius matching (caliper =0.03)	133 (318)	1.72 (1.12)		262 (219)	1..3 (0.86)	
Dietary diversity score	Nearest neighbor (NN = 4)	133 (318)	0.72*** (3.49)	2.0–2.1	273 (219)	0.19 (0.42)	1.1
	Kernel matching (band width = 0.05)	133 (318)	0.67*** (2.68)	1.9–2.0	273 (219)	0.17 (0.86)	1.1
	Radius matching (caliper =0.02)	133 (318)	0.66*** (3.17)	1.8–1.9	262 (219)	0.24 (1.54)	1.2

*Significant at 10%; **Significant at 5%; *** Significant at 1%

consumption are more pronounced among households with small land holdings.

These findings suggest that market-oriented crop production is not sufficient for reducing hunger and under nutrition of smallholder households, even when the marketable crop is a food crop that can also be consumed at home. While reliance on markets for food consumption increases the diversity of the relatively monotonous diet, this income effect is outweighed by the substitution effect; Calorie consumption decreases as food is now valued at market prices, which are higher than the internal shadow price for constrained farmers. This indicates that a substantial share of the additional cash income is allocated to non-food consumption, even when this compromises energy consumption. As explained eloquently by Duflo and Banerjee (2011, p36), this is a rational choice of the household, because "it is clear that things that make life less boring are a priority of the poor". This may for example be a television, something special to eat, or a festival. It is easy to see that this trade-off between enjoyment and food is likely to be higher for poorer households with smaller farms. While rational for the household, the decreased energy consumption has negative effects on public health: malnourished children are less healthy, perform less well in school and malnourished adults earn less income.

What is needed is a mixed approach that combines policies targeted at market production, production for own consumption, and nutrition sensitization. We do not deny that households should produce for the market, if Uganda and Africa as a whole has to feed its fast-growing population, but to ensure food security there must be a fair balance between increasing crop sales and own consumption. This can be achieved through policies that support both market-oriented and own-consumption oriented crops. There is need for technologies that support intensification of food production to enable smallholders raise enough food and surplus for sale. For example, small scale irrigation technologies that can enable households produce throughout the year will minimize the effect of seasonality on food security. Also improving the nutritive value of foods such as sweet potatoes, cassava and maize –which provide the highest proportion of calories for most households, could be key in improving household food security. Furthermore, there must be deliberate efforts to develop value addition technologies and infrastructure in rural areas to enable sellers and buyers easy access to food markets. In addition, nutrition sensitization can help improve the quality of the diet. Increased knowledge on the health effects of nutrition may change consumption preferences more towards food and increase the generally low dietary diversity.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix

Appendix 1 Theoretical model

Model without sales

The Lagrangian for an interior solution to the problem can be written as follows:

$$L = u\big(q_1(l_{f1}) + C_{m1}, q_2(l_{f2}) + C_{m2}, wl_0 - p_1 C_{m1} - p_2 C_{m2}, T - l_{f1} - l_{f2} - l_o\big) \quad (10)$$
$$+ \lambda\big(\overline{W} - l_o\big) + \mu_1 C_{m1} + \mu_2 C_{m2}.$$

Differentiating with respect to market food consumption (C_{mi}), farm labor (l_{fi}), and off-farm labor (l_o) yields the following first order conditions:

$$\frac{\partial L}{\partial C_{mi}} = \frac{\partial u}{\partial C_i} - \frac{\partial u}{\partial C_{nf}} p_i + \mu_i = 0, \quad \forall i \in 1,2 \quad (11)$$

$$\frac{\partial L}{\partial l_{fi}} = \frac{\partial u}{\partial C_i}\frac{\partial q_i}{\partial l_{fi}} - \frac{\partial u}{\partial l_l} = 0, \quad \forall i \in 1,2 \quad (12)$$

$$\frac{\partial L}{\partial l_o} = \frac{\partial u}{\partial C_{nf}} w - \frac{\partial u}{\partial l_l} - \lambda = 0 \quad (13)$$

Which can be summarized as follows:

$$\frac{\partial u}{\partial l_l} \Big/ \frac{\partial u}{\partial C_{nf}} = w - \lambda \Big/ \frac{\partial u}{\partial C_{nf}} = p_1 \frac{\partial q}{\partial l_{fi}} - \mu_1 \frac{\partial q_1}{\partial l_{f1}} \Big/ \frac{\partial u}{\partial C_{nf}}$$

$$= p_2 \frac{\partial q_2}{\partial l_{f2}} - \mu_2 \frac{\partial q_2}{\partial l_{f2}} \Big/ \frac{\partial u}{\partial C_{nf}} \quad (14)$$

$$\frac{\partial u}{\partial C_1}\frac{\partial q_1}{\partial l_{f1}} = \frac{\partial u}{\partial C_2}\frac{\partial q_2}{\partial l_{f2}} \quad (15)$$

