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Research article

More private forests, more pressure on the commons? Puzzling effect of private woodlots on communal forests in Ethiopia

Tewodros Tadesse [a,b,*], Nigsti Hailay [c], Meley Mekonen Rannestad [d], Amanuel Hadera [b], Tafesse W. Gezahegn [a], Melaku Berhe [b], Negasi Solomon [e]

[a] Center in Agro-Food Economy and Development (CREDA–UPC–IRTA), Castelldefels, Barcelona, Spain
[b] Department of Agricultural and Resource Economics, Mekelle University, Mekelle, Tigray, Ethiopia
[c] Department of Land Resources Management and Environmental Protection, Mekelle University, Mekelle, Tigray, Ethiopia
[d] Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences (NMBU), Ås, Norway
[e] Tigray Institute of Policy Studies (TIPS), P.o.Box 902, Mekelle, Tigray, Ethiopia

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ABSTRACT

In many developing countries, farmers manage private forests for a variety of purposes, yet they also rely heavily on public forests to supplement their livelihoods. A key research question that remains underexplored is the relationship between private forest management and provisioning resource extraction from communal forests. In this study, we examine whether managing private forests is correlated with extraction of provisioning resources from the commons. Drawing on data from private woodlot-managing households in northern Ethiopia, we employ a control function approach to estimate the correlation between private forest management and extraction of provisioning resources from public forests, accounting for potential systematic differences and selection bias. Contrary to a priori expected substitution effect, our findings reveal a positive association where farmers who manage private woodlots extract significantly higher provisioning resources from communal forests. Specifically, model estimates indicate that income from communal forest provisioning resources is 42.5 % higher among farmers who manage private woodlots. This suggests that, rather than substituting for communal resource use, private forest management may actually complement it. As such, promoting private forest management without addressing institutional weaknesses in communal forest governance may instead be associated with more pressure on public forests. Thus, policy design should integrate private forestry incentives with robust communal forest management and enforcement strategies to ensure sustainable provisioning services.

1. Introduction

In many developing countries, provisioning ecosystem services (such as fuelwood, timber, fodder, wild food, water, etc.) play a vital role in supporting the livelihoods of forest-dependent communities. Forests, in particular, are key providers of these services. In northern Ethiopia, the Hugumbrda National Forest Priority Area (NFPA), a state-owned forest, is an important source of various ecosystem benefits. These include habitats for wildlife, livestock fodder, non-timber forest products, watershed protection (such as groundwater regulation, flood control, and soil erosion prevention), and climate change mitigation (Birhane et al., 2019; Solomon et al., 2019). Notably, the forest also generates income for local communities through the extraction of resources such as dead wood (used as fuel), fodder, water, medicinal plants, honey, and other non-timber products (Atsbha, 2017).

Forest communities derive a significant portion of their income from communal forests, primarily through various provisioning benefits (Dokken and Angelsen, 2015; Kazungu et al., 2020; Tadesse et al., 2022). However, this heavy reliance also exposes farmers to substantial risks if these forests are overexploited or managed unsustainably. To mitigate such risks and ensure long-term benefits, effective forest governance and the promotion of alternative sources of provisioning resources are essential. These strategies can help increase farmers' incomes from both wood and non-wood forest products (Gebremedhin et al., 2003; Ndayambaje et al., 2013; Gebreegziabher et al., 2021), meet rural energy demands (Ndayambaje et al., 2013; Toth et al., 2019), and reduce pressure on communal forests, thereby enhancing their sustainability (Piiroinen et al., 2016; Kimambo and Naughton-Treves, 2019).

* Corresponding author. Center in Agro-Food Economy and Development (CREDA–UPC–IRTA), Castelldefels, Barcelona, Spain.
E-mail address: tewodros.tadesse.woeldesenbet@upc.edu (T. Tadesse).

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Given the essential ecological and socio-economic roles forests play, it is critical for management authorities to promote alternative agroforestry practices and sustainable management strategies to prevent the overexploitation of communal resources. Key interventions aimed at curbing forest degradation include farmer-managed natural regeneration (FMNR), the devolution of woodlot management to local actors (both individual farmers and communities), and the adoption of alternative agroforestry systems, such as integrated agri-silviculture, silvopastoral, and agro-silvopastoral practices (Gebremedhin et al., 2003, 2023; Miller et al., 2017). When supported by appropriate policies, institutional incentives, and active community participation, these approaches can help reduce pressure on communal forests (Jagger et al., 2005; Piiroinen et al., 2016; Kimambo and Naughton-Treves, 2019; Bailey et al., 2021; Gebremedhin et al., 2023). While the promotion of private forests, community-managed forests, and FMNRs is based on the assumption that they will decrease reliance on communal forests, there is still limited empirical evidence confirming whether private forests effectively reduce resource extraction from communal areas.

Earlier studies (such as Gebremedhin et al., 2003; Jagger et al., 2005) have underscored the importance of devolving woodlot management to lower levels, such as village communities. These studies offer valuable insights into how collective, devolved management can contribute to both livelihood improvement and forest sustainability. However, empirical research that addresses the more critical question of whether farmer-managed (private) forests reduce dependence on (and extraction of provisioning resources from) communal forests is lacking. This is a significant gap, given that one of the main motivations for promoting farmer-managed forests is to relieve pressure on communal forest resources. The related literature highlights the benefits of private tree planting such as restoring tree cover (Piiroinen et al., 2016; Kimambo and Naughton-Treves, 2019), enhancing soil fertility and reducing erosion (Place and Garrity, 2015; Miller et al., 2017), improving rural livelihoods (Belcher et al., 2005), minimizing crop loss (Kimambo and Naughton-Treves, 2019), and increasing access to fuelwood (Toth et al., 2019). Yet, there is a lack of empirical research examining the impact of highly devolved, farmer-managed forests on reducing resource extraction from communal forests. Hence, the objective of this study was to investigate the influence of private forest management on the extraction of provisioning resources from communal forests. Based on this, this study contributes to the literature in two ways. First, it provides a quantitative estimate of the provisioning benefits that farmers derive from both private and communal forests. These estimates offer crucial insights into the economic value of forest-related activities for rural livelihoods in similar socio-economic (e.g., forest-dependent communities) and environmental contexts (presence of interlinked private and communal forests) across many developing countries. As noted in previous research, the absence of such data can lead to poorly informed forest management decisions and, consequently, the overexploitation of forest resources (Miller et al., 2017; Tadesse et al., 2021). Second, the study explores whether farmer-managed forests serve as substitutes for provisioning resources that would otherwise be extracted from communal forests. In doing so, it contributes to ongoing debates about the extent to which private forests can meet farmers' economic needs while easing pressure on the commons.

The rest of the paper is organized as follows. In section 2, we discuss the conceptual framework that explains how private forest management may govern resources collection from communal forests. In section 3, we describe and discuss the data and operational definition of key variables. Section 4 presents the method of estimation. In section 5, we report and discuss the results. Section 6 concludes.

2. Conceptual framework: private forests and resource extraction from the commons

To frame the context, we draw on Entitlement Analysis (EA) (Leach et al., 1999; Sikor and Nguyen, 2007) and the Sustainable Livelihoods Framework (SLF) (UNDP, 2017). Both frameworks emphasize the central role of endowments in shaping rural households' livelihood outcomes. Entitlement Analysis provides a lens through which we examine farmers' tree planting and management practices on privately owned land. In this framework, endowments, which are defined as the rights and resources that social actors possess (Leach et al., 1999) form the basis for generating entitlements, such as access to private trees or communal forest resources. The Sustainable Livelihoods Framework complements this by highlighting the various forms of capital that farmers hold including human, social, financial, natural, and physical capital. Access to and control over these types of capital shape livelihood strategies and determine farmers' ability to gain and maintain productive assets such as land, labor, or technology. These assets, in turn, influence farmers' capacity to convert endowments into entitlements, including rights to harvest trees from private land or communal forests. Importantly, these entitlements are not only shaped by farmers' individual resources but also by the broader institutional environment. In this regard, Schlager and Ostrom (1992) identify a bundle of rights (related to access, resource extraction, management, exclusion [the right to decide who can access and use the resource] and alienation [the right to sell or lease any of the above rights to others]) that can be held individually or collectively in the governance and use of resources from private land and/or communal forests. Institutions govern access to and control over key productive resources, thereby influencing farmers' opportunities and constraints in pursuing different livelihood strategies (Sikor and Nguyen, 2007). Through this integrated lens, we examine how differential access to endowments and capital affects the ability of rural households to engage in private forest management and extraction of resources from communal forests.

Beyond endowments and entitlements, Loison (2015) and Kemigisha et al. (2022) differentiate between *survival-led* and *opportunity-led* livelihood strategies. Farmers with limited assets and capital (such as land) use extraction of resources from the environment as a survival (survival-ed) strategy. These are poor households that are more dependent on non-high-value forest products (such as non-timber products) to meet their basic needs, which contribute a large proportion to non-cash income of such households (Shackleton et al., 2024). On the other hand, wealthier farmers, particularly those with private forests and greater access to various forms of capital may pursue opportunity-led strategies that enable them to derive larger entitlements, including the extraction of more trees, fodder, and other resources from communal forests (Sikor and Baggio, 2014). However, the degree of dependence on forest resources is not uniform and may vary with the availability of substitutes (Sikor and Nguyen, 2007). Farmers who manage private forests might rely less on the commons, as they are more likely to substitute products such as fuelwood and timber from communal forests with those harvested from their private holdings. Nonetheless, several other factors can influence the relationship between private forest management and resource extraction from communal forests. For example, Angelsen and Kaimowitz (2004) argue that communal forest use and conservation are shaped by a range of variables, including farmer characteristics, production systems, market dynamics, and tenure conditions. In particular, weak enforcement of tenure rights over communal forests may create opportunities for exploitation. Under such conditions, farmers with private forests, especially those responding to favorable market incentives may find it economically advantageous to extract additional resources from the commons to increase profits (Robinson et al., 2005).

