Agroforestry and household nutrition in southern Madagascar: does gender matter?

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Abstract

Food security is a pressing challenge in many countries in the Global South. As climate change is exacerbating the uncertainties in agriculture, farmers need to adapt their agricultural production to a changing climate. Agroforestry is a promising adaptation strategy which can improve farmers' resilience to climate change but also their food security and nutrition. Yet, there is lack of robust evidence on this relationship and little is known on the role of gender norms which shape this relation. On the one hand, women decide on food preparation, on the other hand, they often neither control the crop choice at farm level, nor the use of harvest and income. This has consequences for the sign of the relationship between agroforestry and nutrition. To study this topic, we use data on southern Madagascar farmers, who are highly food insecure and exposed to frequent extreme weather events. Using an instrumental variables approach, we estimate the effect of agroforestry on nutrition, looking at the mediating role of gender. Results can inform policies aimed at strengthening adaptation potential and food security.

JEL codes: O12, O13, Q18, Q54

Keywords: agroforestry, nutrition, gender, climate adaptation, Madagascar

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Introduction

Ensuring food security and nutrition remains a primary concern for many countries in the Global South, while frequent climatic (and non-climatic) shocks are creating a serious challenge for sustaining current levels of food security. Agroforestry has been praised for its potential as an adaptation strategy to climate change, in particular for addressing deforestation, biodiversity loss, and environmental degradation, but also for its potential to improve wellbeing and nutrition. Agroforestry can affect nutrition directly through the provision of food (products from trees, shrubs and crops) but also indirectly, by improving yield (through fertility-enhancing synergies), resilience (shade, reduced erosion, reduced pests), and income (through the sale of food products but also timber and medicinal plants), in turn affecting food security and nutrition. Yet, rigorous studies on the link between agroforestry and household nutrition are lacking, and little is known about the role of gender norms in shaping this relationship. On one hand, women are responsible for preparing food, on the other hand, they lack control on the planting choices and on the use of the harvest and of income, ultimately affecting the sign of the relation between agroforestry and nutrition.

To bridge this gap, we focus on Madagascar, whose rural population is largely food insecure (65% prevalence of moderate or severe food insecurity in 2021, World Development Indicators; 2023), while its biodiversity-rich environmental resources are subject to quick depletion. Moreover, the frequency of cyclones and droughts urge farmers to adapt their agriculture. Agroforestry is not new to Madagascar, as farmers have traditionally cultivated food and cash crop perennials in agroforestry systems (*tsabo*). Lately, agroecological measures such as agroforestry have been widely promoted in the country. Moreover, Madagascar is an interesting case study for its traditional division of gender roles. For instance, women in Madagascar can own and inherit land, however, compared to men, they are less engaged with cash crop production, have lower access to extension services, and are less likely to own titled land (Widman and Hart, 2019). The separation of roles is such that men are responsible for the preparation of soil and cattle, while women take care of the weeding, transplanting, household chores and care of the children (Jarosz, 1997).

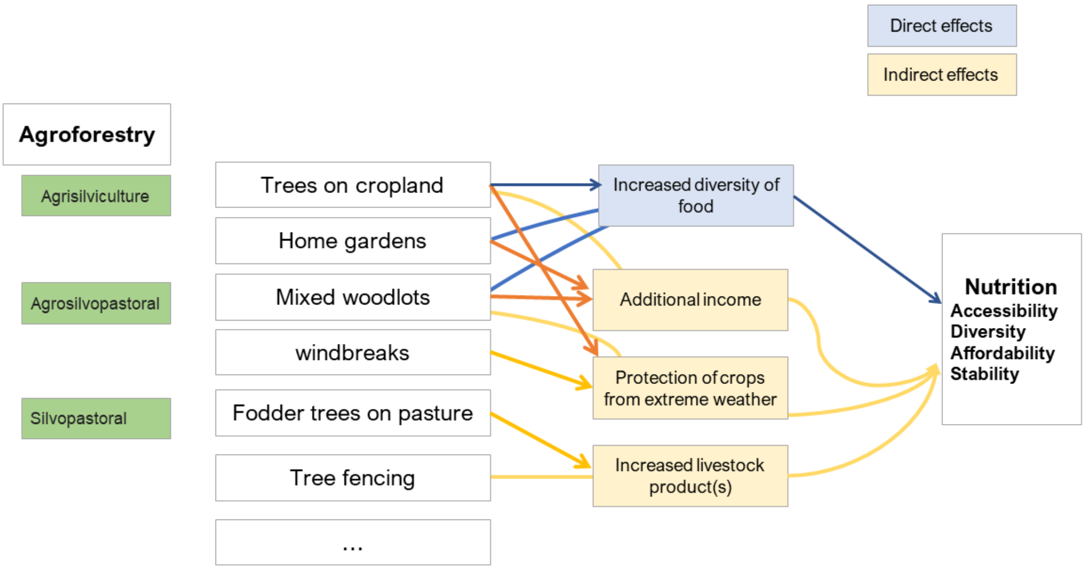
In this paper, we aim to bridge this gap by analysing the causal link between agroforestry and food security and nutrition of the household, while exploring the mediating impact of the gender of the household head and the decision maker for agricultural decisions. To this end, we use novel representative data from three regions in southern Madagascar (Anosy, Androy and Atsimo Atsinanana) collected by the Potsdam Institute for Climate Impact Research (PIK) from 2023. The survey contains information on farm production, agricultural practices and food security and nutrition, amongst others. In particular, we focus on the direct impact of having trees on the parcel on households' nutritional score and food insecurity.

The rest of the paper is organized as follows: Section 2 sets some background and the theoretical framework, Section 3 describes the data used, Section 4 describes the identification strategy with an instrumental variable approach. Then, we report some descriptive statistics in Section 5 and results of the analysis in Section 6. Finally, Section 7 concludes.

2. Background

We consider a basic framework in which agroforestry in its various forms produces a set of services which directly or indirectly affect nutrition (Figure 1). The indirect channel goes through income, increased resilience and livestock.

Figure 1: Theoretical framework



Source: authors' elaboration.

The literature on the relationship between agroforestry and nutrition is timidly growing, however, it is striking lacking rigorous causal studies. In an attempt to fill this gap, we study this topic in southern Madagascar. Agroforestry has been largely promoted in Madagascar for its potential in agroecology. Moreover, agroforestry systems are suitable in all agroecological zones in Madagascar (Raharison et al., 2016). For the many benefits it entails to develop, it takes some time and specific management skills (Raharison et al., 2016)

Notably, studies linking agroforestry and household nutrition are limited and show mixed results. A systematic review studying specifically this direct link of woody plants in agroforestry on human health or nutrition finds very few studies (18) which point to a positive effect but with important quality weaknesses (Knollman, 2024). Summarizing results from 11 studies on agroforestry interventions (RCTs and quasi-experimental studies), a meta-analysis finds mixed evidence in how agroforestry interventions benefit nutrition outcomes, with homegardens having a high likelihood of improving nutrition (Castle et al., 2021). A study in Burkina Faso directly links the diversity of production on farm from agroforestry and the number of agroforestry species with nutrition, showing a positive relation with Women Dietary Diversity Scores (Lourme-Ruiz et al., 2021). In Mexico, the relationship between traditional agroforestry systems and food is assessed in a more qualitative way, finding a strong role of agroforestry in providing food and income (Soto-Pinto et al., 2022). In Uganda, the share of land with trees on farm is positively associated with total household expenditure and higher nutritional outcomes, underweight and wasting (this was especially true for fruit trees) (Miller et al., 2020). In Indonesia, farmers mixing crop and agroforestry outperform only crop and only agroforestry systems in terms of revenues and food production, with mild positive association with nutritional status (Purwestri et al., 2022). In Ethiopia, the number of species in coffee agroforestry systems are positively correlated with children biometric outcomes and food access security (Jemal et al., 2021). Among indigenous communities in India, despite access to rich forest products, agricultural land, rivers and livestock, women have low food accessed diversity and score low in micronutrients and prevalent underweight (Ghosh-Jerath et al., 2021).

Much of this literature only establishes a relationship between agroforestry and intermediate outcomes. For instance, agroforestry as defined as high or medium tree cover on the farm is shown to lead to higher milk production in dual purpose cattle systems in Colombia (Álvarez et al., 2021). In the meta-analysis by Castle (Castle et al., 2021), agroforestry interventions show significant increases in yield but some heterogeneous effects: increased soil fertility where fertility was low but also reduced productivity for conservation benefits. They also find consistent small positive impacts on income (Castle et al., 2021). An agroforestry programme in Kenya brings about modest increases in income from forest products, fuelwood, milk yield and assets (Hughes et al., 2020). The use of agroforestry species for fertilization-purposes shows important gains in Malawi, especially for small farms, with an increase in food crops value (Coulibaly et al., 2017).

Across this literature, there are important heterogeneous effects. The meta-analysis by Castle (2021) shows that agroforestry interventions can have different results for small and large farms, women and men, rich and poor farmers(Castle et al., 2021). Agroforestry produces multiple services and products at low-cost low-inputs, therefore it should be ideal for women, who generally have lower control over resources (Kiptot & Franzel, 2012). Agroforestry can be a way to claim ownership of land under different tenure systems in Malawi in mostly matrilineal land inheritance: inherited land is less likely to be used for agroforestry, while the reverse is true for purchased land (Benjamin et al., 2021). After an agroforestry programme in Kenya, women-led households showed a higher increase in assets (Hughes et al., 2020).

More often, the participation of women in agroforestry is limited because of socioeconomics, cultural and policy factors which are context-dependent (Kiptot & Franzel, 2012). In a review on Africa, women are found at the centre of agroforestry systems as the main supplier for labour for establishing them and are responsible for trees management, planting, weeding and watering. However, women are relegated to low-return labour products such as fodder, indigenous fruit and vegetables collection, and mulch (Kiptot & Franzel, 2012). Indeed, women's participation in men-led agroforestry practices such as timber is low. Women also engage in soil fertility management, fodder production and woodlots, but in these cases, agroforestry involves much smaller plot areas and lower numbers of trees (Kiptot & Franzel, 2012).

Gender is also found to play a role in nutrition and food security outcomes. However, the ultimate effect of gender depends deeply on the decision-making power and the empowerment. Women in different countries in sub-Saharan Africa that have higher decision-making power (empowerment) are found to produce more different food and more nutrient-dense crops (Connors et al., 2023). Relatedly, women in Uganda with certified sustainability standards are able to increase caloric and micronutrient consumption through increased income and gender equity, as they gain higher control over production and use of harvest decisions (Chiputwa & Qaim, 2016). Women's different agricultural output can be explained by lower access to market-oriented crops due to the exclusion from extension services, agricultural cooperatives, networks (wa Gĩthĩnji et al., 2014).

How much time women dedicate to agriculture, and the extent of their decision-making power also rests on gender norms. Gender norms prescribe time allocation of men and women, and often put women at a disadvantage. In case of an idiosyncratic shock, it is shown that women reallocate their time to care activities, which in turn affects negatively agricultural output (Arora & Rada, 2017).

