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Impacts of large-scale forestry investments on neighboring small-scale agriculture in northern Mozambique

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ABSTRACT

Forestry plantations can potentially foster rural development and mitigate environmental threats, but their impacts on neighboring peoples' livelihood strategies are ambiguous. Forestry plantations are particularly important in Mozambique, where a national strategy aims to establish one million hectares of forests by 2030, focusing on Miombo ecoregions in the provinces of Niassa, Cabo Delgado, Nampula and Zambezia. This paper evaluates the causal effects of large-scale forestry investments in northern Mozambique on smallholders' farm size, crop productivity, and employment. We take advantage of a remote sensing approach that produced maps of forestry plantations and their expansion trajectories from 2001 to 2017 and combine them with data from two georeferenced nationally-representative agricultural surveys administered in 2007 and 2017. Using a difference-in-difference approach, we evaluate the effects of exposure to forestry plantations established after 2007, defined by the presence of newly established and expansion of existing plantations and their distance to households within a 20-km buffer. We find that households exposed to forestry plantations increased their planted areas but did not change hired farm employment, which was accompanied by a decrease in crop yields. The heads of households close to forestry plantations were also less likely to work in agriculture as their main activity, especially as salary workers, and more likely to be self-employed and employed in the nonfarm sector. This study contributes to an improved understanding of local dynamics resulting from forestry investments, which have critical implications for investment targeting and sustainable land use planning.

1. Introduction

Global and national strategies aiming to counter greenhouse gas emissions, degradation of natural forests, and the loss of biodiversity, increasingly rely on tree plantations as a means to achieve these targets. These strategies often couple ecosystem services with the provision of jobs and income sources for the local population. This prompts governments to allocate land to forestry companies, although such allocations are sometimes in conflict with the interests of communities and their land rights (Boone, 2012; Bleyer et al., 2016; Kalabamu, 2019; Rasmussen and Lund, 2018). In Mozambique, a National Reforestation Strategy set in 2009 aimed at increasing commercial forest plantation area to 1 million hectares (ha) in 2030, primarily through large-scale corporate plantations, focusing on Miombo ecoregions in the provinces of Niassa, Cabo Delgado, Nampula and Zambezia (referred to hereafter as northern Mozambique[1]). The ambitious mandate included the creation of 250,000 permanent jobs (World Bank, 2016). However, the actual impact of forestry plantations on local populations' welfare, especially the spillovers on agriculture and employment, remains an open empirical question which this research aims to answer.

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[1] Administratively, Zambezia province belongs to central Mozambique, while Niassa, Cabo Delgado and Nampula belong to northern Mozambique. However, we classify Zambezia as northern Mozambique because Zambezia's agroecological conditions are more like the northern region than the central region.

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The effects of large-scale land acquisitions (LSLA) on neighboring small-scale agriculture and local communities' livelihoods is a topic of constant debate in the literature. Studies have explored their effects on a variety of outcomes including displacement of smallholders to other areas or economic sectors, land markets, land use, market access, labor absorption, and small-scale farmers' agricultural productivity (Malkamäki et al., 2018). But the direction and the significance of the effects remain far from consensual. Part of the empirical evidence suggests that large-scale investments may have positive spillovers in their vicinity, such as increased market opportunities for high-value crops, increased connectivity, and lower input costs (Burke et al., 2020; Sitko et al., 2018), increased cultivated area and yields (Lay et al., 2021), increased incomes (Herrmann, 2017), increased employment creation in the surroundings (Deininger and Xia, 2016), and poverty reduction (Afonso and Miller, 2021; Phimmavong and Keenan, 2020). Other studies document that the proximity and exposure to large-scale investments does not contribute to employment generation and provides moderate benefits to small-scale parcels in the vicinity (Anti, 2021; Ali et al., 2019; Jung and Hajjar, 2023), does not lead to increased access to markets, increased cultivated areas or increased agricultural profits (Deininger and Xia, 2016), displaces smaller-scale farmers (Nolte and Ostermeier, 2017; Zaehringer et al., 2021) and would lead to increased welfare inequality (Phimmavong and Keenan, 2020). The evidence also suggests that large-scale investments promote a transition to crops high in calories, but low in nutritional content, oriented towards export markets, which may displace the production of traditional local crops, and lower gradually the dietary diversity (Müller et al., 2021).

These effects might vary because of a series of factors, linked to the context in which the investments take place, as well as to the characteristics of the households and of the investments themselves, which cover a wide variety of actors, business models, and land uses (Abeygunawardane et al., 2022; Oberlack et al., 2021). Given this, we focus on one specific type of large-scale investment here, which is the major one in terms of land area occupied in northern Mozambique, i.e. large-scale forestry plantations that focus on wood production (Bey and Meyfroidt, 2021).

We aim to contribute to the LSLA knowledge base by evaluating the specific effects of large-scale forestry investments and their expansion on the welfare of small-scale farmers in the surroundings. We focus on evaluating their effects on farmland expansion, cropland productivity and labor. For each of these outcomes, different mechanisms may lead to opposite effects. We discuss conceptually such possible mechanisms and assess empirically the net direction of these changes.

The evaluation of the impacts of large-scale investments on neighboring landscapes and peoples' livelihoods is typically challenged by data constraints. Several studies take advantage of the large investments registered in the Land Matrix database on land deals (Müller et al., 2021; Lay and Nolte, 2018), which provide information on the main deals, but have limited data on actual land uses or smaller deals that are implemented on the ground. Other studies obtain the information on land acquisitions from household surveys which may suffer from an under-representation of large-scale landholdings and are also constrained by short time periods in between survey rounds (Deininger and Xia, 2016).

We combine remote sensing and household survey data to evaluate the effects of forestry expansion on the welfare of farmers located in the vicinity. We use land use trajectories of tree plantation expansion into prior natural vegetation and cropland from 2001 to 2017 for northern Mozambique, obtained through remote sensing techniques that distinguish tree plantations from natural vegetation (Bey and Meyfroidt, 2021). We combine this data with two georeferenced nationally-representative agricultural surveys for 2007 and 2017, that collect detailed parcel-level information on crop types, land management, production and labor, among other information such as demographic characteristics, asset ownership, food security. Through a difference-in-difference approach, we evaluate the effects of all forestry investments established in the area on outcomes of agricultural productivity and labor.

This study contributes methodologically to the debate on the impacts of LSLA. We address common challenges in existing studies, such as the short time periods for evaluations and the representativity of the LSLA. We do so by using a census of forestry plantations in northern Mozambique building on remotely sensed data products, which allow us to observe the expansion of the forestry plantations between 2007 and 2017, a rare opportunity in these kinds of studies. This information also contrasts with previous studies in that the "treatment" or exposure information is the actual land use change, not the presence of specific deals or known companies or investments of certain characteristics. We also contribute to the existing literature of causal inference studies that do not distinguish LSLA by land use (Müller et al., 2021; Deininger and Xia, 2016), by disentangling the effects of LSLA for a specific type of investments, forestry plantations, and for prior land uses. The findings of this research contribute to a better understanding of local dynamics of forestry LSLA in northern Mozambique, which has critical implications for more inclusive and sustainable planning and development in the area.

2. Land tenure dynamics in Mozambique's forestry sector

The first foreign-owned plantations in Mozambique date back to the colonial period in the early to mid-20th century, primarily for commercial purposes by Portuguese colonizers. Since then, successive waves of investors attempted to establish plantations but failed and left, or remained but without being successful (Kronenburg García et al., 2022). In recent times, promoting large-scale investments has become one of the agricultural development models pursued by the Government of Mozambique (GoM) (Nova and Rosário, 2022). Between 2005 and 2008 foreign investment companies pioneering a new wave were set up. By 2009, Mozambique had 60,000 ha of large-scale commercial planted forest, directly providing 3000 jobs (Serzedelo de Almeida and Delgado, 2019). In 2012, companies in Niassa only had been issued six Land Use Rights certificates - hereafter referred to as DUATs from its Portuguese acronym for Direito de Uso e Aproveitamento de Terra - covering about 155,000 ha and invested about USD 70 million (World Bank, 2016). These are mostly monoculture tree plantations of pine and eucalyptus. The two major plantation companies with the greatest investment that operate in northern and central Mozambique are Portucel Mozambique and Green Resources (Orlowski, 2016). Portucel Mozambique received land rights covering 356,000 ha (Serzedelo de Almeida and Delgado, 2019).

The expansion of these large-scale plantations has intersected with existing land tenure structures and local community dynamics. Portucel Mozambique, for instance, adopted a "mosaic" model, where two thirds of the total area are planted and one third is reserved for community use. With this approach, community farms end up surrounded by the plantation, potentially with negative impacts on these communities because of the eucalyptus allelopathic effect.[2] Preliminary anecdotal evidence suggests this may be prompting farming households to move to more distant areas in search of fertile land and water resources (Orlowski, 2016), leading to potential conflicts and disruptions in traditional agricultural practices.

Central to these dynamics are land tenure arrangements, which are the most common source of conflicts between forest companies and local communities (Nhantumbo et al., 2013). All land in Mozambique is publicly owned. The land itself cannot be sold, but the GoM can grant concessions of land use rights through DUATs. The Land Law of 1997

[2] Eucalyptus trees release chemical compounds that can influence the growth and development of other plants in the vicinity. The chemicals released by eucalyptus trees into the environment can have either inhibitory or stimulatory effects on the growth of neighboring plants (Zhang and Fu, 2009).

established that DUATs can be acquired either by individual persons or local communities through customary norms, by good-faith occupation for at least ten years by national individual persons; or through the authorization of an application submitted to Public Administration by an individual or corporate person (MozLegal, 2004). The Land Law recognized traditional rights of systems of customary occupancy and the role of communities in management of natural resources, resolution of conflicts, the process of titling, and the definition of boundaries that the communities occupy.