In addition:

$$\lambda, \mu_i, C_{mi} \geq 0, \quad (16)$$

$$l_o \leq \overline{W}, \quad (17)$$

where

$$\lambda > 0 \text{ if } l_o = \overline{W}; \text{ and } \mu_i > 0 \text{ if } C_{mi} = 0. \quad (18)$$

Model with sales

$$L = u\begin{pmatrix} q_1(l_{f1}) - M_1 + C_{1m}, q_2(l_{f2}) + C_{2m}, wl_o + (p_1 - \tau)M_1 - p_1 C_{1m} \\ -p_2 C_{2m}, T - l_{1f} - l_{2f} - l_o \end{pmatrix} \quad (19)$$
$$+ \lambda\big(\overline{W} - l_o\big) + \mu_1 C_{1m} + \mu_2 C_{2m} + \nu S_1.$$

Differentiating with respect to market food consumption (C_{mi}), farm labor (l_{fi}), and off-farm labor (l_o) yields the following first order conditions:

$$\frac{\partial L}{\partial C_{mi}} = \frac{\partial u}{\partial C_i} - \frac{\partial u}{\partial C_{nf}} p_i + \mu_i = 0 \qquad (20)$$

$$\frac{\partial L}{\partial l_{if}} = \frac{\partial u}{\partial C_i} \frac{\partial q_i}{\partial l_{fi}} - \frac{\partial u}{\partial l_l} = 0, \forall i \in 1, 2 \qquad (21)$$

$$\frac{\partial L}{\partial l_o} = \frac{\partial u}{\partial C_{nf}} w - \frac{\partial u}{\partial l_l} - \lambda = 0, \qquad (22)$$

$$\frac{\partial L}{\partial S_1} = -\frac{\partial u}{\partial C_1} + \frac{\partial u}{\partial C_{nf}} (p_1 - \tau) + \nu = 0. \qquad (23)$$

Summarizing, this gives:

$$\frac{\partial u}{\partial l_l} \bigg/ \frac{\partial u}{\partial C_{nf}} = w - \lambda \bigg/ \frac{\partial u}{\partial C_{nf}} = p_1 \frac{\partial q_1}{\partial l_{f1}} - \mu_1 \frac{\partial q_1}{\partial l_{f1}} \bigg/ \frac{\partial u}{\partial C_{nf}} \qquad (24)$$

$$= (p_1 - \tau) \frac{\partial q_1}{\partial l_{f1}} + \nu \frac{\partial q_1}{\partial l_{f1}} \bigg/ \frac{\partial u}{\partial C_{nf}} = p_2 \frac{\partial q_2}{\partial l_{f2}} - \mu_2 \frac{\partial q_2}{\partial l_{f2}} \bigg/ \frac{\partial u}{\partial C_{nf}},$$

$$\frac{\partial u}{\partial C_1} \frac{\partial q_1}{\partial l_{f1}} = \frac{\partial u}{\partial C_2} \frac{\partial q_2}{\partial l_{fi}}, \qquad (25)$$

with:

$$\lambda, \mu_i, C_{mi,}, S_1 \geq 0, \qquad (26)$$

$$l_o \leq \overline{W}, \qquad (27)$$

$$\lambda > 0 \text{ if } l_o = \overline{W}; \mu_i > 0 \text{ if } C_{mi} = 0, \text{ and } \nu > 0 \, S_1 = 0. \qquad (28)$$