Private forest owners have the advantage of being not too reliant on communal forests, compared to non-owners. For woodlot owners, higher prices create incentives to increase extraction of resources from the commons. On the other hand, the price elasticity of farmers who do not own private woodlots is low because of their subsistence use and heavy reliance on communal resources with less ability to respond to market incentives, especially if they face regulatory or social constraints. In addition, private forest owners are likely to be better connected to the market due to the endowments and entitlements (private forests) they have, which helps build social capital and market networking. Moreover, private forest owners may see communal forest resources as a form of insurance, during market shocks (e.g., price shocks). On the other hand, due to their reliance on communal forests, non-owners are often dictated by necessity than market choice.

Furthermore, Adhikari (2005) notes that while poorer households often rely on forest resources as a form of insurance to buffer against consumption shortfalls, wealthier or less poor households may seek to maximize income by selling these resources, particularly when market conditions are favorable. Similarly, Kemigisha et al. (2022) argue that ease of access and proximity to markets can incentivize some farmers to exploit these opportunities and increase their extraction of resources from communal forests. Building on this perspective, opportunity-led farmers, especially those who manage private forests may be drawn to high-value resources available in the commons, such as fuelwood, timber, and charcoal, which offer lucrative prospects for commercial engagement. The subsequent gains in the form of higher provisioning benefits (extraction of forest resources) due to market opportunities or institutional failure (e.g., weak enforcement, selective enforcement of rules and/or lack of capacity) may further lead to uneven benefit distribution (i.e., resource extraction) from communal forests.

Provisioning benefits from communal forests vary both in relative and absolute terms across households. For instance, Adhikari (2005) finds that poorer households tend to receive fewer absolute benefits from communal forests compared to wealthier households. Similarly, López-Feldman (2014) observes an inverted U-shaped relationship between income and forest resource extraction, indicating that reliance on forests initially increases with income but eventually declines as wealth grows. This suggests that economically better-off households, including those who manage private forests (Sikor and Baggio, 2014), may still extract substantial resources from the commons. However, these higher resource extractions may also be explained by household attributes such as human capital and land wealth (McSweeney, 2005). In this regard, Ainembabazi and Angelsen (2014) find that the establishment of individual forest plantations, which are comparable to private forests is associated with only a modest reduction in the extraction of resources from communal forests. Moreover, their study shows that resource extraction tends to increase with farmland size, although at a decreasing rate. Similarly, Adhikari (2005) reports that households with greater land and livestock assets derive higher provisioning benefits from the commons. Consistent with the EA and the SLF, these patterns highlight how differences in endowments such as land, livestock, and other productive assets can lead to varied resource extraction behaviors. Farmers with greater endowments are often better positioned to convert their assets into entitlements, enabling them to access both private and communal forest resources. As such, households with private forests may not necessarily reduce their use of communal forests; instead, their resource extraction practices are shaped by a complex interplay of asset ownership, market access, and institutional conditions. The flow chart in Figure 1 summarizes the conceptual framework.

3. Data and methods

3.1. Forestland, study areas and data

The data for this study were collected from forest-dependent communities in three districts within the Tigray region of northern Ethiopia. The Hugumbrda National State Forest (see Fig. 2) was selected as the case study site. This public forest is situated between 12°33′ and 12°42′ N latitude and 39°30′ and 39°39′ E longitude, and spans across the districts of Enda-Mekoni, Ofla, and Raya-Azebo. Elevation within the forest ranges from 1560 to 2688 m above sea level (Birhane et al., 2019). Hugumbrda is classified as a dry Afromontane Forest and features diverse vegetation, including tree, shrubland, and liana species. The dominant tree species include *Juniperus procera*, *Olea europaea* subsp. *cuspidata*, and *Afrocarpus falcatus* (Birhane et al., 2019). Despite exposure to occasional exploitation by local communities, the forest has remained relatively intact. The government holds responsibility for its use and management, enforcing regulated access to forest resources. While resource extraction from the forest is primarily conducted through legal means, instances of unauthorized collection do occur. Logging and live tree cutting are prohibited. Nevertheless, the forest provides various essential resources to local communities, including firewood, building materials, wild fruits, water, farm tools, and livestock fodder.

A multi-stage sampling procedure was employed to construct the sample of farm households. In the first stage, the three districts intersecting the Hugumbrda forest including Enda-Mekoni, Ofla, and Raya-Azebo were purposively selected, as all are directly located within the forest area. These districts had a total population of 402,000 (Hailay, 2020). In the second stage, six *tabias*[1] (the lowest administrative units) were randomly selected from these districts to ensure that the sample reflected the average characteristics of the broader district populations. Then, population rosters were obtained from each *tabia* to construct the sampling frame based on which the final sample of households were selected. In the final stage, 400 sample households were randomly selected from the *tabias* based on probability proportional to size (proportional to the size of total households of each *tabia*). These final sample of households live in the vicinity of the communal forest (see Table 2) and mainly make a living on mixed crop and livestock livelihood system. Forest resources from private and communal forest resources also make useful contribution to their livelihoods (Hailay, 2020). For data collection, institutional clearance was obtained from Mekelle University Office for Research and Community Services; and farmers' consent was obtained before all interviews. Data were collected through interviews using structured questionnaires. Trained enumerators and two members of the research team went door-to-door to collected the data, and as a result, response rate is full.[2] The data were collected between January and February 2020 just before the war on Tigray (September 2022 to November 2022) broke out, which may have affected collection of provisioning resources due to weakened forest-governance institutions in the same period. Following the end of the war, forest management institutions are functioning; and provisioning resource extraction by farmers is unlikely to have significantly changed from the situation before the war. Data included private forest (woodlot) management activities, access to and use of resources from the communal forest, detailed information on each provisioning benefit obtained from the communal forest (such as type and quantity, price and costs of the provisioning resources harvested), socio-economic characteristics, household asset and income levels, farm attributes, access to institutional services and other community characteristics. Data collection for these different characteristics and variables was disaggregated by gender. In this framework, data from female and male-headed households were collected about, for example, provisioning benefits from the commons and private forest management. Data related to participation in these activities were also disaggregated by gender (male and female members). Appendix Table A.3 presents summary statistics of some of the independent variables and other characteristics of farmers used for analysis.

3.2. Operationalization of farmer-managed forests

The main feature of farmer-managed forests is tree plantation by smallholder farmers on private land. In different countries, the nature

[1] *Tabia* is the smallest administrative unit in Tigray. The selected *tabias* were Meswaeti, Tahtay-Haya, Beru, Werebaye, Hashenge, and Hugumbrda. The total population of these *tabias* was circa 12,000 in 2020 (Hailay, 2020).

[2] This process enabled us to obtain data needed on some of the key variables including provisioning benefits from the commons, income from private forests, etc., and there were no missing data.

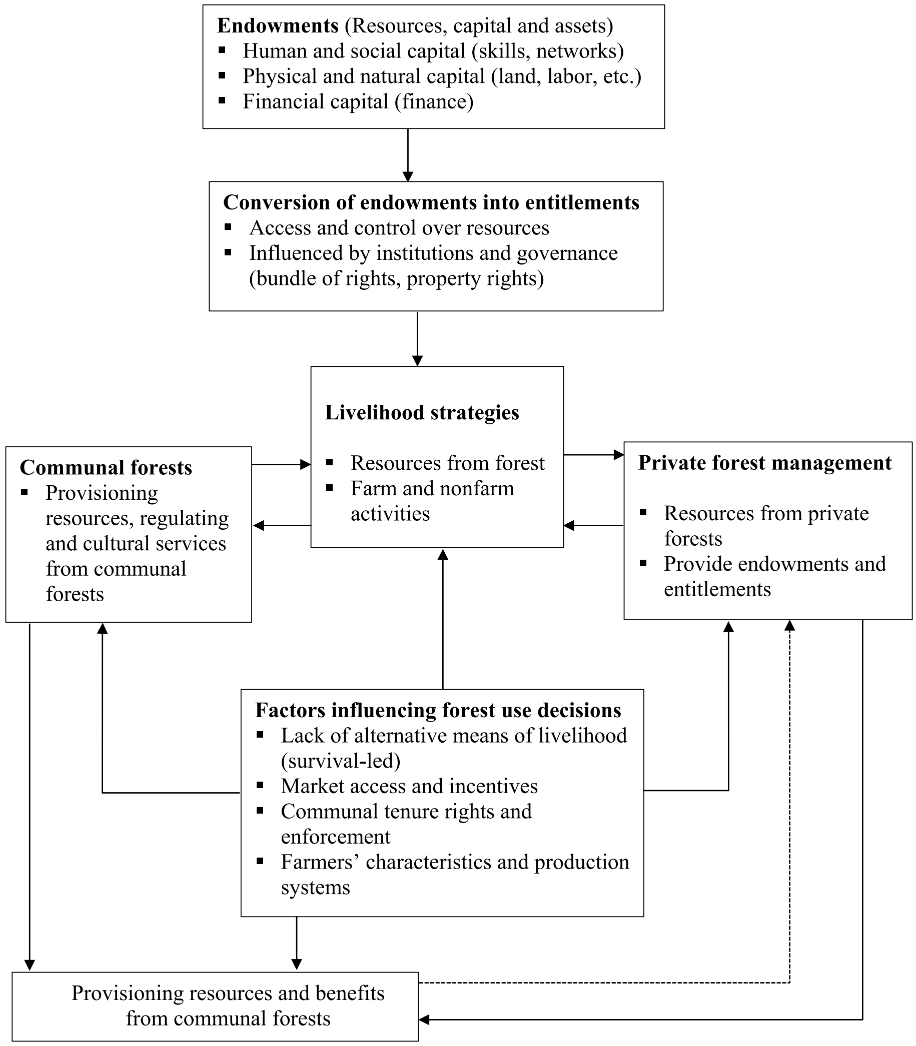

Fig. 1. Flowchart depicting the conceptual framework.

