# Payments for Ecosystem Services (PES) and Food Security in the Drylands: Experimental Evidence from a REDD+* Intervention in Burkina-Faso

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## Abstract

Can Payments for Ecosystem Services (PES), whereby people or communities receive monetary compensation for environmental work, help alleviate the seasonality of food consumption in the drylands? We explore this question using data from a Randomized Controlled Trial (RCT) embedded in a large scale afforestation campaign implemented by the government of Burkina Faso. Members of communities located around targeted gazetted forests were enrolled in tree planting activities and offered small monetary payments based on the number of trees still alive almost a year later. The timing of the payments coincided with the lean season, when most farmers were at risk of food insecurity. Compared to the control group, the recipients of those transfers reported significantly higher food consumption expenditures, and more than 50 percent reduction in the prevalence of food insecurity. The transfers received were spent mostly on cereals, meat, and pulses, with no evidence of increased consumption of temptation goods. In our era of rising urgency of climate action without clear climate financing options, these findings shed light on the synergy opportunities between environmental and social protection goals for maximizing the returns to development investments.

*Keywords:* Payments for Ecosystem Services, Food Security, REDD+, Burkina Faso

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*REDD+==Reducing Emissions from Deforestation and Forests Degradation (https://redd.unfccc.int/)

## 1. Introduction

Severe food insecurity remains a critical issue in the drylands of Sub-Saharan Africa (SSA). In particular, the dependence on agricultural activities for food, and the seasonal patterns of rainfall and therefore food availability, translates into seasonal food insecurity, with potentially serious implications for hunger, malnutrition, health, and early childhood development (Christian and Dillon, 2018). This has prompted conversations amongst development practitioners about how to best address lean season food insecurity, in the Sahel, for example.

Payments for Environmental Services (PES) schemes hold the promise of being able to both foster climate change mitigation and improve welfare. Indeed, proponents of PES characterize them as the ideal tool for tackling both climate change and poverty, as they combine both the incentive for environmental conservation and the potential to improve socio-economic and livelihood outcomes. The monetary transfers might serve as a social protection instrument, similarly to Cash for Work (C4W) programs (Alix-Garcia et al., 2018; Pagiola et al., 2005). Whether PES programs do improve welfare outcomes is, in fact, still an open question; recent reviews of the impact of PES programs document a critical dearth of evidence on welfare outcomes (Borner et al., 2017; Samii et al., 2014).

In this paper we estimate the impact of a PES scheme, aimed at fostering reforestation on degraded forest lands, on food security. We do so using a Randomized Controlled Trial (RCT), implemented in arid Burkina-Faso,

which allows for the causal estimate of PES payments on food security and poverty outcomes. We partnered with the government of Burkina Faso and embedded the RCT into a large scale project called, the Gazetted Forests Participatory Management for REDD+ (PGFC/REDD+ from its French acronym).[2]. The main objective of the project was to improve the carbon sequestration capacity of gazetted forests while reducing poverty in rural areas. As part of this program, the communities living in the proximity of targeted forests were invited to participate in reforestation campaigns, were they planted about 33,500 new trees across 62 afforestation sites, and signed contracts stipulating they would receive about $0.70 for every tree still alive at verification a year later. Our identification strategy relies on randomly assigning half of 630 community members living in the direct proximity of 11 gazetted forests to a PES scheme. The individuals participating in the study are almost exclusively farmers who are dependent on the forest for household inputs like fuelwood. Those assigned to the treatment group were grouped (randomly) in teams of five and were informed that they had the opportunity to collectively earn money conditional on the maintenance and survival of the newly planted trees on a given reforestation plot.

Using primary data collected thirteen months after the start of the PES program, we find that participants in the PES scheme experienced signifi-

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[2]The project is part of Burkina Faso's Forest Investment Program (FIP) funded by the Climate Investment Fund (CIF) and co-supervised by the World Bank (WB) and the African Development Bank (AfDB) (https://www.climateinvestmentfunds.org/country/burkina-faso)

cantly less food insecurity than non-participants. These results are consistent to alternative measures of welfare and food (in)security, including the household food consumption expenditures, the Household Food Insecurity Access Scale and Prevalence - HFIA (Coates *et al.*, 2007), the Household Hunger Scale - HHS (Ballard *et al.*, 2011), as well as a set of robustness tests like multiple hypothesis bias correction (Anderson, 2008; Kling *et al.*, 2004). Given the timing of the payments, these results suggests that the cash transfers from the above-described PES scheme shielded farmers against food insecurity during the lean season, around July and August.[3] The payments coincided with that period where the majority of the farmers were at risk of food insecurity due to an insufficient stock from the previous harvest period.

In essence, PES schemes are comparable to Cash for Work (C4W) programs. Therefore, our results contribute to two main strands of the development economics literature: Payments for Ecosystem Services (PES) as a dual environmental conservation and poverty reduction tool, and C4W as a social protection tool for vulnerable communities in the drylands (De Mel *et al.*, 2008; Tiwari *et al.*, 2016). Policies to conserve forests and to restore habitats while fighting poverty make up an important part of the global climate change agenda.[4] While Jayachandran *et al.* (2017) show that PES schemes

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[3]http://www.fao.org/giews/countrybrief/country.jsp?code=BFA, last accessed on April 16, 2019

[4]Since the 2015 Paris Agreement, when countries from 196 countries committed to Nationally Determined Contributions (NDCs) towards fighting climate change, there has been increased efforts for global and country-led initiatives such as the REDD+, the Bonn Challenge, and the African Forest Landscape Restoration Initiative (AFR100).

are effective in promoting conservation, empirical evidence of their welfare impacts remain lacking.

There is a large and still evolving literature across the developing world showing that *cash transfers*[5] to individuals can relieve capital constraints and lead to positive welfare effects (Ralston *et al.*, 2017; Fiszbein and Schady, 2009). For example, Haushofer and Shapiro (2016) found recently strong improvement in consumption, and large increase in psychological well-being of poor households in rural Kenya, as a result of a purely unconditional cash transfer intervention. However, very little of the evidence-base on "*cash transfers*" focuses on C4W per se. One of the few exception is Galasso and Ravallion (2004) who found positive effects of a C4W program on poverty reduction in Argentina. However, the authors relied on a non-experimental method for identification. The only experimental study of a C4W program, that the authors are aware of, found positive effects on food spending, medicine, and assets, in Sierra Leone (Rosas Raffo *et al.*, 2016). So experimental studies of the impacts of C4W programs, let alone environmental C4W, especially in the drylands of SSA are still lacking critically from the development economics literature. Our study helps to fill this gap and seeks to inform social protection and environmental policies in the drylands of Sub-Saharan Africa where populations are exposed to food insecurity, exac-

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[5]Here, we refer broadly to all types of programs that involve handing cash to people. We recognize that the term "cash transfers" refers to more specific interventions in the development economics literature.

erbated by unstable rainfall patterns, and extreme weather events resulting from climate change.

To the best of our knowledge, this is the first study to establish formally, by means of an RCT, the causal relationship between environmental cash transfers and food security, and hence is of key importance for policy makers in various institutions interested in poverty and vulnerability reduction, as well as environmental protection. With these results, we hope to contribute precisely to the way policy makers think about the design and the cost-benefit-analysis of environmental programs.

The rest of this paper is organized as follows: Section 2 describes the PES intervention evaluated, and the experimental design used for this study. Section 3 lays out the empirical strategy for estimating the treatment effects, while Section 4 describes the data used and defines the main outcomes of interest. In Section 5, we present the results and discuss implications for policy. Section 6 concludes the paper.

## 2. Program Description and Experimental Design

Since the 2015 Paris agreement, forest conservation has become central in international climate policies which demonstrates itself in the rising popularity of REDD+[6] initiatives in many developing countries. As the urgency of climate action is acknowledged worldwide, it is also widely accepted that

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[6]Reducing Emissions from Deforestation and Forests Degradation

forests represent a cost effective source of carbon sequestration regulating climate, while providing economic, environmental, and socio-cultural benefits (Canadell and Raupach, 2008). In recent years, an increasing development budget has been pledged to forest conservation interventions, as exemplified by the World Bank Group's New Forest Action Plan F16-20[7].

In this spirit, the Government of Burkina Faso has been implementing a Forest Investment Program (FIP) with joint technical assistance from the African Development Bank (AfDB), the World Bank Group (WBG), and financial support from the Climate Investment Fund (CIF). One of the main goals of the Burkina Faso FIP is to improve the carbon sequestration capacity of gazetted forests while contributing to poverty reduction in forest-dependent communities. The program started with a pilot phase involving 12 targeted forests out of the 77 gazetted forests across the country. This project stands as a REDD Readiness program with a goal to develop the institutions, policies and measures that will support a full REDD+ implementation in Burkina Faso over the upcoming years.

*2.1. The Intervention*

Burkina Faso is a landlocked country in the Sahel region of Africa, and is characterized by dry forests with very sparse tree coverage. As a result, and similarly to most arid countries in Sub-Saharan Africa, landscape restoration through large scale reforestation appears as one of the most important

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[7]https://openknowledge.worldbank.org/handle/10986/24026

forests interventions (Adjognon *et al.*, 2018).[8] Burkina Faso is no exception, as it aims to achieve its environmental objectives (including improved carbon sequestration) by restoring forest landscapes, as part of its Forest Investment Program (FIP). Consistent with one of its core objectives [9], it does so primarily via a participatory, community-led approach. More specifically, one of the main interventions of Burkina Faso's FIP program is a reforestation campaign, which typically consists of engaging local communities in tree planting activities, with small monetary incentives. These activities are facilitated by the FIP project team as well as by local institutions called Forest Management Committees (Comite de Gestion Forestiere, or CGF). The project targets 12 gazetted forest across the country, each of which has one CGF, which coordinates the forest management activities among the various stakeholders in charge of each forest. Payments are typically quite low compared to the number of individuals participating in the tree planting activity (about $0.10 for each sapling planted), and hence most CGFs simply keep the money in the collective savings at the CGFs level rather than distributing very small amounts to each member.

