Beyond Ostrom: Randomized Experiment of the Impact of Individualized Tree Rights on Forest Management in Ethiopia

Abstract

We argue that while community forest management is effective in protecting forest resources, as argued by Ostrom, such management may fail to provide the proper incentives to nurture such resources because the benefits of forest management are collectively shared. This study proposes a mixed private and community management system characterized by communal protection of community-owned forest areas and individual management of individually owned trees as a desirable arrangement for timber forest management in developing countries. By conducting a randomized experiment in Ethiopia, we found that the mixed management system significantly stimulated intensive forest management activities, including pruning, guarding, and watering. Furthermore, more timber trees and forest products were extracted from the treated areas, which are byproducts of tree management (e.g., thinned trees and pruned branches). In contrast, the extracted volumes of non-timber forest products unrelated to tree management (fodder and honey) did not change with the intervention.

Keywords: property regimes, individual rights, commons, community forest management, RCT
JEL codes: O13, Q23, Q24, P48

1 Introduction

Forest resource conservation is critically important for developing countries (Reed et al., 2017; Sunderlin et al., 2005). As forestland and grazing land grow scarcer, and rural poverty persists, it is imperative to recover and create forest-rich environments by growing trees and fodder grasses to increase and sustain forest resources stocks to generate income and reduce poverty (Otsuka et al., 2015; Takahashi & Todo, 2014). Although securing forestland property rights is fundamental to sustainable forest resource management (Arnot et al., 2011; Owubah et al., 2001; Tucker, 1999), no consensus on which type of property regime most effectively leads to forest recovery and sustainable forest management has been reached (Takahashi & Otsuka, 2016).

On the one hand, Kijima et al. (2000) found that private management is more efficient than community management. This is primarily because individual rightsholders are motivated to invest effort in tree management activities, such as planting, thinning, pruning, watering, and guarding, to maximize profits. Standard microeconomics textbooks (e.g., Pindyck and Rubinfeld (2017) and Perloff (2014)) also argue that private management is more efficient. On the other hand, forest management under common property regimes (hereafter, "community forest management") is commonly adopted in developing countries (Agrawal et al., 2008; Hajjar & Oldekop, 2018), primarily due to the substantial contributions of Ostrom and her colleagues, who advocated carefully designed community management over state ownership and management. A primary advantage of community forest management is the effective protection of forests through collective monitoring, wherein total monitoring costs are reduced by sharing or rotating responsibilities among community members (hereafter, "collective monitoring"). As Otsuka et al. (2015) argued, forest protection activity has economies of scale because one person can oversee large areas. Consequently, community forest management might offer more effective monitoring and protection than private management.

However, the empirical evidence on the effectiveness of community forest management is mixed (Arts & De Koning, 2017; Baynes et al., 2015). Therefore, it remains unclear whether community institution leads to effective forest resource management in developing countries. Another shortcoming of the existing literature on community forest management is that most previous studies primarily focus on forest protection. At the same time, less attention is devoted to identifying the mechanisms for incentivizing tree management activities essential for forest rehabilitation. Specifically, rehabilitating timber forests requires both forest protection and essential tree management activities, such as planting, thinning, pruning, and watering. However, community forest management often faces the free rider problem due to collective revenue sharing, diminishing individual incentives for tree management. In fact, Ostrom did not explicitly address how to provide incentives for tree management among community members.

In this study, we introduce a mixed management system of private and common ownership (hereafter, "mixed management system") as a potential solution for timber forest management in developing countries. The mixed management system is characterized by communal protection of trees and other resources and individual management of these resources (Otsuka et al., 2015). Such a system can be realized by granting control over forestland rights to local communities and granting individual community members ownership rights to trees. Under this system, the capacity of communities to protect trees and other natural resources, as suggested by Ostrom, and the motivation of individual community members are expected to be fully utilized. However, no studies have empirically investigated the effects of mixed management systems on forest management efforts.

The main objective of this study is to empirically investigate the impact of a mixed management system on forest resource management, aiming to provide new empirical insights into the debate over property regimes. More precisely, we explore how introducing the mixed management system affects incentives for tree management compared to conventional community forest management, focusing on the amount of labor devoted to tree management and the volume of natural resources extracted. For this purpose, we conducted a randomized experiment in northern Ethiopia, an area grappling with severe deforestation. In our experiment, out of 68 forest management groups practicing community forest management, we randomly selected 26 groups as the treatment group to introduce the mixed management system.

In the treatment group, members were granted individual ownership rights to specific trees growing on community forest lands (hereafter, "tree rights"). After the tree rights provision, individual tree-rights holders are permitted to harvest their designated trees at any time, which is expected to increase their incentives for tree management. Meanwhile, land ownership remains with the forest management group. Therefore, tree-rights holders are motivated to adhere to communal regulations regarding natural resource usage and to participate in collective actions, including collective monitoring, thereby maintaining the protective advantages of community forest management.

To examine the impact of a mixed management system, we compared the behavior of groups with and without tree rights using the following three indicators: the number of workdays allocated to tree management, tree product extraction, and extraction of other forest products. We hypothesized that community members under the mixed management system would allocate more time to tree management and extract larger volumes of tree resources associated with tree management, such as thinned trees and pruned branches.[1]

The remainder of this article is structured as follows. Based on a review of the existing studies on forest management, we propose the empirical hypotheses for this study in the next section. In the subsequent sections, we describe the details of the experimental design and present the estimation methodology. Finally, we discuss the results and offer conclusions.

[1] Ideally, we should like to assess changes in tree volumes, but it is premature to do so due to short lapse of time from the granting of tree rights.

2 An overview of previous studies

Whether private or common ownership leads to more sustainable forest management has long been debated. Pindyck and Rubinfeld (2017) and Perloff (2014), in their microeconomics textbooks, contend that private management is more efficient than community management because individual rights holders are motivated to manage forest resources sustainably to maximize profits from their forestland. They implicitly assume, however, that common property is open access, as envisaged by Hardin (1968). Kijima et al. (2000) empirically found that private management of timber trees was more efficient than community management in postwar Japan. In contrast, since the 1990s, a growing body of literature has argued that community forest management is both efficient and sustainable compared with state ownership and management, particularly in developing countries, because of the innate ability of the community to prevent excessive resource extraction (Agrawal, 2001; Baland & Platteau, 1997; Hayami & Godo, 2005). Ostrom (1990, 2010) identified eight principles for successful and sustainable natural resource management under common property regimes, one of which involves effective monitoring to protect natural resources. However, increasing population pressure, improved infrastructure, and reduced-cost methods of demarcating and allocating private land rights may cause private ownership and management to be more desirable (Deininger et al., 2008).