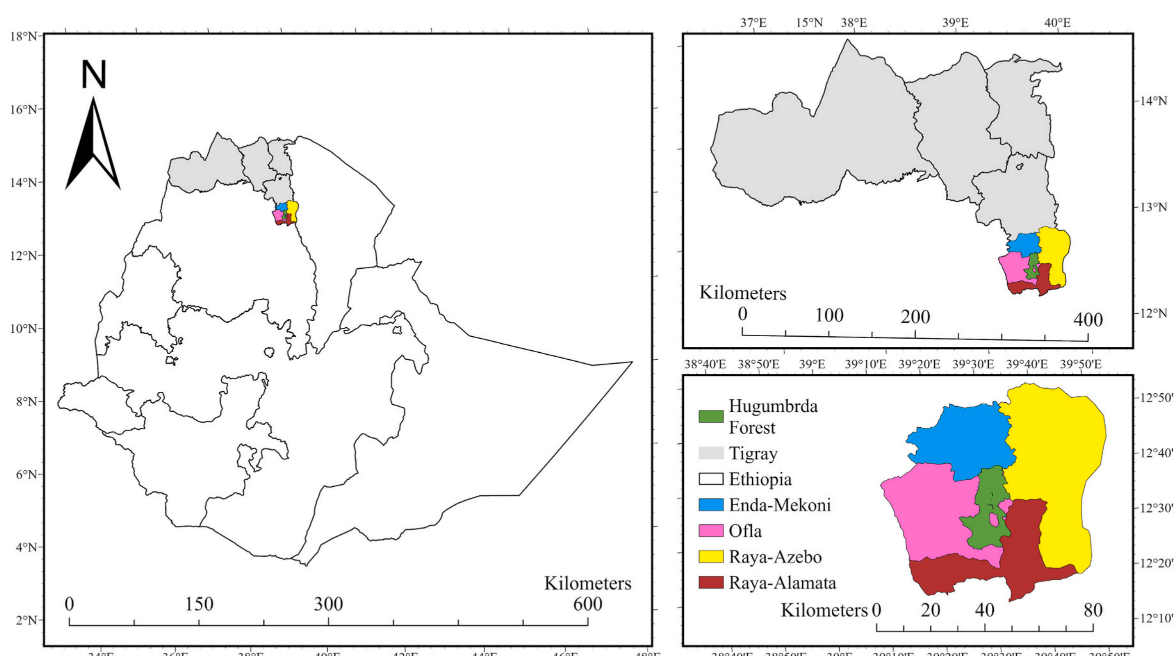

Fig. 2. Location map of the Hugumbrda State Forest.

and scale of farmer-managed forests vary. In the context of east Africa, farmer-managed forests generally are characterized by monoculture or mixed plantation of trees for timber, firewood, and fruits on a small private land (Kimambo and Naughton-Treves, 2019). While these farmer-managed forests are prevalent in many countries and localities, the scale in Tigray is significantly smaller where farmers plant different species of trees on pieces of peripheral land, steep slope land, river banks and gully land (Birhane et al., 2019; Gebremedhin et al., 2003).

In this study, farmer-managed forests are operationally defined as monoculture or mixed plantation of exotic or native trees on a confined area of private land. The private forests or woodlots are typically located in areas such as backyards, the edges of agricultural plots, hillsides, degraded or unused land, and riverbanks that farmers acquired either through traditional (customary) tenure systems or government allocation. While we have no data on the actual area of private forest land, ownership is determined by the presence of a designated parcel of land on which trees are grown. Farmers with trees planted on designated woodlot areas are classified as woodlot (forest) owners, whereas those without any trees on such land are considered non-owners. As we observe from the data, there is divergent woodlot management with some farmers managing several species of trees though monoculture woodlot management is dominated by cultivation of *Acacia albida*, *Ziziphus spina-christi*, *Eucalyptus* and *Euphorbia abyssinica* while the mixed forests in addition include *Cordia Africana*, *Juniperus procera*, *Pterolobium stellatum*, *Olea europaea subs cuspidate*, *Tamarindus indica*, *Euphorbia tirucalli*, *Carissa edulis* and *Acacia sieberiana*.

3.3. Quantifying and valuing provisioning resources (benefits)

As our key response variable, we define provisioning benefits by the monetary value of different provisioning resources[3] (Table 1) obtained from the communal forest in the previous 12-month period. To quantify and value the different provisioning resources, we used the following steps. First, we made an inventory of the different types of provisioning resources farmers obtained from the communal forest and estimated the annual flow, i.e., the quantity of each provisioning resource collected and used by farmers over the last 12 months. For this, we followed the standard literature of quantifying provisioning benefits to identify, count, weigh and measure the flow of forest resources (Kalaba et al., 2013; Darvill and Lindo, 2015). As part of this, we asked farmers to state the quantity of each provisioning resource collected, utilized and sold at the market. We collected these data by asking farmers how many times they collected different provisioning resources per year, and how much of each provisioning resource was utilized for own consumption and/or sold at the market. We used the market price approach to monetize and value the provisioning resources through collecting average village-level prices of each type of resource. Since there is market price for each of the provisioning benefits, the value of each benefit was computed by multiplying quantified flow of each resource by the average market price.

Table 1
Provisioning benefits from the commons (n = 400).

Type of provisioning resource	Percent of households	Mean (SD) (Birr)	Share in total value (%)	% of value generated by females	% of value generated by males
Fuel wood	20.0	635 (2587)	39.4	84.7	15.3
Water	9.5	670 (1882)	26.5	75.8	24.2
Building materials	3.25	450 (641)	7.8	9.20	90.8
Farm tools	17.0	290 (145)	11.8	0.30	99.7
Medicinal herbs	3.0	59.5 (266)	0.3	100	0
Livestock fodder	4.75	574 (647)	8.8	0	100
Honey	1.50	144 (1981)	2.8	19.8	80.2
Others (tooth brush, etc.)	15.0	859 (2762)	2.6	33.9	66.1

Note: At the time of data collection in early 2020, 1 USD was equivalent to circa 34 Ethiopian Birr.
The sum of percent of values generated by male and female members goes beyond 100 % since each member can have values generated from multiple types of provisioning resources. Across gender (males and females) however, the values add up to 100 %.
Source: own calculation.

Table 2
Private forests and provisioning benefits (annual) by distance to the forest (n = 400).

	Distance to the forest within		
	[0–5 km]	(5 km–10km]	(10 km–15km]
Farmers with private forest (%)	58	36	13
Average provisioning benefits (Birr)	2576	1259	1794
Average net provisioning benefits (Birr)	1555	709	1025
Average private forest income (Birr)	2021	1579	1976
Average farm income (Birr)	8846	7297	3879

Note: the percent of farmers with private forests should not be added as they are not a construct of one category. As an example, 58 % of the farmers who live within 5 km of the public forest own private woodlots (the other 42 % do not); 36 % of the farmers who live between 5 and 10 km of the public forest own private woodlots (the other 64 % do not), and so on.
At the time of data collection, 1USD was equivalent to 34 Birr.
Income estimates are annual.
Source: own calculation.

Data on the cost of collecting provisioning resources were also collected. These costs were categorized into labor and non-labor components. Non-labor costs such as those related to tools, transportation, and other inputs were estimated using a cost-based approach. For labor costs, the opportunity cost of time was applied to calculate the value of family labor. Specifically, farmers were asked to report the amount of time spent collecting provisioning resources, which was then multiplied by the prevailing daily agricultural wage rate in the area. All costs and resource values were expressed in monetary terms. The net provisioning benefit was then calculated by subtracting the total collection cost (labor and non-labor) from the total market value of the harvested provisioning resources.

3.4. Measuring income from private forest (woodlot)

Income from private forests was one of the key outcome variables in this study. To measure this, farmers were asked to report the annual income they obtained over the past year from both wood and non-wood products directly harvested from their own forests. These included items such as fruits, fodder, and wood products used for fuel, construction materials, and farm implements. For each identified product, farmers were asked to specify both the quantity used for home consumption[4] and the quantity sold in the market. To estimate total income, the value of

[3] We did not consider the non-use values (such as aesthetic or biodiversity values) as they are difficult to quantify and put value on.

[4] To monetize the quantity of wood and non-wood products used for home consumption, we asked farmers how much the quantity used for home consumption was worth at the village market (based on village-level prices) or how much they would have to spend to buy the same quantity of each product from the village market.

products consumed at home was monetized using prevailing village-level market prices. The aggregate woodlot-related income was then calculated as the sum of the market value of home-consumed products and the actual income from sales.

4. Econometric strategy

The starting point for our modeling is the assumption that farmers decide to manage forests by comparing the benefits and costs of private woodlot (forest) management. If the expected net benefit (B^*) from private forest management is positive, farmers decide to manage private woodlots. In this context, B^* represents the unobserved net benefit from private forest management by farmers, which can be specified as:

$$B^* = \boldsymbol{\alpha}'\boldsymbol{Z}_i + u_i, \text{and} \quad \mathrm{D}_i = \begin{cases} 1 & \text{if } \mathrm{B}^* > 0 \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where **Z** denotes the vector of factors that influence the expected net benefit from private forest management, $\boldsymbol{\alpha}$ represents the corresponding vector of coefficients, D represents the dummy variable for private forest management (which would be equal to 1 if yes, 0 if no), u is the error term and i represents observation units.