In Madagascar, men are usually responsible for the preparation of soil and cattle management, while women are responsible for weeding, transplanting, and household chores and care work (Jarosz, 1997). There is however some heterogeneity in the country, in particular it is the ethnic group's social norms that determine the ultimate share of time that people within the household need to dedicate to household chores. For instance, among Antadroy group in Androy region, women mange 65% of household tasks. Other than that, women also solely work on agriculture, while men sometimes migrate to urban areas (Randriamparany, 2022). Ethnic group is also a strong determinant of technology adoption in Madagascar, as it entails different social norms which also involve agricultural activities (Minten & Barrett, 2008).

In Madagascar, women are less engaged with cash crop production, lack access to extension services, and own less frequently titled land (Widman & Hart, 2019). Women can own and inherit land[1] as men, and patrilinear inheritance is more common than matrilinear inheritance. However, gendered land tenure systems[2] persist even if by Constitutional law (2010) all individuals have equal rights regardless of sex and if by succession law (1968) men and women surviving their spouse should be treated equally. Moreover, the 2007 marriage law mandates that joint property should be divided equally between the divorcing parties. The practice, however, is often different (Widman & Hart, 2019) and women are disadvantaged.

3. Data

We use data from the first and second wave of the AGRICA Madagascar Panel Survey[3] collected by the Potsdam Institute for Climate Impact Research (PIK). The first wave was collected in person in April-May 2023, while the second wave was a follow-up phone survey collected in June-July 2023. The sample size is 624 households in the first wave and 619 households in the second wave. The location of the sample can be seen in Figure 2. We focus on these first two waves as together they capture the harvest season at two different points in time[4]. Indeed, the timing of the survey in rural communities is crucially important for nutritional outcomes.

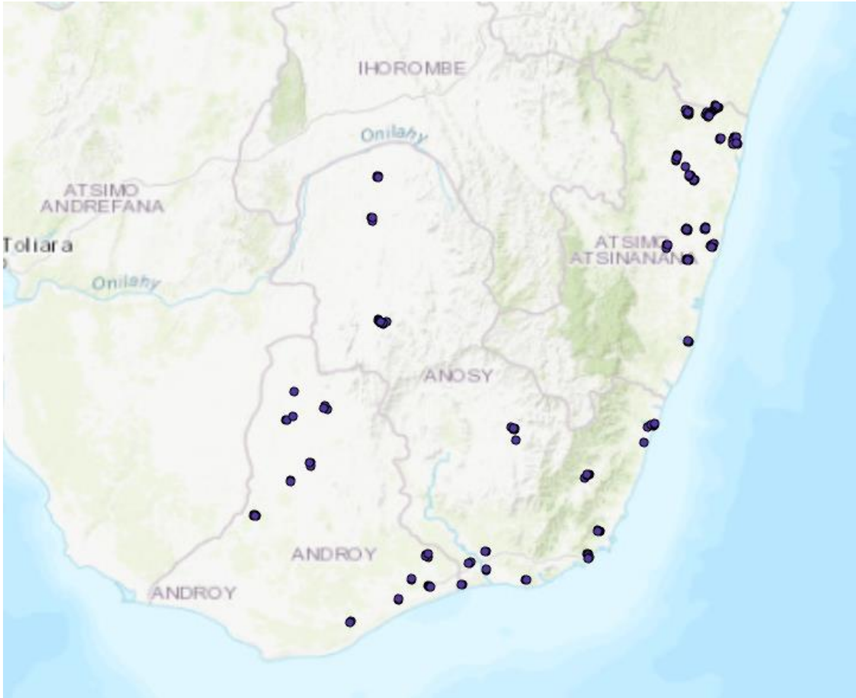
[1] Land titles do not necessarily ensure more security for women, as men can dispose of the land owned by women, whereas customary land tenure systems might not allow one decision maker, therefore protecting women's rights (wa Gĩthĩnji et al., 2014).

[2] In Madagascar customary and statutory land tenure institutions coexist (McLain et al., 2023).

[3] The project is ongoing and currently has collected 5 other follow-up phone calls. The final wave is scheduled for June 2024 and will be in person again.

[4] In principle, we can explore also the follow-up waves. This is one of the next steps of this paper.

Figure 2: Location of the households in the survey (south of Madagascar)



Source: own elaboration

Our outcomes of interest are the food consumption score (FCS) (0-100) which measures the variety of the diet for the household in the past 7 days, a dummy variable for when the FCS is above an acceptable threshold (HFSNA categories), a dummy variable for when the HFIAS (household food insecurity access scale) is secure or mildly insecure, a dummy indicating when the household hunger classification reports little or no hunger, three dummy variables for frequent (more than 7 times a week) consumption of protein-rich foods, vitamin-A rich food and iron-rich foods in the past 7 days. Then we also measure the expenditure on food per capita in the past month (not including self-consumption), the number of food crops cultivated and the Gini-Simpson index of food produced diversity. The latter two should proxy food availability in the household.

Controls in the models are key socio-demographic variables (age of the household head, gender and education as well as size of the household), key assets (size of the land cultivated, soil type and colour dummies, livestock as cattle, poultry and goats or sheep, wealth), as well as farmers' association membership, the ethic group, the distance from protected areas, occurrence of drought or insufficient rain shocks in the past 12 months (self-reported) and region dummies.

Ethnic group and distance from protected areas should control for confounding factors which correlate with agroforestry and possibly could influence nutrition. In particular, ethnic groups controls for cultural factors while being close to a protected area might reduce the availability of forest products and somehow force households to have trees on their land to provide for firewood.

4. Empirical strategy

In our baseline model, we examine whether having trees on the farmland affects households' nutritional score and food security. We estimate a model of the following structural form for the first wave and the second wave (equation 1):

$$Y_{it} = \quad \beta_1 trees_{it} + \delta X_{it} + \varepsilon_{it} \tag{1}$$

where the nutritional outcomes and food security Y of household i at time t are a function of trees on the farmland, a vector of household-level controls, and an error term ε_{it}. The main coefficient of interest is β_1, which measures the association of trees present on the farmland with nutrition and food security. For the second wave, the control variables are lagged one period because of time-invariant variables.

Secondly, to explore the channel of the gender norms in decision making, we interact the agroforestry indicator with an indicator of female decision maker (equation 2):

$$Y_i = \quad \beta_1 trees_i \times fem_i + \delta X_{it} + \varepsilon_i \tag{2}$$

As we do not have information on marital status, we consider here female headed households where there is no spouse in the household.

Methodologically, estimating the causal impact of agroforestry on nutrition and food security is challenging. Combining trees with other crops is potentially endogenous to nutrition and food security for several reasons. First, it is possible that causality runs in the opposite direction, meaning that more food insecure households are more likely to plant trees on their farm and invest in their land long-term. Second, unobserved variables might affect both the use of agroforestry as strategy and the food security and nutritional level of households. To address this endogeneity concern, we use an instrumental variable approach with two instruments (as a robustness test, we will use the endogenous switching regression model[5]).

The first instrument we use is the previous ownership of land by the mother of the respondent. As trees are a long-term investment, the adoption decision strongly depends on the (perceived) tenure security of land and on a long enough presence on the farmland by the household's family. To be a valid instrument, mother owning land needs to have a significant and substantial partial correlation with the endogenous trees on farmland variable and it needs to satisfy the exclusion restriction. The exclusion restriction would be violated if potential alternative pathways from mother land to nutrition and food security exist, which do not run through trees on the farmland. The validity of this restriction cannot be tested. However, we conduct robustness tests and discuss potential alternative impact pathways between mother land and food and nutrition security in Section 4.1.

The second instrument we use is the previous occurrence of cyclones. This data comes from ISIMIP cyclone events maximum wind speed[6]. Specifically, we count the number of times during cyclones in which the maximum wind speed exceeded a certain threshold. We construct these variables for the period 2008-2018, excluding explicitly the last 5 years' events which might still have repercussions on the nutrition and food security at time 0. We chose a threshold of 15 knots but test 10, 20, 25 and 28. According to the literature (Beer, 2013), winds above 28 knots damage trees, but wind speed interacts with the frequency and sustained duration of such winds and height of trees. Wind speed in our locations reached 28 knots only in very rare occasions, so we resorted to using a lower threshold which can also be justified by windbreaks. A priori, wind speed in the past has an ambiguous effect on current agroforestry: strong winds might damage trees or break them (negative coefficient), which might lead to replanting (positive) or protective measures such as windbreaks

[5] The future version of this paper will incorporate this.
[6] https://www.isimip.org/gettingstarted/input-data-bias-adjustment/details/182/

(positive). The assumption here is that strong winds in the past affected perennials in the past but not current food crops (hence nutrition).

Similarly, to be a valid instrument, strong winds in the past needs to have a significant correlation with agroforestry and it needs to satisfy the exclusion restriction. This would be violated if alternative pathways exist from strong winds to nutrition and food security, that do not go through agroforestry. We conduct robustness tests and discuss these alternative impact pathways between wind speed and food and nutrition security in Section 4.1.

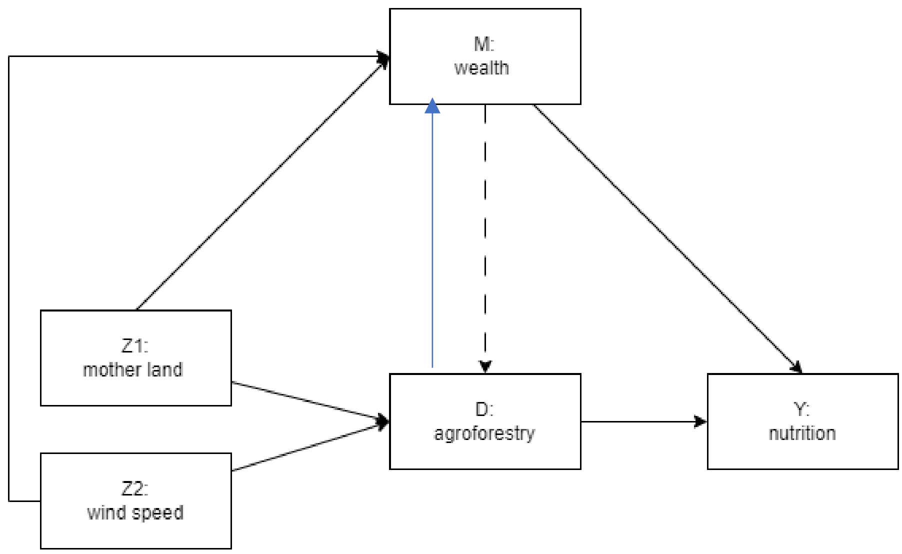
The first stage of the two-stage-least squares (2SLS) estimator is given by equation 3, while the second stage is represented by equation 4.

$$trees_{it} = \quad \pi_1 motherland_i + \pi_2 paststrongwinds_i + \pi X_{it} + \varepsilon_{it} \tag{3}$$

$$Y_{it} = \quad \beta_1 \widehat{trees_{it}} + \delta X_{it} + \varepsilon_{it} \tag{4}$$

In our baseline model, we do not add any controls (no δX_{it} term). Next, we include household-level controls to exclude the possible other (observable) channels through which the instruments affects the outcome (conditional IV independence) (Deuchert & Huber, 2017). Control variables should take care of the possible correlation of the instrument with confounders or another treatment which in turn affects the outcome (Deuchert & Huber, 2017). In this case, we expect a confounding effect from wealth but identification should be possible as long as it does not affect both X and Z (Figure 3).