Land use rights to foreign companies, on the other hand, that require DUATs for economic purposes, are subject to the approval of an investment or land use plan. Companies are granted first a provisional DUAT, which subject to the completion of the land use plan, are granted a definitive DUAT with a validity of up to 50 years, that can be renewed for further 50 years. The rights of land use may be transferred by inheritance or by a public notarial deed; and in the case of companies, pending on authorization by the same entity that approved the DUAT and on the fulfilment of the land use plan.

DUATs are issued to local communities or individual persons who request individual land use rights after the plot has been partitioned from its respective community land. The absence of a DUAT ownership, however, does not prevent land use rights. The application for a DUAT for economic activities must include a statement from local authorities that confirms that the area is free and has no occupants after consultation with the community.

Land mapped for forest activities by the GoM is often already in use by local communities, so conceding land use rights requires long consultations and negotiations (World Bank, 2016). Yet, multiple irregularities have been previously reported with such consultations, such as failure to undertake the consultations, records falsification, poor consultation processes, consultation with only one of several affected parties, corruption acts and bribes, among others (Sitoe et al., 2012; Hanlon, 2002; Vermeulen and Cotula, 2010). Evidence also suggests that in Mozambique non-certified[3] private plantations are less likely to involve local communities in the consultation processes (Degnet et al., 2022).

3. Conceptual framework

Figure 1 presents three possible pathways for the impacts of forestry plantations on households' outcomes of interest, which are cultivated area, crop types, yields, hired farm employment, and household head's employment sector. On the first pathway, we speculate that forestry plantations may attract input suppliers and make inputs more accessible and affordable and open up market opportunities such as attracting traders. If such a pathway was to dominate, households may be able to afford inputs such as improved seeds and more likely to plant high-value crops. This could likely lead to increases in output value and higher yields. If a rebound effect occurs, this pathway may also lead to an expansion of cultivated area (Meyfroidt et al., 2018). If economic returns are greater, households may also be more likely to hire more farm workers, and the household head may stay in agriculture as an own-account worker.

On a second pathway represented in Figure 1, forestry plantations may directly employ plantation workers, so that a positive effect on wage work in agriculture for household heads should be observed. This could impact households' heads engagement in own-account agriculture and potentially agricultural yields, but the direction of this impact is uncertain. Additional income could influence acquisition of inputs and potential higher yields; or new wage-agricultural employment could drive-out own-account agricultural activity. Available evidence suggests nonfarm income increases farm hired labor and decreases agricultural productivity, as farmers use it to move out of agriculture rather than investing in crop production (Kilic et al., 2009; Amare and Shiferaw, 2017).

The third pathway represented in Figure 1 shows that forestry plantations may also induce farm displacement. If farmers were pushed to marginal lands, an increase in cultivated area may be observed, but no changes in crop varieties (traditional crops should still be predominant). Because marginal lands would presumably be of lower soil quality, yields should decrease, and farm employment decrease as the farmer has lower capital to hire workers. No changes in the household heads' employment sector would be expected. On the other hand, if farmers were pushed to other economic sectors, a decline in cultivated area should be expected and a change in the employment sector of household head, with a decrease in the likelihood of having agriculture as the main occupation and an increase in nonfarm employment (either wage or self-employment) or even in unemployment or inactivity.

Given that forestry plantations in Mozambique are mainly monocultures focused on pine and eucalyptus, which are not labor intensive cultivations, we hypothesize that the second pathway, direct employment creation, will not be strong. Since investments into forestry is a new phenomenon and land demarcated for forestry often overlaps with community land inhabited or used for livelihood activities, we hypothesize that the third pathway in Figure 1 is likely to dominate more than the first pathway. Since a combination of a push to marginal lands or other economic sectors is both likely, it is uncertain whether the cultivated area would increase or decrease; but it is expected that farmers may remain cultivating traditional crops, achieving low yields, and maintaining none to minimum levels of hired farm labor. It is also uncertain whether farmers would remain as own-account farm workers or be pushed out of agriculture, either into the nonfarm sector or into unemployment or inactivity.

4. Methodology

4.1. Data

This study relies on two primary sources of data. First, the extent of forestry plantations and their expansion trajectories are obtained from remote sensing algorithms that process United States Geological Survey (USGS) Landsat 7 and Landsat 8 imagery for the years 2001, 2006, 2012, and 2017, as described in Bey and Meyfroidt (2021). The available dataset maps forestry plantations for each year, and the changes in the type of land use over time between 2001 and 2017. Such changes include two types of land use trajectories, depending on the previous land use/cover between 2001 and 2017 where the tree plantations got established, i.e., previous land use/cover being natural vegetation (which includes mosaics of forests, woodlands and grasslands), versus being cropland (Bey and Meyfroidt, 2021). To distinguish large-scale forestry plantations from small-scale operations, this work excluded all woodlots of five ha or less. The forestry investments identified correspond essentially to tree plantations such as pine and eucalyptus, but also to macadamia, mango, and citrus, to a lesser extent. The data only includes plantations which were newly established or expanded after the year 2001.

We combine this information with the second data source, i.e., two cross-sectional nationally representative Integrated Agricultural Surveys (hereafter referred to as IAI from its Portuguese acronym), for the years

[3] Degnet et al. (2022) study the certification of forestry plantations in the context of Mozambique, which involves a market-driven, non-state governance system aimed at promoting sustainable forest management (SFM). This certification seeks to incentivize forest owners to adhere to SFM standards by offering financial or reputational rewards, such as price premiums and enhanced market access for certified products. It is primarily implemented through schemes like the Forest Stewardship Council (FSC), which sets criteria for responsible forest management, including principles addressing community rights and relations within the management area. The certification process is intended to improve social aspects, including interactions between plantation owners and local communities.

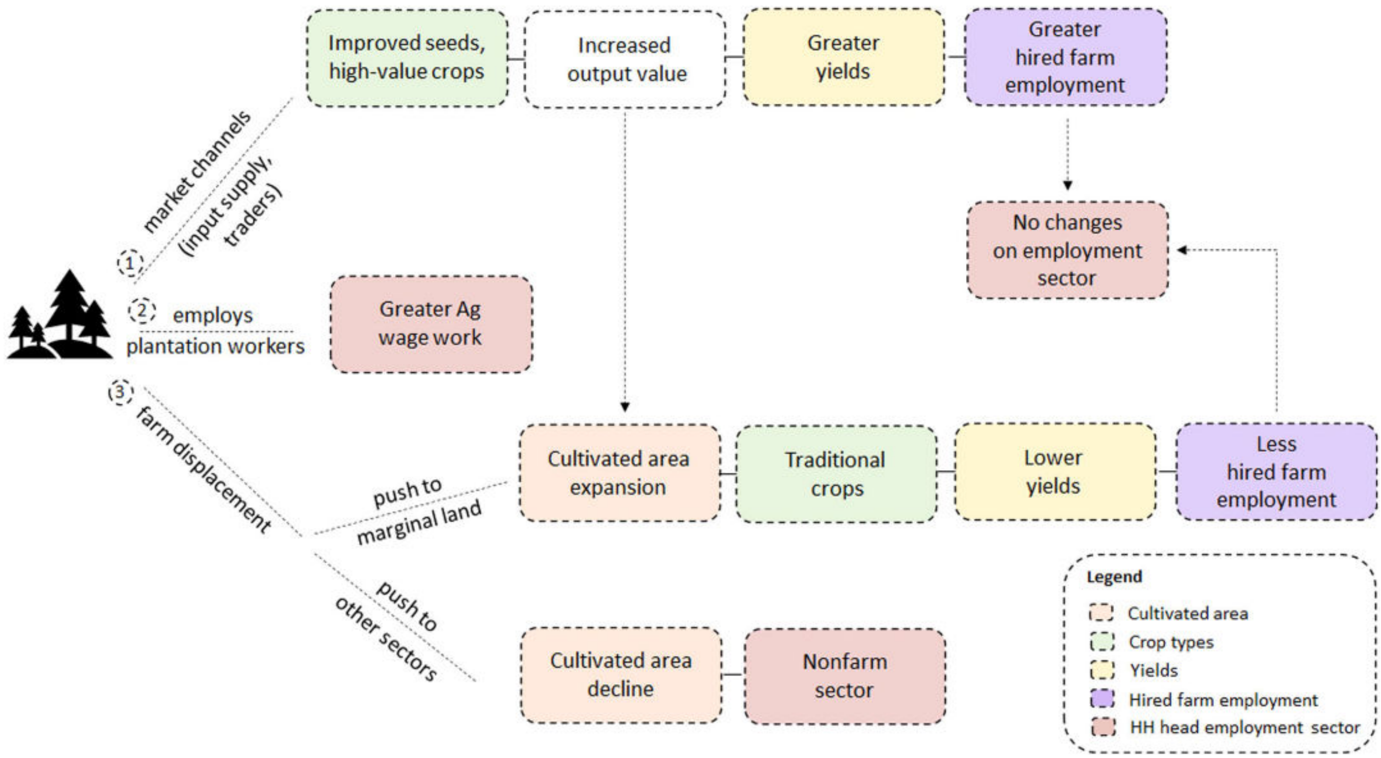

Fig. 1. Possible pathways of plantations impacts.

2007 and 2017. The surveys are administered by the Ministry of Agriculture and Rural Development in close partnership with the National Institute of Statistics. The year 2007 is chosen as the baseline period as it coincides with the start of the newest investment wave (which includes forestry investments), the availability of IAI data, and the remotely sensed maps of forestry plantations (Bey and Meyfroidt, 2021). The year 2017 is well past the end of the major forestry investment wave and complementary data for the IAI and for the remotely sensed maps is available for this year. Thus, 2017 serves as the post-treatment year. These surveys contain GPS coordinates of household locations and the names of the administrative areas down to the community level. The survey includes detailed modules on demographic characteristics, planting and harvesting decisions at the plot and crop level, labor use and earnings, asset ownership, sales, and food security.