Typically, the focus of the project is on planting the trees, and not so much on subsequent maintenance of the saplings. Growing conditions in Burkina

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[8]For example, the African Landscape Restoration Initiative (AFR100) is a large scale multi-country initiative to bring 100 million hectares of African land into restoration by 2030 (https://afr100.org/)

[9]The project result framework mentions directly "...*improving the extent of participation of local stakeholders in the planning, management, and monitoring of forests resources activities*"

Faso are harsh, and survival rates can be improved not only by watering plants but also by putting up fire breaks, maintaining the holes in which saplings are planted, and by removing dead organic material in the plant's vicinity. These activities require time and effort, and hence we partnered with the FIP project to implement a PES scheme aimed at improving tree survival rates for the 2017/2018 campaign, during which 33,500 and plus trees had just been planted across 31 afforestation plots defined within the 12 gazetted forests of intervention. Following the planting phase in July/August 2017, the FIP project team asked the CGF of each of the 12 gazetted FIP forests to identify individual members of the bordering communities who would be willing and able to engage in these activities. In total, 660 individuals were recommended by the CGFs (about 20 people per afforestation plot), of which half were randomly selected to participate in the PES program. Participants employed in the PES contract were grouped into teams of five and informed that they could collectively earn money based on maintenance and survival of the newly planted trees on their assigned afforestation plot. PES contracts assured the groups that they would receive about $0.70 for every tree that was still alive at verification and that every group member would receive an equal share (20%) of the total amount. About 9 months later, in May/June 2018 (just before the start of the next rainy season), all reforestation areas were visited by independent monitors and participants received their payments based on the number of trees that were still alive. From those selected to be part of the FIP PES scheme, more than 95% got to received a positive

paiement amount. The individual payments ranged from about 840 FCFA ($1.40) to 25,620 FCFA (about $43) with a average of 8300 FCFA ($14), which represents approximately a week of food consumption for the median rural household in Burkina Faso.[10] Compliance was even higher amongst the non participants to the PES scheme (99.6%): only one person mistakenly received a payment. The figure A.9 in appendix shows a distribution of the payment amounts received by the participants and non participants.

The intervention, hereon called FIP PES, has the potential to contribute to the welfare of its participants above and beyond the benefits provided by the improved environmental conditions. As mentioned by Pagiola *et al.* (2005), PES can support the social protection of the poorest, by improving their living standard. After all, participation is voluntary, and hence community members are likely to only accept the contract if they expect to gain from it. Our baseline data suggests that the participants in the FIP PES scheme come from the country's poorest and most vulnerable groups. About 90% of them cited farming as their main source of livelihood, from which they had earned an average of $30 over the last 30 days prior to the survey to support a family of, on average, 12 members. During the endline survey period, which was close to the next harvest season, most of the participants were already out of food stocks from the previous harvest, which dates back

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[10]Authors' calculations from the BF 2014 Living Standards Measurement Survey (LSMS) data estimates the median rural household's daily consumption expenditures at about 1580 FCFA ($3). 1 FCFA=0.0017 USD. The FCFA - USD exchange rate is from April 2019 google exchange rate converter.

almost a year before.[11] Therefore, the timing of the PES payments is of particular importance. As shown in Figure 1, the lean period, when food insecurity is most prevalent due to dwindling stocks from the previous harvest amongst non-participants, spans over the months of May to September. Since payments were made around May and June, it suggests that the cash transfers as part of the PES scheme may act as a safety net for the recipient households during such a lean period, thereby supporting climate resilience. As a counter factual the level of food insecurity in the months of June and July might have quicker reached the same level as the month of August. In fact, at the time of payments, the participants were asked what they would do with the money received, and almost 50% of them mentioned food purchases for their family as primary usage plans.

## 2.2. Research Design

This study uses a Randomized Controlled Trial (RCT) to evaluate the impact of an environmental cash transfer program, on participants' well-being, measured by food security. The intervention of focus is an afforestation campaign, implemented as part of the Burkina Faso FIP, and which run from August 2017 to May 2018. Figure 2 shows the timeline of the different activities of this study. The 2017 reforestation campaign targeted about 31 sections of forest distributed across the 11 forests targeted by intervention. Each for-

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[11]Farmers in the study area enjoy only one rainy season per year, and therefore one agricultural production season, from which they have to store enough food until the following season.

est section includes two reforestation plots with about 400 newly planted trees. Immediately after the planting activities, the project team asked the CGFs to find volunteers to join PES schemes; if selected, these volunteers would receive a monetary payment based on the number of trees still alive in their reforestation plot 9 months later. Anticipating over-subscription, the project team and the research team designed a public lottery to select the participants' to the program. This approach was considered the fairest way to enroll people, and preserve the trust of the community members (Gueron, 2017). The lotteries were conducted separately in each reforestation site.[12], each selecting 5 individuals who got to participate in the PES scheme (the treatment group) while the remaining individuals did not sign any contract (the control group). Field agents representing the research team were present and helped the project teams implement these public lotteries. This "random rejection" approach is central to our identification strategy to evaluate the impact of the PES intervention on participants' food security, because randomly rejecting half of the interested individuals from each community implies that the treatment and control groups are likely to be identical in all respects.

Following the treatment assignment, we collected baseline information on socio-economic characteristics and food security indicators of the individuals randomly allocated to the treatment group who signed the PES contracts and

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[12]There is a total of 62 sites.

those who were assigned to the control group. These baseline characteristics allow us to check the validity of the randomization process.

## 3. Empirical Framework

### 3.1. Estimation Strategy

We seek to estimate the average treatment effect of participation in the PES scheme on households' food security outcomes. This can be represented as:

$$\gamma = E[Y_i^T - Y_i^C] \tag{1}$$

$Y_i^T$ and $Y_i^C$, under the Rubin Causal Model (RCM), represent the potential outcomes for individual $i$ under alternative treatment status – treatment (T), or control (C) (Holland, 1986; Rubin, 1974). The core econometric strategy exploits the random assignment of individual members of the communities into a treatment and a control group respectively. With about 315 individuals in each group, random assignment implies that $E[Y_i^C] = E[Y_j^C]$, where $i$ refers to individuals from the treatment group and $j$ those from the control group. That means that $\gamma$ can be estimated by comparing $E[Y^T]$ and $E[Y^C]$.

The treatment group received PES contracts, which guaranteed monetary compensation based on the number of trees still alive on their assigned reforestation area at verification. The control group did not receive any contract, and hence received no cash transfers from the project. We estimate an intention-to-treat (ITT) effect of the PES intervention on households' food

security, using the following ANCOVA estimator (McKenzie, 2012)[13]:

$$Y_{i1} = \alpha + \beta x_i + \lambda Y_{i0} + \gamma T_i + \epsilon_i \tag{2}$$

Here, $Y_{i1}$ and $Y_{i0}$, respectively, represent the endline and baseline values of a measure of food (in)security experienced by household $i$. $x_i$ is a vector of control variables, including forests sections indicators to account for the stratified randomization; $T_i$ is the treatment assignment variable taking values 1 if a household was offered the opportunity to participate in the PES scheme, and zero otherwise. Some food security indicators were collected only at endline. For those, a constrained version of Equation 2 is used, which does not include the baseline outcome value. $\epsilon_i$ is an unobserved error term assumed to be independently and identically distributed (iid).

In Equation 2, $\gamma$ is the main parameter of interest, which, under exogeneity and Stable Unit Treatment Value assumption (SUTVA), identifies the ITT effects of the FIP PES transfers, on beneficiaries' food security outcomes. The exogeneity assumption is a direct implication of the randomized selection of beneficiaries amongst eligible candidates. We also expect zero spillover across treatment and control groups because most of the potential participants came from separate villages, and do not really interact on a reg-

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[13]McKenzie (2012) shows that this approach can yield significant power gains compared to a difference-in-difference approach, especially when the outcome variables have low autocorrelation.

ular basis. In addition, given the relatively high compliance rate[14], $\gamma$ is also a good measure of the Average Treatment effect on the Treated (ATT).

We estimate $\gamma$ by applying Ordinary Least Squares (OLS) to Equation 2 above, an estimator which minimizes the sum of squared residuals, and applies a t-test on the estimated coefficients for inference. We did not apply any clustering of the standard errors given that the randomized treatment was assigned at the individual level. As a robustness check, we also apply a randomization inference test. This approach, still not very widespread in economic research, has been strongly recommended for the analysis of randomized experiments such as ours (Athey and Imbens, 2017; Imbens and Wooldridge, 2009). To calculate the p-value associated with the estimated treatment effect, the randomized inference approach reassigns the treatment status by keeping the number of individuals in each group fixed and calculating the corresponding difference in means. This process is repeated many times, and produces a distribution of "fake" treatment effects under the null hypothesis. The p-value is simply the proportion of cases in which the "fake" treatment effect estimated is at least as large in absolute value as the estimate we seek to test. The method is attractive in part because it relies on less modelling assumptions encountered in a regression framework.

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[14]291 from the 303 PES participants interviewed at endline reported to have received a payment.