Figure 3: Causal diagram



Source: own elaboration

In a next step, we analyse heterogeneity of results by gender of the decision maker. We interact the instrumented agroforestry variable with an indicator variable of female decision maker. We also interact the instrument motherland (Kim et al., 2011). The models estimated become those in equation 5 and 6.

$$trees_{it} \times fem_i = \quad \pi_1 motherland_i \times fem_i + \pi_2 paststrongwinds_i + \delta X_{it} + \varepsilon_{it} \tag{5}$$

$$Y_{it} = \quad \beta_1 \widehat{trees_{it} \times fem_i} + \delta X_{it} + \varepsilon_{it} \tag{6}$$

Validity of IV

The assumptions we make are the following: (1) relevance: mother owning land and past wind speed affect today's agroforestry. (2) Exclusion restriction: mother owning land and past wind speed affect nutrition only through agroforestry, and not through other channels (income, asset accumulation, ...). (3) Exogeneity: neither mother owning land nor past wind speed share common causes with nutritional outcomes. (4) Monotonicity: mother owning land and past wind speed never discourage agroforestry, i.e., if the instruments have a positive relation with the endogenous variable, there should be no cases in which these instruments predict a negative relation (Felton & Stewart, 2022).

A potential violation of the identifying assumption of exogeneity happens if (1) the instrument (mother owning land) shares some unmeasured common causes with the outcome (nutrition) or if the instrument (motherland) shares some unmeasured common causes with the treatment (agroforestry) (Felton & Stewart, 2022). This could be represented by cultural norms that lead to women owning land (buying it), planting trees or choosing some types of diets. We control for this by using ethnic group variables. However, the relevance of this potential channel is higher if the place of residence of the respondent and the mother is the same. Moreover, the agroecological zone likely affects the suitability of agroforestry systems and crop yields, and therefore food security variables. For now, we should roughly capture this with region variables.

The validity of the instrumental variable approach hinges on the exclusion restriction being met. Recently, the validity of using climatic data as instrument has been challenged (Mellon, 2023). In his study, Mellon (2023) counts 14 studies using wind speed as an instrument. If wind speed can be a valid instrument for different treatments, then it is likely that the factors affected by wind speed are many, and that wind speed can affect nutrition through it is impact on other factors than agroforestry. In his review, these are pollution, pirate attacks, and prices. While for the first two the context seems less appropriate, the potential effect of wind speed on prices could be nonnegligible. This could violate the exclusion restriction.Moreover, the use of historical instruments needs to be carefully considered (Casey & Klemp, 2021; Deuchert & Huber, 2017; Glynn et al., 2023). In our case, wind speed (proxying cyclones) and motherland affect past wealth, which in turn affects current wealth and current agroforestry.

We conclude that the exclusion restriction is likely to hold, leading to plausible causal estimates in our IV regressions. We nonetheless will perform some robustness test for the potential violation of the exclusion restriction, controlling for variables that capture alternative links between the instrument and the outcome. We will test the effects of the instruments on potential intermediate channels.

5. Descriptive statistics

The main explanatory variable (agroforestry) is defined as having trees on a parcel[7]. Agroforestry is common (55%) in Atsimo-Atsinana (AA henceforth), and less widespread in the other two regions (especially the semi-arid Androy). Overall, 33% of households in the sample have at least one parcel with trees. On average, in AA, there are more parcels under agroforestry than in the other two regions (Table 1).

[7] We are not able to distinguish between types of agroforestry beyond homegarden and non, or whether its is from intercropping, nor we cannot capture sylvopasture.

Some regional differences emerge, especially in female head share, education, as well land size, livestock, membership in farmers' associations, extension, distance from protected areas, self-reported shocks, cash crop cultivation, mother owned land, parents born in the current commune. Moreover, we find strong differences in the nutritional outcomes, which are quite striking. In particular, households in Androy have the lowest mean food consumption scores and least frequent intake of protein, vitamin A and iron, followed by Anosy. Farmers in AA have the lowest average food expenditure and the smaller number of food crops and trees grown.

Table 1: Mean values per region and total, first wave.

	Atsimo Atsinanana Mean	Anosy Mean	Androy Mean	Total Mean
Agroforestry: trees on the plot	0.55	0.31	0.14	0.33
Number of plots in agroforestry	0.78	0.42	0.20	0.47
Agroforestry from cash crops and other trees	0.39	0.07	0.00	0.15
Age of head	48.48	49.30	45.80	47.86
Female head	0.14	0.27	0.24	0.22
Woman head & no spouse	0.14	0.25	0.24	0.21
Household size	7.23	6.84	6.74	6.94
Years of attending school by respondent	4.68	4.09	2.50	3.76
Parcel land, ares	159.17	264.03	231.61	218.27
Wealth, normalized	0.08	0.10	0.07	0.08
HH owns cattle	0.33	0.37	0.43	0.38
HH owns poultry	0.75	0.61	0.50	0.62
HH owns goats/sheep	0.00	0.15	0.45	0.20
Member of farmer group or cooperative	0.24	0.29	0.35	0.29
Whether respondent has taken out loan	0.36	0.39	0.40	0.38
Received extension and information from extension officer	0.26	0.15	0.18	0.20
Protected areas (km)	22.74	20.25	37.13	26.71
Shock in the last 12 months: drought	0.50	0.38	0.79	0.56
Shock in the last 12 months: little rain	0.13	0.45	0.45	0.34
Cultivates cash crops	0.64	0.33	0.51	0.49
Inherited land	0.83	0.78	0.91	0.84
Right to plant trees	0.97	0.98	0.99	0.98
Mother owned land	0.80	0.58	0.65	0.68
Father owned land	0.96	0.80	0.90	0.89
Mother born in respondent's commune	0.72	0.58	0.64	0.65
Father was born in respondent's commune	0.83	0.63	0.78	0.75
Food consumption score (WFP)	42.64	37.24	30.72	36.87
FCS acceptable, HFSNA cat	0.42	0.33	0.12	0.29
HFIAS mild or food secure	0.14	0.19	0.13	0.15
HHS no or little hunger	0.87	0.77	0.83	0.83
Frequent protein intake - at least 7 times	0.81	0.54	0.28	0.54
Frequent vit A intake - at least 7 times	0.23	0.27	0.17	0.22
Frequent iron intake - at least 7 times	0.07	0.03	0.01	0.04
Food exp pc last 4 weeks (/1,000)	14.97	18.84	16.61	16.81
N. of food crops/trees grown	2.96	3.84	4.75	3.85

Agroforestry shows positive correlation with (in order) the cultivation of coffee, cloves, banana, cassava, pepper, vanilla, and maize, while showing a strong negative correlation with rice (Table 2).

Table 2: Pairwise correlation coefficients at parcel level at 10% significance level. First wave

	Atsimo-Atsinanana agrofor	Anosy agrofor	Androy agrofor
Agroforestry: trees on the parcel	1.00	1.00	1.00
Cultivates rice	-0.39	-0.18	-0.02
Cultivates maize	0.12	0.00	0.06
Cultivates cassava	0.22	0.13	0.10
Cultivates peanuts	-0.01	0.01	0.07
Cultivates vanilla	0.13	0.14	
Cultivates cloves	0.30		
Cultivates pepper	0.17	0.22	
Cultivates coffee	0.57	0.24	

Cultivates sweet potato	0.07	0.08	-0.01
Cultivates banana	0.28	0.20	0.05
Cultivates sugarcane	0.04	0.11	0.09
Cultivates beans		0.06	-0.07
Cultivates peas	-0.01	-0.01	-0.04
Cultivates vegetable	0.04	0.01	0.05
Cultivates onions			0.02
Cultivates other	0.06	0.23	-0.08

Households with agroforestry generally score higher on the nutritional outcomes, especially food consumption score, household hunger score (HHS), frequent protein intake (Table 3). Nonetheless, households without agroforestry cultivate more food crops or trees.

Table 3: T-test on outcomes, by agroforestry. First wave

Variables	No agroforestry		Agroforestry		Mean Diff
	N. obs	Mean	N. obs	Mean	
Food consumption score (WFP)	416	34.87	208	40.87	-6.000***
FCS acceptable, HFSNA cat	416	0.257	208	0.351	-0.094**
HFIAS mild or food secure	416	0.144	208	0.168	-0.0240
HHS no or little hunger	416	0.796	208	0.885	-0.089***
Frequent protein intake - at least 7 times	416	0.440	208	0.750	-0.310***
Frequent vit A intake - at least 7 times	416	0.212	208	0.245	-0.0340
Frequent iron intake - at least 7 times	416	0.0310	208	0.0530	-0.0220
Food exp pc last 4 weeks (/1,000)	416	16.74	208	16.95	-0.209
N. of food crops/trees grown	416	4.026	208	3.505	0.522***

Our preferred instrument, mother owning land, is positively correlated with agroforestry, both the binary indicator and the count indicator (Table 4). Households in which the mother of the respondent previously owned land own more frequently cattle, poultry, have more frequently the right to plant trees (in both cases, this is the majority). Moreover, in cases in which the mother owned land, also the father did more frequently. Finally, we do not see much relation of motherland with food nutrition outcomes. The only exceptions are food expenditure and the number of food crops and trees grown (both higher). This is consistently found also in the second wave (table not shown).

Table 4: T-test on main variables, by mother land. First wave

Variables	Mother owned no land before		Mother owned land before		Mean Diff
	N. obs.	Mean	N. obs.	Mean	
Agroforestry: trees on the parcel	202	0.208	422	0.393	-0.185***
Number of plots in agroforestry	202	0.257	422	0.569	-0.311***
Agroforestry from cash crops and other trees	202	0.144	422	0.156	-0.0130
Age of head	202	48.56	422	47.53	1.031
Female head	202	0.243	422	0.204	0.0390
Woman head & no spouse	202	0.233	422	0.199	0.0340
Household size	202	6.886	422	6.962	-0.0760
Years of attending school by respondent	202	3.540	422	3.860	-0.321
Parcel land, ares	202	196.9	422	228.5	-31.58
Wealth, normalized	202	0.0880	422	0.0810	0.00700
HH owns cattle	202	0.327	422	0.398	-0.071*
HH owns poultry	202	0.540	422	0.661	-0.122***
HH owns goats/sheep	202	0.203	422	0.201	0.00200
Member of farmer group or cooperative	202	0.282	422	0.294	-0.0120
Whether respondent has taken out loan	202	0.361	422	0.393	-0.0320
Received extension and information from extension officer	202	0.178	422	0.206	-0.0280
Protected areas (km)	202	27.66	422	26.25	1.418
Shock in the last 12 months: drought	202	0.569	422	0.550	0.0200
Shock in the last 12 months: little rain	202	0.391	422	0.320	0.071*
Cultivates cash crops	202	0.505	422	0.486	0.0190
Inherited land	202	0.807	422	0.855	-0.0490

Right to plant trees	202	0.965	422	0.986	-0.020*
Father owned land	202	0.752	422	0.955	-0.203***
Mother born in respondent's commune	202	0.515	422	0.709	-0.194***
Father was born in respondent's commune	202	0.723	422	0.761	-0.0380
Food consumption score (WFP)	202	36.01	422	37.28	-1.272
FCS acceptable, HFSNA cat	202	0.272	422	0.296	-0.0240
HFIAS mild or food secure	202	0.178	422	0.140	0.0380
HHS no or little hunger	202	0.847	422	0.815	0.0310
Frequent protein intake - at least 7 times	202	0.564	422	0.533	0.0310
Frequent vit A intake - at least 7 times	202	0.203	422	0.232	-0.0290
Frequent iron intake - at least 7 times	202	0.0250	422	0.0450	-0.0200
Food exp pc last 4 weeks (/1,000)	202	18.78	422	15.86	2.914**
N. of food crops/trees grown	202	4.183	422	3.694	0.489***

Finally, the mean values of the outcome variables increased in the second wave (Table 5). The exception is the number of crops and trees grown. Also the prevalence of agroforestry increased.