We overlap the household locations[4] from 2007 and 2017 with the location of the plantations for each of the evaluated rounds, as well as their expansion trajectories as illustrated in Figure 2. This figure shows the four provinces where the study takes place in northern Mozambique, the GPS locations of households surveyed in years 2007 and 2017, and zooms in the forestry plantations trajectories between 2001 and 2017. In orange is the trajectory corresponding to plantations that expanded on cropland, and in purple the trajectory corresponding to plantations that expanded on natural vegetation. The time between 2007 and 2017 corresponds to the increase in foreign forestry investments in the area, which began around 2008 and peaked in 2012 (Bey and Meyfroidt, 2021). Accordingly, the mapped plantation area increased from 4983 ha in 2006, to 7832 ha in 2012, to 18,178 ha in 2017, with 70 % of the plantations expanding on previous agricultural land (Bey and Meyfroidt, 2021).

4.2. Empirical strategy

The study covers the farming households in the provinces of Nampula, Niassa, Zambezia and Cabo Delgado, which is the coverage of the remote sensing-based maps of forestry plantations. We limit the analysis to those households within 250 km of any forestry plantation, to exclude contexts that are expected to be too different from those affected by plantations (consistent with Deininger and Xia, 2016).

We evaluate the impacts of exposure to forestry plantations on neighboring smallholders' productive and employment outcomes, using a Difference-in-Difference (DID) approach. To implement the DID, we construct a sample of households exposed (i.e., treated) and unexposed (i.e., control) to forestry plantations. We define exposed households as those having a minimum share of 0.1 % area occupied with forestry plantations within a circular buffer of r radius around the household in the post-treatment period (i.e., 2017). Since the IAI did not revisit the same farming households in both years (2007 and 2017), we use the data from households located within the same areas subsequently affected, to replace the pre-exposure productive and employment measures, i.e., pre-exposure treated households are those having a minimum 0.1 % area occupied with post-treatment forestry plantation within a circular buffer of r radius.[5] This ensures that households in the 2007 pre-exposure group are located in similar areas as those in 2017 post-exposure group.

We chose to define both exposed and un-exposed households in relation to forestry plantations in the post-treatment period deliberately to adhere to the 'no compositional differences' assumption of the DID model. By selecting treated households based on their proximity to the 2017 plantations, our intent is to ensure consistent definition of treated households in both pre and post periods, situating them within similar plantation-suitable areas. This approach is similar to a regression

[4] Seventy seven percent of the sampled households in 2007 were missing GPS coordinates. We hence inputed the GPS coordinates of the Primary Sampling Units (PSU) centroids to these households. Eight farming households were sampled per PSU.

[5] This is, exposed households in the pre-exposure period (i.e., 2007) are those having area occupied with 2017 forestry plantations within a circular buffer of r radius around the household.

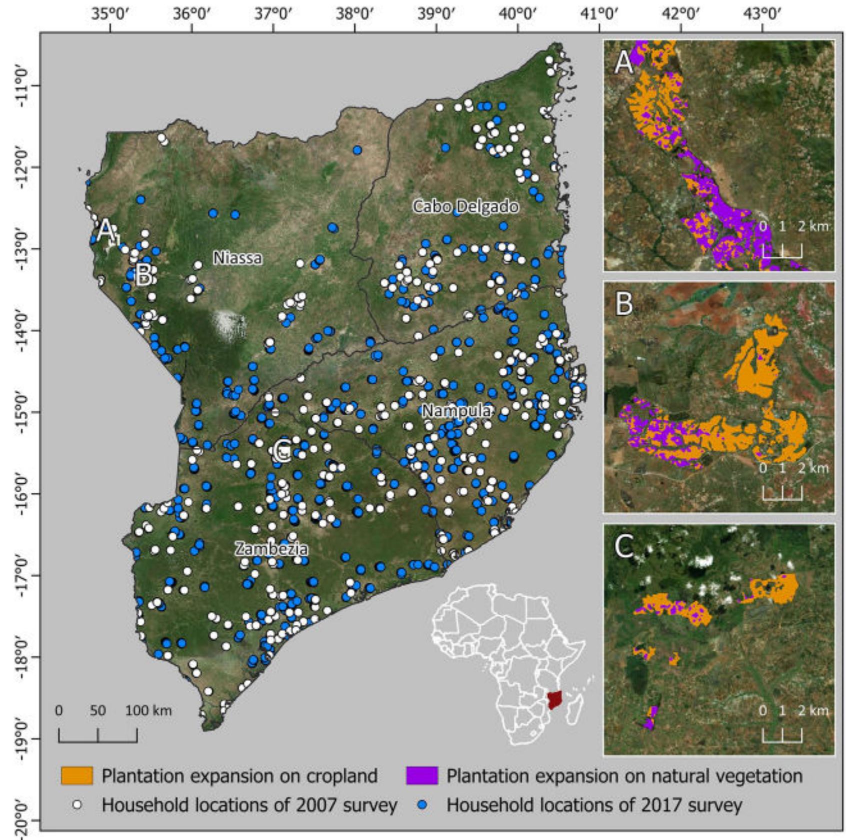

Fig. 2. Mapping of forestry plantations trajectories and households surveyed in 2007 and 2017.

discontinuity design, in that it involves designating households just outside the 'area of exposure' as controls, demarcating and capping the extent of this exposure area. Hence, treated and control groups are comparable not just in proximity but also in observable and unobservable characteristics. While this approach may not entirely eliminate compositional differences inherent in repeated cross-sections, it provides a more robust comparison in the absence of panel data, ensuring no compositional differences between groups.

Many reasons explain the establishment of forestry investment in certain areas, such as available land, appropriate slope, fertile soils, among many others. Households located in the vicinity of such forestry investments may hence differ from households located further away, a difference known as selection bias. There is additionally a time variant component. Outcome variables for all households change over time regardless of their exposure to forestry investments, a component known as a time trend. When the selection bias is timely invariant and the time trend is the same for both exposed and unexposed groups, a parallel trends or common trends assumption holds and we can causally evaluate the effects of forestry investment using the DID approach. Given that we compare households that are within 250 km of forestry plantations, in the same areas of the four provinces, we consider the latter two conditions reasonable, as exposed households are not too distant from control households. As a robustness check, we also vary the definition of such exposure threshold through a sensitivity analysis. Equation (1) details the DID strategy.

$$Y_{ip} = \beta + \gamma Exp_{ip} + \lambda Post_{ip} + \delta Exp_{ip} \times Post_{ip} + X_{ip}\kappa + \alpha_p + \epsilon_{ip} \quad (1)$$

Where i is a subscript for each household and p a subscript for each province. α_p are province fixed effects, which we include to account for possible regional heterogeneities. *Post* is the time trend which equals one for households surveyed at the endline period in 2017 and zero for those surveyed at the baseline period in 2007. *Exp* indicates the exposure to forestry plantations. For our basic specification we define *Exp* as a 'presence' indicator variable that takes the value of one if at least 0.1 % of the area of a concentric circle around each household is occupied with forestry plantations established after 2007. We choose a threshold of 0.1 % of the area around each household as the indicator of the 'presence' of a plantation, as opposed to a binary variable indicating the presence of a plantation in the concentric circle regardless of plantation area, which may lead to the inclusion of households as treated, despite negligible area occupied with plantations around the household. This adds an extra layer of robustness by preventing small classification or location errors. This basic exposure variable allows us to estimate a standard DID model with a binary 'treatment' variable, before and after the expansion of the plantations. This specification considers as 'control' or counterfactual group all those households with less than 0.1 % of the area of the concentric buffer around the household occupied with forestry plantations, noting that the majority of households have no plantation presence at all.

X_{ip} is a vector of household characteristics, in which we include demographic characteristics of the household head (sex, age and years of education), and whether the head of household works as an employee or is self-employed.[6] ϵ_{ip} are random disturbances, which are independent and identically distributed $N(0, \sigma^2)$. Standard errors are clustered at the district level. Y_{ip} corresponds to the outcome variables, which are: i) a set of productive outcomes: farm size in ha (total area self-reported by the household, cultivated land size, area under permanent crops, and total area measured by enumerators), the value of all crops produced (in 2017 USD PPP), total agricultural yields (the value of all crops produced

[6] We consider as controls the head of household employment status for productive outcomes and crop choices but not for employment outcomes.

in 2017 USD PPP per ha), the value of all crops sold (in 2017 USD PPP), the value of such sales per ha, and the total cost of seeds (in 2017 USD PPP); ii) a set of employment outcomes: farm employment (whether the household employed workers full time, part-time, the total number of workers employed, and number of men and women employed), dichotomous variables for whether the head of household worked as an employee or self-employed, dummy variables for whether agriculture was the main activity, a secondary activity or the head of household did not practice agriculture; and iii) a set of crop choice outcomes: dummy variables for whether the household cultivated the main crops cultivated in the area, maize, rice, sorghum, groundnuts, beans, and sesame.

The parameter of interest in the above specification is δ, the coefficient of the interaction between exposure and post status, which captures the impact of exposure to plantations on the outcomes of interest at the end of the period (2017). It estimates the Average Treatment Effect on the Treated (ATT), for those households that were exposed to the appearance of forestry plantations after 2007. By accounting for a double difference, the DID approach can distinguish between effects of the treatment itself (caused by the exposure to plantations) and other time-dependent factors that may be affecting the outcome variable in both exposed and unexposed areas.

The delimitation of the radius of influence for the exposure variable is a sensitive decision. To obtain results that are robust to uncertainties in the actual distance up to which plantations might affect households, we first consider a radius of influence of 20 km around each household, and conduct sensitivity analysis varying the radius of exposure to: 5, 10, 15, 25 and 30 km around each household.