In general, effective monitoring is a fundamental condition to prevent excessive extraction of forest resources (Ostrom & Nagendra, 2007). Compared to private forest management, community forest management has the advantage of reducing protection costs because it reduces the total monitoring costs through sharing or rotating monitoring activities among community members. Sakurai et al. (2004) found that the cost of protecting community forestry is significantly smaller than that of private forests, which requires employing a full-time monitor for small patches of private forests.

Economies of scale may be present in harvesting some types of forest products, such as timber, where mechanization may play a role. In China, Holden et al. (2013) found that individual forestland owners rented out their lands to forest companies who conducted the harvesting. One plausible reason individual tenure was better than community tenure in forest management was that individuals received longer-term rights (25-70 years), while community leaders in charge of communal forests were elected for only five years; therefore, they tended to focus on short-term rent-seeking and to overharvest forest resources during their tenure.

However, empirical evidence on the effectiveness of community forest management is mixed (Arts & De Koning, 2017; Baynes et al., 2015; Slough, Rubenson, et al., 2021). While many studies have reported that introducing community management had a positive impact on protecting forest resources compared with management under state ownership (Edmonds, 2002; Gibson et al., 2002; Leone, 2019; Persha et al., 2011; Takahashi & Todo, 2012), more recent studies based on randomized control trials (RCTs) have found no evidence that the introduction of community management alleviates deforestation (Christensen et al., 2021; Eisenbarth et al., 2021). Furthermore, other studies indicate that community property systems are less effective than private property systems (Araujo et al., 2009; Godoy et al., 1998; Kijima et al., 2000; Nelson et al., 2001). In Ethiopia, Takahashi and Otsuka (2016) employed the propensity score matching method to control for the endogeneity of property rights and found that the quality of forest in private property areas degraded less than that in common property areas.

One potential reason for these mixed results is the heterogeneity of forests, which can be timber or non-timber forests. Intensive tree management or silvicultural operations, such as planting, thinning, pruning, singling, and weeding, are required to grow valuable timber trees sustainably (Otsuka et al., 2015). Furthermore, harvesting timber trees is an important activity for enhancing forest ecosystem regeneration (Karsenty & Gourlet-Fleury, 2006; Langmaier & Lapin, 2020). Thus, in addition to protecting trees, both management and harvesting efforts are essential for timber forest management.[2] In contrast, because non-timber forest resources can regrow without much oversight, the most important aspect of non-timber forest management is primarily protection (Otsuka et al., 2015).

We conjecture that community management works particularly well in non-timber forest management due to its substantial advantages for reducing protection costs. However, under conventional community management systems, the individual incentives for intensive tree management and harvesting activities are diluted because the benefits obtained from community forests are more or less equally shared among members in most cases (Balana et al., 2010; Conroy et al., 2002). In this context, conventional community forest management may face social dilemmas stemming from insufficient tree management and limited harvesting efforts. In fact, such inefficient community management of timber forests has been reported (Baland et al., 2010; Bhattacharya et al., 2010; Kijima et al., 2000).

The preceding argument does not immediately imply that private ownership is a more desirable system for timber forest management. If timber forests are located in areas with a high demand for forest products (e.g., timber, firewood, feed grasses, medicinal plants, honey, mushrooms, and spices), the protection cost for private forest management may be high due to the risk of illegal logging and theft (Leipold et al., 2016; McElwee, 2004). Additionally, timber forests under private management may risk accelerating deforestation due to converting forest land to agricultural land, which results in negative environmental externalities in the locality (Angelsen, 1999). If the expected private benefit from forest conversion is greater than the private profit from forestland, forest conversion becomes a rational choice for individual landholders (Arima et al., 2007; Busch et al., 2015; Deininger & Minten, 2002; Hargrave &

[2] Like timber forest, both protection and tree management are important for orchards growing fruit and nut trees.

Kis-Katos, 2013; Marchand, 2012). Therefore, neither private nor community management may be the optimal system for timber forests in developing countries.

3 Conceptual Framework

Following the discussion in the previous section, this section develops an analytical framework and delivers empirical hypotheses. As mentioned, to protect and recover timber forests, it is essential to incentivize rights holders in forest areas to engage in tree management activities. The mixed private and community management system can be a potential solution, particularly in developing countries with high demand for forest products (Otsuka & Place, 2001; Otsuka et al., 2015). In a practical situation where community forest management is established, a mixed management system can be introduced by granting members individual ownership of specific trees within the community forest lands. In this case, the ownership of the community forest land remains unchanged and continues to be held by the community. Thus, tree-right holders do not gain ownership of the land itself.[3]

In a mixed management system, individual tree-rights holders are fully motivated to conduct intensive tree management to their owned trees because they can accrue all the benefits. This perspective is supported by previous studies indicating that granting individual ownership leads to increased investment in land (Banerjee et al., 2002; Deininger & Jin, 2008; Deininger et al., 2021). This incentive for intensive tree management is vital in advancing Ostrom's design principles. For example, Holden and Tilahun (2018) examined the degree of compliance with

[3] It must be pointed out that we do not consider the cost of establishing registered individual land rights, but it can be a crucial element in the property regime optimization problem depending on the level of trust among community members, existing tenure rights (customary and statutory), motivation and trust among relevant staff in public institutions, and the institutional capacity in the country. A study in Ethiopia by Deininger et al. (2008) showed that low-cost land registration and certification was affordable in a poor country and was in high demand among poor smallholders facing tenure insecurity. Over the last decade modern technology has facilitated the establishment of modern land registries in the Tigray region where our study occurred at a cost an order of magnitude lower than that of traditional land titling (Holden & Tilahun, 2020).

these principles among youth groups in Ethiopia involved in various production activities, including livestock rearing, apiculture, forestry, horticulture/irrigation, and mining. They found significant negative outcomes for forestry groups, in contrast to the predominantly positive and significant results in other types of groups. Specifically, forestry groups more rigorously adhering to the principles experienced significant member loss and lower income per member, attributable to the limited short-term returns from forestry compared to other activities that offer immediate incentives. Providing tree rights for forestry group members, therefore, could be a potential solution to this challenge, creating incentives for better forest management.