Appendix 2 Propensity score matching
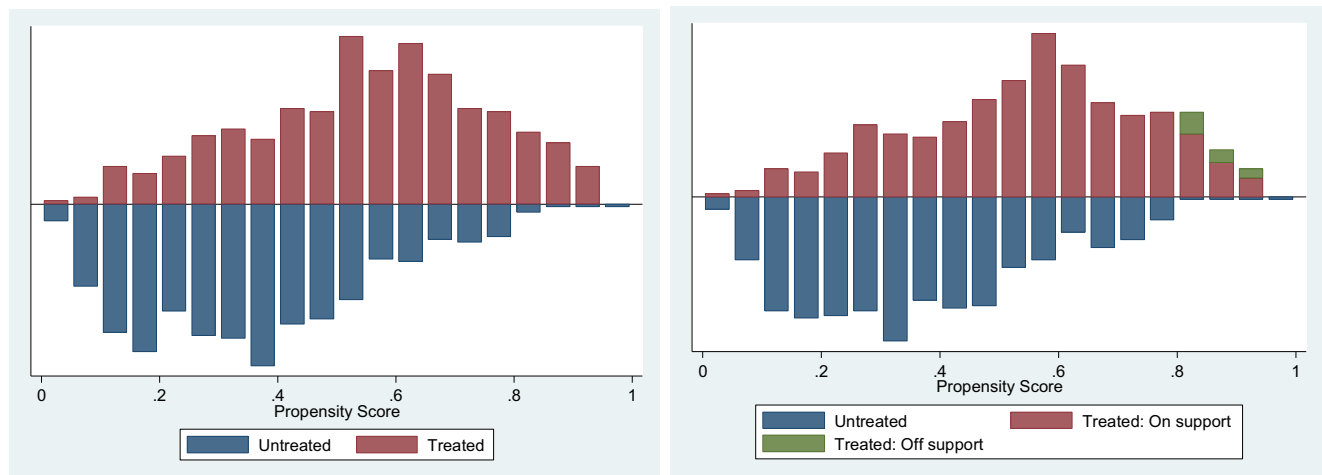
Fig. 2 Distribution of propensity scores and the region of common support

Table 7 Propensity score matching and covariate balancing test

Variable	Sample	Mean		%reduction	t-test
		Treated	Control	(bias)	p > t
Age of household head	Unmatched	42.181	42.716		0.536
	Matched	42.181	43.176	−86.0	0.265
Education of household head	Unmatched	5.8353	5.3711		0.045
	Matched	5.8353	5.8175	96.2	0.939
Education of spouse	Unmatched	4.7819	4.9258		0.585
	Matched	4.7819	4.9637	−26.3	0.461
Education of spouse Squared	Unmatched	35.339	44.195		0.010
	matched	35.339	38.282	66.8	0.322

Table 7 (continued)

Variable	Sample	Mean		%reduction	t-test
		Treated	Control	(bias)	p > t
Number of persons in the household	Unmatched	6.6473	5.7421		0.000
	Matched	6.6473	6.3797	70.4	0.131
Land owned (Acres)	Unmatched	5.441	3.5855		0.000
	Matched	5.441	6.0145	69.1	0.157
Land owned squared	Unmatched	62.405	38.951		0.017
	Matched	62.405	73.819	51.3	0.284
Distance from home to the road (km)	Unmatched	2.4801	1.4003		0.106
	Matched	2.4801	2.1682	71.1	0.711
Distance to the road squared	Unmatched	216.71	25.13		0.309
	Matched	216.71	99.163	38.6	0.584
Access to extension services	Unmatched	2.0162	1.4991		0.000
	Matched	2.0162	2.2026	64.0	0.162
Married = 1;otherwise = 0	Unmatched	.86311	.72542		0.000
	Matched	.86311	.83449	79.2	0.241
Main occupation; farming =1; otherwise =0	Unmatched	.94896	.89796		0.003
	Matched	.94896	.95437	89.4	0.711
No secondary occupation =1; otherwise =0	Unmatched	.49652	.55288		0.081
	Matched	.49652	.52359	52.0	0.427
Member in farmer group =1; otherwise =0	Unmatched	.65661	.43414		0.000
	Matched	.65661	.68987	85.1	0.298
Member of saving & credit group =1; otherwise =0	Unmatched	.78422	.83673		0.037
	Matched	.78422	.7966	76.4	0.656

Table 8 Chi-square test for significance of variable before and after matching

Outcome	Matching algorithm	Pseudo R2 Before (After) matching	p > chi^2 Before (After) matching
Calorie consumption	Nearest neighbour (NN = 4)	0.149 (0.010)	0.000 (0.687)
	Kernel matching (band width = 0.06)	0.149 (0.004)	0.000 (0.991)
	Radius matching (caliper =0.02)	0.149 (0.004)	0.000 (0.995)
Dietary diversity score	Nearest neighbour (NN = 3)	0.151 (0.010)	0.000 (0.692)
	Kernel matching (band width = 0.05)	0.151 (0.006)	0.000 (0.956)
	Radius matching (caliper =0.02)	0.151 (0.005)	0.000 (0.982)
Household Food Insecurity Access score	Nearest neighbour (NN = 3)	0.149 (0.010)	0.000 (0.688)
	Kernel matching (band width = 0.05)	0.149 (0.005)	0.000 (0.985)
	Radius matching (caliper =0.03)	0.149 (0.004)	0.000 (0.995)