What constitutes exposures to plantations is another sensitive decision. Plantation exposure can take the form of the mere presence of a plantation in a households' vicinity, but it may also be considered as stronger or weaker depending on the proximity of the household to the plantation (distance), and on how much area the plantation or group of plantations occupies in the surrounding landscape (intensity of exposure). To test for these measures of intensity, we consider two additional indicators: i) a continuous variable with the inverse of the distance to the closest point where a forestry plantation was established after 2007; and ii) a continuous variable with the share of the area of a concentric circle around each household occupied with forestry plantations established after 2007. We evaluate both intensity variables through the following DID specification:

$$Y_{ip} = \beta + \gamma Exp_{ip} + \lambda Post_{ip} + \delta Exp_{ip} \times Post_{ip} \times Int_{ip} + X_{ip}\kappa + \alpha_p + \epsilon_{ip} \quad (2)$$

where *Int* corresponds to the *intensity* variables described above. Testing these continuous variables may result important in the case of evaluating forestry investments, as we may care more about the effect of the changes in the intensity of exposure (intensive margin) than about the existence of the forestry investments (extensive margin).

To further understand the mechanisms explaining the impacts, we disentangle the exposure variable by the expansion trajectories. We consider three possible cases depending on previous land uses, i.e., all plantations in the buffer zone were established in natural vegetation, all plantations in the buffer zone were established in cropland, and plantations in the buffer zone were established both in natural vegetation and cropland areas. As the basic specification, we consider a household -'exposed' if a forestry plantation from one of these trajectories occupied an area greater than 0.1 % of the 20 km buffer zone around each household. With this information, we estimate equation (3).

$$Y_{ip} = \beta + +\lambda Post_{ip} + \gamma_1 ExpNV_{ip} + \gamma_2 ExpCL_{ip} + \gamma_3 ExpNVCL_{ip} + \delta_1 ExpNV_{ip} \times Post_{ip} + \delta_2 ExpCL_{ip} \times Post_{ip} + \delta_3 ExpNVCL_{ip} \times Post_{ip} + X_{ip}\kappa + \alpha_p + \epsilon_{ip} \quad (3)$$

where *NV* and *CL* correspond to natural vegetation and cropland trajectories, and *NVCL* to a household that experienced the establishment of both trajectories in the vicinity. δ_1, δ_2, and δ_3 estimate the ATT effects of each of the trajectories and their interaction.

5. Results

In this section we first present descriptive statistics of the exposure, outcome, and control variables. We then show the results of the estimations of exposure to forestry plantations, by grouping outcomes in three groups: productive outcomes (farm size, yields, sales), employment outcomes (hired employment and the sector of employment of the household head), and crop choices (whether the household farms the main crops grown in the area). We first present the results of the basic specification, which evaluates the extensive margin of exposure to plantations. We also conduct the sensitivity analysis on the chosen 20-km buffer, to evaluate how responsive are the effects to the choice of the buffer radius. We then evaluate the intensive margin, by estimating the effects of distance to forestry investments and the extension of the occupied area. Finally, we show heterogeneous impacts for the expansion trajectories.

5.1. Descriptive statistics

First, we present descriptive statistics of the exposure indicators of plantation presence, share of plantation in each buffer ring, and of distance to nearest plantation, for pre-and post-exposure samples (Table 1). As a reminder, we define these treatment or exposure variables relative to the plantations at endline (2017) also for pre-exposure households. Hence, Table 1 shows how balanced in location are pre and post-exposure samples. About 4 % of households in both pre- and post-exposure periods observed a plantation within a 20 km buffer radius around the household. The share varies slightly for different radii of the concentric circles, but there are no significant differences across the periods. Households' exposure to plantations, i,e., in terms of both the presence of plantations and the share of plantations, at a 5 km buffer radius is higher in the pre-exposure period. Beyond the 5 km radius, exposure to plantations shows no significant difference across pre-and post-exposure periods. But households in post-exposure sample are significantly closer to plantations than those in the pre-exposure sample.

Table 2 shows the mean differences in outcome variables and covariates across exposed and control households, for before and after exposure. The metrics show that prior to exposure, the sample of exposed households were more likely to rely on agriculture as their primary livelihood activity than the unexposed control households[7]: i.e., in the pre-exposure period, the exposed households were likely to work larger farms both in terms of total area and cultivated area, hire more full-time workers, cultivate maize and sorghum, and incurred higher seed costs. These exposed households were also likely to have a dependent source of income (salary) and be headed by females than

[7] i.e., comparing the unexposed and exposed columns in the left panel (or Pre-period) of Table 2

Table 1
Mean differences pre versus post on plantation exposure variables.

	Pre			Post			
	Mean	S.D.	Obs.	Mean	S.D.	Obs.	Diff.
Presence of forestry plantation at 5 km (Yes/No)	0.032	0.18	2106	0.019	0.14	2753	− 0.01***
Presence of forestry plantation at 10 km (Yes/No)	0.036	0.19	2106	0.034	0.18	2753	− 0.00
Presence of forestry plantation at 15 km (Yes/No)	0.036	0.19	2106	0.034	0.18	2753	− 0.00
Presence of forestry plantation at 20 km (Yes/No)	0.036	0.19	2106	0.037	0.19	2753	0.00
Presence of forestry plantation at 25 km (Yes/No)	0.036	0.19	2106	0.044	0.21	2753	0.01
Presence of forestry plantation at 30 km (Yes/No)	0.041	0.20	2106	0.050	0.22	2753	0.01
Share of plantation at 5 km buffer (%)	0.002	0.01	2106	0.001	0.01	2753	− 0.00***
Share of plantation at 10 km buffer (%)	0.001	0.01	2106	0.001	0.01	2753	− 0.00
Share of plantation at 15 km buffer (%)	0.001	0.01	2106	0.001	0.01	2753	0.00
Share of plantation at 20 km buffer (%)	0.001	0.00	2106	0.001	0.00	2753	0.00
Share of plantation at 25 km buffer (%)	0.001	0.00	2106	0.001	0.00	2753	0.00
Share of plantation at 30 km buffer (%)	0.001	0.00	2106	0.001	0.00	2753	0.00
Distance to nearest 2017 plantation	2391.410	2136.36	2106	1911.937	1583.34	2753	− 479.47***

*$p < 0.10$. **$p < 0.05$, *** $p < 0.01$.
Diff. column shows difference between 2007 and 2017 means

Table 2
Mean differences by exposure status on outcome and control variables pre and post exposure.

	Pre			Post		
	Unexposed	Exposed	Diff.	Unexposed	Exposed	Diff.
Productive outcomes						
Total area self-reported (ha)	1.66	2.02	0.36**	1.32	2.30	0.98***
Cultivated area (ha)	1.56	2.00	0.45***	1.22	2.13	0.91***
Area with permanent crops (ha)	0.02	0.00	− 0.02	0.01	0.00	− 0.01
Total area as measured by enumerators (ha)	1.51	1.63	0.12	1.23	1.23	0.00
Value of output of all crops, 2017 USD PPP	87.07	135.89	48.82	334.40	380.10	45.70
Yields for all crops, 2017 USD PPP per HA	53.27	56.76	3.49	356.21	278.49	− 77.71
Sales value of all crops, 2017 USD PPP	26.38	48.12	21.74	198.15	166.15	− 32.00
Sales per ha of all crops, 2017 USD PPP per HA	14.52	18.87	4.35	373.19	160.34	− 212.85
Seeds cost of all crops, 2017 USD PPP	0.60	3.97	3.37***	4.45	13.41	8.96***
Employment outcomes						
Hired workers full-time (Yes/No)	0.02	0.05	0.03*	0.02	0.08	0.05***
Hired workers part-time (Yes/No)	0.20	0.26	0.07	0.14	0.16	0.02
Number of total workers hired (N)	6.51	5.50	− 1.01	3.79	5.43	1.64
Hired male workers (N)	4.13	4.00	− 0.13	2.98	3.43	0.45
Hired female workers (N)	2.38	1.50	− 0.88	0.80	2.00	1.20*
H head works as wage worker (Yes/No)	0.24	0.36	0.12**	0.23	0.23	− 0.01
HH head works as self-employed (Yes/No)	0.52	0.48	− 0.04	0.45	0.48	0.03
Agriculture is main activity for HH head (Yes/No)	0.82	0.93	0.11**	0.88	0.90	0.03
Agriculture is secondary activity for HH head (Yes/No)	0.13	0.07	− 0.07*	0.09	0.05	− 0.03
HH head does not practice agriculture (Yes/No)	0.04	0.00	− 0.04*	0.04	0.04	0.01
Crop choices						
Cultivated maize (Yes/No)	0.68	0.99	0.31***	0.74	0.89	0.15***
Cultivated rice (Yes/No)	0.27	0.04	− 0.24***	0.15	0.06	− 0.09**
Cultivated sorghum (Yes/No)	0.29	0.54	0.25***	0.18	0.30	0.13***
Cultivated groundnuts (Yes/No)	0.41	0.28	− 0.13**	0.44	0.18	− 0.27***
Cultivated beans (Yes/No)	0.62	0.71	0.09	0.62	0.61	− 0.01
Cultivated sesame (Yes/No)	0.00	0.00	0.00	0.06	0.01	− 0.05**
Control variables						
HH head female	0.20	0.32	0.11**	0.27	0.28	0.01
HH head age	41.15	41.91	0.76	42.09	42.53	0.45
HH head years of education	2.77	1.79	− 0.99***	3.68	3.91	0.24

*$p < 0.10$,**$p < 0.05$, ***$p < 0.01$.
Diff. column shows the mean difference and significance between households exposed and unexposed to forestry plantations, for 2007 and 2017

unexposed households. The unexposed households on the other hand were more likely to have agriculture as a secondary activity, cultivate rice and groundnuts, and to be headed by a person with more years of education. Exposed and unexposed samples prior to exposure are balanced in total farm area that was measured by enumerators, total value of the output, the sale value of the output, the total number of workers, the number of part-time workers, whether the workers were male or female, the cultivation of beans, and the age of the household head.

These differences at pre-exposure should not constitute a problem for identification as long as the exposed and control areas have followed parallel trends. Ideally, we would have repeated pre-exposure measures to check for parallel trends,[8] but as Roth (2022) suggest, given limitations in the practice of testing for pre-trends, using context-specific knowledge to discuss possible violations of parallel trends will yield in more credible inference. We know that 70 % of plantation expansion occurs on cropland rather than on natural vegetation. It has been shown also that community lands and proximity to prior state farms are the main drivers of plantation expansion (Bey, 2021). Since such are the characteristics of the areas where most sampled farms are established,

[8] although given that we do not follow the same households over time, this would still be an imperfect proxy

Table 3
Diff-in-Diff effects of exposure based on plantation share on productive outcomes.