In the study area, there exist many farmers who manage own forests. More broadly in Tigray, close to 90 % of the *tabias* have woodlots where local authorities further partition hillsides and degraded land among individual farmers to manage forests (Bekele, 2011). In our sample, the data show that circa 44 % ($n = 175$) of the farmers manage private woodlots, indicating the presence of still many farmers who do not have woodlots. While farmers decide to manage forests based on expected net benefits, this decision is likely to be endogenous[5] that systematically varies among farmers. These systematic differences may stem from differences in observable and unobservable factors that are common to the decision to manage private forests and decision to collect forest resources from the commons (i.e., provisioning benefits). For example, the endowments and entitlements farmers have may systematically influence not only private forest management but also collection of provisioning resources from the commons. As such, observed or unobserved heterogeneities may lead to self-selection in access to communal forests. Authorities also promote the uptake of different kinds of agroforestry practices (including private forests) as part of livelihood diversification and landscape rehabilitation programs, improvement of agricultural productivity and reduction of pressure on communal forests. These targeted promotions to expand private forests through for example endowment supports on private land, hillsides, and degraded lands, etc. are not random but based on observed farmers' characteristics, which are likely to be systematically related with access to communal forest-land and resource extraction from the commons.

Given these arguments about the potential endogeneity of private forest management, let us define our main model of provisioning benefits farmers obtain from the commons as follows:

$$y_i = \boldsymbol{\theta}'\boldsymbol{X_i} + \beta D_i + \varepsilon_i \tag{2}$$

where y is provisioning benefits from communal forest, **X** is the vector of exogenous control variables, and D is the treatment variable for the management of own forests. The other terms, $\boldsymbol{\theta}$ (vector of) and β denote the coefficients to be estimated, and ε is an independently and identically (*iid*) distributed random (error) component.

In estimating Eq. (2), we may assume that all the variables that affect both treatment assignment (private forest management) and the outcome variable (provisioning benefits) are observable. However, this is unlikely given the potential for omitted variables bias. Even if we manage to control all the observables that are common to the treatment and outcome variables, there will still be unobservables that can affect both variables. To consistently estimate the impact after conditioning on observable controls therefore, we used the control function approach (Wooldridge, 2015; Murtazashvili and Wooldridge, 2016). The control function approach allows consistent estimation of the treatment impact by allowing some unobservables to affect both treatment assignment and the outcome variable (Wooldridge, 2015). Moreover, Wooldridge (2010) argues that this model is robust to the nonlinear form of the binary endogenous variable's conditional mean that the standard two-stage least squares instrumental variable (2SLS IV) model does not accommodate.

Procedurally, the estimation involved two steps. In the first step, we estimated a probit model of the endogenous variable (which is private forest management) on a set of exogenous variables and an instrument. From this first-stage model, we obtained the generalized residuals. In the second step, the generalized residuals and their interactions with the endogenous variable were then incorporated in Eq. (2) to account for selectivity bias and unobserved heterogeneity. Finally, we specify the model in Eq. (3) to estimate the impact of own (private) forest management on provisioning benefits from the commons:

$$y_i = \theta_0 + \theta_D D_i + \boldsymbol{\theta}_1'\boldsymbol{X}_i + \boldsymbol{\theta}_2'(D_i \times \mathbf{X}_i) + \alpha_1 \widehat{w}_r + \alpha_2 (D_i \times \widehat{w}_r) + v_i \tag{3}$$

where y is *provisioning benefits* from communal forest, D is the endogenous switching variable (i.e., D = 1 for *private forest management*, D = 0 for *no private forest management*); **X** is the vector of exogenous variables, $D \times \mathbf{X}$ is the interaction term among private forest management and exogenous variables; $D \times \widehat{w}$ is the interaction term between the endogenous variable and the generalized residual, $\widehat{w}_r$, from the first-stage probit model, and the $\boldsymbol{\theta}'s$ and $\boldsymbol{\alpha}'s$ represent vector of coefficients that need to be estimated. Murtazashvili and Wooldridge (2016) state that due to the potential endogeneity attributed to unobservables in the random component $v_i = D \times u_i$, standard instrumental variable estimators will not provide consistent estimates for Eq. (3). However, the control function involving multi-stage estimation gives consistent estimates (Wooldridge, 2015; Murtazashvili and Wooldridge, 2016).

The key coefficients from Eq. (3) that help us show the effect of private forest management on provisioning benefits from communal forests and whether there is selection bias due to unobservables respectively are θ_D; and α_1 and α_2. If α_1 or α_2 is statistically significant, the presence of selection bias is confirmed. More specifically, α_1 shows the presence of negative or positive selection bias, in which case $\alpha_1 > 0$ implies negative selection suggesting that farmers with lower-than-average provisioning benefits from the commons would be more likely to manage private forests. In estimating different specifications of equation (3), we clustered the standard errors at tabia level, and report correct standard errors that account the two-stage nature of the control function approach.

To facilitate identification, we used distance[6] to the communal forest as an instrument. We argue the instrument is valid and robustly meets the exclusion restriction assumption. The instrument is relevant because farmers residing at longer distance from the communal forest are likely to own private forests to compensate for the lower effective access they have to communal forests (i.e., lower access and higher cost of access due to distance). With higher effective access, farmers closer to the communal forest on the other hand would find it less attractive to manage private forests as the communal forest is likely to be seen as a 'substitute' source of important forest resources. On the other hand, though, these farmers may also be likely to participate in private forest

[5] Endogeneity refers to a situation where an explanatory variable is correlated with the error term in a regression model. It occurs mainly due to measurement error, simultaneity and omitted variable bias. It is a modeling problem because, if left unaddressed, it results in wrong causal implications.

[6] Distance to the forest was measured by both the length in km to the forest from farmers' residence and the time it takes them to reach the nearest edge of the forest.

management because they value the importance of readily accessible forest products more. Management of private forests by these farmers may be driven by intrinsic pro-biodiversity or ecosystem motivation of such farmers to retain key tree species amidst continued deforestation (Muhamad et al., 2014).

We also argue that the instrument provides a source of exogenous variation in private forest management. The relationship between this distance and private forest management can be considered exogenous for two reasons. First, while one might suggest that farmers more inclined to establish private forests could self-select into locations closer to communal forests, such relocation is highly unlikely. Encroachment or settlement near the forest is illegal,[7] and expansion into protected forestland for agricultural or residential purposes is strictly prohibited. In practice, illegal resettlement or farmland expansion into the forest area is negligible (Atsbha, 2017). Therefore, both private forest owners and non-owners are unlikely to be systematically located closer to or farther from the communal forest due to legal constraints and enforcement of forest boundaries. Second, it might be argued that farmers with a higher propensity to manage private forests could have been preferentially located closer to the forest through processes such as land reallocation or redistribution.[8] However, this is also unlikely. Land redistribution in the region has not occurred for over three decades, and the historical redistribution that did take place was limited to reallocating existing agricultural land among long-established residents. The process did not involve assigning new land (e.g., land closer to the forest) and did not result in systematic changes in proximity to the forest. As such, farmers' current distances from the communal forest are unlikely to be correlated with private forest management decisions in a way that would invalidate the instrument.

In the study area, there are no alternative economic activities that are likely to be correlated with proximity to the forest, such as logging, which is strictly prohibited or artisanal mining. Furthermore, while out-migration does occur, in-migration (i.e., relocation into the area) is negligible. This further minimizes the likelihood of any systematic relationship between distance to the communal forest and household characteristics. Additionally, there are no other forests in the vicinity that could undermine the validity of our instrument; the nearest alternative forest is approximately 30 km away. Given that all sampled households reside within a 15 km radius of the Hugumbrda forest, it is highly unlikely that they would travel such a long distance to access forest resources from a protected forest elsewhere. One potential concern is that proximity to the public forest may coincide with agro-ecological conditions favorable for private forest management. To partially address this, we control for unobservable agro-ecological and institutional heterogeneity at the local level by including tabia fixed effects in our analysis. Another consideration is that distance from the communal forest might be correlated with distance to markets or roads, such that households living farther from the forest might be closer to markets, thereby having better opportunities to commercialize forest products. While we do not have a direct measure to control for this potential confounding factor, we explore its implications by conducting a balance test and re-estimating our results after excluding the 109 households located more than 10 km from the communal forest. We return to this issue in Section 5.2.

Finally, drawing on our argument related to the relevance of the instrument, we use the effective access framework (to the forest, which is mainly through legal means) as a robust condition for the exclusion restriction (i.e., our instrument affects the extraction of provisioning benefits from the commons only its effect on private forest management). In this regard, our argument is that the direct effect of distance on provisioning benefits from the communal forest is limited. As a protected forestland, effective access to the Hugumbrda communal forest is through legal ways. While we cannot rule out illegal resource collection from the communal forest, the Hugumbrda state forest is a protected[9] forest where much of the provisioning resource extraction by farmers including litter, grass, medicinal herbs, water[10] and fire wood is through formal permits from local authorities. That said, there may still be indirect channels other than managing private forests that affect collection of provisioning benefits from the communal forest. Yet, after conditioning on observables, the control function allows us to attribute some remaining unobservable components to affect both treatment assignment and the potential outcome (Wooldridge, 2015), and make consistent estimation of the impact of private forest management. Tests related to the admissibility of our instrument (appendix Table A.4, with column 2 being the first-stage model) provide support for the argument as distance to the communal forest significantly affects private forest management while affecting neither provisioning benefits from communal forests nor income from private forests.

5. Results and discussion

First, we performed a test for the presence of selection bias in private forest management. The generalized residuals (α_1 *and* α_2) corresponding to private woodlot management are statistically significant (Table 3). This indicates the presence of unobservable factors that potentially influence both farmers' private forest management and collection of resources from the commons. But we know that the control function approach helps obtain consistent impact estimates by allowing some unobservables to affect both the participation in private forest management and provisioning benefits from the communal forests.