Table 5: Outcome variables and agroforestry, first and second waves. T-test over time

Variables	Apr-May 2023		Jun-Jul 2023		
	N. obs.	**Mean**	**N. obs.**	**Mean**	**Mean Diff**
Food consumption score (WFP)	624	36.87	624	40.45	-3.588***
FCS acceptable, HFSNA cat	624	0.288	624	0.383	-0.095***
HFIAS mild or food secure	624	0.152	624	0.418	-0.266***
HHS no or little hunger	624	0.825	624	0.963	-0.138***
Frequent protein intake - at least 7 times	624	0.543	624	0.692	-0.149***
Frequent vit A intake - at least 7 times	624	0.223	624	0.264	-0.042*
Frequent iron intake - at least 7 times	624	0.0380	624	0.0690	-0.030**
Food exp pc last 4 weeks (/1,000)	624	16.81	624	16.55	0.259
N. of food crops/trees grown	624	3.853	624	1.160	2.692***
Agroforestry: trees on the parcel	624	0.333	619	0.535	-0.201***

6. Analysis

OLS

We report results for the first and second wave separately, as we cannot construct a proper panel setting. OLS results indicate a non-significant or positive relationship between agroforestry and food security outcomes (Tables 6 and 7). In particular, having trees on the parcel shows a positive and significant association with the probability of no or little hunger (HHIS) and the frequent consumption of protein-rich foods, as well as negative and significant associations with the diversity index of food crops produced (Table 6). Control variables have the expected sign.

In the second wave, agroforestry shows a positive and significant relation only with the probability of mild or no food insecurity, food expenditure and the number of food crops grown, and a negative and significant relation with the probability of a frequent protein intake (Table 7).

Table A3 and A4 in the Appendix report these results using different definitions of agroforestry. For food consumption score, the only definition of agroforestry that has a significant coefficient (positive) is the number of parcels with tree on them (Table A3). In the second wave (Table A4), this is agroforestry defined as intercrop with trees (both cash crops and other trees).

So, in the OLS case, agroforestry does not have a consistent positive and significant relation with our nutrition and food security outcomes. We suspect two order of reasons. The first is the sample size, the second is the possible presence of mediating channels such as decision making in the household and gender. Notably, female headship (when significant) has a negative coefficient.

To explore this, we estimate equation 2, in which agroforestry is interacted with a refined version of female headed household. In particular, we consider here only female headed households where there is no spouse in the household. This should reflect that the main decision maker in both planting decisions and use of harvest decision is a woman. As an alternative, we also consider whether the oldest person in the household is a woman (not shown in this draft).

Unfortunately, only 30 households fall into this intersection. Nonetheless, we see some role of the gender of the decision making into shaping the relationship between agroforestry and nutrition. The coefficient for female decision maker (no agroforestry) is significant (negative) only in the case of diversity index (first and second wave) and acceptable FCS (second wave only). The coefficient for agroforestry (and male decision maker) is significant and positive for the probability of no hunger in the household and frequent protein intake in the first wave. Similarly, in the second wave this is for mild or no food insecurity and number of food crops. Finally, the coefficient for female decision maker with agroforestry is positive in the case of frequent protein intake and negative for food diversity at production (first wave). In the second wave, a positive coefficient is for the probability of mild or no food insecurity and a negative one for the frequency of protein-rich food.

Table 6: OLS, food insecurity outcomes. First wave

VARIABLES	(1) fcs_score	(2) fcs_accept	(3) hfias_mild	(4) hhs_nohung	(5) freqprot	(6) freqvita	(7) freqiron	(8) foodexp	(9) nfoodcrops	(10) simp
agrofor	1.080	-0.023	-0.009	0.069**	0.150***	0.007	-0.003	0.611	-0.058	-0.037*
	(1.224)	(0.039)	(0.033)	(0.034)	(0.043)	(0.039)	(0.020)	(1.376)	(0.141)	(0.022)
agehead	0.101***	0.002**	-0.001	-0.001	0.002	0.002*	-0.000	-0.002	0.000	-0.001
	(0.035)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.050)	(0.005)	(0.001)
femalehead	0.966	0.038	-0.006	-0.017	0.020	0.025	0.008	-0.234	-0.170	-0.092***
	(1.161)	(0.040)	(0.033)	(0.041)	(0.048)	(0.040)	(0.017)	(1.673)	(0.165)	(0.024)
hhsize	-0.147	-0.005	-0.009**	-0.011**	-0.002	0.001	0.002	-1.323***	-0.018	-0.000
	(0.195)	(0.005)	(0.004)	(0.005)	(0.006)	(0.006)	(0.003)	(0.203)	(0.021)	(0.003)
education	0.434**	0.019***	0.005	0.004	-0.014***	0.007	-0.001	0.357	-0.018	-0.002
	(0.172)	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)	(0.003)	(0.217)	(0.018)	(0.003)
landsize	0.001	0.000	0.000	0.000**	-0.000	0.000	0.000	0.002	0.000*	0.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
1.cattle	2.419*	0.108**	0.035	0.072**	-0.050	0.070*	0.000	-0.030	-0.063	0.020
	(1.309)	(0.043)	(0.036)	(0.034)	(0.042)	(0.042)	(0.020)	(1.516)	(0.148)	(0.022)
1.poultry	4.237***	0.093**	0.018	0.041	0.117***	0.033	0.014	-2.253	-0.059	0.034
	(1.110)	(0.036)	(0.029)	(0.036)	(0.041)	(0.036)	(0.015)	(1.386)	(0.152)	(0.021)
1.goats	1.389	0.006	0.021	-0.033	0.119**	0.006	-0.022	1.319	0.483**	0.011
	(1.465)	(0.048)	(0.045)	(0.047)	(0.056)	(0.050)	(0.016)	(1.951)	(0.212)	(0.030)
wealth	33.838***	0.693***	0.696***	0.342***	0.166	0.734***	0.417***	12.473**	1.456*	0.021
	(7.191)	(0.156)	(0.161)	(0.089)	(0.169)	(0.162)	(0.131)	(5.719)	(0.782)	(0.075)
1.coop	-1.115	-0.089***	0.032	-0.021	-0.005	-0.024	0.009	-1.827	0.354***	-0.014
	(1.085)	(0.034)	(0.029)	(0.034)	(0.041)	(0.035)	(0.017)	(1.336)	(0.136)	(0.021)
Protected areas	0.046*	-0.000	0.002***	-0.000	-0.000	0.001	-0.000	-0.036	-0.001	0.001
	(0.025)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.038)	(0.004)	(0.001)
1.shocktype__1	1.557	0.051	0.048	0.028	-0.019	0.065*	0.036*	0.034	0.264**	-0.004
	(1.126)	(0.038)	(0.032)	(0.031)	(0.040)	(0.037)	(0.019)	(1.291)	(0.124)	(0.020)
1.shocktype__3	0.588	-0.008	-0.012	0.086**	-0.036	0.034	0.010	-0.857	0.198	-0.021
	(1.171)	(0.037)	(0.030)	(0.035)	(0.041)	(0.038)	(0.016)	(1.399)	(0.151)	(0.022)
Constant	32.277***	0.193	-0.082	0.800***	0.633***	-0.078	0.044	18.175***	1.976***	0.357***
	(3.790)	(0.134)	(0.143)	(0.133)	(0.153)	(0.146)	(0.060)	(6.766)	(0.608)	(0.084)

Observations	624	624	624	624	624	624	624	624	624	601
R-squared	0.348	0.274	0.164	0.122	0.260	0.158	0.130	0.165	0.273	0.078
Adj R2	0.317	0.240	0.125	0.0804	0.225	0.118	0.0887	0.126	0.239	0.0331

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included not shown: soil type and colour, ethnic group, region dummies.

Table 7: OLS, food insecurity outcomes. Second wave

VARIABLES	(1) fcs_score	(2) fcs_accept	(3) hfias_mild	(4) hhs_nohung	(5) freqprot	(6) freqvita	(7) freqiron	(8) foodexp	(9) nfoodcrops	(10) simp
agrofor	0.882	0.030	0.186***	-0.005	-0.072**	0.027	0.020	3.819*	0.211***	0.020
	(1.180)	(0.039)	(0.036)	(0.015)	(0.036)	(0.037)	(0.018)	(2.112)	(0.072)	(0.020)
L.agehead	0.056	0.000	-0.002	0.000	0.001	0.001	0.001	-0.030	0.001	-0.001
	(0.045)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.055)	(0.003)	(0.001)
L.femalehead	-1.869	-0.068	-0.052	0.017	-0.083*	-0.006	-0.010	-1.284	-0.225***	-0.091***
	(1.299)	(0.043)	(0.041)	(0.022)	(0.045)	(0.041)	(0.020)	(2.306)	(0.079)	(0.024)
L.hhsize	0.294	0.008	0.005	0.001	0.001	0.006	0.005	-1.442***	0.008	-0.001
	(0.207)	(0.006)	(0.006)	(0.002)	(0.005)	(0.006)	(0.004)	(0.346)	(0.012)	(0.003)
L.education	0.254	0.008	0.021***	0.001	-0.007	0.003	0.003	0.517	-0.010	-0.002
	(0.186)	(0.006)	(0.005)	(0.002)	(0.005)	(0.005)	(0.003)	(0.368)	(0.010)	(0.003)
L.landsize	0.003	0.000***	0.000**	-0.000	0.000	0.000	0.000	-0.000	0.000**	0.000
	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)
1L.cattle	-0.054	0.004	0.082*	0.023	-0.082*	0.016	-0.018	0.439	0.061	0.019
	(1.429)	(0.044)	(0.043)	(0.015)	(0.042)	(0.042)	(0.027)	(1.915)	(0.076)	(0.022)
1L.poultry	1.657	0.053	0.010	-0.011	-0.028	-0.003	0.013	-0.846	0.026	0.030
	(1.243)	(0.040)	(0.038)	(0.017)	(0.037)	(0.038)	(0.021)	(2.555)	(0.073)	(0.021)
1L.goats	3.917**	0.038	0.040	0.080***	0.102*	0.036	-0.039**	-1.635	-0.144	0.010
	(1.890)	(0.051)	(0.054)	(0.026)	(0.054)	(0.053)	(0.018)	(2.315)	(0.105)	(0.030)
L.wealth	44.927***	0.769***	0.545***	0.078*	0.367***	0.853***	0.244**	25.058***	0.004	0.012
	(5.824)	(0.145)	(0.128)	(0.040)	(0.129)	(0.145)	(0.114)	(9.129)	(0.255)	(0.075)
1L.coop	-1.227	-0.043	-0.009	-0.011	-0.021	-0.033	-0.022	-3.587*	0.001	-0.019
	(1.308)	(0.040)	(0.039)	(0.020)	(0.039)	(0.037)	(0.019)	(1.852)	(0.074)	(0.022)
L.protectedareas	0.075**	0.000	-0.000	0.001*	0.002**	0.000	0.001	-0.078	-0.000	0.001
	(0.032)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.050)	(0.002)	(0.001)
1L.shocktype__1	0.755	0.061	-0.024	0.010	0.001	0.012	0.023	-0.161	-0.075	-0.004
	(1.251)	(0.041)	(0.038)	(0.014)	(0.036)	(0.039)	(0.021)	(2.852)	(0.074)	(0.020)
1L.shocktype__3	-0.989	0.012	-0.022	-0.022	0.059	0.015	-0.024	-3.023	-0.075	-0.017
	(1.238)	(0.041)	(0.039)	(0.019)	(0.041)	(0.039)	(0.018)	(2.572)	(0.076)	(0.022)
Constant	28.654***	0.240	0.486***	0.888***	0.796***	-0.013	0.049	14.168	1.100***	0.335***
	(4.274)	(0.154)	(0.140)	(0.046)	(0.138)	(0.143)	(0.076)	(9.676)	(0.298)	(0.084)
Observations	619	619	619	619	619	619	619	619	619	596
R-squared	0.373	0.222	0.325	0.089	0.245	0.172	0.164	0.163	0.381	0.076
Adj R2	0.343	0.185	0.293	0.0460	0.209	0.132	0.125	0.123	0.352	0.0307

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included not shown: (lagged) soil type and colour, ethnic group, region dummies.