	Area total (Ha)	Area cultivated (Ha)	Area Perm (Ha)	Area measured (Ha)	Output value (PPP)	Yields (PPP/Ha)	Sales value (PPP)	Sales/Ha (PPP/Ha)	Seeds cost (PPP)
Dummy exposure	0.05	0.14	− 0.00	− 0.17	− 294.27	− 142.08	− 50.40*	− 24.48	3.77***
	(0.17)	(0.18)	(0.01)	(0.19)	(191.71)	(119.92)	(27.47)	(65.82)	(1.41)
Dummy post	− 0.35***	− 0.34***	− 0.00	− 0.26**	236.24***	289.97***	174.92***	385.65	3.62***
	(0.09)	(0.08)	(0.01)	(0.12)	(48.17)	(42.78)	(57.60)	(270.17)	(0.45)
ExposureXPost	0.58*	0.44	0.00	− 0.15	36.17	− 80.79	− 33.28	− 74.70	5.07
	(0.32)	(0.32)	(0.01)	(0.17)	(75.94)	(61.32)	(46.40)	(121.93)	(8.11)
Female HHhead	− 0.39***	− 0.37***	− 0.01**	− 0.52***	− 123.18***	− 50.69**	68.27	603.61	0.02
	(0.05)	(0.04)	(0.01)	(0.11)	(28.14)	(24.07)	(129.54)	(640.38)	(0.84)
Age HHhead	0.01***	0.01***	0.00**	0.01***	0.91	− 0.02	− 1.64**	− 3.90	0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.59)	(0.70)	(0.75)	(3.10)	(0.02)
Years ofEdu HHhead	0.01	0.01	0.00	− 0.03	3.70	6.52	− 3.38	− 28.06	0.35***
	(0.01)	(0.01)	(0.00)	(0.02)	(4.19)	(3.94)	(5.91)	(26.79)	(0.13)
Dummy wage employed	− 0.01	− 0.01	− 0.01	0.11	12.85	30.45	105.41	628.60	0.58
	(0.07)	(0.07)	(0.01)	(0.16)	(27.96)	(26.72)	(123.51)	(623.06)	(0.68)
Dummy self employed	0.11**	0.08*	0.01	− 0.07	25.12	14.59	106.77	378.26	1.58***
	(0.05)	(0.05)	(0.01)	(0.11)	(21.68)	(25.15)	(69.70)	(340.77)	(0.57)
Province fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.05	0.05	0.00	0.04	0.07	0.06	0.00	0.00	0.03
N	4637	4637	4637	1118	4763	4621	4664	4572	4664
Mean of dep. var control at baseline	1.66	1.56	0.02	1.51	87.07	53.27	26.38	14.52	0.60

Notes: Standard errors in parentheses
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

and since agricultural income and employment outcomes have been fairly stable across exposed and control areas as these are predominantly subsistence households that have been working in farming for years, it is reasonable to assume that the outcomes of interest have evolved in parallel prior to exposure across these areas.

Differences between the exposed and unexposed households continue over to the post-exposure period, except for the following: i.e., in the post-exposure period, the exposed households tend to hire female workers and the unexposed households tend cultivate sesame, while previous differences that existed in other employment (farm or non-farm), main income activity, household head’s participation in agriculture, and household head being female and having more years of education tend to disappear.

5.2. *Impacts of exposure in terms of the presence of plantations*

Table 3 shows the estimated impacts of exposure to plantations on households’ productive outcomes. Exposed households experience an increase in the self-reported total farm area of 0.6 ha, which is large given the average size of farms in the sample. However, no significant difference is detected in cultivated area, area with permanent crops, and total farm area as measured by enumerators. Exposure to plantation also

Table 4
Diff-in-Diff effects of exposure based on plantation share on employment outcomes.

	Employed fulltime (Yes/No)	Employed parttime (Yes/No)	Workers employed (N)	Male workers employed (N)	Female workers employed (N)	Wage Emp (Yes/No)	Self Emp (Yes/No)	Ag MainAct (Yes/No)	Ag Secondary Act (Yes/No)	Nonfarm (Yes/No)
Dummy exposure	− 0.02	0.03	1.68*	0.86	0.82	0.18**	0.03	0.04	− 0.03	− 0.01
	(0.02)	(0.07)	(0.99)	(0.64)	(0.93)	(0.08)	(0.06)	(0.03)	(0.02)	(0.01)
Dummy post	− 0.01	− 0.07***	− 2.25*	− 0.88	− 1.36*	− 0.02	− 0.05***	0.08***	− 0.07***	− 0.02
	(0.01)	(0.02)	(1.16)	(0.68)	(0.80)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)
ExposureXPost	0.03	− 0.07	0.52	− 0.56	1.08	− 0.16**	0.03	− 0.04	− 0.00	0.04*
	(0.04)	(0.09)	(1.67)	(0.65)	(1.31)	(0.08)	(0.06)	(0.03)	(0.02)	(0.02)
Female HHhead	− 0.01**	− 0.05***	− 1.51	− 0.62	− 0.89	− 0.07***	− 0.18***	0.01	− 0.03***	0.02**
	(0.00)	(0.01)	(1.07)	(0.69)	(0.71)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
Age HHhead	0.00***	0.00***	− 0.04	− 0.02	− 0.02	− 0.00***	− 0.00***	− 0.00**	0.00	0.00**
	(0.00)	(0.00)	(0.03)	(0.02)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Years ofEdu HHhead	0.00***	0.02***	0.04	0.09	− 0.05	0.02***	0.01***	− 0.04***	0.03***	0.01***
	(0.00)	(0.00)	(0.10)	(0.07)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Province fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.02	0.05	0.14	0.12	0.13	0.05	0.05	0.12	0.09	0.03
N	4763	4763	111	111	111	4763	4763	4763	4763	4763
Mean of dep. var control at baseline	0.02	0.20	6.51	4.13	2.38	0.24	0.52	0.82	0.13	0.04

Notes:Standard errors in parentheses
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

Table 5
Diff-in-Diff effects of exposure based on plantation share on crop choices.

	Maize (Yes/No)	Rice (Yes/No)	Sorghum (Yes/No)	Groundnuts (Yes/No)	Beans (Yes/No)	Sesame (Yes/No)
Dummy exposure	0.11***	− 0.13**	0.17	0.09	0.10	0.03**
	(0.03)	(0.05)	(0.16)	(0.06)	(0.16)	(0.01)
Dummy post	0.09***	− 0.12***	− 0.10***	0.06**	0.02	0.07***
	(0.02)	(0.03)	(0.02)	(0.03)	(0.03)	(0.01)
ExposureXPost	− 0.09***	0.13**	− 0.09	− 0.15***	− 0.05	− 0.06***
	(0.02)	(0.06)	(0.17)	(0.05)	(0.18)	(0.02)
Female HHhead	− 0.06***	− 0.00	− 0.00	− 0.02	− 0.05***	− 0.02**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)
Age HHhead	− 0.00***	0.00***	0.00	0.00	− 0.00	− 0.00*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Years ofEdu HHhead	− 0.00	0.00*	− 0.01**	− 0.00	− 0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Dummy wage employed	− 0.02	0.00	0.02	− 0.02	0.01	0.01
	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.01)
Dummy self employed	0.01	0.02	− 0.01	0.00	− 0.00	0.00
	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)
Province fixed effects	✓	✓	✓	✓	✓	✓
R^2	0.11	0.10	0.08	0.15	0.01	0.07
N	4763	4763	4763	4763	4763	4763
Mean of dep. var control at baseline	0.68	0.27	0.29	0.41	0.62	0.00

Notes: Standarderrors in parentheses
$^{*}p < 0.10$,$^{**}p < 0.05$, $^{***}p < 0.01$.

does not have a significant impact on yields, total output value, total sales, sales per ha, or seed cost.

Table 4 shows the results of the exposure to plantations on employment outcomes, both in terms of household head's own employment and hired farm labor. We find no significant effects on the type of hired labor (i.e., full-time or part-time) or the number of workers hired, men or women. Exposed households have a notably 16 percentage point lower probability that the head of household works as a wage employee; and a 4 percentage point lower probability that agriculture is practiced by the household head, although there are no effects on self-employment, or on whether agriculture is considered the primary or secondary activity.

To evaluate whether exposure to plantations influenced a change in crop choices, Table 5 shows the effects of the presence of a plantation in the 20 km buffer zone on binary variables for whether key regional crops, i.e. maize, rice, sorghum, groundnuts, beans, and sesame, were planted. The results show a decrease in the likelihood of planting maize (by 9 percentage points), groundnuts (by 15 percentage points) and