The instrument carries a negative coefficient, suggesting that private forest management is more likely for farmers who are situated closer to the communal forest, ceteris paribus. This result is consistent with data from Table 2 that indicate the proportion of farmer-managed forests increases with proximity to the communal forest. In this regard, our data show that of the farmers who live within 5 km of the public forest, 58 % manage own forests. Of those farmers who live in the range of 5–10 km and 10–15 km of the public forest, 36 % and 13 % manage private woodlots. While we empirically test whether the positive association between private forest management and proximity to communal forests translates into higher provisioning benefits (subsection 5.1), the indication is that proximity to communal forests drives private forest management. Consistent with this, Miller et al. (2017) also single out proximity to communal forests as the most important factor for tree plantation and management. On the other hand, assessment of provisioning benefits for woodlot-managing farmers across distance categories shows mixed pattern or trend (Table 2). Similarly, the correlation with net provisioning benefits and income from own forests paint a less clear picture. Otherwise, the results indicate that both private forest (woodlot) management and income from own forests are the highest among woodlot-managing farmers located within 5 km of the communal forest. The relationship however is not incremental in the sense that income does not linearly decrease (or increase) with distance (Table 2). For example, provisioning benefits from the commons for farmers who

[7] Ceteris paribus, it is legal to relocate away from the communal forest.

[8] In rural areas of Ethiopia, farmers often reside on or nearer to their farmlands. That said, some farmers also cultivate farm plots that are distant from their residence. This may result in some farmers living closer to the forest. Nevertheless, it is highly unlikely to be systematically related to those farmers who manage private forests.

[9] Weak enforcement may allow some form of illegal resource collection by farmers who live closer to the forest.

[10] Water is not a direct product of forests and it is not immediately clear how private forests contribute to water provision. However, there are studies which document the role of vegetation (such as forests) in helping slow down and filter runoff, reducing erosion and improving water availability and quality (Cornacchia et al., 2020) and maintaining a healthy stream flow (Cornacchia et al., 2020; Saklaurs et al., 2022).

Table 3
Second-stage results: income from private forests, provisioning benefits & other income ($n = 400$).

Variables	Income from private forest (Birr)	Provisioning benefits from public forest (Birr)
Own woodlot management	2722 (1171)**	3581 (1234)***
Gender of head	1386 (804.5)*	1241 (658.8)*
Age of head	64.85 (64.02)	70.20 (78.94)
Age-squared	−0.685 (0.681)	−0.687 (0.819)
Years of schooling of head	47.83 (51.27)	60.04 (49.45)
Marital status of head	201.6 (582.6)	57.42 (485.6)
Number of male members	627 (284.7)**	638.5 (217)***
Number of female members	−199.1 (210.1)	−205.5 (189.5)
Land size	1255 (607)**	−2180 (1198)*
Livestock size	306.8 (207.4)	350.8 (205.6)*
Years lived in the community	16.35 (10.61)	17.7 (9.31)*
Distance to all-weather roads	−90.2 (52.3)*	−95.3 (52.4)*
Distance to markets	−76.37 (72.8)	−80.6 (57.8)
Electricity connection	44.3 (398.6)	−63.9 (347.6)
Mobile ownership	2.293 (295)	28.05 (271.4)
GR: woodlot management (α_1)	1797 (642)**	2397 (1368)*
GR: interacted with woodlot management (α_2)	−3245 (2163)	−3649 (1761)**
Constant	−2775 (1860)	−2847 (1879)

At the time of data collection, 1USD was equivalent to 34 Birr.
GR denotes the generalized residual.
Robust standard errors are reported in parentheses.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
Source: own estimates.

live between 10 and 15 km is on average higher than that of farmers who live between 5 and 10 km.

5.1. Private forest management, provisioning benefits and other forest-based income

In this part of the analysis, we are interested in estimating the average impact across the whole population that managing private forests by farmers has. This average impact, defined as the average treatment effect (ATE) is the average difference in provisioning benefits farmers would obtain if all farmers in the population had private forests versus if no one had. Tables 3 and 5 present second-stage and average treatment effect (ATE) results of the impact of private forest management computed using Eq. (3). The results indicate significant differences in income from provisioning benefits from communal forests and net provisioning benefits. Estimates indicate that farmer-managed forests on average brought 54 % higher income, as compared to mean income of farmers that did not manage own forests (Table 4). Fig. 3 also provides support for the significance difference in mean income from provisioning resources among farmers with and without private forests. This is in line with findings by previous studies that document the importance of devolving forest or woodlot management to lower levels to increase not only income (Ramadhani et al., 2002; Jagger et al., 2005) but also environmental sustainability (Ramadhani et al., 2002; Toth et al., 2019). More importantly, we find private forests are correlated with higher extraction of provisioning benefits from communal forests where farmers with private forests were estimated to obtain on average 42.5 % higher provisioning benefit than farmers who do not manage own forests. However, farmers incur transaction costs, leading to significantly lower but still sizeable net provisioning benefits. The net provisioning benefits of farmers who manage own forests are 22.4 % higher, compared to the average net provisioning benefit of farmers in the study communities (Table 4). The results imply that participation in private woodlot management is positively correlated with higher extraction of provisioning resources from the commons. This suggest that farmers who manage private woodlots extract more provisioning resources from the commons. We probe into the robustness of this result through alternative specifications in subsection 5.2.

Table 4
Average treatment effect of private forest management ($n = 400$).

Outcome variables	Mean outcome	ATE	z-statistic	% of change
Income from private forest (Birr)	1856.2	2721.5	2.32**	54.0
Provisioning benefits from communal forest (Birr)	2260.2	3580.5	2.90***	42.5
Net provisioning benefits from the commons (Birr)	1198.7	2162.1	4.15***	22.4
Farm income (Birr)	7554.3	2733.2	1.30	28.2

At the time of data collection, 1USD was equivalent to 34 Birr.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
Source: own estimates.

In line with the sustainable livelihood framework, different forms of capital create endowments for farmers. Amidst prevailing market incentives and institutional failure, farmers use of these endowments that could explain resource collection from the commons vis-à-vis private forest management. One, endowments pave the way for tree entitlements on private land that in turn may be positively correlated with resource extraction from the commons. Land and labor endowments create an enabling condition for collecting resources from the commons (Ainembabazi and Angelsen, 2014). These endowments also help farmers overcome liquidity and credit constraints, making them more likely to adopt agroforestry practices, including private tree planting (Miller et al., 2017). In this context, tree entitlements such as private forests may open up market opportunities that incentivize farmers to increase the extraction and commercialization of high-value resources from communal forests.

Second, market incentives, particularly those related to the demand and prices of forest products can further motivate farmers who manage private forests to intensify engagement in resource extraction from communal forests. Farmers with private forests may be driven by the potential to exploit favorable market conditions and maximize returns by tapping into the commons. In this context, Kemigisha et al. (2022) suggest that such farmers are often ‘opportunity-led,’ strategically responding to high market demand or prices for forest products by extracting additional resources from communal lands. Moreover, private forest owners are likely to be better connected to the market due to the endowments and entitlements (private forests) they have, which helps build social capital and market networking. Moreover, private forest owners may see communal forest resources as a form of insurance, during market shocks (e.g., price shocks). These market-driven farmers may be particularly drawn to high-value resources available in the commons, such as fuelwood, timber, and charcoal, which present lucrative commercial opportunities. Third, institutional failures such as weak or selectively enforced forest regulations and limited enforcement capacity may exacerbate this dynamic by allowing these actors to extract disproportionately from communal forests. In such contexts, economies of scale in forest product harvesting and marketing may further incentivize farmers to capitalize on communal resources, thereby increasing their provisioning benefits through both legal and informal channels.

5.2. Robustness checks

To probe the robustness of the main results, we estimated several alternative models. In Table 5, we report results related to these. We first inspected the robustness of our results to an alternative proxy for provisioning benefits. We used a measure of provisioning benefits that nets

Table 5
Alternative models for robustness check (($n = 400$).

Dependent variable: Provisioning benefits (Birr)	Main results from Table 3	Alternative proxy: Net provisioning benefits	Travel time as instrument	Dropping obs. with less or equal to 5 km ($n = 201$)	Endogenous switching regression
	(1a)	(2a)	(2b)	(2c)	(2d)
Private forest management	3581 (1234)***	2162 (521)***	3167 (1035)***	3845 (1457)***	2700 (334.2)***
Gender of head	1241 (658.8)*	1319 (835.7)	1132 (772)	253.3 (844.6)	1571 (776.2)*
Age of head	70.20 (78.94)	−70.67 (119.9)	61.00 (65.24)	207.2 (131.4)	137 (152)
Age-squared	−0.687 (0.819)	0.846 (1.282)	−0.617 (0.695)	−1.794 (1.167)	−1.703 (1.798)
Years of schooling of head	60.04 (49.45)	64.62 (85.36)	49.10 (50.45)	80.37 (69.52)	64.28 (74.58)
Marital status of head	57.42 (485.6)	417.9 (587.9)	−14.30 (573.1)	389.4 (972.7)	1292 (991.3)
Number of male members	638.5 (217)***	580.6 (293.0)**	589.9 (265.9)***	528.3 (112.9)***	525.6 (312.9)*
Number of female members	−205.5 (189.5)	−451 (197.3)**	−200.0 (212.8)	−93.63 (104.5)	−89.82 (248.7)
Land size	−2180 (1198)*	−1608 (1103)	−2302 (1287)*	−2100 (1135)*	−2196 (1203)*
Livestock size	350.8 (205.6)*	146.3 (168.4)	318.0 (206.5)*	312.7 (174.1)*	345.7 (163.5)**
Years lived in the community	17.7 (9.31)*	5.828 (12.99)	16.25 (10.57)	11.85 (11.45)	41.86 (26.12)
Distance to all-weather roads	−95.3 (52.4)*	−115.1 (54.9)**	−85.15 (45.8)*	−82.71 (48.1)*	−28.2 (65.14)
Distance to markets	−80.6 (57.8)	−21.59 (69.5)	−64.62 (70.3)	−12.79 (91.8)	−33.43 (176.4)
Electricity connection	−63.9 (347.6)	87.0 (510)	−19.73 (390.3)	−71.06 (329.7)	−22.34 (103)
Mobile ownership	28.05 (271.4)	11.7 (296.4)	48.25 (301.2)	35.8 (344.1)	71.0 (365.2)
Forest resources collection (pred. prob.)	−770.7 (448)*	629.5 (685.1)	−754.8 (441.9)*	−1005 (531)*	
GR: woodlot management (α_1)	2397 (1368)*	1270 (1278)	1776.6 (801)**	3186 (1802)**	
GR: woodlot management (α_2)	−3649 (1761)**	1383 (1530)	−4359 (1558)***	−2299 (1131)**	
Constant	−2847 (1879)	268.1 (2998)	−2652 (1821)	−6312 (3342)*	−2399 (2665)