## 4. Data and Descriptive Statistics

### 4.1. Data Sources

During the tree planting, 660 individuals were enrolled into the study and equally distributed among a treatment and a control group. In September to October 2017, right after the PES contracts were signed with farmers, we administered a baseline household survey in the villages of the respondents. The survey team was able to track 630 out of the original 660 individuals enrolled in the study: 305 control households, and 325 treatment households. The survey instrument included modules capturing households' socio-demographic characteristics, asset ownership, and food consumption. Table 1 presents the baseline characteristics of our participants (and their households) in both the treatment and control group, as well as the tests to what extent the distributions of these characteristics in the two groups are similar. The table indicates that the treatment and control groups are fairly balanced with respect to most characteristics. In particular, there is no statistically significant difference between treatment and control groups in terms of baseline values of food consumption expenditures and household dietary diversity scores – two of our key variables of interest. There are, however, some imbalances with respect to other potentially important variables such as the share of female participants in the treatment and control group, asset ownership, as well as the distance to the reforestation site. Differences are relatively small in absolute terms, but in our regression analysis we try to mitigate any possible selection effects by including them as control variables.

In addition, an F-test of the joint significance across baseline covariates fails to reject the null hypothesis of no significant difference between treatment and control groups. This gives us confidence that any observed difference is likely the result of chance and therefore should not affect our treatment effects estimation.

An endline survey was administered in between November/December 2018, 5 to 6 months after the monetary transfers were disbursed to the PES participants, based on the tree survival rate on the respective reforestation plot. This follow-up survey was similarly structured as the baseline survey with the exception of a more exhaustive food security module. During this phase, we were able to track down 574 out of the 630 households interviewed at baseline, which corresponds to an attrition rate of 9%, which is fairly balanced across treatment and control households. [15] As a result, given the relatively low attrition rate, potential biases are likely to be small. Nevertheless, we test for balance in between treatment and control group on baseline characteristics using the endline sample (See Table 2), and confirm that most characteristics remain balanced between treatment and control.

*4.2. Food Security Measures*

To estimate the impacts of Burkina Faso's FIP PES scheme on beneficiaries' food security outcomes, we use the following common household

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[15]The difference in attrition rate between treatment and control groups was fairly low (0.044 percentage points), and was only significant at the 10 percent level (See Table 2)

level food security indicators, which broadly capture dietary diversity and consumption behaviors considered to be symptomatic of food insecurity.

- The Household Food Consumption Expenditures

  Food consumption expenditures (FExp) represents a direct indicator of economic access to food, as it captures the value of food consumed by the household over a given time period. Our survey instrument included a detailed food consumption module which asked each household $i$, from a list of food items $f \in \{1,...,F\}$, the quantities consumed $q_{if}$ and the total value of the consumption $v_{if}$, over a 7-day recall period. The total value of food consumed by the household $i$ ($\text{FExp}_i$) is calculated as:

$$\text{FExp}_i = \sum_f v_{if} \tag{3}$$

- The Household Dietary Diversity Score (HDDS)

  The HDD score is also an indicator that captures access to food. [16] As a simple count of the number of different food groups consumed by a household during a defined period, it is meant to provide an insight into a household's economic ability to access a variety of foods (Kennedy *et al.*, 2011; Upton *et al.*, 2016). The HDD score has been validated in multiple contexts as a very strong proxy for nutrition ade-

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[16]The HDDS is a modified version of the U.S. Household Food Security Survey Module (HFSSM), adapted for use in a developing country context.

quacy, and energy availability (Hoddinott and Yohannes, 2002). In this study, we calculate HDDS by first categorizing the food items consumed by household members over a 7-day recall period into 7 food groups, excluding sugar, alcohol and tobacco. Then we generate a binary indicator $Z_{ig}$ that takes value 1 for a food group $g$, if household $i$ had consumed a food item from that group during the recall period, and 0 otherwise. The HDD score for household $i$ ($\text{HDD}_i$) is then calculated as in Equation 4 below:

$$\text{HDDS}_i = \sum_g Z_{ig} \tag{4}$$

- The Household Food Insecurity Access Scale (HFIAS)

  This indicator of consumption behavior infers food security status from people's responses to questions about consumption patterns that are considered to be correlated with food insufficiency and anxiety - for example, whether and how often the household members had to eat less preferred food based on a lack of resources (FAO, 2012; Maxwell and Caldwell, 2008; Carletto et al., 2013).

  The indicator has been adapted from the current US approach to estimate the national food insecurity prevalence. Following Coates et al. (2007), we included a set of nine questions designed to capture the degree and anxiety associated with households' access to food. We sum up the frequency of food insecurity events to obtain the HFIAS Score.

We also compute the HFIA prevalence by splitting our sample into 4 classes based on the severity of food insecurity: (i) the food secure, (ii) the mildly food insecure, (iii) the moderately food insecure, (iv) the severely food insecure. Figure 3 shows the distribution of our sample households into the 4 categories of food insecurity based on the HFIA Scale.

A closely related measure is the Household Hunger Scale (HHS). It includes only 3 out of the 9 questions that are used to compute the HFIAS and is considered most appropriate in capturing the most severe forms of food insecurity. The survey instrument includes questions such as, "*whether and how often the household members had to go to bed hungry because of lack in food provision*". Based on Ballard *et al.* (2011) we compute the HHS and check the distribution of our sample across the three defined categories of food insecurity.

The 1996 World Food Summit stated that "food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). We acknowledge the ongoing debate over how well the existing indicators really capture food security in all its dimensions and formal definition (availability, access, utilization, stability) [17]. This study does not make a contribution to the measurement of food

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[17]See Carletto *et al.* (2013) and Upton *et al.* (2016) discussions on the various food

security, but uses a variety of existing indicators to ensure the results are robust to the choice of indicators.

## 5. Results and Discussion

### 5.1. Food Consumption Expenditures

Figure 4 presents the Kernel density distribution of the reported household food consumption expenditures (in logarithm) during the last 7 days prior to the survey for individuals in treatment and control group respectively. The distribution of the weekly food consumption expenditures for the treatment group is shifted to the right compared to the control group. This suggests a positive effect of the FIP PES on food consumption expenditures. The point estimates of the treatment effects from Equation 2 are summarized in Table 3. The results indicate an increase in weekly household food consumption expenditures of about 12% or 1798 FCFA, significant at the 5% level. These results are robust to the inclusion of covariates as well as baseline outcomes. However, when we run the same results using per capita household consumption expenditures, the average treatment effect drops to 7% with a confidence interval spanning estimates from 6% to 18%.

We then use an instrumental variable approach to estimate the effects of the actual amount received on the food consumption expenditures. The results presented in table 4 show that every 100 FCFA received by farmers,

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security measures.

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increases the weekly household food consumption expenditures on average by 22.49 FCFA. This means that about 20 percent of the transfer received was invested in food consumption by the household, thereby contributing directly to improving household food security.

*5.2. Household's Dietary Diversity*

Did the FIP PES transfer improve Household Dietary Diversity? In Figure 5, we display a bar graph stacking up the food consumption expenditures for each food group, separately for the participants and non-participants in the PES scheme. This figure thus simultaneously represents households' total food consumption expenditure value (represented by the height of the bars) as well as their food consumption diversity (reflected by the shares of total food expenditures allocated to each of the food categories). The graph suggests that, in general, cereals, roots and tubers take up more than 50 percent of the household's food expenditures for both the treatment and the control group. This is consistent with the relatively low HDDS observed at baseline for both groups (HDDS=4.4 at baseline). Depending on the income elasticity of the consumption expenditures in the various food groups, we would expect to observe some change in the HDDS, as a result of the PES cash transfers received.

To explore this, we compare the distribution of HDDS between treatment and control group individuals and conclude that those are fairly similar (see Figure 6). The p-value for the Kolmogorov-Smirnov test of equality of the

two distributions equals 0.99 suggesting no evidence of statistical difference between the two. This is corroborated by the regression results in Table 5 showing no evidence of a significant treatment effect on HDDS.

This implies that although there is a positive and significant effect of the FIP PES transfers on households' overall food consumption expenditures, the effect did not translate into an improved dietary diversity. Which food items did households finance with the FIP PES transfers then? When we compare the mean expenditures for each food group between treatment and control, we find that the additional income received through the transfer increased significantly household expenditures on starchy foods (cereals and tubers), but also more meats and pulses, although only on the intensive margin (see table A.9 in the Appendix). The FIP PES tranfers show no effects on the likelihood of households consumption of any of these food groups. These results are also confirmed when we use a multivariate Tobit regression[18] to account not only for the multiple zeros recorded in the expenditures by food groups, but also to improve the efficiency of the estimation, taking into account the inter-dependency of these equations[19]. Finally, our data also allows us to estimate the elasticity of expenditures in different food groups with respect to overall food consumption expenditures. As mentioned above, we find that for each percentage increase in food budget, only expenditures on starchy foods (cereals and tubers) are affected significantly (See results in Appendix

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[18]see Wooldridge (2010) and Greene (2003) for details on the mvtobit model
[19]mvtobit results available from authors upon request

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### 5.3. Household Food Insecurity Access Scale

Table 6 summarizes the regression estimation results of the FIP PES treatment effects on food security captured by the HFIAS. The table reports the results for 3 alternative transformations of the HFIAS: the overall score in Columns 1 and 2; the binary indicator for being food secure in columns 3 and 4; and the binary indicator for being severely food insecure in columns 5 and 6. The conclusions are consistent across all those regressions.