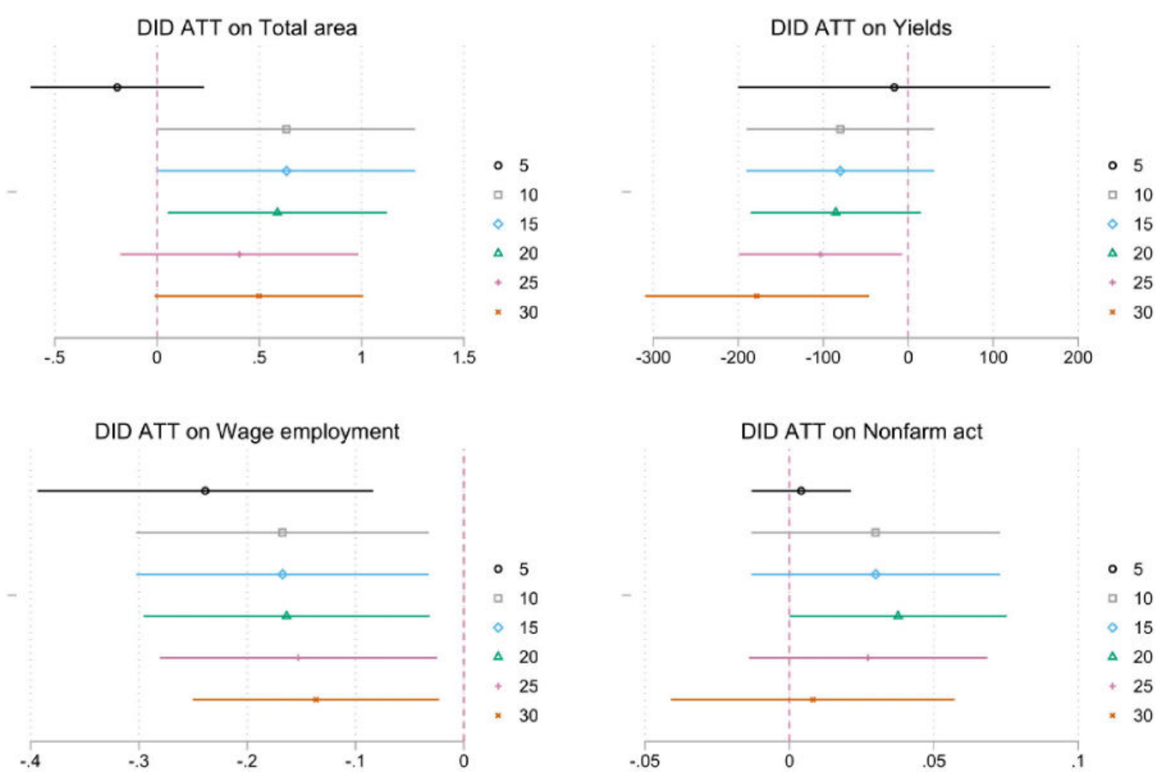

Fig. 3. ATT coefficients from the basic DID model on total area, yields, wage employment and nonfarm activity, considering different radiuses for the buffer area. Note: Figure shows the coefficients and 90 % confidence intervals from the interaction term of the DID estimation of the basic model, considering as 'exposure' the presence of forestry plantations in the 5, 10, 15, 20, 25 and 30 km buffers around each household (defined as having greater than 0.1 % of the buffer area occupied by the plantations).

sesame (by 6 percentage points), and an increase in the likelihood of planting rice (by 13 percentage points).

5.3. Sensitivity analysis

To assess whether our finding are sensitive to the size of the buffer, we estimate the DID regressions on the household effects to plantation exposure for varying buffer radii at 5, 10, 15, 20, 25 and 30 km. Tables S1-S5 (SI) show the results on productive outcomes and Tables S6-S10 (SI) on employment outcomes. We present the results for the productive and employment outcomes with significant impact for at least one of the radii. Figure 3 plots the coefficients of the interaction term of the DID estimations for the different buffers.

Results on productive outcomes show that positive effects for area size are barely insignificant for buffer zones of more than 10 km and only significant for a buffer zone of 20 km; and negative effects on yields emerge when considering a buffer zone of 25 km or more. Similarly, results on employment outcomes show that the negative effects found on the likelihood that the head of household is a wage worker are found consistently for all the radii considered, although the size of the effect diminishes as the distance at which plantation exposure is measured increases. The increase in nonfarm work for the head of household is only significant when considering a buffer zone of 20 km.

5.4. Impacts of exposure depending on the distance to plantations and their spatial extent

This section presents the results of the DID specification that evaluates the interaction of the presence of a plantation with the intensity of plantation exposure, using the inverse of the distance to the closest plantation (Table 6 and Table 7 for productive and employment outcomes, respectively) and the share in a 20 km buffer occupied with

Table 6
Diff-in-Diff effects of exposure based on inverse of distance on productive outcomes.

	Area total (Ha)	Area cultivated (Ha)	Area Perm (Ha)	Area measured (Ha)	Output value (PPP)	Yields (PPP/Ha)	Sales value (PPP)	Sales/Ha (PPP/Ha)	Seeds cost (PPP)
Exposure	0.18	0.21	− 0.00	− 0.23	− 291.81	− 163.38	− 82.59***	− 82.44	0.03
	(0.21)	(0.20)	(0.00)	(0.15)	(183.57)	(116.96)	(24.30)	(64.92)	(1.55)
Dummy post	− 0.34***	− 0.34***	− 0.00	− 0.26**	236.38***	288.62***	172.86***	381.86	3.37***
	(0.09)	(0.08)	(0.01)	(0.12)	(47.22)	(41.98)	(57.14)	(268.50)	(0.44)
ExposureXPostXInt	103.50***	92.99***	0.56	− 14.10	9641.28	− 13020.20**	7584.30	9103.00	3623.99***
	(27.83)	(26.91)	(0.74)	(21.43)	(6272.04)	(5411.36)	(5240.01)	(17849.74)	(347.80)
Female HHhead	− 0.39***	− 0.38***	− 0.01**	− 0.52***	− 123.27***	− 50.47**	68.44	603.98	0.03
	(0.05)	(0.04)	(0.01)	(0.11)	(28.18)	(24.13)	(129.60)	(640.66)	(0.85)
Age HHhead	0.01***	0.01***	0.00**	0.01***	0.91	− 0.02	− 1.64**	− 3.91	0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.59)	(0.70)	(0.75)	(3.10)	(0.02)
Years ofEdu HHhead	0.01	0.01	0.00	− 0.03	3.72	6.47	− 3.44	− 28.17	0.35**
	(0.01)	(0.01)	(0.00)	(0.02)	(4.21)	(3.94)	(5.92)	(26.85)	(0.13)
Dummy wage employed	− 0.01	− 0.01	− 0.01	0.11	12.81	30.77	105.85	629.46	0.63
	(0.07)	(0.07)	(0.01)	(0.16)	(27.94)	(26.67)	(123.56)	(623.43)	(0.68)
Dummy self employed	0.11**	0.08	0.01	− 0.07	24.91	14.83	106.52	377.89	1.49***
	(0.05)	(0.05)	(0.01)	(0.11)	(21.67)	(25.19)	(69.78)	(341.12)	(0.55)
Province fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.05	0.05	0.00	0.04	0.07	0.06	0.00	0.00	0.04
N	4637	4637	4637	1118	4763	4621	4664	4572	4664
Mean of dep. var control at baseline	1.66	1.56	0.02	1.51	87.07	53.27	26.38	14.52	0.60

Notes: Standard errors in parentheses
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 7
Diff-in-Diff effects of exposure based on inverse of distance on employment outcomes.

	Employed fulltime (Yes/No)	Employed parttime (Yes/No)	Workers employed (N)	Male workers employed (N)	Female workers employed (N)	Wage Emp (Yes/No)	Self Emp (Yes/No)	Ag MainAct (Yes/No)	Ag Secondary Act (Yes/No)	Nonfarm (Yes/No)
Exposure	− 0.03	− 0.02	2.41	0.62	1.79	0.11*	0.01	0.04*	− 0.03**	− 0.00
	(0.02)	(0.06)	(1.81)	(0.74)	(1.41)	(0.06)	(0.04)	(0.02)	(0.01)	(0.01)
Dummy post	− 0.01	− 0.08***	− 2.16*	− 0.91	− 1.25	− 0.02	− 0.05***	0.08***	− 0.07***	− 0.01
	(0.01)	(0.02)	(1.14)	(0.67)	(0.78)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)
ExposureXPostXInt	17.12***	9.79	− 84.09	− 35.72	− 48.37	− 13.95	19.61***	− 9.61***	1.13	8.48***
	(1.63)	(8.48)	(260.38)	(99.60)	(196.52)	(8.48)	(5.46)	(2.31)	(1.85)	(1.34)
Female HHhead	− 0.01**	− 0.05***	− 1.55	− 0.60	− 0.95	− 0.07***	− 0.18***	0.01	− 0.03***	0.02**
	(0.00)	(0.01)	(1.09)	(0.69)	(0.74)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
Age HHhead	0.00***	0.00***	− 0.05	− 0.02	− 0.02	− 0.00***	− 0.00***	− 0.00**	0.00	0.00**
	(0.00)	(0.00)	(0.03)	(0.02)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Years ofEdu HHhead	0.00***	0.02***	0.04	0.09	− 0.05	0.02***	0.01***	− 0.04***	0.03***	0.01***
	(0.00)	(0.00)	(0.10)	(0.07)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Province fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.02	0.05	0.14	0.12	0.13	0.05	0.05	0.12	0.09	0.03
N	4763	4763	111	111	111	4763	4763	4763	4763	4763
Mean of dep. var control at baseline	0.02	0.20	6.51	4.13	2.38	0.24	0.52	0.82	0.13	0.04

Notes: Standard errors in parentheses
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 8
Diff-in-Diff effects of exposure based on plantation share on productive outcomes.