At the time of data collection, 1USD was equivalent to 34 Birr.
GR denotes the generalized residual. Robust standard errors are reported in parentheses.
$*p < 0.10$, $**p < 0.05$, $***p < 0.01$.
Source: own estimates

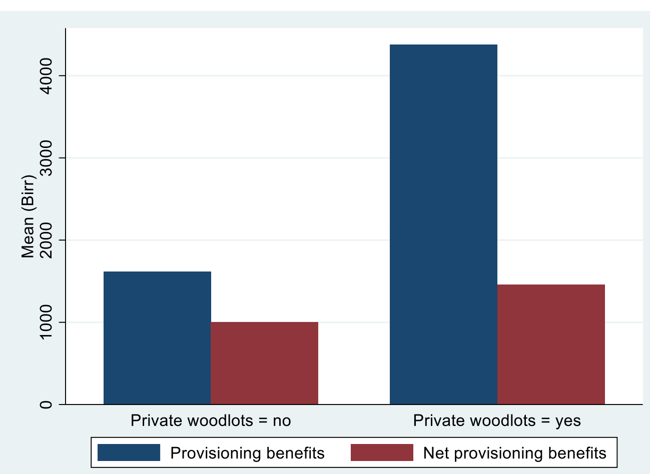

Fig. 3. Average provisioning benefits by private forest ownership.

out the costs associated with collecting and marketing provisioning resources. Then, we estimated a model using the control function approach where the corresponding results are reported in column (2a)[11] of Table 5. From the results, we observe that there is a robust correlation between predicted private forest management and the measure of provisioning benefits that nets out costs. In this specification, the smaller coefficient that private forest management carries is a mere indication of the cost farmers incur when collecting and marketing forest resources.

In Table 5, we report further robustness checks through changing the measure of our instrument–distance to the forest. We now use distance to the forest measured by travel time. Beyond physical proximity, farmers' access to the forest may vary based on the time it takes to travel to and from the forest. For example, even if the physical distance is close, there may not be viable transport due to scenery-related inaccessibility. In this regard, distance measured by travel time may better reflect the differences in terrain and quality of services such as roads and transport, and hence access to the forest. Moreover, travel time as a measure of distance may also attenuate measurement error as it accounts for differences in terrain (Melesse and Cecchi, 2017). Results based on using travel time as an instrument are reported in column (2b) of Table 5. The results are qualitatively the same as those reported in column (1a), which show the positive correlation of private forest management with resource collection from communal forests.

We further probe the robustness of our results by exploring unobserved heterogeneity that might potentially confound the relationship between private forest management and provisioning benefits. Unobserved heterogeneity may be observed from the fact that distance to the forest may reflect non-forest attributes that may challenge the exclusion restriction between distance to the forest and provisioning benefits. Farmers living close to the forest may self-select into managing own forests because for example the agroecology near the communal forest is suitable for private forest management. For these farmers, distance to the forest therefore might not capture only the effect of private forest management. That is, the short distance may not pick only the effect of private forest management on provisioning benefits (it may for example capture the effect of agroecological suitability of the area close to the communal forest). To test this potentially unobserved heterogeneity, we use two approaches. One, we drop the 199 farmers that reside within 5 km[12] of the communal forest and re-estimate the model with the remaining sample. The results from this model are presented in column (2c) of Table 5. These results are once more qualitatively the same as those reported in column (1a) of Table 5. This suggest that self-selection by farmers living close to the communal forest into private forest

[11] These results are second-stage results from a model based on the control function approach.

[12] We probed the robustness of our results further by iteratively dropping farmers who live within 3 (shorter) and 10 (longer) kilometers of the communal forest. The results (which are not reported) related to the main variables remain qualitatively robust.

management just because the climate and agroecology near the communal forest is suitable for private forest management is limited. In section 4, we noted the potential correlation between distance from the communal forest and distance to markets where farmers situated farther away from the communal forest may be actually closer to markets, which may enable them to sell forest products easily and obtain higher income from provisioning resources. To test this, we dropped the 109 farmers living more than 10 km away from the communal forest. Results from this model show that farmers with private forest management still earned significantly higher gross (by Birr 2810 = \$82.6) and net (by Birhane et al., 2019 = \$54.9) income from public forest resources.

The second approach we used to explore the effect of unobserved heterogeneity is to estimate an endogenous switching regression (ESR). As a regime, farmers who have private forests (the treatment group) may differ from those that do not in ways that affect provisioning benefits from the commons. ESR adjusts for this selection bias by explicitly modeling the selection process into treatment and correcting for it in the outcome model. Column (2d) in Table 5 presents results related to this alternative model. The estimated average treatment effect on the treated (ATT) shows that farmers with private forests earned on average 2700 Birr (=\$74.9) higher provisioning benefits, which is qualitatively the same but considerably lower than estimated effects reported in column (1a). This result from the endogenous switching regression may better reflect the correlation of private forest management with provisioning benefits as it accounts for unobserved heterogeneity among farmers that do and do not manage own forests. We also estimated a naïve ordinary least square (OLS) and propensity score matching (PSM) models to probe into how sensitive the estimates are to observed confounders. Despite the estimates from the OLS (Table A.6) and PSM (Table A.7) models differ significantly from the results of the main model, they nonetheless yield results that depict a qualitatively similar relationship. In addition, we have conducted subgroup analysis across gender and wealth proxies (land and livestock). These results reported in Figs. 4 and 5 and Table A.2 indicate varying but significant provisioning benefits by both male and female-headed households.[13] Moreover, spatial spillover effects where farmers who are neighbors of private forest owners could increase resource extraction from the commons (e.g., due to perceived opportunity or weak enforcement) may also affect the relationships. While we have not explicitly accounted for spatial spillover effects, a model we estimated by controlling for tabia fixed effects (which partially control for spatial effects) did not lead to qualitatively different

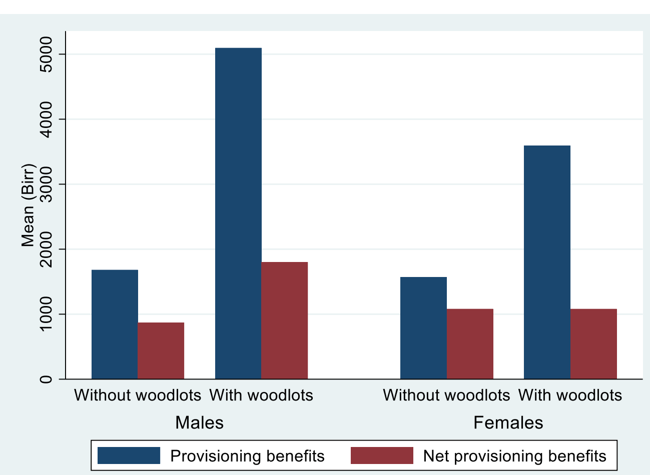

Fig. 4. Provisioning benefits by male and female-headed households.

[13] More results and discussion are presented in Section 3A in the appendix.

estimates. Through interacting wealth indicators (such as land and livestock size of farmers) with private forest management furthermore, we explored farmers' heterogeneity in resource extraction behavior from the commons. Consistent earlier results, we find that these wealth proxies (land and livestock size) exert heterogenous influence on resources extraction. Specifically, increasing land/livestock among private forest owners are not associated with a lower but more extraction of resources from the commons, as shown by the upward-sloping curves in Fig. 5. Consistent with sustainable livelihood framework, this indicates that wealthier private forest owners with greater endowments and entitlements may engage more in commercial or large-scale use of communal forest resources (e.g., for market sale); and they may be the 'opportunity-led' farmers (Kemigisha et al., 2022) who see communal forest resources as complementary to private resources rather than a fallback.

6. Conclusion and policy implication

This paper examined whether private forest management is positively correlated with the extraction of provisioning resources from communal forests. Recognizing that private forest management may influence decisions related to communal resource collection and associated benefits, we employed a control function approach to account for potential endogeneity and systematic relationships. This allowed us to identify the correlation between private forest management and the provisioning benefits derived from the commons.

We present two main conclusions. First, private forest management is positively correlated with the extraction of provisioning resources from communal forests (i.e., farmers with private forests extract more provisioning resources from the commons). Robustness checks across multiple model specifications consistently support this finding. Second, contrary to the expected substitution effect, the results indicate a complementary relationship between private forest management and provisioning benefits from the commons. This suggests that managing private forests does not reduce, but may instead incentivize greater extraction of resources from communal forests.