The results indicate that the FIP PES payments helped to significantly reduce food insecurity. The overall HFIA score was reduced by about 40 percent relative to the control group. In Columns 3 and 4, we see a 14.9 percentage points increase in the likelihood of being food secure in general, while in columns 5 and 6, we observe a 9 percentage point reduction in the likelihood of being severely food insecure. Relative to the control group, these estimates amount to 25 to 55 percent improvement in food security as a result of the FIP PES tranfers. All reported impacts are significant at the 1% level, or lower. These results are illustrated graphically in Figure 7.

The results on the HFIAS are even stronger when we consider the Household Hunger Scale as a food security indicator instead of the HFIAS. As shown in Table A.11 in the appendix, participation in the PES scheme has reduced the proportion of households who experienced hunger during the months prior to the survey by almost 70%.

## 5.4. Robustness Analyses

The results presented above suggest significant and positive impacts of Burkina faso's FIP PES scheme on households' food security outcomes. In this section we perform a series of robustness checks to ensure that those results were not driven by the choice of estimation strategies.

### 5.4.1. Randomized inference tests

The results presented so far are derived from regression analysis, with inferences based on asymptotic theory and distributional assumptions. In this section, we use a randomized inference approach to ensure that our main results are robust to relaxing those assumptions (Athey and Imbens, 2017; Imbens and Wooldridge, 2009). In Table 7, we summarize the p-values for each of our outcome variables from the randomized inference tests alongside the t-test used in the main analysis. The t-test and the randomized inference p-values in the last two columns of the table are very similar, which supports our main results.

### 5.4.2. Multiple Inference Adjustments

As explained by Anderson (2008), the probability of incorrectly rejecting the null increases as the number of hypotheses being tested increases. Failing to correct for multiple inference can lead to misleading policy advice. Given the number of food security indicators under consideration, might it be possible that the results obtained were the product of pure hazard?

Overall, it is not very likely that our analysis suffers from (severe) multiple

hypothesis bias. In our main analysis, we have tested seven outcomes, all of which are from the same family (food security), fairly correlated, and expected to be affected in the same direction by the treatment. We were able to reject the null hypothesis for all but one of them. Nevertheless, we follow Anderson (2008) and correct for multiple hypothesis testing in two main ways.

First, we apply Bonferroni's adjustment procedure, which estimates the probability that one or more of our outcome "families" of multiple tests is false – the so-called Family Wise Error Rate (FWER). It does so by upwardly adjusting the p-value for each of the tests within the family. The standardized results, summarized in Figure 8 are fully consistent with our main results. Almost all food security indicators have confidence intervals excluding zero, and in the expected side of the zero line. The exceptions are the HDDS and the food consumption expenditure estimates.

The drawback of the above approach is that, by adjusting p-values upwards, it effectively reduces power of any given test. As an alternative, we use the summary index tests which pools all outcomes into a single test and thereby reduces overtesting, increases power, and provides a test on the general effect of the treatment on the outcomes of interest. We implement Kling et al. (2004)'s approach[20] by combining all our food security outcomes into one weighted standardized index, and estimate the mean standardized effect

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[20]We use avg_effect command in STATA

size. To align all variables in the same direction we multiply the consumption expenditure variables by -1, and subtracted the food secure status binary variables from 1. We obtain a point estimate of -0.2 standard deviation and a p-value of 0.00 for the summary index. This confirms that the Burkina Faso FIP PES scheme has reduced food insecurity for the beneficiary households.

## 6. Conclusion

We use data on a sample of households across 32 communes in Burkina Faso and an experimental design to investigate the causal impact of the participation in an environmental cash transfer scheme on a variety of food security outcomes. The RCT was embedded in a REDD+ project as part of Burkina Faso's Forest Investment Plan (FIP). The specific intervention of interest is a reforestation campaign through which randomly selected community members were invited to plant trees in designated areas of the forest and subsequently offered PES contracts according to which they would receive monetary payments based on the number of trees still alive at verification - 9 months after the implementation. Considering several different food security indicators, we find consistently significant and positive effects of the PES transfers on food security. Participants' households reported 12% higher food consumption expenditures, and more than a 50% reduction in the likelihood of being classified as severely food insecure.

From a policy perspective, our findings suggest that there is potential for creating synergies between environmental and social protection goals, espe-

cially among vulnerable communities in the drylands. Given that the primary focus for climate change mitigation actions are usually the same communities who are also in need for coping strategies against extreme poverty as well as more extreme climate shocks. Beyond food security, other dimensions of household welfare, such as youth employment, women economic empowerment, and rural entrepreneurship, could be built explicitly into environmental projects to maximize impacts from each dollar invested into a development intervention.

While our empirical framework relies on an RCT establishing confidence in the internal validity of our findings, there may be concerns that the same results do not replicate outside of the context of this study. In fact, the relevant sample for this study did not come from a random draw of a larger population of policy interest, nor were we able to implement a stratified randomization strategy to fully characterize the heterogeneity of treatment effects. Moreover, our study remains silent on spillover issues, in particular because the scale of the intervention suggests relatively mitigated spillover possibilities. However, there are reasons to think about capturing potentially positive spillovers and general equilibrium effects when such intervention is implemented at a larger scale. There are many potential similar areas in the Sahel region where PES interventions could be implemented to provide further insights on the impact on food security, but also general psychological well-being - which we did not capture in detail in this study but which is closely linked. Furthermore, additional research is be needed to better

understand household's expenditure elasticities of the very poor and vulnerable to climate shocks. This would allow better and more efficient designs of future PES or CCT interventions.

Designing multifaceted interventions present substantial challenges, which are further complicated because of the diversity of the context across which such interventions might be relevant. To gain insights into the impact of such multifaceted interventions on the various outcome variables they wish to affect, more insights are needed in the heterogeneity of the treatment effects across sub-groups in society. Similarly, it is also important to consider equilibrium effects, in the case of scale-ups or implementations on a larger scale. Our study is not able to address these issues, as these effects can only be estimated using large-scale RCTs. In addition, it would be interesting to test the long-run effects of this type of PES interventions on food security, but also on other outcome variables, such as moment-based resilience measures as proposed by (Barrett and Constas, 2014).

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Figure 1: Seasonality of Food Insecurity (Oct '17 to Sept '18)
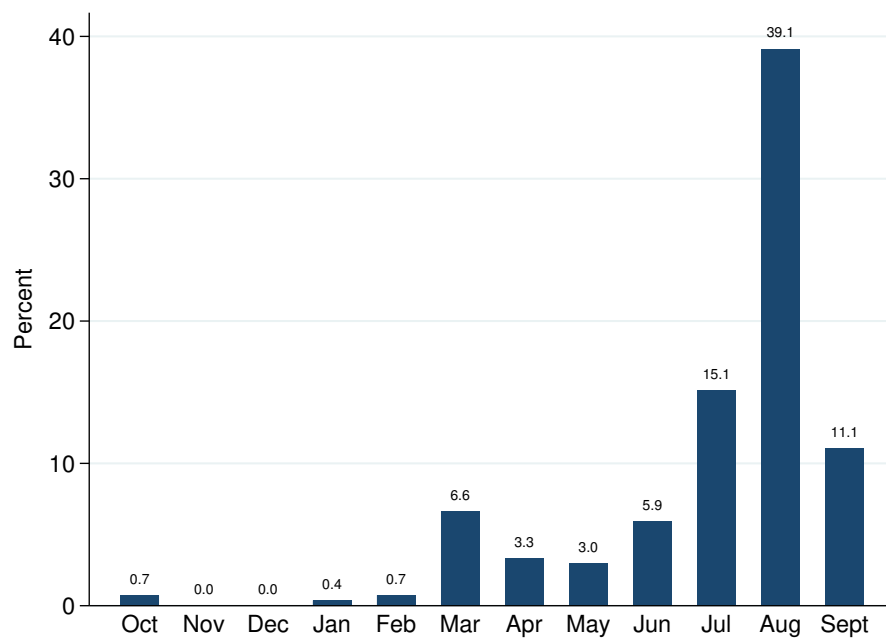


*Note*: This figure, uses data from our control group only, and summarizes the percentage of households with insufficient food by months across the previous 12 months prior to the endline. Right after harvests (Oct-Nov), hunger rates are the lowest; but a few months later, people run out of food reserves and hunger rates increase.

Figure 2: Timeline of the Randomized Controlled Trial

| Organization of | Baseline HH survey | | Verification of | Endline HH survey |
|---|---|---|---|---|
| PES contract groups | | | Tree Survival rates & payments | |
| July '17 | Sept - Oct '17 | | June - **July '18**, **Aug '18** | Nov - Dec '18 |
| | | | **Lean season** | |
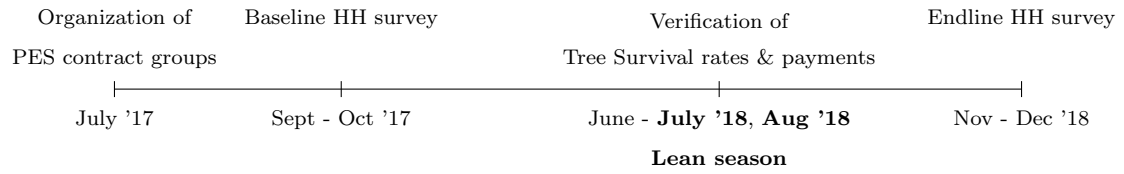
Figure 3: Distribution of the sample by food insecurity status (HFIAP)
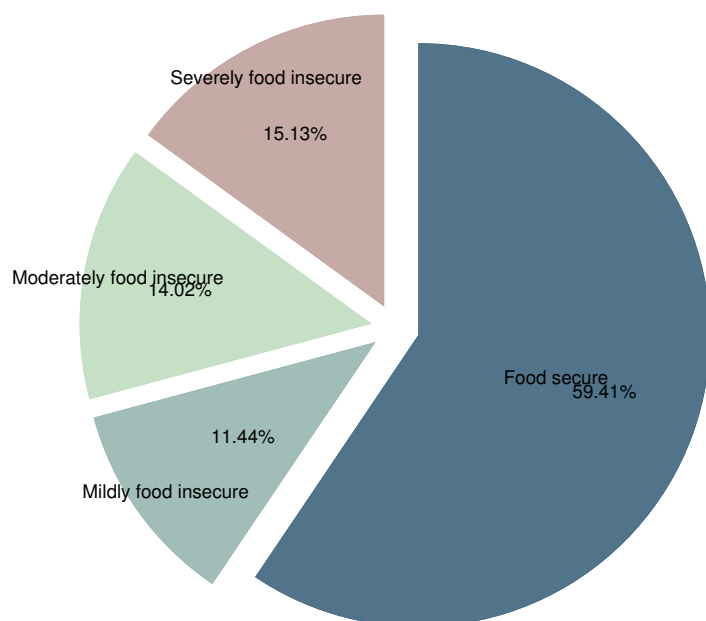


*Note*: At endline, 40 percent of the control group sample seem to experience some form of food insecurity, with around 15% suffering severe food insecurity.