Furthermore, the incentives for protection in the mixed management system are potentially greater than those in both private management and conventional community management. Prior studies have already pointed out that, due to economies of scale, protection costs for forests are lower when conserved collectively rather than individually (Sakurai et al., 2004). One important factor promoting the sustainable implementation of collective monitoring activities is norm enforcement. For instance, Rustagi et al. (2010) and Kosfeld and Rustagi (2015) conducted a field experiment in Ethiopia and reported that costly norm enforcement in the community enhanced monitoring cooperation among its members. Given that land rights in the mixed management system belong to the community or groups, the presence of norm enforcement could stimulate members' motivation to engage in conventional collective actions, such as collective monitoring.

In addition, if collective monitoring persists after implementing the mixed management system, similar protection efforts are expected in both mixed and conventional community forest management systems. However, granting tree ownership could stimulate incentives for forest protection, particularly to mitigate risks of illegal logging and unauthorized grazing by outsiders to protect their owned trees. Consequently, individuals might be more motivated to intensify their collective monitoring efforts following the adoption of the mixed management system.

Finally, introducing the mixed management system could also reduce the risk of forest conversion, mainly observed in private forests. As mentioned, when the expected benefit is higher for agricultural land than for forests, the risk of forest conversion is very high for private forests (Arima et al., 2007; Busch et al., 2015). In contrast, in a mixed management system where land is communally owned, the likelihood of such conversion is mitigated. This is due to the necessity of obtaining community agreement for conversion, which in turn results in increased transaction costs. However, this study does not empirically investigate the impact of the mixed management system on land conversion, as that falls outside its scope.

Building on the preceding discussion, we formulate our first hypothesis. We posit that implementing the mixed management system in community timber forests enhances individuals' motivation for intensive management activities, including thinning, pruning, watering, guarding, and planting tree seedlings. Consequently, our proposed hypothesis is as follows:

Hypothesis 1. The mixed management system stimulates tree and forest management activities.

After the introduction of the mixed management system, tree-rights holders can make their own decisions about when to harvest their owned trees. This change could enhance their incentive for engaging in both tree management and harvesting activities. If the mixed management system successfully stimulates the incentives of harvesting activities, the extracted volumes of tree resources will increase. More specifically, there could be a rise in the volume of thinned trees, pruned branches, and extracted timber trees. Importantly, the mixed management system motivates tree-rights holders to engage in tree management activities, as they can gain direct benefits from it. Thus, an increase in the extracted volumes of tree resources is desirable, as it provides the incentives for tree-rights holders to continue tree management.

Although it is reasonable to expect that the extracted volume of timber trees would increase after introducing the mixed management system, its introduction does not necessarily mean that the mixed management system causes excessive extraction of forest resources or forest degradation. Selective extraction of timber trees is a crucial activity for regenerating forest ecosystems, and the risk of resource degradation can be minimized if proper forest management practices, like plantation, are followed (Karsenty & Gourlet-Fleury, 2006; Langmaier & Lapin, 2020). Moreover, to maintain optimal forest conditions, relatively useless timber trees and densely grown trees, in particular, should be removed. Therefore, the following hypothesis is proposed:

Hypothesis 2. The introduction of the mixed management system will increase the extracted volumes of thinned trees, pruned branches, and timber trees.

Because the mixed management system does not change the land ownership regime, it seems reasonable to assume that conventional resource extraction activities unrelated to tree management will be continuously maintained even after the mixed management system is introduced. One typical example of such activities is the collection of non-timber forest products, such as feed grasses, medicinal plants, honey, mushrooms, and spices. Particularly in developing countries, the motivation for maintaining miscellaneous resource extraction activities after the introduction of the new system will remain high because such resources are in high demand. As discussed later, none of the communities investigated in this study changed the rules of extraction of non-timber resources after the mixed management system was introduced. Therefore, we expect that introducing the mixed management system will not affect the extracted volumes of non-timber forest products unrelated to tree management. This argument leads to the third hypothesis:

Hypothesis 3. Introducing the mixed management system will not affect the collection of non-timber forest products unrelated to tree management.

4 Experimental Design and Data Collection

To identify the impact of the mixed management system on tree management efforts, we conducted a randomized experiment in Ethiopia, a country facing significant deforestation challenges. In the early twentieth century, forests covered 35% of the land, while this number had plummeted to just 16% by the early 1950s (Urgessa, 2003). Until the late 1990s, the Ethiopian government, like those in many other developing countries, implemented centralized forest management, which failed to stop the declining trend of forest cover (Ameha et al., 2014). By around 2000, forest cover in Ethiopia had further diminished to just 4% (Earth Trends, 2007). In response, community-based forest management in line with Ostrom's principles was introduced and has been widely adopted in Ethiopia since 2000 (Wood et al., 2019). According to Gilmour (2016), by 2015, approximately 30% of Ethiopia's forests were managed under community-based management schemes. However, despite these efforts, Ethiopia still experienced an average annual deforestation rate of 0.4%, resulting in an 8% loss of its forests from 2000 to 2021.

Considering these circumstances, exploring effective incentives for both the conservation and restoration of forests is crucial. Therefore, this study conducted an experiment in the semi-arid Tigray region, located in northern Ethiopia, as a case study. A primary reason for selecting the Tigray region is the feasibility of obtaining official permission of the local authority (i.e., the Bureau of Agriculture and Natural Resources) to grant individualized tree rights due to a long-term relationship with the local government.