Table 8: OLS, gender. First wave

VARIABLES	(1) fcs_score	(2) fcs_accept	(3) hfias_mild	(4) hhs_nohung	(5) freqprot	(6) freqvita	(7) freqiron	(8) foodexp	(9) nfoodcrops	(10) simp
0b.agrofor#1.fem	1.559	0.054	0.014	-0.014	0.028	0.044	0.014	-1.984	-0.160	-0.078***
	(1.374)	(0.045)	(0.038)	(0.049)	(0.057)	(0.047)	(0.017)	(1.793)	(0.197)	(0.028)
1.agrofor#0b.fem	1.217	-0.017	0.008	0.064*	0.153***	0.013	0.000	-0.311	-0.058	-0.033
	(1.382)	(0.043)	(0.036)	(0.036)	(0.046)	(0.042)	(0.022)	(1.456)	(0.153)	(0.024)
1.agrofor#1.fem	2.056	0.005	-0.077	0.083	0.167*	0.026	-0.004	3.103	-0.217	-0.133***
	(1.990)	(0.081)	(0.057)	(0.067)	(0.090)	(0.075)	(0.036)	(3.428)	(0.287)	(0.044)
agehead	0.101***	0.002**	-0.001	-0.001	0.002	0.002*	-0.000	-0.003	0.000	-0.001
	(0.035)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.050)	(0.005)	(0.001)
hhsize	-0.146	-0.005	-0.010**	-0.010**	-0.002	0.001	0.002	-1.315***	-0.018	-0.000
	(0.195)	(0.005)	(0.004)	(0.005)	(0.006)	(0.006)	(0.003)	(0.201)	(0.021)	(0.003)
education	0.433**	0.019***	0.005	0.004	-0.014***	0.007	-0.001	0.361*	-0.018	-0.002
	(0.172)	(0.005)	(0.004)	(0.004)	(0.005)	(0.005)	(0.003)	(0.217)	(0.018)	(0.003)
landsize	0.001	0.000	0.000	0.000**	-0.000	0.000	0.000	0.002	0.000*	0.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
1.cattle	2.496*	0.110**	0.035	0.073**	-0.049	0.072*	0.001	-0.144	-0.062	0.021
	(1.310)	(0.043)	(0.036)	(0.034)	(0.043)	(0.042)	(0.020)	(1.500)	(0.148)	(0.022)
1.poultry	4.206***	0.092**	0.016	0.042	0.116***	0.032	0.014	-2.101	-0.060	0.033
	(1.115)	(0.037)	(0.029)	(0.036)	(0.042)	(0.036)	(0.015)	(1.392)	(0.151)	(0.021)
1.goats	1.376	0.005	0.021	-0.033	0.119**	0.005	-0.022	1.344	0.484**	0.012
	(1.468)	(0.048)	(0.044)	(0.047)	(0.056)	(0.050)	(0.016)	(1.947)	(0.213)	(0.030)
wealth	33.956***	0.697***	0.705***	0.342***	0.167	0.738***	0.419***	11.903**	1.462*	0.027
	(7.222)	(0.157)	(0.162)	(0.089)	(0.169)	(0.162)	(0.131)	(5.675)	(0.787)	(0.075)
1.coop	-1.162	-0.091***	0.030	-0.021	-0.005	-0.026	0.009	-1.688	0.354**	-0.015
	(1.091)	(0.034)	(0.029)	(0.034)	(0.041)	(0.035)	(0.017)	(1.326)	(0.137)	(0.021)
protectedareas	0.046*	-0.000	0.002***	-0.000	-0.000	0.001	-0.000	-0.037	-0.001	0.001
	(0.025)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.038)	(0.004)	(0.001)
1.shocktype__1	1.549	0.051	0.047	0.028	-0.019	0.065*	0.036*	0.097	0.265**	-0.004
	(1.129)	(0.038)	(0.032)	(0.031)	(0.041)	(0.037)	(0.019)	(1.286)	(0.124)	(0.020)
1.shocktype__3	0.565	-0.008	-0.013	0.087**	-0.037	0.033	0.010	-0.783	0.199	-0.020
	(1.173)	(0.037)	(0.030)	(0.035)	(0.041)	(0.038)	(0.016)	(1.397)	(0.151)	(0.022)
Constant	32.115***	0.188	-0.086	0.799***	0.631***	-0.083	0.043	18.622***	1.970***	0.352***
	(3.789)	(0.134)	(0.143)	(0.133)	(0.153)	(0.146)	(0.061)	(6.766)	(0.608)	(0.084)
Observations	624	624	624	624	624	624	624	624	624	601
R-squared	0.348	0.274	0.167	0.122	0.260	0.158	0.130	0.169	0.273	0.074

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1 Controls included not shown: soil type and colour, ethnic group, region dummies.

Table 9 OLS, gender. Second wave

VARIABLES	(1) fcs_score	(2) fcs_accept	(3) hfias_mild	(4) hhs_nohung	(5) freqprot	(6) freqvita	(7) freqiron	(8) foodexp	(9) nfoodcrops	(10) simp
0b.agrofor#1L.fem	-1.432	-0.116**	-0.042	0.027	-0.051	-0.058	0.007	-3.778	-0.126	-0.092***
	(1.722)	(0.056)	(0.051)	(0.026)	(0.055)	(0.051)	(0.028)	(2.594)	(0.106)	(0.032)
1.agrofor#0bL.fem	0.974	0.003	0.194***	0.001	-0.054	-0.000	0.027	2.451	0.250***	0.017

	(1.388)	(0.044)	(0.042)	(0.017)	(0.041)	(0.041)	(0.023)	(2.491)	(0.083)	(0.023)
1.agrofor #1L.fem	-0.848	0.008	0.116*	0.005	-0.186***	0.062	0.005	4.689	-0.046	-0.057
	(1.919)	(0.066)	(0.064)	(0.034)	(0.070)	(0.064)	(0.024)	(3.882)	(0.119)	(0.035)
Observations	619	619	619	619	619	619	619	619	619	596
R-squared	0.372	0.224	0.325	0.090	0.247	0.174	0.165	0.165	0.381	0.072

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included: age of the household head, female head, household size, education, land size, soil type and colour, livestock (cattle, poultry, goats/sheep), wealth index, cooperative, ethnic group, distance from protected areas, dry shocks (drought and too little rain) in the last 12 months, region dummies.

2SLS

To control for possible endogeneity bias related to agroforestry, we estimate a 2-stages least squares (2SLS) model, using as instruments the indicator for mother of the respondent owning land before the birth of the respondent and a variable counting the number of times in the period 2008-2018 that wind speed during cyclones exceeded 15 knots (ranging between 0 and 2)[8]. We estimate equations 3 and 4 simultaneously; Table 10 reports first stage in column 1 and second stages in columns 2-11. These results refer to the case where no control variables are used in the model.

As diagnostic tests for the appropriateness of our instrumenting strategy, we report the following weak instrument tests:

- Effective F statistic from the Montiel-Pflueger (2013) robust weak instrument test for alpha=5%. H0: weak instruments for both Two-Stage Least Squares (TSLS) and Limited Information Maximum Likelihood (LIML) with one single endogenous regressor
- Anderson-Rubin (AR) (1949) test statistic and p-value: a joint test of the structural parameter (beta=b0, where beta is the coefficient on the endogenous regressor) and the exogeneity of the instruments (E(Zu)=0)
- Cragg-Donald (1993) Wald test statistics (weak identification test)
- Kleibergen-Paap (2006) rk statistic (chi2) (weak identification test)

Finally, we also report the Hansen J statistic for overidentification test of all instruments. H0: the instruments are valid instruments, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation. Both in the first (Table 10) and second wave results (Table 11), the two instruments are not weak according to the test of Montiel-Pflueger (2013), and Kleibergen-Paap (2006). The Anderson-Rubin indicates a well-specified model (cannot reject the joint hypothesis) in the cases of mild or no food insecurity, no hunger, frequent protein intake, food expenditure (only first wave), and diversity of food produced.

The overidentification test provides mixed results which are in line with the AR: the instruments are valid in half of the cases: mild or no food insecurity (only first wave), no hunger, frequent protein intake, food expenditure, and diversity of food produced. This is consistent with second wave's results (for the cases of mild or no food insecurity, no hunger, frequent protein intake, and diversity of food produced, but not for food expenditure).

Mother owning land and the number of strong winds in the past are good predictors of the probability of current agroforestry (Tables 10 and especially Table 11). Agroforestry, as in the OLS case,

[8] Tables A5 and A6 in the Appendix report some alternatives to the winds instrument for the case with controls variables. In general, all of our strong wind variables perform well in AR and Hansen test, however the effective F statistics and the Kleibergen-Paap are not high enough in the first wave (Table A5), while in the second wave they are generally better, although for higher speed threshold these drop (Table A6).

does not play an important role for nutrition and food security indicators. When significant (food expenditure, number of food crops produced) it has a negative sign, so in contrast with some OLS results (Table 10). In the second wave, which corresponds to a later stage in the harvest season, agroforestry has a stronger relation with the outcomes, however this relation is generally negative (Table 11).