Table 9 Sensitivity analysis: Rosenbaum Bounds

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	1.2e-06	1.2e-06	−376.44	−376.44	−517.35	−226.616
1.1	1.3e-08	.000057	−438.855	−312.895	−575.795	−158.906
1.2	9.3e-11	.00101	−493.491	−253.079	−628.817	−96.7301
1.3	5.5e-13	.008566	−543.83	−197.147	−677.867	−37.9797
1.4	2.7e-15	.041284	−588.088	−144.24	−722.018	20.8813
1.5	0	.128194	−629.625	−95.9149	−764.324	77.0881
1.6	0	.282981	−668.363	−49.2977	−803.401	130.27
1.7	0	.48101	−704.19	−4.0281	−838.623	180.895
1.8	0	.673149	−736.197	41.2362	−871.58	227.21
1.9	0	.820785	−769.557	82.8618	−901.617	276.157
2	0	.913813	−799.053	124.327	−930.764	319.927

gamma log odds of differential assignment due to unobserved factors; *sig +* upper bound significance level; *sig-* lower bound significance level; *t-hat+* upper bound Hodges-Lehmann point estimate; *t-hat-* lower bound Hodges-Lehmann point estimate; *CI+* upper bound confidence interval (a = .95); *CI-* lower bound confidence interval (a = .95)

Table 10 Covariate balancing test for disaggregated data

Outcome	Matching algorithm	Land owned < 3		Land owned >= 3	
		Pseudo R2 Before (after) matching	p > chi^2 Before (after) matching	Pseudo R2 Before (After) matching	p > chi^2 Before (after) matching
Calorie consumption	Nearest neighbour (NN = 8)	0.168 (0.005)	0.000 (1.000)	0.137 (0.004)	0.000 (0.998)
	Kernel matching (band width = 0.04)	0.168 (0.004)	0.000 (1.000)	0.137 (0.005)	0.000 (0.989)
	Radius matching (caliper =0.02)	0.168 (0.005)	0.000 (1.000)	0.137 (0.004)	0.000 (0.997)
Dietary diversity score	Nearest neighbour (NN = 10)	0.172 (0.009)	0.000 (0.997)	0.139 (0.006)	0.000 (0.984)
	Kernel matching (band width = 0.05)	0.172 (0.005)	0.000 (1.000)	0.139 (0.004)	0.000 (0.9997)
	Radius matching (caliper =0.02)	0.172 (0.006)	0.000 (1.000)	0.139 (0.005)	0.000 (0.995)
Household Food Insecurity Access score	Nearest neighbour (NN = 4)	0.171 (0.011)	0.000 (1.000)	0.112 (0.007)	0.000 (0.999)
	Kernel matching (band width = 0.05)	0.171 (0.007)	0.000 (1.000)	0.112 (0.004)	0.000 (1.000)
	Radius matching (caliper =0.03)	0.171 (0.007)	0.000 (1.000)	0.112 (0.004)	0.000 (1.000)

Appendix 3 LATE

Table 11 Estimated coefficient of the first stage 2 SLS regression

Market production Index	Coef.	Std. Err.	z
Exposure to rice project	7.68245***	1.580099	4.86
Education of husband	−.1749223	.2221204	−0.79
Education of wife	1.017373***	.2602783	3.91
Gender of household head	−4.84718	4.571034	−1.06
Married = 1;otherwise = 0	19.92665***	6.482632	3.07
Household size	−.0558088	.4080594	−0.14
Dependency ratio	−.6931154	.6324333	−1.10
Wealth	7.48e-08*	4.41e-08	1.70
Size of land owned	.4288732**	.1683591	2.55
Household own livestock =1, 0 otherwise	2.605883*	1.44398	1.80
Distance to the market	.1677065	.257535	0.65
Depends on family labor =1; 0 = otherwise	−7.162626***	1.560961	−4.59
Main occupation; farming =1; otherwise =0	7.271373***	2.667086	2.73
No secondary occupation =1; otherwise =0	2.097032	1.472364	1.42
Member of farmer group =1; otherwise =0	1.222312	1.483673	0.82
Member of saving & credit group =1; otherwise =0	1.657622	1.862058	0.89
Member of marketing group =1; otherwise =0	3.946095	3.147769	1.25
Constant	14.4916**	7.506279	1.93
N = 897			
Prob > chi2 = 0.0003			
Adj R-squared = 0.1595			

Table 12 Estimated coefficient of the local average response function for calorie consumption