Figure 4: (Log) Food Consumption Expenditures during the past 7 days
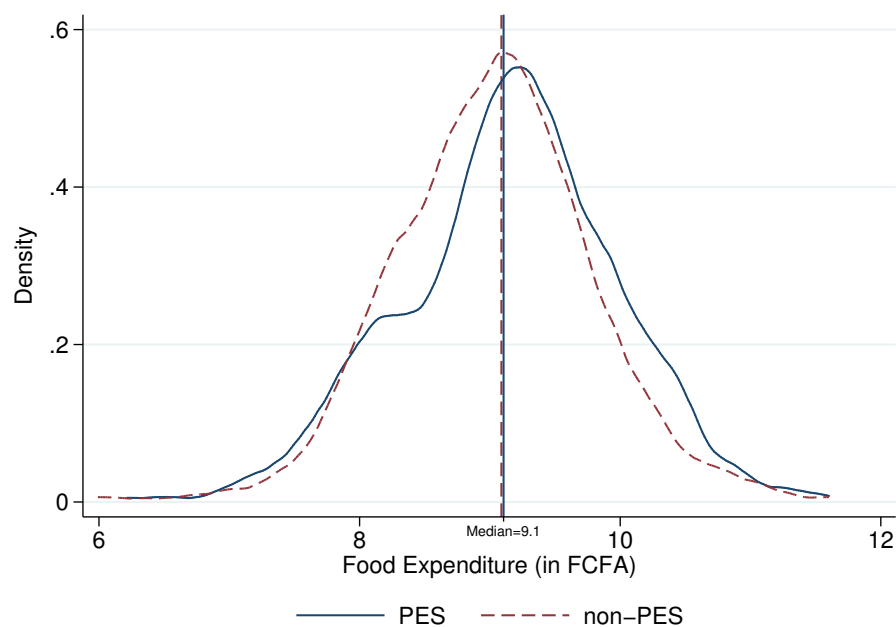


*Note:* The log food consumption expenditure covers the household's expenditures on Cereal and Tubers, Pulses, Vegetables, Fruits, Meat and Fish, Milk, Oil, Sugar as well as expenses for other items such as tobacco, alcohol and condiments, for the seven days prior to the survey.

Figure 5: Average Food Expenditure by Food Groups
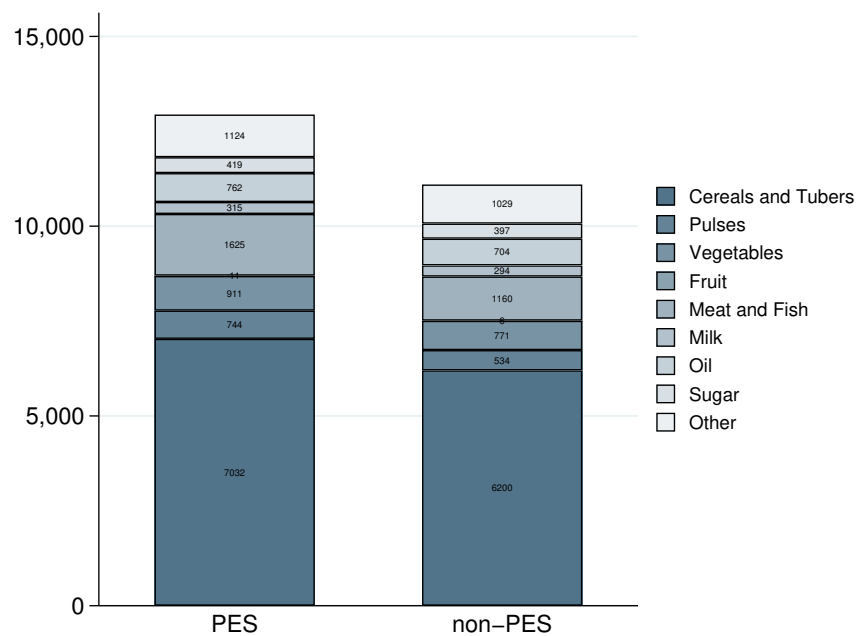
Figure 6: Distribution of Household Dietary Diversity Score (HDDS) by PES participants and non-participants
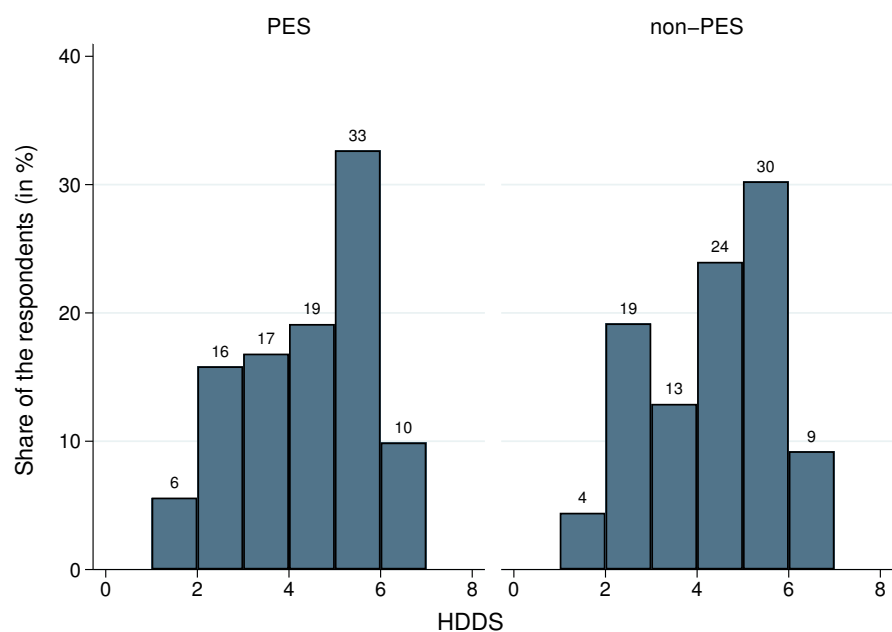


*Notes: The p-value for the Kolmogorov-Smirnov test of equality of the two distributions equals 0.99 suggesting no difference in the distributions of HHDS between the recipients and non-recipients of the FIP PES transfers.*

Figure 7: PES and Food Security
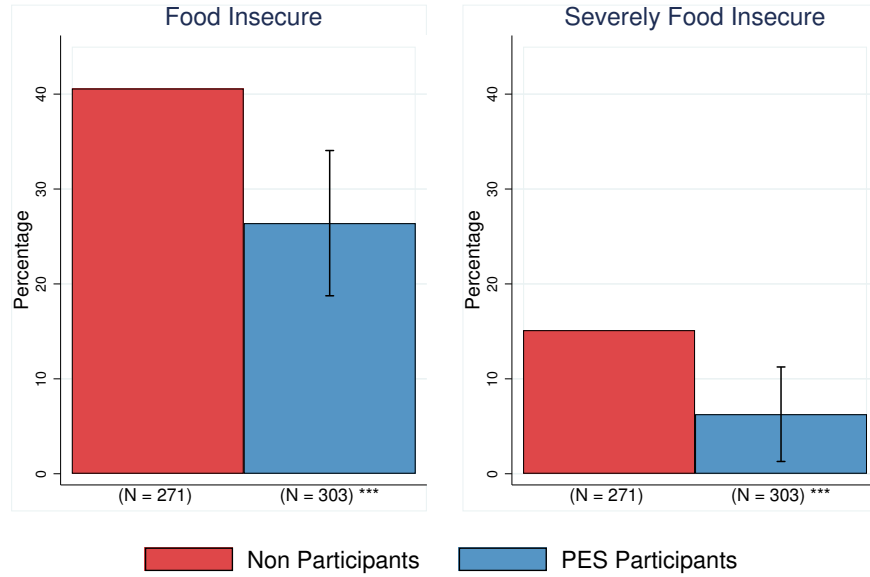
Note: Food security categories based on Household Food Insecurity Access Prevelance (HFIAP)
Bars represent coefficient sizes estimated using OLS regressions

*The figure presents the share of PES participants and non-participants that are food insecure at endline, and also the share of those that are severely food insecure, taking into account the treatment effect. While 40% of the non-participants are food insecure, only about 26% of the PES participants are so too. Furthermore, 15% of the non-participants are severely food insecure, compared to about 6% of the participants. This means that we observe treatment effect sizes of 35-60% in the reduction of the prevalence of food insecurity as well as severe food insecurity.*