Table 10: IV estimates, first and second stage, no controls. First wave

VARIABLES	(1) first agrofor	(2) second fcs_score	(3) second fcs_accept	(4) second hfias_mild	(5) second hhs_nohung	(6) second freqprot	(7) second freqvita	(8) second freqiron	(9) second foodexp	(10) second nfoodcrops	(11) second simp
motherland	0.184***										
	(0.0372)										
nstrong15winds_0818	-0.0246										
	(0.0276)										
agrofor		0.742	-0.0616	-0.187	-0.150	-0.242	0.0258	0.0817	-16.81**	-1.974**	-0.0607
		(6.800)	(0.207)	(0.182)	(0.173)	(0.240)	(0.186)	(0.0811)	(8.198)	(0.889)	(0.103)
Constant	0.288***	36.62***	0.309***	0.215***	0.875***	0.624***	0.214***	0.0112	22.41***	4.511***	0.381***
	(0.0930)	(2.362)	(0.0716)	(0.0638)	(0.0586)	(0.0819)	(0.0639)	(0.0264)	(2.836)	(0.306)	(0.0369)
Observations	624	624	624	624	624	624	624	624	624	624	601
R-squared		0.008	-0.017	-0.076	-0.076	-0.187	0.001	-0.019	-0.247	-0.131	-0.003
Effective F-stat		12.33	12.33	12.33	12.33	12.33	12.33	12.33	12.33	12.33	12.27
A R Chi2		26.39	30.97	1.981	1.227	4.248	13.88	6.677	5.328	22.96	2.410
A R p-val		0.000	0.000	0.371	0.542	0.120	0.001	0.036	0.070	0.000	0.300
Cragg-Donald Wald F statistic		11.28	11.28	11.28	11.28	11.28	11.28	11.28	11.28	11.28	11.23
Kleibergen-Paap rk Wald F statistic		12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.50
Hansen J statistic p-val		0.000	0.000	0.519	0.492	0.113	0.000	0.033	0.575	0.000	0.152

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Controls included: age of the household head, female head, household size, education, land size, soil type and colour, livestock (cattle, poultry, goats/sheep), wealth index, cooperative, ethnic group, distance from protected areas, dry shocks (drought and too little rain) in the last 12 months, region dummies. The first column reports the first stage which applies to the second stage in all remaining columns (2-11).

Table 11: IV estimates, first and second stage, no controls. Second wave

VARIABLES	(1) first agrofor	(2) second fcs_score	(3) second fcs_accept	(4) second hfias_mild	(5) second hhs_nohung	(6) second freqprot	(7) second freqvita	(8) second freqiron	(9) second foodexp	(10) second nfoodcrops	(11) second simp
L.motherland	0.085**										
	(0.042)										
L.nstrong15winds_0818	-0.162***										
	(0.025)										
agrofor		-33.623***	-0.892***	0.134	-0.078	-0.187	-0.585***	-0.014	-26.275***	-1.231***	0.078
		(8.022)	(0.211)	(0.168)	(0.074)	(0.159)	(0.168)	(0.070)	(10.061)	(0.374)	(0.085)
Constant	0.998***	58.760***	0.863***	0.350***	1.005***	0.798***	0.579***	0.077*	30.731***	1.828***	0.320***
	(0.085)	(4.666)	(0.122)	(0.091)	(0.039)	(0.086)	(0.097)	(0.039)	(5.801)	(0.213)	(0.047)
Observations	619	619	619	619	619	619	619	619	619	619	596
R-squared		-1.046	-0.923	0.046	-0.030	-0.015	-0.491	-0.005	-0.278	-0.525	-0.005
Effective F-stat		20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	18.47

A R Chi2	38	38.59	**3.682**	**1.131**	**1.401**	29.38	9.853	**9.816**	18.05	**2.722**
A R p-val	0.000	0.000	**0.159**	**0.568**	**0.496**	0.000	0.007	**0.007**	0.000	**0.256**
Cragg-Donald Wald F statistic	17.19	17.19	**17.19**	**17.19**	**17.19**	17.19	17.19	**17.19**	17.19	**15.50**
Kleibergen-Paap rk Wald F statistic	24.36	24.36	**24.36**	**24.36**	**24.36**	24.36	24.36	**24.36**	24.36	**21.85**
Hansen J statistic p-val	0.014	0.039	**0.073**	**0.805**	**0.968**	0.007	0.002	**0.611**	0.018	**0.182**

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Controls included: age of the household head, female head, household size, education, land size, soil type and colour, livestock (cattle, poultry, goats/sheep), wealth index, cooperative, ethnic group, distance from protected areas, dry shocks (drought and too little rain) in the last 12 months, region dummies. The first column reports the first stage which applies to the second stage in all remaining columns (2-11).

When we add controls, the tests report similar results in the case of the first wave, but much improved in the case of the second wave. In the first wave (Table 12), adding control variables shows more significant results but they still show a negative coefficient (frequent protein intake and food expenditure). In the second wave (Table 13), adding control variables to the specification reduces in size coefficients which were significant, and turns the coefficient for frequent protein consumption a positive and significant.

Table 12: IV estimates, first and second stage, with controls. First wave

VARIABLES	(1) first agrofor	(2) second fcs_score	(3) **second fcs_accept**	(4) second hfias_mild	(5) **second hhs_nohung**	(6) **second freqprot**	(7) second freqvita	(8) **second freqiron**	(9) **second foodexp**	(10) second nfoodcrops	(11) **second simp**
motherland	0.140***										
	(0.0367)										
nstrong15winds_0818	-0.0661**										
	(0.0336)										
agehead	0.00127	0.108***	**0.00252****	-0.000731	**-0.000775**	**0.00249**	0.00228*	**-0.000588**	**0.0172**	0.00159	**-0.000644**
	(0.00127)	(0.0352)	**(0.00117)**	(0.000969)	**(0.00116)**	**(0.00153)**	(0.00118)	**(0.000493)**	**(0.0575)**	(0.00495)	**(0.000662)**
femalehead	-0.0475	0.590	**0.0295**	-0.00943	**-0.0326**	**-0.0141**	0.0265	**0.0124**	**-1.243**	-0.229	**-0.0948*****
	(0.0425)	(1.205)	**(0.0398)**	(0.0336)	**(0.0435)**	**(0.0568)**	(0.0397)	**(0.0166)**	**(1.954)**	(0.175)	**(0.0238)**
hhsize	0.00162	-0.141	**-0.00439**	-0.00930**	**-0.0103***	**-0.00119**	0.00135	**0.00176**	**-1.306*****	-0.0174	**-0.000366**
	(0.00596)	(0.201)	**(0.00531)**	(0.00423)	**(0.00528)**	**(0.00747)**	(0.00559)	**(0.00303)**	**(0.242)**	(0.0222)	**(0.00334)**
education	-0.000956	0.427**	**0.0186*****	0.00466	**0.00338**	**-0.0148****	0.00699	**-0.00103**	**0.337**	-0.0188	**-0.00240**
	(0.00531)	(0.174)	**(0.00549)**	(0.00447)	**(0.00439)**	**(0.00649)**	(0.00502)	**(0.00248)**	**(0.246)**	(0.0189)	**(0.00287)**
landsize	6.55e-05**	0.00169	**3.52e-05**	7.92e-05	**6.19e-05****	**2.55e-05**	2.27e-05	**5.50e-06**	**0.00318****	0.000513**	**1.48e-05**
	(2.70e-05)	(0.00157)	**(5.50e-05)**	(6.17e-05)	**(2.43e-05)**	**(5.50e-05)**	(4.57e-05)	**(2.15e-05)**	**(0.00149)**	(0.000261)	**(1.79e-05)**
1.cattle	-0.0104	2.438*	**0.108****	0.0353	**0.0724****	**-0.0485**	0.0698*	**0.000248**	**0.0227**	-0.0603	**0.0198**
	(0.0438)	(1.340)	**(0.0423)**	(0.0353)	**(0.0355)**	**(0.0528)**	(0.0408)	**(0.0194)**	**(1.712)**	(0.153)	**(0.0215)**
1.poultry	0.0726*	4.878***	**0.106*****	0.0246	**0.0686***	**0.175*****	0.0300	**0.00598**	**-0.533**	0.0409	**0.0384***
	(0.0397)	(1.194)	**(0.0398)**	(0.0324)	**(0.0408)**	**(0.0572)**	(0.0379)	**(0.0159)**	**(1.738)**	(0.166)	**(0.0229)**
1.goats	0.0305	1.650	**0.0113**	0.0239	**-0.0219**	**0.143****	0.00439	**-0.0249**	**2.021**	0.523**	**0.0133**
	(0.0483)	(1.474)	**(0.0487)**	(0.0445)	**(0.0486)**	**(0.0651)**	(0.0498)	**(0.0160)**	**(2.127)**	(0.217)	**(0.0286)**
wealth	0.198	34.89***	**0.716*****	0.707***	**0.387*****	**0.262**	0.729***	**0.404*****	**15.29****	1.620*	**0.0295**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	(0.165)	(7.137)	(0.157)	(0.160)	(0.108)	(0.198)	(0.158)	(0.127)	(6.399)	(0.828)	(0.0781)
1.coop	0.0428	-0.664	-0.0797**	0.0367	-0.00149	0.0365	-0.0261	0.00383	-0.618	0.424***	-0.0110
	(0.0394)	(1.093)	(0.0346)	(0.0297)	(0.0363)	(0.0522)	(0.0353)	(0.0176)	(1.611)	(0.152)	(0.0222)
protectedareas	-0.000452	0.0481*	-0.000122	0.00224***	-0.000339	-6.52e-05	0.000889	-0.000114	-0.0297	-0.000459	0.000591
	(0.00105)	(0.0261)	(0.000828)	(0.000781)	(0.000999)	(0.00127)	(0.000887)	(0.000371)	(0.0433)	(0.00425)	(0.000603)
1.shocktype__1	-0.0433	1.192	0.0435	0.0447	0.0123	-0.0521	0.0666*	0.0406**	-0.944	0.207	-0.00660
	(0.0406)	(1.181)	(0.0396)	(0.0337)	(0.0336)	(0.0517)	(0.0367)	(0.0187)	(1.597)	(0.136)	(0.0199)
1.shocktype__3	-0.0425	0.216	-0.0156	-0.0155	0.0703**	-0.0704	0.0354	0.0148	-1.855	0.140	-0.0242
	(0.0375)	(1.263)	(0.0383)	(0.0300)	(0.0357)	(0.0499)	(0.0382)	(0.0159)	(1.598)	(0.169)	(0.0225)
agrofor		-6.889	-0.195	-0.0904	-0.270	-0.578*	0.0447	0.0975	-20.76**	-1.302	-0.0991
		(6.803)	(0.218)	(0.201)	(0.209)	(0.296)	(0.199)	(0.0752)	(8.882)	(0.946)	(0.122)
Constant	0.577***	36.05***	0.274	-0.0433	0.961***	0.978***	-0.0956	-0.00307	28.29***	2.565***	0.387***
	(0.182)	(4.995)	(0.167)	(0.175)	(0.172)	(0.231)	(0.169)	(0.0719)	(8.394)	(0.799)	(0.0976)
Observations	624	624	624	624	624	624	624	624	624	624	601
R-squared		0.299	0.249	0.155	-0.018	-0.113	0.156	0.082	-0.141	0.187	0.065
Effective F-stat		9.364	9.364	9.364	9.364	9.364	9.364	9.364	9.364	9.364	9.306
A R Chi2		4.484	4.091	5.121	3.542	6.392	3.502	1.815	7.327	8.579	2.189
A R p-val		0.106	0.129	0.0773	0.170	0.0409	0.174	0.403	0.0256	0.0137	0.335
Cragg-Donald Wald F statistic		8.880	8.880	8.880	8.880	8.880	8.880	8.880	8.880	8.880	8.836
Kleibergen-Paaprk Wald F statistic		9.811	9.811	9.811	9.811	9.811	9.811	9.811	9.811	9.811	9.747
Hansen J statistic p-val		0.0883	0.101	0.0262	0.217	0.464	0.0636	0.800	0.794	0.0210	0.198

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included not shown: soil type and colour, ethnic group, region dummies. The first column reports the first stage which applies to the second stage in all remaining columns (2-11).