4.1 Description of the study area and establishment of youth groups

The natural vegetation in this region receives annual precipitation ranging from 200 mm to 950 mm, and has an average yearly air temperature between 15° and 25°C (Birhane et al., 2011). Similar to other regions in Ethiopia, people in Tigray depend on forestland for firewood, building materials, fodder grasses, and honey extraction, and they also sell timber to the market (Babulo et al., 2009; Balana et al., 2010; Gebremedhin et al., 2003).

Land degradation such as vegetation cover loss, soil erosion, and nutrient depletion, has been a major environmental issue in the Tigray region (Mekuria et al., 2007; Nyssen et al., 2004). To rehabilitate degraded forests and grazing lands, regional authorities have strictly restricted access to communal lands (restricted communal areas are called “exclosures”). The use of natural resources has been prohibited since 1991 (Mekuria et al., 2007), and the prohibition continued until recently (Holden & Tilahun, 2018). According to Holden and Tilahun (2018), 13% of the total land in Tigray was reserved for rehabilitation. Several previous studies have indicated that the restrictive approach adopted in the Tigray region improves soil quality (Welemariam et al., 2018), biomass volumes (Mekuria et al., 2019; Solomon et al., 2017), and the yield of non-timber forest products (Tilahun et al., 2007).

The duration of land rehabilitation is not formally fixed. Yayneshet et al. (2009) indicated that degraded lands in Tigray are conserved from 5 to 15 years for rehabilitation. After a certain rehabilitation period, some restricted communal lands are allocated to groups of landless youth in the community (hereafter, “youth groups”) (Holden & Tilahun, 2018). On average, these youth groups were established in 2014. Once registered as an official primary cooperative, each youth group takes responsibility for sustainably managing demarcated forest and grazing areas.

The primary purpose behind communal land allocation is to provide income opportunities for landless youth. The land entitlement given to a youth group depends on its performance and compliance with sustainable resource management practices. The youth groups establish business plans and conduct livelihood activities by utilizing natural resources such as forestry, apiculture, horticulture, mining, and livestock rearing in the allocated communal lands. Similar to other developing countries (Balana et al., 2010; Conroy et al., 2002), the benefits obtained from youth group activities are shared equally among the group's members.[4]

Once a youth group has established, only its members have access rights to the allocated lands. The broader community, including those not in youth groups, is restricted from using these lands—for instance, for collecting non-timber forest products or grazing their livestock. Nonetheless, there remains a risk of illegal harvesting and unauthorized grazing by outsiders. Holden and Tilahun (2018) found that 27% of the youth groups encountered illegal harvesting, while 11% reported external livestock intruding on their lands.

Holden and Tilahun (2018) conducted a census of 742 youth groups in five districts in Tigray and observed variations in adherence to Ostrom's design principles, yet found that most groups followed the principles of collective action for sustainable natural resource management. For example, more than 97% of the groups developed bylaws that specify how responsibilities for group activities are shared and that ensure equal sharing of generated income (Holden & Tilahun, 2018). In addition, although approximately 25% of the groups experienced disputes within the group, approximately 83% of internal disputes were resolved within the group using the local informal conflict resolution system. Therefore, in this study, we define communal lands allocated to the youth groups as regulated common property areas. It is crucial to highlight, however, that Holden and Tilahun (2018) also observed that groups involved in forestry and strongly adhering to Ostrom's design principles experienced greater member loss and lower

[4] Since the primary motivation of allocation was to increase the income of individual landless youth members, the obtained benefits were not used for public goods purposes.

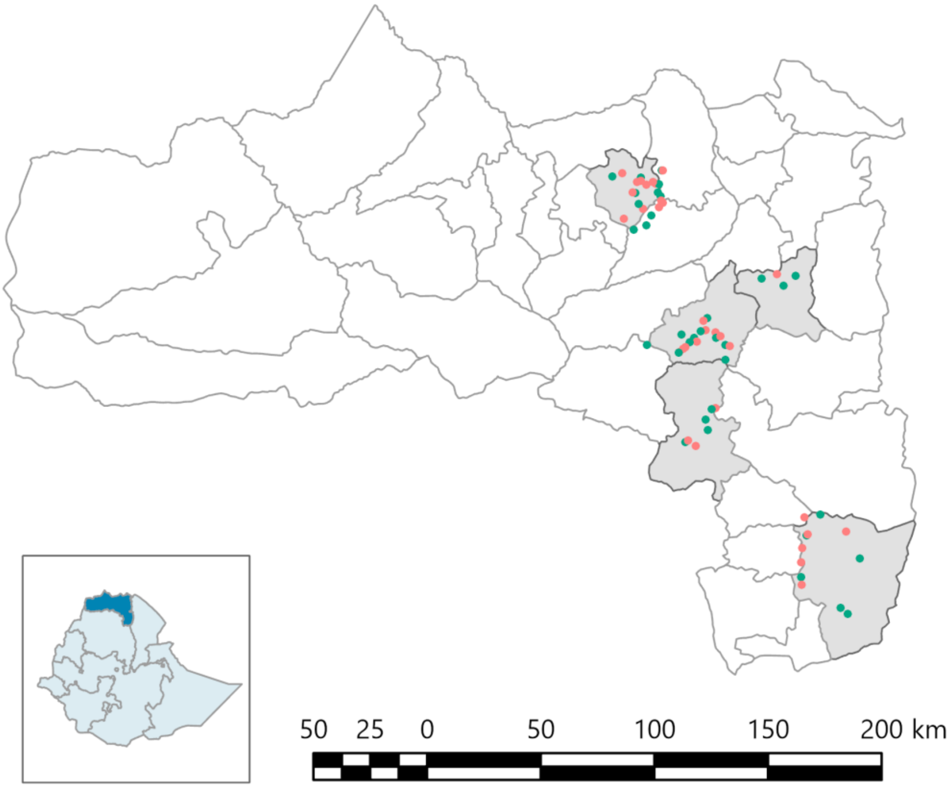
income per member compared to groups engaged in other activities, such as livestock rearing, apiculture, horticulture/irrigation, and mining. This underscores the importance of incentivizing tree management for forestry youth groups.