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Figure 8: Bonferroni Multiple Hypothesis Adjustment

## Table 1: Balance Table: Baseline Characteristics

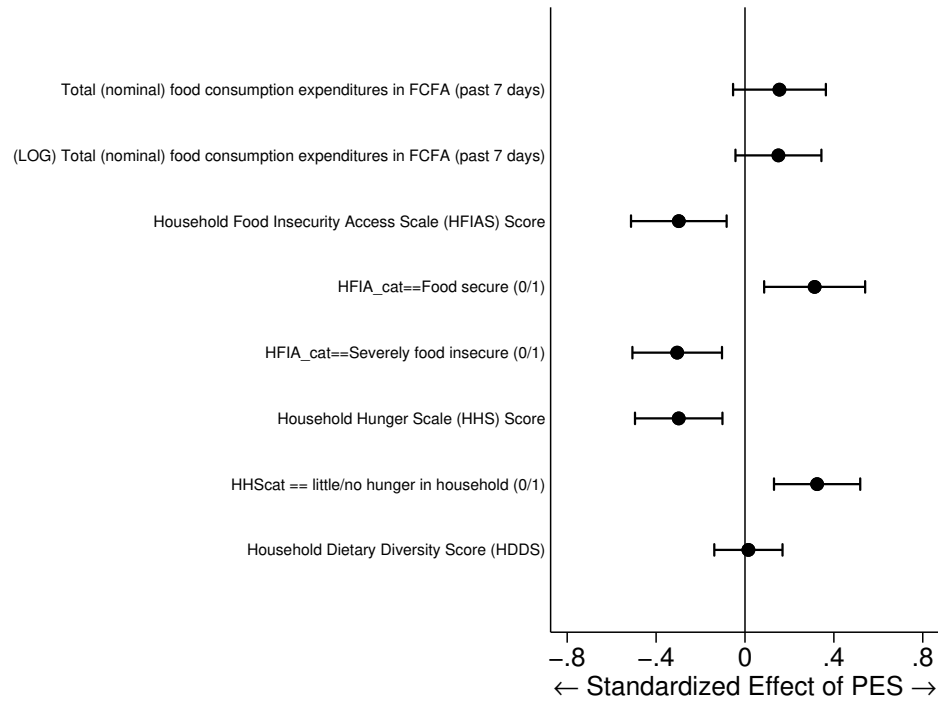| Variable | N | (1) PES Mean/SE | N | (2) non-PES Mean/SE | N | (3) Total Mean/SE | T-test Difference (1)-(2) |
|---|---|---|---|---|---|---|---|
| Age of respondent | 325 | 39.871 (0.597) | 305 | 38.433 (0.621) | 630 | 39.175 (0.431) | 1.438* |
| Female respondent (1/0) | 325 | 0.123 (0.018) | 305 | 0.193 (0.023) | 630 | 0.157 (0.015) | -0.070** |
| Agriculture as primary activity (1/0) | 325 | 0.908 (0.016) | 305 | 0.885 (0.018) | 630 | 0.897 (0.012) | 0.022 |
| Annual revenu from primary activity (LOG) | 325 | 3.057 (0.411) | 305 | 3.064 (0.415) | 630 | 3.061 (0.292) | -0.007 |
| Annual total revenu (LOG) | 325 | 9.893 (0.526) | 305 | 9.927 (0.531) | 630 | 9.909 (0.374) | -0.035 |
| Has a secondary activity (1/0) | 325 | 0.277 (0.025) | 305 | 0.262 (0.025) | 630 | 0.270 (0.018) | 0.015 |
| Married (1/0) | 325 | 0.905 (0.016) | 305 | 0.862 (0.020) | 630 | 0.884 (0.013) | 0.042* |
| Household size | 325 | 13.286 (0.405) | 305 | 12.666 (0.467) | 630 | 12.986 (0.308) | 0.621 |
| Some formal schooling (1/0) | 325 | 0.182 (0.021) | 305 | 0.190 (0.023) | 630 | 0.186 (0.016) | -0.009 |
| Member of a forest management group (1/0) | 325 | 0.588 (0.027) | 305 | 0.538 (0.029) | 630 | 0.563 (0.020) | 0.050 |
| Homestead far from the reforestation site (1/0) | 325 | 0.877 (0.018) | 305 | 0.944 (0.013) | 630 | 0.910 (0.011) | -0.067*** |
| Agric. Asset Index (PCA) | 325 | 0.132 (0.093) | 305 | -0.141 (0.089) | 630 | -0.000 (0.065) | 0.273** |
| Household Asset Index (PCA) | 325 | 0.177 (0.130) | 305 | -0.189 (0.068) | 630 | 0.000 (0.075) | 0.366** |
| Household landholdings (ha) | 265 | 15.668 (4.077) | 257 | 10.982 (3.125) | 522 | 13.361 (2.579) | 4.685 |
| Land area cultivated (ha) | 265 | 4.923 (0.233) | 257 | 4.686 (0.229) | 522 | 4.806 (0.163) | 0.237 |
| Total (nominal) food consumption expenditures in FCFA (past 7 days) | 325 | 11258.837 (639.395) | 305 | 11602.666 (729.457) | 630 | 11425.294 (482.895) | -343.829 |
| (LOG) Total (nominal) food consumption expenditures in FCFA (past 7 days) | 311 | 8.908 (0.060) | 300 | 8.875 (0.068) | 611 | 8.891 (0.045) | 0.033 |
| Household Dietary Diversity Score (HDDS) | 325 | 4.425 (0.080) | 305 | 4.466 (0.082) | 630 | 4.444 (0.057) | -0.041 |
| F-test of joint significance (p-value) | | | | | | | 0.121 |
| F-test, number of observations | | | | | | | 517 |

*Notes*: The value displayed for t-tests are the differences in the means across the groups. The value displayed for F-tests are p-values. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table 2: Balance Table: Attrition and Characteristics of the Endline Sample

| Variable | N | (1) PES Mean/SE | N | (2) non-PES Mean/SE | N | (3) Total Mean/SE | T-test Difference (1)-(2) |
|---|---|---|---|---|---|---|---|
| Respondent found (Yes=1, No=0) | 325 | 0.932 (0.014) | 305 | 0.889 (0.018) | 630 | 0.911 (0.011) | 0.044* |
| Age of respondent | 303 | 39.818 (0.622) | 271 | 38.996 (0.653) | 574 | 39.430 (0.450) | 0.822 |
| Female respondent (1/0) | 303 | 0.122 (0.019) | 271 | 0.207 (0.025) | 574 | 0.162 (0.015) | -0.085*** |
| Agriculture as primary activity (1/0) | 303 | 0.904 (0.017) | 271 | 0.889 (0.019) | 574 | 0.897 (0.013) | 0.015 |
| Annual revenu from primary activity (LOG) | 303 | 3.071 (0.425) | 271 | 2.899 (0.455) | 574 | 2.990 (0.310) | 0.172 |
| Annual total revenu (LOG) | 303 | 9.914 (0.544) | 271 | 9.719 (0.583) | 574 | 9.822 (0.397) | 0.194 |
| Has a secondary activity (1/0) | 303 | 0.287 (0.026) | 271 | 0.277 (0.027) | 574 | 0.282 (0.019) | 0.010 |
| Married (1/0) | 303 | 0.904 (0.017) | 271 | 0.871 (0.020) | 574 | 0.889 (0.013) | 0.033 |
| Household size | 303 | 13.323 (0.410) | 271 | 12.690 (0.494) | 574 | 13.024 (0.318) | 0.633 |
| Some formal schooling (1/0) | 303 | 0.188 (0.022) | 271 | 0.181 (0.023) | 574 | 0.185 (0.016) | 0.007 |
| Member of a forest management group (1/0) | 303 | 0.584 (0.028) | 271 | 0.535 (0.030) | 574 | 0.561 (0.021) | 0.049 |
| Homestead far from the reforestation site (1/0) | 303 | 0.868 (0.019) | 271 | 0.945 (0.014) | 574 | 0.904 (0.012) | -0.077*** |
| Agric. Asset Index (PCA) | 303 | 0.134 (0.095) | 271 | -0.130 (0.095) | 574 | 0.009 (0.067) | 0.264* |
| Household Asset Index (PCA) | 303 | 0.200 (0.139) | 271 | -0.191 (0.070) | 574 | 0.015 (0.081) | 0.391** |
| Household landholdings (ha) | 251 | 14.367 (3.842) | 233 | 11.582 (3.443) | 484 | 13.026 (2.590) | 2.785 |
| Land area cultivated (ha) | 251 | 5.002 (0.242) | 233 | 4.688 (0.235) | 484 | 4.851 (0.169) | 0.314 |
| Total (nominal) food consumption expenditures in FCFA (past 7 days) | 303 | 11207.086 (664.619) | 271 | 12057.793 (804.172) | 574 | 11608.726 (516.794) | -850.708 |
| (LOG) Total (nominal) food consumption expenditures in FCFA (past 7 days) | 289 | 8.900 (0.063) | 267 | 8.913 (0.073) | 556 | 8.906 (0.048) | -0.014 |
| Household Dietary Diversity Score (HDDS) | 303 | 4.406 (0.084) | 271 | 4.491 (0.084) | 574 | 4.446 (0.060) | -0.085 |
| F-test of joint significance (p-value) | | | | | | | 0.198 |
| F-test, number of observations | | | | | | | 479 |