Table 13: IV estimates, first and second stage, with controls. Second wave

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	first	second	second	second	second	second	second	second	second	second	second
VARIABLES	agrofor	fcs_score	fcs_accept	hfias_mild	hhs_nohung	freqprot	freqvita	freqiron	foodexp	nfoodcrops	simp
L.motherland	0.045										
	(0.041)										
L.nstrong15winds_0818	-0.264***										
	(0.033)										
agrofor		-12.845***	-0.321**	0.142	-0.037	0.234*	-0.166	0.027	2.802	-0.480**	0.036
		(4.195)	(0.130)	(0.118)	(0.059)	(0.134)	(0.110)	(0.062)	(6.991)	(0.232)	(0.067)
Constant	1.379***	36.696***	0.446***	0.512***	0.908***	0.616***	0.100	0.045	14.764	1.505***	0.325***
	(0.193)	(4.983)	(0.166)	(0.151)	(0.060)	(0.168)	(0.152)	(0.082)	(11.501)	(0.371)	(0.091)
Observations	619	619	619	619	619	619	619	619	619	619	596

R-squared		**0.234**	**0.108**	**0.323**	**0.083**	**0.148**	0.130	**0.164**	**0.163**	**0.277**	**0.075**
Effective F-stat		**28.74**	**28.74**	**28.74**	**28.74**	**28.74**	28.74	**28.74**	**28.74**	**28.74**	**27.67**
A R Chi2		**12.93**	**8.177**	**1.955**	**1.128**	**4.932**	7.256	**2.382**	**0.234**	**4.792**	**2.583**
A R p-val		**0.00156**	**0.0168**	**0.376**	**0.569**	**0.0849**	0.0266	**0.304**	**0.890**	**0.0911**	**0.275**
Cragg-Donald Wald F statistic		**25.55**	**25.55**	**25.55**	**25.55**	**25.55**	25.55	**25.55**	**25.55**	**25.55**	**24.58**
Kleibergen-Paap rk Wald F statistic		**32.47**	**32.47**	**32.47**	**32.47**	**32.47**	32.47	**32.47**	**32.47**	**32.47**	**31.46**
Hansen J statistic p-val		**0.167**	**0.314**	**0.484**	**0.314**	**0.230**	0.0323	**0.126**	**0.695**	**0.677**	**0.131**

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included: age of the household head, female head, household size, education, land size, soil type and colour, livestock (cattle, poultry, goats/sheep), wealth index, cooperative, ethnic group, distance from protected areas, dry shocks (drought and too little rain) in the last 12 months, region dummies. The first column reports the first stage which applies to the second stage in all remaining columns (2-11).

Next, as in the case of the OLS, we interact agroforestry with the indicator of female decision maker and obtain two endogenous variables[9]. The instrumenting strategy does not work anymore in the first wave (Table 14) but works very well in the second wave (Table 15). From the second wave, it is interesting to see how motherland predicts the first stage in two opposite directions depending on the endogenous variable and with similar magnitude, while the strong winds instrument remains negative (stronger coefficient for male decision makers).

The additional effect of female decision makers and agroforestry is negative and significant for FCS (score and acceptable threshold), and number of food crops cultivates. The effect of male decision makers and agroforestry is negative and significant for food consumption score and its dummy, and for the frequent consumption of vitamin-rich foods. Additionally, there is also a positive and significant effect for agroforestry with male decision makers and the probability of mild food insecurity and the frequent intake of protein-rich foods.

Table 14: IV estimates, interaction with fem, first and second stage. First wave

VARIABLES	(1) first femaleaf	(2) first maleaf	(3) second fcs_score	(4) second fcs_accept	(5) second hfias_mild	(6) second hhs_nohung	(7) second freqprot	(8) second freqvita	(9) second freqiron	(10) second foodexp	(11) second nfoodcrops	(12) second simp
motherlandfem	0.199***	-0.233***										
	(0.046)	(0.029)										
nstrong15winds_0818	0.015	-0.083***										
	(0.017)	(0.032)										
femaleaf			-30.307	-0.700	0.861	-0.096	-0.313	-0.633	0.174	-39.715	1.745	-0.211
			(24.591)	(0.685)	(0.754)	(0.540)	(0.772)	(0.731)	(0.216)	(33.180)	(2.878)	(0.347)
maleaf			-27.535	-0.770	0.696	0.139	-0.177	-0.681	0.082	-28.679	2.588	0.108
			(19.465)	(0.551)	(0.574)	(0.402)	(0.594)	(0.559)	(0.155)	(25.978)	(2.230)	(0.263)
Observations	624	624	624	624	624	624	624	624	624	624	624	601

[9] Some tests are no longer feasible as now the model is exactly identified.

R-squared	-0.309	-0.188	-0.576	0.103	0.171	-0.310	0.073	-0.512	-0.086	-0.005
Effective F-stat	4.501	4.732	2.888	1.228	0.228	3.220	0.945	2.053	3.836	6.384
A R Chi2	0.105	0.0939	0.236	0.541	0.892	0.200	0.623	0.358	0.147	0.0411
A R p-val	1.590	1.590	1.590	1.590	1.590	1.590	1.590	1.590	1.590	1.657
Cragg-Donald Wald F statistic	1.769	1.769	1.769	1.769	1.769	1.769	1.769	1.769	1.769	1.862

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included: age of the household head, female head, household size, education, land size, soil type and colour, livestock (cattle, poultry, goats/sheep), wealth index, cooperative, ethnic group, distance from protected areas, dry shocks (drought and too little rain) in the last 12 months, region dummies. Columns 1 and 2 report the first stage which applies to the second stage in all remaining columns (3-11).

Table 15: IV estimates, interaction with fem, first and second stage. Second wave

VARIABLES	(1) first femaleaf	(2) first maleaf	(3) second fcs_score	(4) second fcs_accept	(5) second hfias_mild	(6) second hhs_nohung	(7) second freqprot	(8) second freqvita	(9) second freqiron	(10) second foodexp	(11) second nfoodcrops	(12) second simp
L.motherlandfem	0.460***	-0.455***										
	(0.055)	(0.034)										
L.nstrong15winds_0818	-0.075***	-0.192***										
	(0.023)	(0.034)										
femaleaf			-15.187***	-0.415***	0.026	-0.026	0.121	-0.176	0.002	1.613	-0.865***	-0.062
			(4.928)	(0.149)	(0.136)	(0.073)	(0.159)	(0.127)	(0.070)	(7.598)	(0.277)	(0.080)
maleaf			-12.349***	-0.313**	0.219*	-0.034	0.314**	-0.216*	0.020	4.124	-0.350	0.089
			(4.637)	(0.142)	(0.123)	(0.057)	(0.138)	(0.119)	(0.060)	(7.916)	(0.249)	(0.070)
Observations	624	624	624	624	624	624	624	624	624	624	624	601
R-squared			0.219	0.090	0.320	0.083	0.130	0.111	0.165	0.159	0.272	0.046
A R Chi2			12.06	9.646	4.689	0.355	6.282	3.628	0.250	0.382	12.55	6.384
A R p-val			0.00240	0.00804	0.0959	0.837	0.0432	0.163	0.883	0.826	0.00188	0.0411
Cragg-Donald Wald F statistic			25.14	25.14	25.14	25.14	25.14	25.14	25.14	25.14	25.14	24.53
Kleibergen-Paap rk Wald F statistic			31.79	31.79	31.79	31.79	31.79	31.79	31.79	31.79	31.79	31.26

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included: age of the household head, female head, household size, education, land size, soil type and colour, livestock (cattle, poultry, goats/sheep), wealth index, cooperative, ethnic group, distance from protected areas, dry shocks (drought and too little rain) in the last 12 months, region dummies. Columns 1 and 2 report the first stage which applies to the second stage in all remaining columns (3-11).

7. Discussion

In conclusion, the effect of agroforestry on nutrition and food security outcomes is mostly not significant or is negative. Moreover, the role played by the gender of the decision maker partially makes this relation more explicit, signaling some important differences.

Climate change urges effective solutions in adaptation for agricultural systems in the Global South, which are dominated by smallholder agriculture. Agroforestry presents a multi-purpose adaptation strategy which not only improves environmental conditions, but can also (potentially) contribute substantially to reduce food insecurity.

Yet, establishing the direct impact of agroforestry on household nutrition is not an easy task. The difficulties are shaped by not only the potential endogeneity of agroforestry strategy adoption but also by the existence of different linkages connecting agroforestry and nutrition. Also, the availability of the right data is fundamental, and a small sample can be informative up to a certain limit. Moreover, analysing the relationship between agroforestry and nutrition with the intermediation of gender is relevant for the interpretation of this relationship, and it can also shed light on possible obstacles which limit the efficacy of policies aiming to promote agroforestry.

Indeed, the results from this study, while contributing to create evidence of this relationship, will also inform the design of policies aimed at strengthening household adaptation in agriculture and household resilience.

Next steps of this analysis involve including more waves of the panel to study more closely how the seasonality works with agroforestry, but most importantly, include the last in-person wave of the panel (expected June 2024). Moreover, we will include results from the endogenous switching regression model.

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Appendix

Table A. 1: Summary statistics, total sample, first wave.

	Obs	Mean	Std. dev.	Min	Max
Agroforestry: trees on the plot	624	0.33	0.47	0	1
Number of plots in agroforestry	624	0.47	0.87	0	11
Agroforestry from cash crops and other trees	624	0.15	0.36	0	1
Age of head	624	47.86	14.79	18	91
Female head	624	0.22	0.41	0	1
Woman head & no spouse	624	0.21	0.41	0	1
Household size	624	6.94	3.34	1	30
Years of attending school by respondent	624	3.76	3.92	0	20
Parcel land, ares	624	218	488	0	9201
wealth, normalized	624	0.08	0.14	0	1
HH owns cattle	624	0.38	0.48	0	1
HH owns poultry	624	0.62	0.49	0	1
HH owns goats/sheep	624	0.20	0.40	0	1
Member of farmer group or cooperative	624	0.29	0.45	0	1
Whether respondent has taken out loan	624	0.38	0.49	0	1
Received extension and information from extension officer	624	0.20	0.40	0	1
Protected areas (km)	624	27	23	0	84
Shock in the last 12 months: drought	624	0.56	0.50	0	1
Shock in the last 12 months: little rain	624	0.34	0.48	0	1
Cultivates cash crops	624	0.49	0.50	0	1
Inherited land	624	0.84	0.37	0	1
Right to plant trees	624	0.98	0.14	0	1
Mother owned land	624	0.68	0.47	0	1
Father owned land	624	0.89	0.31	0	1
Mother born in respondent's commune	624	0.65	0.48	0	1
Father was born in respondent's commune	624	0.75	0.43	0	1
Food consumption score (WFP)	624	36.87	15.03	4	100
FCS acceptable, HFSNA cat	624	0.29	0.45	0	1
HFIAS mild or food secure	624	0.15	0.36	0	1
HHS no or little hunger	624	0.83	0.38	0	1
Frequent protein intake - at least 7 times	624	0.54	0.50	0	1
Frequent vit A intake - at least 7 times	624	0.22	0.42	0	1
Frequent iron intake - at least 7 times	624	0.04	0.19	0	1
Food exp pc last 4 weeks (/1,000)	624	16.81	16.16	0	100
N. of food crops/trees grown	624	3.85	1.77	1	13