In 2018, to identify tree species and vegetation conditions in the allocated lands, we conducted a vegetation survey using 20m x 20m sample plots at three random sites within each allocated land. The dominant tree species in the allocated lands consist of timber trees such as *Acacia*, *Albizia amara*, *Balanites aegyptiaca*, *Calpurnia aurea*, *Carissa edulis*, *Cordia africana*, *Croton macrostachyus*, *Olea europaea*, *Eucalyptus camaldulensis*, *Grevillea robusta*, *Rhus glutinosa*, and *Maytenus senegalensis*. Moreover, youth group members harvest non-timber forest products from these lands, such as fodder grasses and honey. Therefore, the allocated land for youth groups comprise timber forests located in areas with high demand for both timber and non-timber products, ensuring that the study area was suitable for the purpose of this study.

4.2 Provision of individual tree rights

In this study, we focused on youth groups in five districts in Tigray: Adwa, Degua Temben, Kilite Awlalo, Raya Azebo, and Seharti Samire (Figure 1). Between 2003 and 2016, a total of 742 youth groups were established that still existed during the 2016 census in these districts. Although communal lands were allocated to the youth groups after vegetation rehabilitation, most of the allocated lands consist of grazing lands with no trees. As we explain later, because this study provided individual tree rights for existing trees located in the allocated communal lands, we excluded the youth groups allocated to land without trees in this study. Thus, we conducted the initial screening based on the presence of trees in allocated communal lands. Finally, for this study, we selected 68 youth groups, shown in Figure 1.

Figure 1. Location of the allocated communal lands in five districts in Tigray



Note. The location of Tigray is shown in dark blue in the lower left map. The areas illustrated in light gray on the main map are the districts selected for the experiment. The communal lands for the treated youth groups are shown by the green dots, while the red dots are the locations of the control groups.

Of the 68 selected youth groups, we randomly selected 26 as the treatment group; these groups received an offer to manage their community forestland under the mixed management system.[5] The number of treatment groups, approximately 30% of the total, was determined after discussions with the local authority (i.e., the Bureau of Agriculture and Natural Resources). The remaining 42 groups served as control groups that continued their existing community management. The treatment and control groups were from separate communities and were geographically dispersed at varied distances from each other. This geographical separation

[5] Random numbers were allocated to the 68 groups, and the top 26 groups, based on these values, were selected.

substantially reduced the likelihood of interaction between the two groups. Consequently, members of the control group remained unaware of the interventions being introduced to the treatment group. Although the number of selected groups was small in this study, the sample size was similar to recent experimental studies on community management, which ranged from 76 to 120 (Christensen et al., 2021; Eisenbarth et al., 2021; Slough, Kopas, et al., 2021). Strictly speaking, randomization was applied to the youth groups themselves, not to individual members. Therefore, we use not only individual data but also group-level data in the econometric analyses.

To provide individual tree rights, we divided the entire allocated communal lands equitably into smaller parcels based on the vegetation conditions and discussion with the group members. To ensure a fair distribution and consistency in distribution methods across youth groups, forestry experts from Mekelle University also participated in the demarcation and assisted in the parcel division, considering the natural conditions. After reaching an agreement regarding the demarcation of parcels among the youth group members, property rights for all trees located in each divided parcel (i.e., individual tree rights) were given to individual members who were willing to receive the rights.[6]

On average, each individual was allocated 81 trees. Among these, 63% were shorter trees with a diameter at breast height (DBH) of 5 cm. The predominance of shorter trees can be attributed to the group's recent establishment—only approximately three years ago—and the inherently slow tree growth in the semi-arid climate, which impedes quick vegetation recovery. Through the intervention, tree-rights holders were provided an average of four different tree species, while there was not a significant variation in the species allocated to members within

[6] When we provided tree rights, both the tree species and their diameter at breast height were recorded for every tree. As we did not take precise measurements, the exact size of each individual parcel is unclear. Consequently, it is not feasible to compare the parcel sizes among the tree right holders. However, the youth group was allocated a total land area of approximately 6 ha on average. With an average of 11 members in the group, this suggests that each member was allocated roughly 0.5 ha.

the same youth group. The primary species of trees provided consisted of timber trees, including *Acacia*, *Albizia amara*, *Balanites aegyptiaca*, *Calpurnia aurea*, *Carissa edulis*, *Cordia africana*, *Croton macrostachyus*, *Olea europaea*, *Eucalyptus camaldulensis*, *Grevillea robusta*, *Rhus glutinosa*, and *Maytenus senegalensis*.

Although an individual tree-rights holder holds the ownership rights for the designated trees, the entire land remained continuously common property even after introducing the mixed management system. Therefore, individual tree-rights holders are incentivized to comply with communal rules for using natural resources and conducting collective activities (i.e., collective monitoring activities), which would not be expected if the parcels were simply privatized.

In this experiment, securing tree rights is fundamentally important because members' management and investment behaviors are influenced by insecure tenure (Goldstein et al., 2018). To ensure the security of tree rights, we provided a paper document indicating that the local authority granted official permanent permission.

The tree rights provisions allow tree-rights holders to extract their owned trees at any time. After the extraction, tree-rights holders can continuously remain tree owners if they replant tree seedlings in the same allocated parcel. However, using an allocated parcel for a different purpose after extraction, such as constructing compounds or expanding agricultural land, is strictly prohibited. Through our intervention, although ownership of the timber tree property rights was transferred from the entire youth group to its individual members, we did not change the property rights owners of forestland. That is, forestland was an unfragmented common property in both the treatment and control groups, and community agreement was required for land use changes.[7] Furthermore, conventional resource extraction activities, such as gathering fodder, honey collection, and livestock rearing, remained under the control of the youth group, even post-intervention.

[7] There are no plans to convert the allocated parcel into private property, nor to grant land ownership rights to individual tree-rights holders currently or in the near future.

Before implementing the tree rights provision intervention, we provided the same tree and forest management training program to both the treatment and control groups. This training program lasted one day and consisted of a lecture and tree management field activities, such as thinning, pruning, and watering. Forestry experts from Mekelle University, who delivered the training, recommended thinning five years after planting, while pruning should be conducted annually. Therefore, knowledge of tree management between the treatment and control groups was expected to be similar.