Notes: The value displayed for t-tests are the differences in the means across the groups. The value displayed for F-tests are p-values. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table 3: Regression Results: PES and Food Consumption Expenditures

|  | Food Expenditures | | | log(Food Expenditures) | | |
|---|---|---|---|---|---|---|
|  | (1) | (2) | (3) | (4) | (5) | (6) |
| PES | 1780.8** | 1798.1** | 1775.4* | 0.119** | 0.128** | 0.126** |
|  | (2.04) | (2.06) | (1.74) | (2.14) | (2.25) | (2.01) |
| Baseline outcome |  | 0.0317 | 0.0634 |  | 0.0446 | 0.0519 |
|  |  | (0.80) | (1.04) |  | (1.49) | (1.43) |
| Constant | 7126.2*** | 6856.1** | 5168.1 | 8.619*** | 8.231*** | 7.975*** |
|  | (2.65) | (2.53) | (1.10) | (50.13) | (26.86) | (20.34) |
| Observations | 574 | 574 | 484 | 574 | 556 | 479 |
| $R^2$ | 0.231 | 0.232 | 0.229 | 0.341 | 0.336 | 0.345 |
| Adjusted $R^2$ | 0.183 | 0.182 | 0.148 | 0.299 | 0.291 | 0.275 |
| Covariates included | No | No | Yes | No | No | Yes |
| Bloc fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Control mean |  |  | 11097 |  |  | 9 |

$t$ statistics in parentheses

The baseline outcomes represent respectively the food expenditure and log-food expenditure at baseline.

The covariates include age, gender, occupation, landholdings, revenue, size of the household,

education, distance to the reforestation site, and memnership of a forest membership group.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: IV Regression Results: PES and Food Consumption Expenditures

| | Food Expenditures | | | log(Food Expenditures) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| PES tranfers received (in 100 FCFA) | 22.49** | 22.71** | 21.97* | 0.00151** | 0.00159** | 0.00154** |
| | (2.10) | (2.12) | (1.83) | (2.20) | (2.32) | (2.12) |
| | | | | | | |
| Baseline outcome | | 0.0327 | 0.0648 | | 0.0467 | 0.0546 |
| | | (0.85) | (1.12) | | (1.61) | (1.58) |
| | | | | | | |
| Constant | 7673.7*** | 7400.6*** | 5643.3 | 8.656*** | 8.253*** | 7.989*** |
| | (2.99) | (2.86) | (1.26) | (52.60) | (27.82) | (21.43) |
| Observations | 574 | 574 | 484 | 574 | 556 | 479 |
| $R^2$ | 0.229 | 0.230 | 0.227 | 0.337 | 0.331 | 0.342 |
| Adjusted $R^2$ | 0.180 | 0.179 | 0.146 | 0.295 | 0.285 | 0.272 |
| Covariates included | No | No | Yes | No | No | Yes |
| Bloc fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Control mean | | | 11097 | | | 9 |

$t$ statistics in parentheses

The baseline outcomes represent respectively the food expenditure and log-food expenditure at baseline.

The covariates include age, gender, occupation, landholdings, revenue, size of the household,

education, distance to the reforestation site, and memnership of a forest membership group.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Regressions Results: HDDS

|  | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| PES | 0.0218 | 0.0215 | -0.0466 | |
|  | (0.27) | (0.27) | (-0.53) | |
| HDDS at baseline | | -0.00389 | 0.0352 | 0.0349 |
|  | | (-0.11) | (0.75) | (0.78) |
| PES tranfers received (in 100 FCFA) | | | | -0.000577 |
|  | | | | (-0.56) |
| Constant | 1.996*** | 2.012*** | 1.725*** | 1.714*** |
|  | (8.18) | (6.95) | (3.87) | (4.06) |
| Observations | 574 | 574 | 484 | 484 |
| $R^2$ | 0.585 | 0.585 | 0.606 | 0.605 |
| Adjusted $R^2$ | 0.558 | 0.558 | 0.565 | 0.564 |
| Covariates included | No | No | Yes | Yes |
| Bloc fixed effects | Yes | Yes | Yes | Yes |
| Estimation approach | OLS | OLS | OLS | IV |
| Control mean | | | | 4 |

$t$ statistics in parentheses
The covariates include age, gender, occupation, landholdings, revenue, size of the household, education, distance to the reforestation site, and membership of a forest membership group.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Regressions Results: Household Food Insecurity Access Scale (HFIAS)

| | Overall Scale $\in [0,4]$ | | Being food secure(0/1) | | Being severely food insecure(0/1) | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| PES | -0.607*** | -0.592*** | 0.148*** | 0.149*** | -0.0934*** | -0.0881*** |
| | (-3.80) | (-3.34) | (3.79) | (3.41) | (-4.16) | (-3.53) |
| | | | | | | |
| Constant | 0.800 | 1.436* | 0.595*** | 0.516** | 0.0625 | 0.201* |
| | (1.63) | (1.76) | (4.96) | (2.56) | (0.90) | (1.74) |
| Observations | 574 | 484 | 574 | 484 | 574 | 484 |
| $R^2$ | 0.184 | 0.223 | 0.089 | 0.119 | 0.283 | 0.324 |
| Adjusted $R^2$ | 0.132 | 0.143 | 0.032 | 0.029 | 0.238 | 0.255 |
| Covariates included | No | Yes | No | Yes | No | Yes |
| Bloc fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Control mean | | 1.517 | | 0.594 | | 0.151 |

$t$ statistics in parentheses

The control covariates include age, gender, occupation, landholdings, revenue, size of the household, education,

distance to the reforestation site, and memnership of a forest membership group.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Food Security Outcomes in between PES participants and non-participants

| Variable | N/[Clusters] | (1) PES Mean/SE | N/[Clusters] | (2) non-PES Mean/SE | t-test p-value | Randomization inference p-value |
|---|---|---|---|---|---|---|
| Total (nominal) food consumption expenditures in FCFA (past 7 days) | 303 | 12940.488 (690.208) | 271 | 11097.077 (655.157) | 0.041 | 0.038 |
| (LOG) Total (nominal) food consumption expenditures in FCFA (past 7 days) | 303 | 9.147 (0.047) | 271 | 9.022 (0.046) | 0.033 | 0.041 |
| Household Food Insecurity Access Scale (HFIAS) $\in [0,4]$ | 303 | 0.931 (0.108) | 271 | 1.517 (0.132) | 0.000 | 0.000 |
| HFIAS = 1 (food secure) | 303 | 0.736 (0.025) | 271 | 0.594 (0.030) | 0.000 | 0.000 |
| HFIAS = 4 (severely insecure) | 303 | 0.063 (0.014) | 271 | 0.151 (0.022) | 0.000 | 0.000 |
| Household Hunger Scale (HHS) $\in [0,3]$ | 303 | 0.155 (0.030) | 271 | 0.336 (0.044) | 0.000 | 0.000 |
| HHS = 1 (no hunger) | 303 | 0.964 (0.011) | 271 | 0.882 (0.020) | 0.000 | 0.000 |
| HHS = 2 (moderate hunger) | 303 | 0.036 (0.011) | 271 | 0.118 (0.020) | 0.000 | 0.000 |
| Household Dietary Diversity Score (HDDS) | 303 | 3.878 (0.082) | 271 | 3.845 (0.085) | 0.781 | 0.815 |

*Notes*: We show both standard p-values and p-values computed by randomization inference (RI) with 1000 repetitions.

# Appendix A. Appendix

Figure A.9: Payment received by participation status
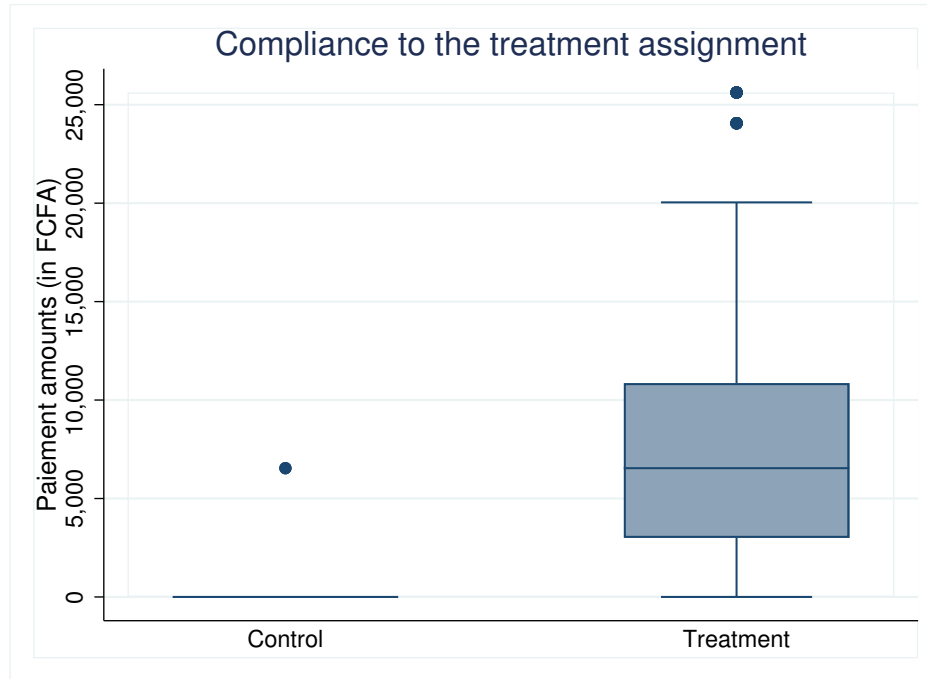


*Note*: This figure, shows the distribution of the payments amounts received by individuals in our sample, by PES participation status. The graph shows high compliance in both participant and non participant groups.