Table A. 2. Summary statistics by region and total, first wave. Mean value and standard deviation in parenthesis

	Region			
	Atsimo Atsinanana	Anosy	Androy	Total
N	208 (33.3%)	208 (33.3%)	208 (33.3%)	624 (100.0%)
Agroforestry: trees on the plot	0.553 (0.498)	0.308 (0.463)	0.139 (0.347)	0.333 (0.472)
Number of plots in agroforestry	0.784 (1.132)	0.418 (0.718)	0.202 (0.554)	0.468 (0.870)
Agroforestry from cash crops and other trees	0.389 (0.489)	0.067 (0.251)	0.000 (0.000)	0.152 (0.360)
Age of head	48.481 (13.992)	49.303 (14.151)	45.803 (15.996)	47.862 (14.793)
Female head	0.144 (0.352)	0.269 (0.445)	0.236 (0.425)	0.216 (0.412)
Woman head & no spouse	0.139 (0.347)	0.255 (0.437)	0.236 (0.425)	0.210 (0.408)
Household size	7.231 (3.024)	6.841 (3.585)	6.740 (3.395)	6.938 (3.344)
Years of attending school by respondent	4.678 (3.757)	4.091 (3.871)	2.500 (3.826)	3.756 (3.922)
Parcel land, ares	159.169 (298.857)	264.025 (755.686)	231.611 (223.254)	218.269 (487.754)
wealth, normalized	0.078 (0.090)	0.096 (0.172)	0.075 (0.146)	0.083 (0.140)
HH owns cattle	0.332 (0.472)	0.365 (0.483)	0.428 (0.496)	0.375 (0.485)
HH owns poultry	0.755 (0.431)	0.611 (0.489)	0.500 (0.501)	0.622 (0.485)
HH owns goats/sheep	0.000 (0.000)	0.154 (0.362)	0.452 (0.499)	0.202 (0.402)
Member of farmer group or cooperative	0.236 (0.425)	0.288 (0.454)	0.346 (0.477)	0.290 (0.454)
Whether respondent has taken out loan	0.356 (0.480)	0.389 (0.489)	0.404 (0.492)	0.383 (0.487)
Received extension and information from extension officer	0.260 (0.439)	0.154 (0.362)	0.178 (0.383)	0.197 (0.398)
Protected areas (km)	22.736 (12.266)	20.249 (22.696)	37.130 (27.243)	26.705 (22.874)
Shock in the last 12 months: drought	0.505 (0.501)	0.375 (0.485)	0.788 (0.409)	0.556 (0.497)

Shock in the last 12 months: little rain	0.130 (0.337)	0.447 (0.498)	0.452 (0.499)	0.343 (0.475)
Cultivates cash crops	0.639 (0.481)	0.327 (0.470)	0.510 (0.501)	0.492 (0.500)
Inherited land	0.827 (0.379)	0.779 (0.416)	0.913 (0.282)	0.840 (0.367)
Right to plant trees	0.971 (0.168)	0.981 (0.138)	0.986 (0.120)	0.979 (0.143)
Mother owned land	0.803 (0.399)	0.577 (0.495)	0.649 (0.478)	0.676 (0.468)
Father owned land	0.962 (0.193)	0.803 (0.399)	0.904 (0.296)	0.889 (0.314)
Mother born in respondent's commune	0.716 (0.452)	0.582 (0.494)	0.639 (0.481)	0.646 (0.479)
Father was born in respondent's commune	0.832 (0.375)	0.635 (0.483)	0.779 (0.416)	0.748 (0.434)
Food consumption score (WFP)	42.639 (14.400)	37.240 (16.107)	30.716 (11.901)	36.865 (15.032)
FCS acceptable, HFSNA cat	0.418 (0.494)	0.332 (0.472)	0.115 (0.320)	0.288 (0.453)
HFIAS mild or food secure	0.139 (0.347)	0.192 (0.395)	0.125 (0.332)	0.152 (0.360)
HHS no or little hunger	0.870 (0.337)	0.774 (0.419)	0.832 (0.375)	0.825 (0.380)
Frequent protein intake - at least 7 times	0.808 (0.395)	0.543 (0.499)	0.279 (0.450)	0.543 (0.499)
Frequent vit A intake - at least 7 times	0.231 (0.422)	0.269 (0.445)	0.168 (0.375)	0.223 (0.416)
Frequent iron intake - at least 7 times	0.067 (0.251)	0.034 (0.181)	0.014 (0.120)	0.038 (0.192)
Food exp pc last 4 weeks (/1,000)	14.974 (12.783)	18.840 (17.733)	16.606 (17.342)	16.806 (16.162)
N. of food crops/trees grown	2.962 (1.175)	3.841 (1.630)	4.755 (1.937)	3.853 (1.768)

Table A. 3 Different definitions of agroforestry, OLS. Food consumption score. First wave.

VARIABLES	(1) fcs_score	(2) fcs_score	(3) fcs_score	(4) fcs_score	(5) fcs_score	(6) fcs_score
Agroforestry: trees on the parcel	1.080 (1.224)					
Agroforestry: trees on the parcel (home only)		2.324 (1.735)				
Agroforestry: trees on the parcel (home out)			0.821 (1.397)			
Agroforestry from cash crops and other trees				-1.685 (1.775)		
Agroforestry, intercrop or trees on parcel					0.353 (1.226)	
Number of parcels in agroforestry						1.692** (0.765)
Constant	32.277*** (3.790)	32.241*** (3.814)	32.645*** (3.778)	33.071*** (3.808)	32.603*** (3.825)	32.103*** (3.726)
Observations	624	624	624	624	624	624
R-squared	0.348	0.349	0.347	0.348	0.347	0.355

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included: age of the household head, female head, household size, education, land size, soil type and colour, livestock (cattle, poultry, goats/sheep), wealth index, cooperative, ethnic group, distance from protected areas, dry shocks (drought and too little rain) in the last 12 months, region dummies.

Table A. 4 Different definitions of agroforestry, OLS. Food consumption score. Second wave

VARIABLES	(1) fcs_score	(2) fcs_score	(3) fcs_score	(4) fcs_score	(5) fcs_score	(6) fcs_score
Agroforestry: trees on the parcel	0.882 (1.180)					
Agroforestry: trees on the parcel (home only)		-0.047 (1.766)				
Agroforestry: trees on the parcel (home out)			0.743 (1.233)			
Agroforestry from cash crops and other trees				4.510* (2.458)		
Agroforestry, intercrop or trees on parcel					0.981 (1.184)	
Number of parcels in agroforestry						1.277** (0.598)
Constant	28.654***	29.184***	28.949***	28.159***	28.586***	28.875***

	(4.274)	(4.202)	(4.255)	(4.186)	(4.274)	(4.232)
Observations	619	619	619	619	619	619
R-squared	0.373	0.372	0.372	0.377	0.373	0.378

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included: age of the household head, female head, household size, education, land size, soil type and colour, livestock (cattle, poultry, goats/sheep), wealth index, cooperative, ethnic group, distance from protected areas, dry shocks (drought and too little rain) in the last 12 months, region dummies.

Table A. 5: IV, robustness on the winds instrument. First wave

VARIABLES	(1) first agrofor	(2) second fcs_score	(3) first agrofor	(4) second fcs_score	(5) first agrofor	(6) second fcs_score	(7) first agrofor	(8) second fcs_score	(9) first agrofor	(10) second fcs_score
motherland	0.141***		0.140***		0.144***		0.142***		0.142***	
	(0.037)		(0.037)		(0.037)		(0.037)		(0.037)	
nstrong10winds_0818	0.019									
	(0.033)									
agrofor		1.222		-6.889		-1.894		-5.044		0.068
		(7.281)		(6.803)		(7.191)		(7.492)		(7.177)
nstrong15winds_0818			-0.066**							
			(0.034)							
nstrong20winds_0818					-0.046					
					(0.035)					
nstrong25winds_0818							-0.026			
							(0.034)			
wsi_max_2017									0.005	
									(0.008)	
Observations	624	624	624	624	624	624	624	624	624	624
R-squared		0.348		0.299		0.341		0.319		0.347
Effective F-stat		7.425		9.364		8.502		7.021		7.289
A R Chi2		7.059		4.484		0.106		5.592		1.417
A R p-val		0.029		0.106		0.948		0.061		0.492
Cragg-Donald Wald F statistic		7.153		8.880		7.748		7.313		7.179
Kleibergen-Paap rk Wald F statistic		7.801		9.811		8.111		7.669		7.571
Hansen J statistic p-val		0.008		0.088		0.839		0.024		0.236

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included: age of the household head, female head, household size, education, land size, soil type and colour, livestock (cattle, poultry, goats/sheep), wealth index, cooperative, ethnic group, distance from protected areas, dry shocks (drought and too little rain) in the last 12 months, region dummies. Odd columns report the first stage regression, even columns report the second stage.

Table A. 6: IV, robustness on the winds instrument. Second wave

VARIABLES	(1) first agrofor	(2) second fcs_score	(3) first agrofor	(4) second fcs_score	(5) first agrofor	(6) second fcs_score	(7) first agrofor	(8) second fcs_score	(9) first agrofor	(10) second fcs_score
L.motherland	0.042		0.045		0.053		0.051		0.051	
	(0.042)		(0.041)		(0.043)		(0.043)		(0.043)	
L.nstrong10winds_0818	0.201***									
	(0.033)									
agrofor		0.544		-12.845***		15.100		2.650		28.982

		(5.241)		**(4.195)**		**(17.171)**		**(19.293)**		**(29.563)**
L.nstrong15winds_0818			**-0.264*** (0.033)**							
L.nstrong20winds_0818					**-0.065 (0.043)**					
L.nstrong25winds_0818							**-0.034 (0.036)**			
L.wsi_max_2017									**0.004 (0.010)**	
Constant	**-0.826*** (0.286)**	**28.852*** (5.052)**	**1.379*** (0.193)**	**36.696*** (4.983)**	**0.686*** (0.187)**	**20.323* (10.988)**	**0.572*** (0.164)**	**27.618** (12.051)**	**0.484** (0.223)**	**12.190 (18.390)**
Observations	**619**	**619**	**619**	**619**	**619**	**619**	**619**	**619**	**619**	**619**
R-squared		**0.373**		**0.234**		**0.224**		**0.370**		**-0.208**
Effective F-stat		**16.81**		**28.74**		**1.821**		**1.154**		**0.762**
A R Chi2		**1.039**		**12.93**		**1.261**		**2.048**		**2.113**
A R p-val		**0.595**		**0.00156**		**0.532**		**0.359**		**0.348**
Cragg-Donald Wald F statistic		**15.49**		**25.55**		**1.849**		**1.133**		**0.767**
Kleibergen-Paap rk Wald F statistic		**19.08**		**32.47**		**1.694**		**1.158**		**0.776**
Hansen J statistic p-val		**0.311**		**0.167**		**0.670**		**0.154**		**0.660**

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Controls included: age of the household head, female head, household size, education, land size, soil type and colour, livestock (cattle, poultry, goats/sheep), wealth index, cooperative, ethnic group, distance from protected areas, dry shocks (drought and too little rain) in the last 12 months, region dummies. Odd columns report the first stage regression, even columns report the second stage.