	Area total (Ha)	Area cultivated (Ha)	Area Perm (Ha)	Area measured (Ha)	Output value (PPP)	Yields (PPP/Ha)	Sales value (PPP)	Sales/Ha (PPP/Ha)	Seeds cost (PPP)
Exposure	0.19	0.24	− 0.00	− 0.21	− 250.05	− 154.06	− 68.41***	− 61.55	4.50**
	(0.17)	(0.18)	(0.00)	(0.18)	(184.75)	(116.65)	(25.73)	(65.88)	(2.02)
Dummy post	− 0.34***	− 0.33***	− 0.00	− 0.26**	239.04***	289.25***	173.77***	383.24	3.66***
	(0.09)	(0.08)	(0.01)	(0.12)	(47.67)	(42.17)	(57.28)	(268.79)	(0.47)
ExposureXPostXInt	15.18	11.85	0.14	− 3.26	− 1970.34	− 2703.37	− 37.91	− 362.23	171.46
	(15.66)	(16.21)	(0.23)	(8.28)	(1898.68)	(2484.92)	(1980.66)	(4143.79)	(207.83)
Female HHhead	− 0.39***	− 0.37***	− 0.01**	− 0.52***	− 123.54***	− 50.72**	68.39	603.86	0.03
	(0.05)	(0.04)	(0.01)	(0.12)	(28.13)	(24.07)	(129.55)	(640.42)	(0.84)
Age HHhead	0.01***	0.01***	0.00**	0.01***	0.91	− 0.03	− 1.64**	− 3.91	0.02
	(0.00)	(0.00)	(0.00)	(0.00)	(0.59)	(0.70)	(0.75)	(3.11)	(0.02)
Years ofEdu HHhead	0.01	0.01	0.00	− 0.03	3.77	6.46	− 3.42	− 28.14	0.36***
	(0.01)	(0.01)	(0.00)	(0.02)	(4.20)	(3.95)	(5.92)	(26.87)	(0.13)
Dummy wage employed	− 0.01	− 0.01	− 0.01	0.11	12.13	30.49	105.66	629.14	0.58
	(0.07)	(0.07)	(0.01)	(0.16)	(27.95)	(26.72)	(123.53)	(623.24)	(0.68)
Dummy self employed	0.11**	0.08	0.01	− 0.07	25.31	14.69	106.73	378.18	1.57***
	(0.05)	(0.05)	(0.01)	(0.11)	(21.70)	(25.16)	(69.73)	(340.86)	(0.57)
Province fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.05	0.05	0.00	0.04	0.07	0.06	0.00	0.00	0.03
N	4637	4637	4637	1118	4763	4621	4664	4572	4664
Mean of dep. var control at baseline	1.66	1.56	0.02	1.51	87.07	53.27	26.38	14.52	0.60

Notes: Standard errors in parentheses
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

plantations (Table 8 and Table 9 for productive and employment outcomes, respectively). Distance to the closest plantation is measured in pixels of 30 m each; but since the inverse of the distance is a nonlinear function, coefficients do not have a direct interpretation and we focus on the direction and significance.

For distance, the results on productive outcomes are largely in line with those of the basic specification (considering plantation presence). Households that are closer to forestry plantations established after 2007 have a significant increase on total area and on cultivated area. Negative effect on yields are also observed, possibly driven by the increase on area size given that total output value does not show significant changes. Households closer to forestry plantations after the plantations were established also spent significantly more on seeds than households further away.

The results of distance on employment outcomes show an increase in the probability that households employed full-time workers, although again no effects are found on the probability of hiring part-time workers or on the number of workers hired. The results on employment of the head of household interestingly complement the prior findings. Head of households that are closer to forestry plantations have an increased likelihood of being self-employed, a lower likelihood of having agriculture as the main activity, and an increased likelihood of being employed in the nonfarm sector. Results for crop choices (Table S11, SI) confirm the previously found results.

The results of the intensity of exposure using the share of the area in a 20-km buffer around the household occupied with forestry plantations (Tables 8 and 9) show that a greater area does not have an extra impact on productive outcomes of the household. Results on employment outcomes show again an increased likelihood that households hire full-time workers, and confirm the previously found effects of a decrease in wage employment for the head of household. Results for crop choices are again in line with the basic specification (Table S12, SI).

Table 9
Diff-in-Diff effects of exposure based on plantation share on employment outcomes.

	Employed fulltime (Yes/No)	Employed parttime (Yes/No)	Workers employed (N)	Male workers employed (N)	Female workers employed (N)	Wage Emp (Yes/No)	Self Emp (Yes/No)	Ag MainAct (Yes/No)	Ag Secondary Act (Yes/No)	Nonfarm (Yes/No)
Exposure	− 0.02	0.01	1.52	0.61	0.91	0.16**	0.02	0.02	− 0.03	0.01
	(0.02)	(0.06)	(1.33)	(0.67)	(1.14)	(0.07)	(0.05)	(0.03)	(0.02)	(0.02)
Dummy post	− 0.01	− 0.08***	− 2.27*	− 0.91	− 1.36*	− 0.02	− 0.05***	0.08***	− 0.07***	− 0.01
	(0.01)	(0.02)	(1.15)	(0.67)	(0.80)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)
ExposureXPostXInt	2.02**	− 1.20	27.69	− 7.62	35.32	− 5.60***	2.42	− 0.16	− 0.29	0.45
	(0.91)	(2.84)	(94.86)	(27.84)	(74.33)	(2.11)	(3.06)	(1.05)	(0.76)	(0.65)
Female HHhead	− 0.01**	− 0.05***	− 1.47	− 0.61	− 0.87	− 0.07***	− 0.18***	0.01	− 0.03***	0.02**
	(0.00)	(0.01)	(1.07)	(0.70)	(0.70)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
Age HHhead	0.00***	0.00***	− 0.04	− 0.02	− 0.02	− 0.00***	− 0.00***	− 0.00**	0.00	0.00**
	(0.00)	(0.00)	(0.03)	(0.02)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Years ofEdu HHhead	0.00***	0.02***	0.04	0.09	− 0.05	0.02***	0.01***	− 0.04***	0.03***	0.01***
	(0.00)	(0.00)	(0.11)	(0.07)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Province fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.02	0.05	0.14	0.12	0.13	0.05	0.05	0.12	0.09	0.03
N	4763	4763	111	111	111	4763	4763	4763	4763	4763
Mean of dep. var control at baseline	0.02	0.20	6.51	4.13	2.38	0.24	0.52	0.82	0.13	0.04

Notes: Standard errors in parentheses
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

Table 10
Diff-in-Diff effects of exposure on natural vegetation and cropland on productive outcomes.

	Area total (Ha)	Area cultivated (Ha)	Area Perm (Ha)	Area measured (Ha)	Output value (PPP)	Yields (PPP/Ha)	Sales value (PPP)	Sales/Ha (PPP/ Ha)	Seeds cost (PPP)
Dummy post	− 0.35***	− 0.34***	− 0.00	− 0.26**	236.21***	289.96***	174.93***	385.73	3.62***
	(0.09)	(0.08)	(0.01)	(0.12)	(48.18)	(42.80)	(57.63)	(270.30)	(0.45)
Exposure Only CL	0.04	0.11	− 0.00	0.03	− 314.48	− 142.57	− 29.62	97.18	1.44
	(0.13)	(0.11)	(0.01)	(0.21)	(193.70)	(121.42)	(41.13)	(146.38)	(0.95)
Exposure Both CL-NV	0.05	0.16	− 0.00	− 0.33	− 279.21	− 141.74	− 65.96*	− 115.50	5.52***
	(0.26)	(0.27)	(0.01)	(0.22)	(187.92)	(120.01)	(33.49)	(107.01)	(1.29)
OnlyCL XPost	1.55***	1.33***	0.00	− 0.05	205.40***	− 0.70	− 30.61	− 207.66	− 0.43
	(0.11)	(0.12)	(0.01)	(0.15)	(66.69)	(48.01)	(46.94)	(202.26)	(1.17)
BothCL-NV XPost	0.25	0.12	0.00	− 0.05	− 28.63	− 108.10*	− 25.68	20.07	5.98
	(0.35)	(0.35)	(0.01)	(0.23)	(67.83)	(60.24)	(55.28)	(83.04)	(9.72)
Female HHhead	− 0.39***	− 0.38***	− 0.01**	− 0.52***	− 123.35***	− 50.80**	68.23	603.58	0.04
	(0.05)	(0.04)	(0.01)	(0.12)	(28.16)	(24.08)	(129.56)	(640.43)	(0.84)
Age HHhead	0.01***	0.01***	0.00**	0.01***	0.92	− 0.01	− 1.64**	− 3.90	0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.59)	(0.70)	(0.75)	(3.10)	(0.02)
Years ofEdu HHhead	0.01	0.01	0.00	− 0.03	3.75	6.55	− 3.38	− 28.11	0.35***
	(0.01)	(0.01)	(0.00)	(0.02)	(4.19)	(3.94)	(5.92)	(26.83)	(0.13)
Dummy wage employed	− 0.00	− 0.01	− 0.01	0.11	13.08	30.70	105.73	630.04	0.53
	(0.07)	(0.07)	(0.01)	(0.16)	(27.98)	(26.78)	(123.81)	(624.68)	(0.67)
Dummy self employed	0.11**	0.08*	0.01	− 0.07	25.36	14.75	106.89	378.62	1.55***
	(0.05)	(0.05)	(0.01)	(0.11)	(21.67)	(25.15)	(69.80)	(341.27)	(0.56)
Province fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.05	0.05	0.00	0.04	0.07	0.06	0.00	0.00	0.03
N	4637	4637	4637	1118	4763	4621	4664	4572	4664
Mean of dep. var control at baseline	1.66	1.56	0.02	1.51	87.07	53.27	26.38	14.52	0.60

Notes: Standard errors in parentheses
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

5.5. Heterogeneity of impacts

We find differences in households' productive and employment outcomes depending on the type of previous land uses over time of the localities where the plantations were established (equation (3); Tables 10 and 11). No household in our study sample was exposed to plantations that were established on previous natural vegetation exclusively. We detect increases in total farm and cultivated areas only among those households in "cropland only" trajectories, where "cropland only" is defined as such if all plantations in the buffer zone were established where previous land use was cropland (32 % of exposed households). Plantations established on previous cropland also increased the households' farm output value. We detect yield decreases among households exposed to plantations established on previous cropland as well as natural vegetation.

The results on employment outcomes (Table 11) show that households that experienced the establishment of a cropland only trajectory reported employing less full-time workers. The previously found negative effects on wage employment are consistent across the different trajectories. The increase in nonfarm employment for the head of

Table 11
Diff-in-Diff effects exposure on natural vegetation and cropland on employment outcomes.