Given these findings, sustainable forest management interventions should move beyond the narrow promotion of private forest management and instead adopt integrated agroforestry systems. The anticipated substitution effect where private forest management reduces reliance on communal forests does not appear to hold. Rather, the observed positive correlation between private forest management and communal forest use suggests complementarity, particularly in contexts of weak institutional enforcement and strong market incentives. For policymakers, this underscores the need to integrate private forestry promotion with strengthened communal forest governance, equitable access to endowments, and market regulation to prevent overexploitation and support sustainable rural livelihoods. The tendency of private forests to cluster near communal forests may reflect intrinsic pro-environmental motivations among farmers, possibly driven by socio-cultural and economic values tied to specific tree species (Miller et al., 2017). While private tree planting contributes to ecological sustainability, its association with increased resource extraction from the commons underscores the need for broader, landscape-level management strategies. These policies should aim to balance forest conservation with local livelihoods and poverty alleviation goals. Such holistic approaches shall integrate key factors like household endowments (e.g., land and labor), market dynamics (e.g., resource prices and demand), and access to alternative livelihood options. These elements not only shape farmers' capacity to manage private forests but also enable economies of scale that may drive increased extraction from communal forests. Therefore, forest policy and management efforts should be context-specific and responsive to these structural conditions.

To address the increased pressure on communal forests associated with private woodlot management, policy efforts should focus on strengthening communal forest governance through community-based

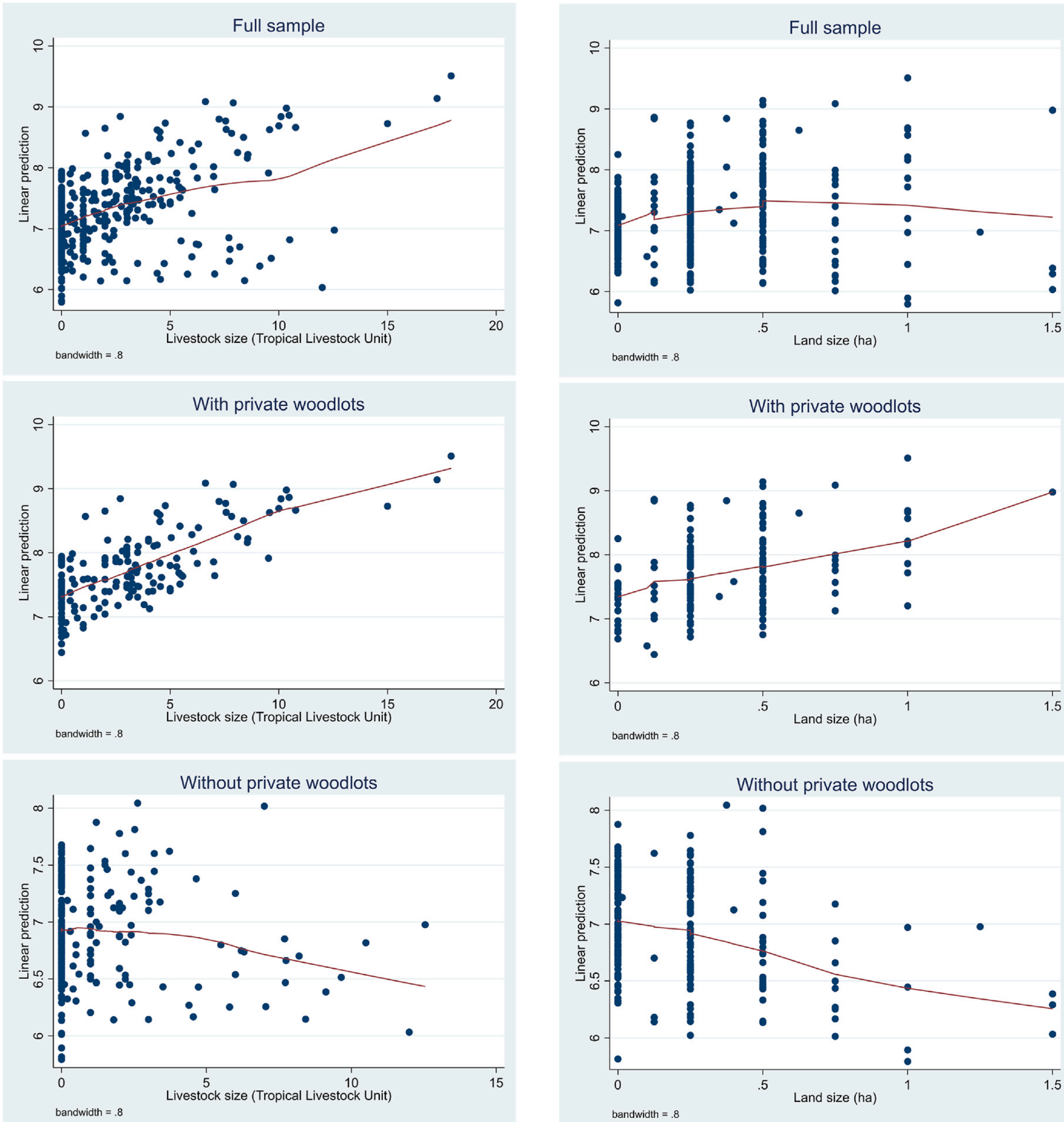

Fig. 5. Resource use prediction (log-form) vis-à-vis wealth indicators (land and livestock).

monitoring and incentive-linked conservation agreements. Community-based monitoring empowers local forest user groups to actively track resource conditions and enforce sustainable use, fostering collective forest conservation grounded in local knowledge and ownership. When combined with incentive structures such as conditional payments, access rights, or technical support tied to conservation outcomes, these mechanisms align farmers' individual incentives with communal sustainability goals, encouraging reduced overextraction and promoting forest regeneration.

Institutionally, strengthening governance may also require establishing and empowering local forest user associations by providing legal recognition, capacity building, and clear enforcement authority. These forest user associations can formalize collective decision-making, regulate resource use, and resolve conflicts while collaborating with forest authorities to enhance policy coherence and accountability. In the Ethiopian context, effective institutional arrangements should be adaptive to local social-economic and ecological conditions. Such integrated, community-centered forest conservation and governance models are critical for balancing private forestry incentives with sustainable management of communal forests.

Community-based monitoring, incentive-linked conservation agreements, and strengthened local forest governance are broadly applicable to many parts of Sub-Saharan Africa and other developing countries with similar communal land tenure and forest management systems. In contexts where farmers depend on private and communal forests, integrating locally legitimate institutions such as forest user associations with adaptive enforcement and incentive mechanisms can effectively balance livelihood needs with sustainable resource use. By recognizing the socio-cultural, economic and ecological diversity and customary governance structures common across the developing world, these approaches offer a flexible framework to mitigate the unintended pressures private forestry expansion may place on communal forests, thereby supporting more resilient and equitable forest use and conservation.

As a final remark, while we have relied on the control function approach to explore the way private forest management influences resource extraction, unobservables may still confound the relationship given our data is cross-sectional data. These issues can be better addressed using longitudinal data or experimental studies that capture time-varying heterogeneities and/or systematic (unobserved) heterogeneity in private forest management to better reflect its relationship with extraction of provisioning resources from the commons, which can be future area of research. Moreover, a limitation of this study is the reliance on self-reported data for income and provisioning resource extraction from communal forests, which may introduce bias due to underreporting. While this potential problem is unlikely to be systematically related with the status of private forest ownership, given our randomized sample, the possibility of misreporting remains despite measures we used to build trust and ensure confidentiality during data collection. Future research could incorporate methods to cross-validate self-reported data with administrative records or even satellite imagery to improve data reliability and provide a more accurate assessment of resource use patterns.

CRediT authorship contribution statement

Tewodros Tadesse: Writing – review & editing, Writing – original draft, Supervision, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Nigsti Hailay:** Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Meley Mekonen Rannestad:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Funding acquisition, Formal analysis, Conceptualization. **Amanuel Hadera:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Formal analysis. **Tafesse W. Gezahegn:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology. **Melaku Berhe:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology. **Negasi Solomon:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, 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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2025.126717.

Data availability

Data will be made available on request.

References

Adhikari, B., 2005. Poverty, property rights and collective action: understanding the distributive aspects of common property resource management. Environ. Dev. Econ. 10 (1), 7–31. https://doi.org/10.1017/S1355770X04001755.

Ainembabazi, J.H., Angelsen, A., 2014. Do commercial forest plantations reduce pressure on natural forests? Evidence from forest policy reforms in Uganda. For. Pol. Econ. 40, 48–56. https://doi.org/10.1016/j.forpol.2013.12.003.

Angelsen, A., Kaimowitz, D., 2004. Is agroforestry likely to reduce deforestation? In: Schroth, G., da Fonseca, G.A.B., Harvey, C.A., Gascon, C., Vasconcelos, H.L., Izac, A. M.N. (Eds.), Agroforestry and Biodiversity Conservation in Tropical Landscapes. Island Press, Washington DC, pp. 87–106.

Atsbha, H., 2017. Mapping and Valuation of Forest Ecosystem Services in Hugumbrda Forest. Mekelle University, Mekelle, Ethiopia. MSc Thesis.

Bailey, K., Salerno, J., Newton, P., Bitariho, R., Namusisi, S., Tinkasimire, R., Hartter, J., 2021. Woodlot management and livelihoods in a tropical conservation landscape. Ambio 50, 1351–1363. https://doi.org/10.1007/s13280-020-01484-9.

Bekele, M., 2011. Forest plantations and woodlots in Ethiopia. In: African Forest Forum Working Paper Series, vol. 1. African Forest Forum, Nairobi, Kenya. Issue 2.

Belcher, B., Ruiz-Perez, M., Achdiawan, R., 2005. Global patterns and trends in the use and management of commercial NTFPs: implications for livelihoods and conservation. World Dev. 33 (9), 1435–1452. https://doi.org/10.1016/j.worlddev.2004.10.007.