## Table A.8: Balancing Test: Attrited - Endline

| Variable | N | (1) Attrited Mean/SE | N | (2) Endline Mean/SE | N | (3) Total Mean/SE | T-test Difference (1)-(2) |
|---|---|---|---|---|---|---|---|
| Age of respondent | 56 | 36.554 (1.456) | 574 | 39.430 (0.450) | 630 | 39.175 (0.431) | -2.877* |
| Female respondent (1/0) | 56 | 0.107 (0.042) | 574 | 0.162 (0.015) | 630 | 0.157 (0.015) | -0.055 |
| Agriculture as primary activity (1/0) | 56 | 0.893 (0.042) | 574 | 0.897 (0.013) | 630 | 0.897 (0.012) | -0.004 |
| Annual revenu from primary activity (LOG) | 56 | 3.784 (0.816) | 574 | 2.990 (0.310) | 630 | 3.061 (0.292) | 0.794 |
| Annual total revenu (LOG) | 56 | 10.806 (1.034) | 574 | 9.822 (0.397) | 630 | 9.909 (0.374) | 0.984 |
| Has a secondary activity (1/0) | 56 | 0.143 (0.047) | 574 | 0.282 (0.019) | 630 | 0.270 (0.018) | -0.139** |
| Married (1/0) | 56 | 0.839 (0.050) | 574 | 0.889 (0.013) | 630 | 0.884 (0.013) | -0.049 |
| Household size | 56 | 12.589 (1.183) | 574 | 13.024 (0.318) | 630 | 12.986 (0.308) | -0.435 |
| Some formal schooling (1/0) | 56 | 0.196 (0.054) | 574 | 0.185 (0.016) | 630 | 0.186 (0.016) | 0.012 |
| Member of a forest management group (1/0) | 56 | 0.589 (0.066) | 574 | 0.561 (0.021) | 630 | 0.563 (0.020) | 0.028 |
| Homestead far from the reforestation site (1/0) | 56 | 0.964 (0.025) | 574 | 0.904 (0.012) | 630 | 0.910 (0.011) | 0.060 |
| Indice des actifs agricoles (ACP) | 56 | -0.097 (0.222) | 574 | 0.009 (0.067) | 630 | -0.000 (0.065) | -0.106 |
| Indice des actifs du mnage (ACP) | 56 | -0.157 (0.161) | 574 | 0.015 (0.081) | 630 | 0.000 (0.075) | -0.173 |
| Household landholdings (ha) | 38 | 17.632 (13.054) | 484 | 13.026 (2.590) | 522 | 13.361 (2.579) | 4.606 |
| Land area cultivated (ha) | 38 | 4.237 (0.643) | 484 | 4.851 (0.169) | 522 | 4.806 (0.163) | -0.614 |
| Total (nominal) food consumption expenditures in FCFA (past 7 days) | 56 | 9545.107 (1187.852) | 574 | 11608.726 (516.794) | 630 | 11425.294 (482.895) | -2063.619 |
| (LOG) Total (nominal) food consumption expenditures in FCFA (past 7 days) | 55 | 8.743 (0.139) | 556 | 8.906 (0.048) | 611 | 8.891 (0.045) | -0.163 |
| Household Dietary Diversity Score (HDDS) | 56 | 4.429 (0.200) | 574 | 4.446 (0.060) | 630 | 4.444 (0.057) | -0.017 |

*Notes*: The value displayed for t-tests are the differences in the means across the groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

## Table A.9: Treatment effects on food expenditure shares

| Variable | N | (1) Treatment Mean/SE | N | (2) Control Mean/SE | N | (3) Total Mean/SE | T-test Difference (1)-(2) |
|---|---|---|---|---|---|---|---|
| Consume foodgroup1 (0/1) | 303 | 0.997 (0.003) | 271 | 0.989 (0.006) | 574 | 0.993 (0.003) | 0.008 |
| Consume foodgroup2 (0/1) | 303 | 0.756 (0.025) | 271 | 0.742 (0.027) | 574 | 0.749 (0.018) | 0.014 |
| Consume foodgroup3 (0/1) | 303 | 0.858 (0.020) | 271 | 0.838 (0.022) | 574 | 0.848 (0.015) | 0.020 |
| Consume foodgroup4 (0/1) | 303 | 0.013 (0.007) | 271 | 0.011 (0.006) | 574 | 0.012 (0.005) | 0.002 |
| Consume foodgroup5 (0/1) | 303 | 0.498 (0.029) | 271 | 0.487 (0.030) | 574 | 0.493 (0.021) | 0.011 |
| Consume foodgroup6 (0/1) | 303 | 0.139 (0.020) | 271 | 0.118 (0.020) | 574 | 0.129 (0.014) | 0.021 |
| Consume foodgroup7 (0/1) | 303 | 0.568 (0.029) | 271 | 0.605 (0.030) | 574 | 0.585 (0.021) | -0.038 |
| Consume foodgroup8 (0/1) | 303 | 0.508 (0.029) | 271 | 0.539 (0.030) | 574 | 0.523 (0.021) | -0.030 |
| Consume foodgroup9 (0/1) | 303 | 0.868 (0.019) | 271 | 0.911 (0.017) | 574 | 0.889 (0.013) | -0.043* |
| Expenditure on Crales, racines, et tubers | 303 | 7031.601 (403.045) | 271 | 6200.461 (480.380) | 574 | 6639.199 (311.180) | 831.139 |
| Expenditure on Gousses / fruits pericarpes | 303 | 743.937 (86.191) | 271 | 534.225 (40.981) | 574 | 644.927 (49.594) | 209.712** |
| Expenditure on Lgumes | 303 | 911.211 (83.138) | 271 | 771.402 (50.417) | 574 | 845.204 (49.970) | 139.809 |
| Expenditure on Fruits | 303 | 10.561 (5.901) | 271 | 6.273 (4.181) | 574 | 8.537 (3.686) | 4.288 |
| Expenditure on Viande et poisson | 303 | 1624.670 (176.658) | 271 | 1160.055 (131.700) | 574 | 1405.314 (112.406) | 464.615** |
| Expenditure on Produits laitiers | 303 | 314.521 (66.953) | 271 | 294.280 (71.768) | 574 | 304.965 (48.920) | 20.241 |
| Expenditure on Huiles | 303 | 761.634 (56.656) | 271 | 704.151 (52.581) | 574 | 734.495 (38.853) | 57.482 |
| Expenditure on Sucre | 303 | 418.647 (59.175) | 271 | 396.985 (43.091) | 574 | 408.420 (37.249) | 21.662 |
| Expenditure on other items - tabac, alcool, condiments | 303 | 1123.706 (86.570) | 271 | 1029.244 (66.435) | 574 | 1079.108 (55.415) | 94.463 |

*Notes*: The value displayed for t-tests are the differences in the means across the groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table A.10: Regressions Results: Elasticity of consumption expenditures per food group

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| IHS tranformed Household Total Food Concumption Expenditures | 1.388** | 0.686 | 0.568 | 0.470 | 1.111 | -1.062 | -2.696 | -1.465 | -1.942 |
| | (2.25) | (0.38) | (0.31) | (0.80) | (0.50) | (-0.50) | (-1.08) | (-0.57) | (-1.02) |
| | | | | | | | | | |
| Constant | -3.774 | -3.363 | -1.193 | -4.173 | -13.13 | 10.49 | 25.30 | 13.20 | 20.70 |
| | (-0.67) | (-0.20) | (-0.07) | (-0.78) | (-0.65) | (0.54) | (1.10) | (0.56) | (1.18) |
| Observations | 484 | 484 | 484 | 484 | 484 | 484 | 484 | 484 | 484 |
| $R^2$ | 0.487 | 0.423 | 0.275 | 0.073 | 0.535 | . | 0.266 | 0.157 | 0.049 |
| Adjusted $R^2$ | 0.434 | 0.364 | 0.200 | -0.022 | 0.487 | . | 0.190 | 0.070 | -0.048 |
| Covariates included | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Bloc fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Control mean | 6200 | 534 | 771 | 6 | 1160 | 294 | 704 | 397 | 1029 |

$t$ statistics in parentheses

The covariates include age, gender, occupation, landholdings, revenue, size of the household,

education, distance to the reforestation site, and memnership of a forest membership group.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.11: Regressions Results: Household Hunger Scale (HHS)

| | Scale $\in [0,3]$ | | Scale $= 1$ (no hunger) | | Scale $= 2$ (moderate hunger) | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| PES | -0.189*** | -0.180*** | 0.0855*** | 0.0852*** | -0.0855*** | -0.0852*** |
| | (-4.16) | (-3.58) | (4.60) | (4.16) | (-4.60) | (-4.16) |
| | | | | | | |
| Constant | 0.123 | 0.371 | 0.945*** | 0.929*** | 0.0549 | 0.0711 |
| | (0.88) | (1.60) | (16.48) | (9.81) | (0.96) | (0.75) |
| Observations | 574 | 484 | 574 | 484 | 574 | 484 |
| $R^2$ | 0.317 | 0.360 | 0.336 | 0.376 | 0.336 | 0.376 |
| Adjusted $R^2$ | 0.274 | 0.294 | 0.294 | 0.311 | 0.294 | 0.311 |
| Controls | No | Yes | No | Yes | No | Yes |
| Bloc fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |

$t$ statistics in parentheses

The control covariates include age, gender, occupation, landholdings, revenue, size of the household, education, distance to the reforestation site, and memnership of a forest membership group.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$