4.3 Experiment timeline and sample characteristics

We provided tree management training to both the treatment and control groups between May and June 2018. After the training was complete, we offered individual tree rights only to the treatment group members. The tree rights allocation process was completed by July, and tree management activities began in August 2018. To evaluate the impact of the tree rights provisions on tree management efforts and tree and other resource extraction, we conducted a questionnaire survey before and after the experiment. The baseline survey was conducted between January and February 2018, and the endline survey was conducted between November and December 2019.

Census data show that 728 members belong to the 68 youth groups. Although we invited all the members to complete the questionnaire survey, only 63% of them participated in both the baseline and endline surveys. Therefore, the number of observations in this study was 459, which included 197 and 262 potential observations for the treatment and control groups, respectively. Although we offered all members of the treatment group the opportunity to receive individual tree rights, some members declined (hereafter, "non-accepters") mostly because they held the perception that group rights are preferable.[8] In our observations, 25 members (12.7%)

[8] The non-accepters in the treatment group belong to the same community as the accepters. The distance to

of the treatment group members declined the individual tree rights. Thus, among the 197 members in the treatment groups offered tree rights, 172 actually received the rights (i.e., tree-rights holders).

The average demographic and forest characteristics are presented in Table 1. There was no statistically significant difference among members in average years of education, number of household members, total annual income, or annual income from youth group activities between the treatment group (including the 25 non-accepters) and the control group. In contrast, there was a statistical difference in the average age, indicating that youth group members who were offered individual tree rights were older than the members in the control group. Furthermore, the average distance to allocated communal land parcels from the individual residence was larger for the treatment group than for the control group.

In addition, at the end of Table 1, we present the average area, average number of timber trees, and tree species at the group level. The data for the average number of timber trees and tree species were derived from the 20m x 20m sample plots collected during the pre-experimental vegetation survey. The area of allocated land was approximately six ha. On these plots, we identified approximately 65 trees across about four different species, with no statistically significant differences between the means of the treatment and control groups.

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the allocated land is similar for both groups, averaging 2.6 km. To ensure that misunderstandings or lack of knowledge about the mixed management system did not lead to non-participation, we provided comprehensive explanations. Even though the non-accepters did not receive the tree rights, they continued to participate in the conventional collective activities. Moreover, the non-accepters respected the tree rights of other members, suggesting they were not entirely against our intervention.

Table 1: Average demographic and forest characteristics

	Treatment groups (1)	Control groups (2)	Total (3)
Number of youth groups	26	42	68
Total number of youth group members	291	437	728
Number of observations at the individual level	197	262	459
Participation rate for the survey (%)	67.7	60.0	63.0
Youth group member characteristics			
Age	30.00	27.82**	28.75
	(9.97)	(8.57)	(9.25)
Education year	5.63	5.15	5.35
	(3.74)	(4.06)	(3.93)
Number of household members in hhs that each member belongs to	5.44	5.26	5.34
	(2.12)	(2.22)	(2.18)
Annual income (thousands Ethiopian Birr)	8.24	7.43	7.78
	(13.30)	(8.04)	(10.61)
Distance to the allocated community land from the individual residence (km)	2.60	2.18**	2.36
	(2.63)	(1.74)	(2.17)
Forest characteristics based on the sample plot			
Average area (ha)	5.97	5.51	5.71
	(4.18)	(4.24)	(4.22)
Average number of timber trees	59.19	68.76	64.93
	(11.99)	(17.11)	(11.28)
Average number of timber tree species	4.73	4.20	4.41
	(0.41)	(0.34)	(0.26)

Note. The treatment group represents the intention-to-treat group, including the 25 non-accepters; the total annual income includes the annual income from the youth group activities and the annual income from other complementary sources; forest characteristics, specifically tree species and the number of trees, were assessed using 20m x 20m sample plots at three random sites within each allocated land; standard deviations are in parenthesis; ** indicates statistical significance (paired *t*-test) at the 5% level.

Moreover, we obtained information on the work efforts for tree management and the extracted volumes of trees and other resources from the allocated community lands. Specifically, we asked for the number of workdays allocated to tree management activities in a year, such as thinning, pruning, guarding, watering planted tree seedlings, and planting tree seedlings. Regarding the protective activity, we collected data on time allocated for guarding allocated communal lands, which is basically a collective activity and is usually conducted on a rotating basis. To assess the total efforts dedicated to forest management, we constructed a tree management index by aggregating the workdays of each management activity (hereafter, "management index").

In addition, we collected data regarding the annual extracted volumes of five types of resources available in the allocated communal lands: removed timber trees, thinned trees, pruned branches, fodder, and honey. To identify the efforts allotted to tree planting, we obtained the number of planted tree seedlings at the individual level. The summary statistics at the individual level between the treatment and control groups before the experiment are provided in columns 1 and 2 of Table 2.

We employed a *t*-test to check the balance between the two groups and found that the differences in the means of all the variables showing tree management workdays were insignificant. In addition, there was no significant difference in the number of planted trees and the extracted volumes of the five types of resources between the two groups. The summary statistics show that none of the members in either group extracted timber or thinned trees from allocated communal lands. This lack of thinning activities before tree management training is reasonable, and the absence of timber tree extraction was probably due to a lack of motivation for harvesting under the conventional community management system. In fact, the youth groups in neither the treatment nor control groups had established a management plan before our intervention, including when they would harvest timber.