Birhane, E., Ashfare, H., Fenta, A., Hishe, H., Gebremedhin, M.A., Gebrewahed, H., Negassi, S., 2019. Land Use Land Cover Along Topographic Gradients in Hugumbrda National Forest Priority Area, Northern Ethiopia, vol. 13. Society and Environment, pp. 61–68. https://doi.org/10.1016/j.rsase.2018.10.017.

Cornacchia, L., Wharton, G., Davies, G., Grabowski, R.C., Temmerman, S., van der Wal, D., Bouma, T.J., van de Koppel, J., 2020. Self-organization of river vegetation leads to emergent buffering of river flows and water levels. Proc. Biol. Sci. 287, 20201147. https://doi.org/10.1098/rspb.2020.1147.

Darvill, R., Lindo, Z., 2015. Quantifying and mapping ecosystem service use across stakeholder groups: implications for conservation with priorities for cultural values. Ecosyst. Serv. 13, 153–161. https://doi.org/10.1016/j.ecoser.2014.10.004.

Dokken, T., Angelsen, A., 2015. Forest reliance across poverty groups in Tanzania. Ecol. Econ. 117, 203–211. https://doi.org/10.1016/j.ecolecon.2015.06.006.

Gebreegziabher, Z., Mekonnen, A., Gebremedhin, B., Beyene, A.D., 2021. Determinants of success of community forestry: empirical evidence from Ethiopia. World Dev. 138, 105206. https://doi.org/10.1016/j.worlddev.2020.105206.

Gebremedhin, B., Pender, J., Tesfay, T., 2003. Community natural resource management: the case of woodlots in Northern Ethiopia. Environ. Dev. Econ. 8, 129–148. https://doi.org/10.1017/S1355770X0300007X.

Gebremedhin, B., Tadesse, T., Hadera, A., Tesfay, G., Rannestad, M.M., 2023. Risk preferences, adoption and welfare impacts of adopting multiple agroforestry practices. For. Pol. Econ. 156, 103069. https://doi.org/10.1016/j.forpol.2023.103069.

Hailay, N., 2020. Economic Value of the Major Provisioning Ecosystem Services Provided by Afromontane Forests: Case Study of Hugumburda Forest. Mekelle University, Mekelle, Ethiopia. MSc Thesis.

Jagger, P., Pender, J., Gebremedhin, B., 2005. Trading off environmental sustainability for empowerment and income: woodlot devolution in northern Ethiopia. World Dev. 33 (9), 1491–1510. https://doi.org/10.1016/j.worlddev.2004.10.010.

Kalaba, F.K., Quinn, C.H., Dougill, A.J., 2013. The role of forest provisioning ecosystem services in coping with household stresses and shocks in Miombo woodlands, Zambia. Ecosyst. Serv. 5, 143–148. https://doi.org/10.1016/j.ecoser.2013.07.008.

Kazungu, M., Zhunusova, E., Yang, A.L., Kabwe, G., Gumbod, D.J., Günter, S., 2020. Forest use strategies and their determinants among rural households in the miombo woodlands of the Copperbelt Province, Zambia. For. Pol. Econ. 111, 102078. https://doi.org/10.1016/j.forpol.2019.102078.

Kemigisha, E., Angelsen, A., Babweteera, F., Mugisha, J., 2022. Survival- versus opportunity-driven environmental reliance: evidence from Uganda. For. Pol. Econ. 135, 102639. https://doi.org/10.1016/j.forpol.2021.102639.

Kimambo, N.E., Naughton-Treves, L., 2019. The Role of woodlots in forest regeneration outside protected areas: lessons from Tanzania. Forests 10, 621. https://doi.org/10.3390/f10080621.

Leach, M., Mearns, R., Scoones, I., 1999. Environmental entitlements: dynamics and institutions in community-based natural resource management. World Dev. 27 (2), 225–247. https://doi.org/10.1016/S0305-750X(98)00141-7.

López-Feldman, A., 2014. Shocks, income and wealth: do they affect the extraction of natural resources by rural households? World Dev. 64, S91–S100. https://doi.org/10.1016/j.worlddev.2014.03.012.

Loison, S.A., 2015. Rural livelihood diversification in Sub-Saharan Africa: a literature review. J. Dev. Stud. 51 (9), 1125–1138. https://doi.org/10.1080/00220388.2015.1046445.

McSweeney, K., 2005. Natural insurance, forest access, and compounded misfortune: forest resources in smallholder coping strategies before and after hurricane Mitch, northeastern Honduras. World Dev. 33 (9), 1453–1471. https://doi.org/10.1016/j.worlddev.2004.10.008.

Melesse, M.B., Cecchi, F., 2017. Does market experience attenuate risk aversion? Evidence from landed farm households in Ethiopia. World Dev. 98, 447–466. https://doi.org/10.1016/j.worlddev.2017.05.011.

Miller, D.C., Muñoz-Mora, J.C., Christiaensen, L., 2017. Prevalence, economic contribution, and determinants of trees on farms across Sub-Saharan Africa. For. Pol. Econ. 84, 47–61. https://doi.org/10.1016/j.forpol.2016.12.005.

Muhamad, D., Okubo, S., Harashina, K., Parikesit, Gunawan, B., Takeuchi, K., 2014. Living close to forests enhances people′s perception of ecosystem services in a forest–agricultural landscape of West living close to forests enhances people′s perception of ecosystem services in a forest–agricultural landscape of West Java, Indonesia Java, Indonesia. Ecosyst. Serv. 8, 197–206. https://doi.org/10.1016/j.ecoser.2014.04.003.

Murtazashvili, I., Wooldridge, J.M., 2016. A control function approach to estimating switching regression models with endogenous explanatory variables and endogenous switching. J. Econom. 190, 252–266. https://doi.org/10.1016/j.jeconom.2015.06.014.

Ndayambaje, J.D., Heijman, W.J.M., Mohren, G.M.J., 2013. Farm woodlots in rural Rwanda: purposes and determinants. Agrofor. Syst. 87, 797–814. https://doi.org/10.1007/s10457-013-9597-x.

Piiroinen, T., Valtonen, A., Roininen, H., 2016. Exotic plantations can ignite forest succession in the Afrotropics where natural forest regeneration is slow. Afr. J. Ecol. 54, 478–484. https://doi.org/10.1111/aje.12339.

Place, F., Garrity, D., 2015. Tree-Based Systems in Africa's Drylands. World Bank Group, Washington, DC, pp. 1–84.

Ramadhani, T., Otsyina, R., Franzel, S., 2002. Improving household incomes and reducing deforestation using rotational woodlots in Tabora district, Tanzania. Agric. Ecosyst. Environ. 89, 229–239. https://doi.org/10.1016/S0167-8809(01)00165-7.

Robinson, E.J.Z., Albers, H.J., Williams, J.C., 2005. Analysing the Impact of Excluding Rural People from Protected Forests: Spatial Resource Degradation and Rural Welfare. Center for the Study of African Economies, University of Oxford, Oxford, UK. Working Paper Series 2005-3.

Saklaurs, M., Dubra, S., Liepa, L., Jansone, D., Jansons, A., 2022. Vegetation affecting water quality in small streams: case Study in hemiboreal forests. Latvia. Plants (Basel) 11 (10), 1316. https://doi.org/10.3390/plants11101316.

Schlager, E., Ostrom, E., 1992. Property-Rights regimes and natural resources: a conceptual analysis. Land Econ. 68 (3), 249–262. https://doi.org/10.2307/3146375.

Shackleton, C.M., Garekae, H., Sardeshpande, M., Sanni, G.S., Twine, W.C., 2024. Non-timber forest products as poverty traps: fact or fiction? For. Pol. Econ. 158, 103114. https://doi.org/10.1016/j.forpol.2023.103114.

Sikor, T., Nguyen, T.Q., 2007. Why may forest devolution not benefit the rural poor? Forest entitlements in Vietnam's Central Highlands. World Dev. 35 (11), 2010–2025. https://doi.org/10.1016/j.worlddev.2006.11.011.

Sikor, T., Baggio, J.A., 2014. Can smallholders engage in tree plantations? An entitlements analysis from Vietnam. World Dev. 64 (1), S101–S112. https://doi.org/10.1016/j.worlddev.2014.03.010.

Solomon, N., Segnon, A.C., Birhane, E., 2019. Ecosystem service values changes in response to land-use/land-cover dynamics in dry Afromontane forest in northern Ethiopia. Int. J. Environ. Res. Publ. Health 16, 46–53. https://doi.org/10.3390/ijerph16234653.

Tadesse, T., Berhane, T., Mulatu, D.W., Rannestad, M.M., 2021. Willingness to accept compensation for afromontane forest ecosystems conservation. Land Use Policy 105, 105382. https://doi.org/10.1016/j.landusepol.2021.105382.

Tadesse, T., Teklay, G., Mulatu, D.W., Rannestad, M.M., Meresa, T.M., Woldelibanos, D., 2022. Forest benefits and willingness to pay for sustainable forest management. For. Pol. Econ. 138, 102721. https://doi.org/10.1016/j.forpol.2022.102721.

Toth, G.G., Nair, P.K.R., Jacobson, M., Widyaningsih, Y., Duffy, C.P., 2019. Malawi's energy needs and agroforestry: impact of woodlots on fuel wood sales. Energy Sustain. Dev. 50, 101–108. https://doi.org/10.1016/j.esd.2019.02.006.

UNDP, 2017. Guidance Note: Application of the Sustainable Livelihoods Framework in Development Projects. UNDP.

Wooldridge, J.M., 2010. Econometric Analysis of Cross-section and Panel Data. MIT Press, Cambridge, US.

Wooldridge, J.M., 2015. Control function methods in applied econometrics. J. Hum. Resour. 50 (2), 420–445. https://doi.org/10.3368/jhr.50.2.420.