Calorie consumption per adult equivalent	Coef.	Std. Err.	z
Market production Index	−157.5608***	36.45049	−4.32
Education of husband	−31.58104	40.29058	−0.78
Education of wife	149.7397**	57.86873	2.59
Gender of household head	−60.76985	833.3442	−0.07
Married = 1;otherwise = 0	4054.641***	1304.231	3.11
Household size	−182.6151**	72.30085	−2.53
Dependency ratio	−152.5741	114.1156	−1.34
Wealth	2.13e-06	8.14e-06	0.26
Size of land owned	97.87317***	34.98307	2.80
Household own livestock =1, 0 otherwise	697.1903**	280.0948	2.49
Distance to the market	3.367714	48.26052	0.07
Depends on family labor =1; 0 = otherwise	−1735.366***	405.2877	−4.28
Main occupation; farming =1; otherwise =0	1363.313**	560.565	2.43
No secondary occupation =1; otherwise =0	328.2531	266.3926	1.23
Member of farmer group =1; otherwise =0	570.7794**	271.4545	2.10
Member of saving & credit group =1; otherwise =0	−61.03763	331.6799	−0.18
Member of marketing group =1; otherwise =0	586.8338	584.4817	1.00
Constant	149.7397**	57.86873	2.59
N = 897			
Prob > chi2 = 0.0003			

Table 13 Tests of endogeneity and instruments

Ho: Variables are exogenous

Durbin (score) chi2(1)			= 121.643 (p = 0.0000)	
Wu-Hausman F(1,878)			= 137.746 (p = 0.0000)	

First-stage regression summary statistics

Variable	R- Sq.	Adjusted R- sq.	Partial R-sq	F(1,879)	Prob > F
MPI	0.1754	0.1595	0.0262	23.6391	0.0000

Minimum eigenvalue statistic = 23.6391

Critical Values number of endogenous regressors: 1

Ho: Instruments are weak number of excluded instruments: 1

	10%	15%	20%	25%
2SLS Size of nominal 5% Wald test	16.38	8.96	6.66	5.53
LIML Size of nominal 5% Wald test	16.38	8.96	6.66	5.53

Table 14 Estimated coefficient of the local average response function for Household Dietary Diversity Score

Household Dietary Diversity Score	Coef.	Std. Err.	z
Market production Index	.0304804**	.0155964	1.95
Education of husband	.0312325*	.0172472	1.81
Education of wife	.0580049**	.0244773	2.37
Gender of household head	.0219911	.356446	0.06
Married = 1;otherwise = 0	.0987408	.5501953	0.18
Household size	−.0714728**	.0306793	−2.33
Dependency ratio	−.0034592	.0536184	−0.06
Wealth	1.37e-08***	3.45e-09	3.98
Size of land owned	−.0219401	.0149333	−1.47
Household own livestock =1, 0 otherwise	.0631537	.1189971	0.53
Distance to the market	−.0052599	.0204845	−0.26
Depends on family labor =1; 0 = otherwise	−.4825438***	.176539	−2.73
Main occupation; farming =1; otherwise =0	.0511938	.2530207	0.20
No secondary occupation =1; otherwise =0	−.7376765***	.1140387	−6.47
Member of farmer group =1; otherwise =0	.1474312	.1174353	1.26
Member of saving & credit group =1; otherwise =0	−.0117	.141576	−0.08
Member of marketing group =1; otherwise =0	−.1992775	.2482912	−0.80
Constant	5.325605***	.6544239	8.14

N = 888

Prob > chi2 = 0.0000

Table 15 Estimated coefficient of the local average response function for Household Food Insecurity Access Score

HFIAS_score	Coef.	Std. Err.	z
Market production Index	.1000418*	.0537134	1.86
Education of husband	−.087747	.0686355	−1.28
Education of wife	−.3201816***	.0923193	−3.47
Gender of household head	.9252308	1.40235	0.66
Married = 1;otherwise = 0	−1.336416	2.14871	−0.62
Household size	.1028982	.1223999	0.84
Dependency ratio	.7163163***	.2110866	3.39
Wealth	−3.16e-08**	1.38e-08	−2.29
Size of land owned	−.0962419*	.0582743	−1.65
Household own livestock =1, 0 otherwise	.6970592	.4637458	1.50
Depends on family labor =1; 0 = otherwise	2.287898***	.6539706	3.50
Main occupation; farming =1; otherwise =0	−2.74002***	.9234499	−2.97
No secondary occupation =1; otherwise =0	.1713491	.4514841	0.38
Member of farmer group =1; otherwise =0	−.367583	.4607165	−0.80
Member of saving & credit group =1; otherwise =0	−1.579066***	.5631965	−2.80
Constant	4.370352*	2.494946	1.75
N = 897			
Prob > chi2 = 0.0000			

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