Table 2: Average individual-level characteristics: pre- and post-treatment periods

	Pre-treatment		Post-treatment	
	Treatment groups	Control groups	Treatment groups	Control groups
	(1)	(2)	(3)	(4)
Number of workdays in a year				
Thinning	0.29	0.15	0.29	0.05**
	(1.38)	(0.90)	(1.89)	(0.36)
Pruning	0.72	0.41	1.41	0.62***
	(2.87)	(1.02)	(2.93)	(2.12)
Guarding	19.92	18.21	46.29	23.37***
	(22.79)	(19.53)	(53.27)	(42.51)
Watering seedlings	4.73	7.69	4.19	0.92***
	(11.40)	(26.57)	(7.98)	(5.24)
Planting tree seedlings	2.87	2.78	2.44	1.92
	(5.80)	(4.90)	(4.66)	(3.72)
Total workdays	28.53	29.24	54.62	26.89***
(management index)	(2.08)	(2.18)	(3.89)	(2.67)
Number of planted tree seedlings	189.43	177.61	150.81	344.06**
	(425.66)	(482.57)	(501.04)	(1080.17)
Extracted volumes (kg)				
Thinned trees	0	0	1.79	0.23**
			(11.98)	(3.71)
Pruned branches	48.22	76.57	49.25	10.78***
	(237.95)	(198.84)	(88.62)	(33.11)
Timber	0	0	6.19	0***
			(26.61)	
Fodder	34.00	29.85	63.64	80.63
	(81.74)	(50.01)	(91.13)	(132.22)
Honey	2.45	2.35	53.17	18.60
	(5.07)	(3.72)	(502.30)	(187.86)

Note. Standard deviations in parentheses. ** and *** indicate statistical significance (paired t-test) at the 5% and 1% levels, respectively. The members who declined the tree rights are included in the treatment group.

5 Estimation Methodology

The primary motivation behind this study was to investigate the impact of awarding individual tree rights on forest management efforts and the extracted volumes of natural resources. However, we cannot estimate the treatment effects with simple OLS regression models because 12.7% of the members in the treatment group refused the individual tree rights, which causes endogeneity problems (Imbens & Wooldridge, 2009). To address endogeneity, we utilized three regression models.

First, following previous studies (Angrist, 1990; Takahashi et al., 2018; Wang et al., 2020), we apply an instrumental variable (IV) method to reduce selection bias. This study used a dummy variable for random assignment of the treatment youth group (i.e., the treatment dummy) as an IV for the actual receipt of individual tree rights (i.e., the individual tree rights dummy). The random assignment of the treatment youth group was highly correlated with the endogenous variable (i.e., the actual receipt of rights) but unrelated to the management efforts and the extracted volume.

Second, we employed the intention-to-treat (ITT) model to estimate the treatment effects. In the ITT model, we compared the outcomes between the control and treatment groups; in this case, the 197 members belonging to the treatment group were offered individual tree rights. Because the 25 non-accepters included in the groups offered individual tree rights, the effects of treatment were likely to be underestimated in the ITT model (Angrist, 2006). Third, we conducted a youth group-level analysis to identify how the random selection of the treatment youth groups affect the group means of management efforts and extracted volumes.

Furthermore, we employed a difference-in-differences (DID) approach for all models. By employing the DID approach, we can estimate the average impact of providing/offering tree rights by controlling for any baseline-level differences at the individual or group level.[9] The estimation models are as follows:

First stage:

$$Rights_i = \alpha_0 + \alpha_1 Treatment_i + \alpha_2 Time_t + \alpha_3 Treatment * Time_t + \theta X_i + u_i, \qquad (1)$$

Second stage:

$$\log Y_{ijt} = \beta_0 + \beta_1 Treatment_i + \beta_2 Time_t + \beta_3 \widehat{Rights}_i + \theta X_i + \varepsilon_i, \qquad (2)$$

ITT model:

$$\log Y_{ijt} = \gamma_0 + \gamma_1 Treatment_i + \gamma_2 Time_t + \gamma_3 Treatment * Time_t + \theta X_i + \omega_i, \qquad (3)$$

Group level:

$$\log \bar{Y}_{jt} = \delta_0 + \delta_1 Treatment_j + \delta_2 Time_t + \delta_3 Treatment * Time_{jt} + \theta \bar{X}_j + \mu_j, \qquad (4)$$

where Y_{it} is the outcome of interest (i.e., the number of days worked for tree management, the extracted volume of trees and other natural resources, and the number of planted trees per year) for individual i in year t; therefore, $\log Y_{it}$ - $\log Y_{it-1}$ indicates the rate of change in the outcome between years t and t-1 (i.e., before and after the experiment). $Rights_i$ is a dummy variable (i.e., the individual tree rights dummy) that takes the value 1 when individual i accepted and received the individual tree rights.[10] $Treatment_i$ represents a treatment dummy that takes the value 1 if individual i was offered individual tree rights. $\bar{Y}_{jt}$ and $Treatment_j$ in Equation 4 are the group mean outcome and treatment dummy for youth group j, respectively. X_i is a set of observable

[9] Allocated communal lands are separated by physical distance. Thus, in this study, we did not consider spatial spillover effects from treated to control communities.

[10] The 25 non-accepters in the treatment group take the value 0 for *TreeRights*.

demographic characteristics of individual i, while $\bar{X}_j$ represents the average demographic characteristics for youth group j. The standard errors for the individual estimations are clustered at the youth group level to account for autocorrelation in the error term (i.e., u_i, ε_i, and ω_i).

Equations 1, 2, and 3 are estimated at the individual level, but we employ a group-level analysis for Equation 4. In the second stage estimation for the IV model shown in Equation 2, we use the fitted values of the individual tree rights dummy ($\widehat{Rights}$), which is instrumented by the treatment dummy in the first stage estimation. The ITT model (Equation 3) and the group-level analysis use the dummy variable representing whether an individual member or the youth group was offered tree rights (*Treatment*). Thus, β_1 in Equation 2 indicates the effects of individual tree rights provision on each outcome, while γ_1 and δ_1 are expected to capture the effects of offering individual tree rights at the individual and group levels, respectively.

Because Hypothesis 1 concerns the stimulation of forest management activities by the introduction of the mixed management system, we tested it by examining whether the intervention (provision or offer of tree rights) increases the workdays allocated for such tree management activities as thinning, pruning, watering, and guarding. Although the groups in this study area have already adopted collective monitoring to protect the allocated communal lands, the allocated time for guarding can be expected to increase proportionally to the increased value of the protected resources. Hence, the regression equations of those activities for the intervention dummies can be expected to have positive coefficients.