	Employed fulltime (Yes/No)	Employed parttime (Yes/No)	Workers employed (N)	Male workers employed (N)	Female workers employed (N)	Wage Emp (Yes/No)	Self Emp (Yes/No)	Ag MainAct (Yes/No)	Ag Secondary Act (Yes/No)	Nonfarm (Yes/No)
Dummy post	− 0.01	− 0.07***	− 2.25*	− 0.88	− 1.37*	− 0.02	− 0.05***	0.08***	− 0.07***	− 0.02
	(0.01)	(0.02)	(1.16)	(0.69)	(0.80)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)
Exposure Only CL	− 0.03*	0.02	0.11	0.79	− 0.68	0.01	− 0.04	0.04	− 0.04	− 0.01
	(0.02)	(0.08)	(1.47)	(1.22)	(1.11)	(0.03)	(0.04)	(0.04)	(0.04)	(0.01)
Exposure Both CL-NV	− 0.01	0.05	2.36***	0.90	1.46**	0.31***	0.08	0.03*	− 0.03*	− 0.00
	(0.04)	(0.08)	(0.84)	(0.63)	(0.68)	(0.03)	(0.09)	(0.02)	(0.01)	(0.01)
OnlyCL XPost	− 0.03**	− 0.12				− 0.08***	0.02	− 0.05	0.01	0.04***
	(0.01)	(0.08)				(0.02)	(0.02)	(0.04)	(0.04)	(0.01)
BothCL-NV XPost	0.05	− 0.07	− 0.17	− 0.60	0.43	− 0.26***	0.00	− 0.03	− 0.01	0.04
	(0.05)	(0.09)	(1.77)	(0.79)	(1.26)	(0.02)	(0.10)	(0.03)	(0.02)	(0.03)
Female HHhead	− 0.01**	− 0.05***	− 1.36	− 0.61	− 0.75	− 0.07***	− 0.18***	0.01	− 0.03***	0.02**
	(0.00)	(0.01)	(1.15)	(0.76)	(0.76)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
Age HHhead	0.00***	0.00***	− 0.04	− 0.02	− 0.02	− 0.00***	− 0.00***	− 0.00**	0.00	0.00**
	(0.00)	(0.00)	(0.03)	(0.02)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Years ofEdu HHhead	0.00***	0.02***	0.03	0.09	− 0.05	0.02***	0.01***	− 0.04***	0.03***	0.01***
	(0.00)	(0.00)	(0.10)	(0.07)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Province fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.02	0.05	0.14	0.12	0.13	0.05	0.05	0.12	0.09	0.03
N	4763	4763	111	111	111	4763	4763	4763	4763	4763
Mean of dep. var control at baseline	0.02	0.20	6.51	4.13	2.38	0.24	0.52	0.82	0.13	0.04

Notes: Standard errors in parentheses
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

household is found to be driven by the cropland only trajectory. We estimate similar regressions on crop choice outcomes (Table S13, SI), and find that the results found previously are consistent across trajectory types.

6. Discussion

Our findings show that households exposed to forestry investments at the extensive margin experienced farmland expansion (cultivated or not). This effect was more prominent for households located closer to the forestry investments. However, we did not detect farmland expansion for households exposed to forestry investments at the intensive margin (i.e., depending on the extent of the plantation a household is exposed to). We believe that these differential effects on farmland expansion at the extensive and intensive margin are due to the small size of the farm holdings, which average below two hectares. In other words, since the farms are too small, the mere presence of plantations in a surrounding may affect them but not the variation in the level of exposure to plantations, a key finding that may guide the spatial planning of forestry investments.

Further, farmland expansion at the extensive margin was essentially present among those households exposed to plantations that were established in former croplands. Hence, we assume that these farmlands are displaced into more marginal land, where a larger area is necessary to maintain the same level of production. Households exposed to forestry investments also experienced a decrease in yields (consistent with Bottazzi et al., 2018, Hofman et al., 2019), although these effects become statistically significant only at a buffer radius greater than 25 km, possibly because of the greater number of exposed households. Given that productivity of smallholder farms in Sub-Saharan Africa is often attributed to an oversupply of labor (Barrett, 1996; Henderson, 2015; Ali and Deininger, 2015; Barrett et al., 2010; Muyanga and Jayne, 2019; Chiarella et al., 2023), in the absence of such labor intensification efforts, it is plausible that farmland expansion into marginal land could lead to a drop in yields.

Although our findings on farmland expansion seem to contradict other works on LSLA at large (Bottazzi et al., 2018; Zaehringer et al., 2021), much of these works focus on agricultural investments. There is evidence to suggest that investment locations are associated with production types and forestry investments. Partly due to its extensive nature, forestry investments are more likely to establish in populated smallholder lands (Abeygunawardane et al., 2022). Also given that agriculturally superior soils are already farmed and occupied, any displacement is likely to happen in marginal land leading to a decrease in yields. These results are also consistent with previous LSLA impact studies that found lower yields but no significant impacts on output value and sales (Bottazzi et al., 2018; Hofman et al., 2019; Sitoe and Lisboa, 2020).

In terms of employment, we did not find evidence to support significant direct employment in the plantation sector subject to exposure (as also found by Nolte and Ostermeier, 2017 and Serzedelo de Almeida and Delgado, 2019 for Mozambique). Exposed households showed a lower likelihood of wage employment coupled with an increased likelihood to move away from agriculture (found also in Anti, 2021). This could be due to an increase in employment in the nonfarm sector. However, an increase in unemployment or inactivity[9] might also explain this. Households closest to forestry investments were also more likely to be self-employed in sectors outside of agriculture. Based on this information alone, it is difficult to discern whether these changes in employment trends among exposed households are an effect subject to plantations promoting external scale economies (e.g., logging, milling, transportation, etc.) or a mere displacement out of the agricultural sector or out of employment itself.

There is some evidence that may point toward the possibility of plantations triggering agricultural commercialization. Exposed households showed a decrease in planting traditional crops, and incurred higher seed costs. These may indicate an opportunity to diversify and move toward cash crops. The effect of this on food security remains unknown. While some studies indicate a move toward cash crops to negatively affect food security (Matavel et al., 2022; Müller et al., 2021; Anderman et al., 2014), other studies have shown the additional income generated from cash crops compensates for the loss of staple crops (Kuma et al., 2019; Hashmiu et al., 2022).

7. Conclusions

The realised impacts of the forestry plantations on employment and incomes of the local population, to date, are not as promising as those first intended when the ambitious reforestation plans were designed. Although there is evidence of positive spillovers among households exposed to forestry plantations, such as the inclusion of higher value crops in the crop mix, our results also show that households increased their cultivated area, possibly into more marginal land, without hiring more agricultural labor; both factors which contributed to a decrease of total crop yields. Forestry investments also motivated a shift of economic activities, where the local population was less likely to be employed as salaried workers, more likely to be self-employed, and less likely to work in agriculture, which could either mean a shift toward employment in the nonfarm sector, unemployment or inactivity.

Our findings can help rethink reforestation plans, to consider the nuances of land tenure arrangements. If the allocation of public land to large-scale forestry companies is not producing important employment benefits to the local population, alternative strategies such as providing public grants coupled with private investments to the local community to cultivate community woodlots through contract farming, as suggested by Serzedelo de Almeida and Delgado (2019), could be considered. Strategic spatial planning that integrates considerations of land tenure can also have an important role in governing land-use frontiers for the well-being of rural communities and for sustainability outcomes (Oliveira and Meyfroidt, 2022). This implies that policymakers can carefully consider the spatial distribution of forestry investments to minimize adverse impacts on smallholder farmlands, especially those established in former croplands and those affected by land tenure conflicts.

Given the potential negative effects of farmland expansion into marginal lands and drop in yields, there is also a need for policies to continue supporting land intensification efforts in smallholder agriculture. Evidence also suggests forestry investments could catalyze agricultural commercialization. This presents an opportunity to facilitate a transition towards cultivating high-value cash crops; which could be supported by providing access to markets, credit facilities, and supporting the mid-stream segments of value chains. However, careful monitoring is necessary to assess the impact on food security and ensure that a transition does not disproportionately harm vulnerable populations.

Monitoring employment trends among households exposed to forestry investments is also a key area derived from our findings. Further research is needed to understand whether changes in employment patterns are due to a transition to the nonfarm sector (either promoted by external scale economies from forestry plantations or not) or due to a displacement out of employment. Interventions may be needed to support displaced workers in transitioning to alternative livelihoods.

Additionally, given that local communities are not seeing payoffs in their independent agricultural activities, plans to include local stakeholders and local agricultural organizations in land use discussions or negotiations are essential. This could be implemented through the use of integrated land use planning approaches, which involve considering the

[9] The IAI survey does not collect information to distinguish between unemployment (individuals actively seeking employment but currently without a job) or inactivity (individuals not participating in the labor force at all; those who are neither employed nor actively seeking for a job).

multiple competing land uses and stakeholders in decision-making processes to achieve sustainable and equitable land use outcomes. Pre-existing inequalities in local contexts may also be incorporated in the agreements of compensation mechanisms, as otherwise there is a risk of unequal distribution of benefits and of favoring elites (Bruna, 2023).

As better data becomes available, future work could re-evaluate these questions using panel data that follows the same households over time and matches plot-level information with remote sensing data. Further work could focus on clarifying the processes of farm displacement to marginal areas and the alternative activities of households whose main agricultural activities are disrupted, but longitudinal data is needed for such type of questions. Plot geo-referenced data matched with remote sensing information could help refine the selection of a counterfactual, add important geophysical controls, and evaluate other important outcomes that are not possible to track through self-reporting. Future work could also investigate the mechanisms driving the effects found. Few studies have investigated drivers of the impacts of LSLA through mediation analysis, finding for example that contract farming and the conversion to high-value crops are behind positive shifts in agricultural productivity (although with an unequal distribution of benefits), whereas market access and technology adoption have little effect in such changes (Sullivan et al., 2022). Similar analysis or qualitative work could help elucidate the drivers behind displacement and sector switch.

CRediT authorship contribution statement

Cristina Chiarella: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Conceptualization. **Philippe Rufin:** Writing – review & editing, Visualization, Software. **Dilini Abeygunawardane:** Writing – review & editing, Validation. **Adia Bey:** Data curation. **Sá Nogueira Lisboa:** Resources. **Helder Zavale:** Resources. **Patrick Meyfroidt:** Writing – review & editing, Supervision, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2024.107251.

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