In contrast, although planting new tree seedlings is an important forest management activity, our intervention may not have significant effects on the number of planted trees. In the longer term, to maximize profits from forest products, individual tree-rights holders are likely to increase labor input for plantation activity. However, if individual tree-rights holders already have a sufficient number of trees, they may allocate more labor to management activities of the existing trees (i.e., thinning, pruning, and guarding). Furthermore, they may prefer to take well care of the limited number of planted tree seedlings, rather than plating a large number of them. Hence, in the short term, the mixed management system may not significantly affect the plantation activity of individual tree-rights holders. Unfortunately, due to data constraints, we can only examine the short-term impact of the mixed management system. Therefore, the coefficient of the provision dummy may be insignificant or negatively significant in the regression analysis of the plantation activity, such as the number of workdays for planting tree seedlings and the number of planted tree seedlings.

Finally, we tested Hypotheses 2 and 3 by focusing on how the tree rights dummy in Equation 2 and the treatment dummy in Equation 3 affected the extracted volumes of trees and other natural resources. If the tree rights provision successfully motivates individuals to engage in harvesting activities, the extracted volumes of timber trees, thinned trees, and pruned branches should increase, while the extracted volumes of non-timber resources such as fodder and honey should remain unchanged.

In addition to the benchmark estimations, we conducted two robustness checks. First, we conducted robustness checks by excluding the non-accepters from the observations. Considering that 25 non-accepters from the treatment group were included in the benchmark estimations, in this first robustness check, our observations focused solely on those who accepted tree rights and those who were never offered such rights.

Second, to address imbalances between the treatment and control groups, a propensity score matching combined with difference-in-differences (PSM-DID) regression was employed. Even though treated youth groups were randomly selected for this study, significant differences in certain demographic characteristics, such as age and distance to allocated lands, existed between the groups. While these characteristics were considered in our benchmark estimations as control variables, the PSM approach was utilized to mitigate potential biases. This study employed the nearest-neighbor matching with a caliper of 0.01 and computed the standard error by bootstrapping with 100 replications.

6 Results

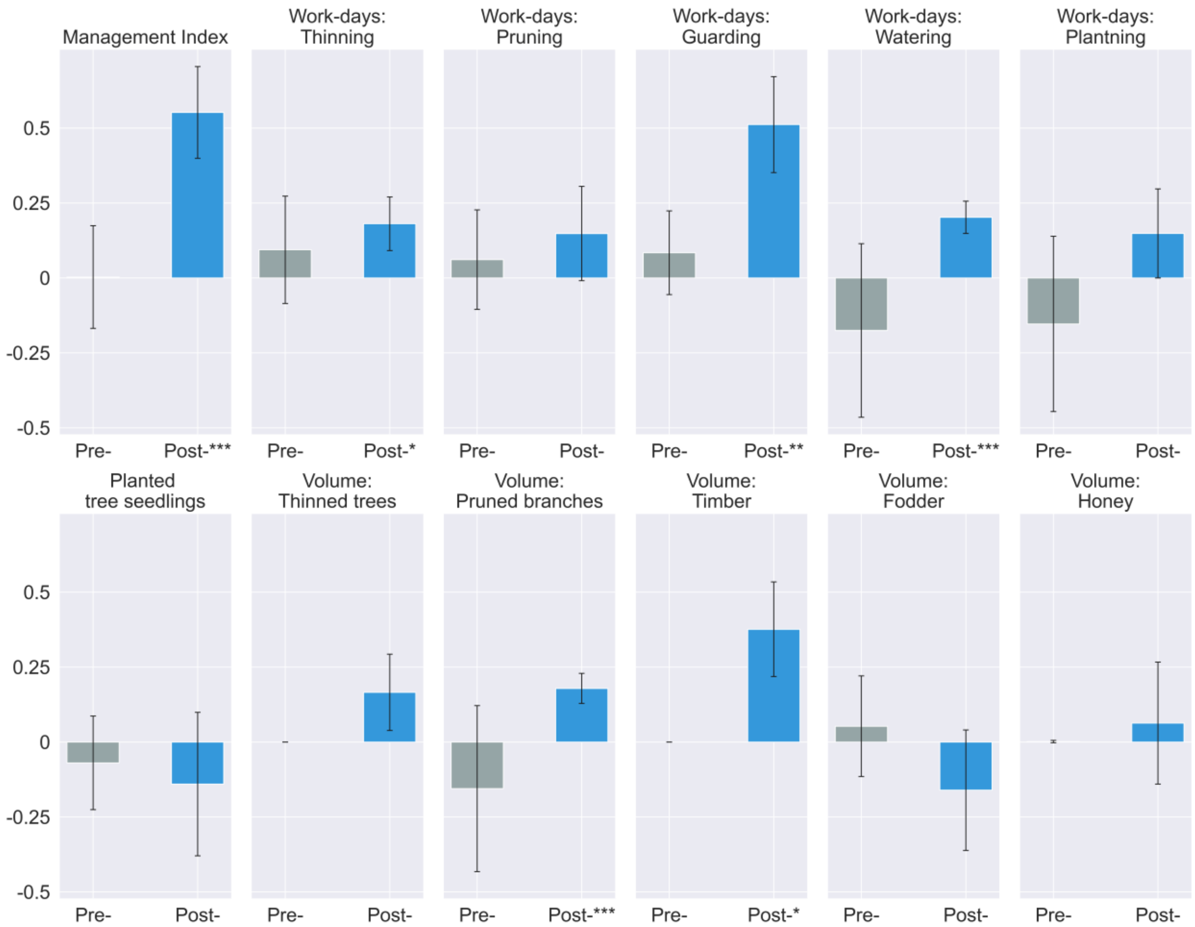
6.1 Forest management efforts and the extracted volumes of natural resources after the intervention

Columns 3 and 4 of Table 2 show the average differences in outcomes between the treatment and control groups at the individual level after the experiment. Many outcomes differed significantly between individuals in the treatment and control groups, even though we found no significant difference in each outcome before the experiment. For example, the average number of workdays for thinning, pruning, guarding, and watering was significantly higher for the individuals in the treatment group. Roughly speaking, the working days spent pruning and guarding doubled from the pre- to post-treatment period for the individuals in the treatment group, whereas no such large changes were observed for the control members. More precisely, for the pruning activity, the annual workdays at the individual level increased from 0.72 to 1.41. Although the days allocated for pruning were still limited after the intervention, an increase of even one day in pruning can be expected to improve tree growth (Skovsgaard et al., 2018). Furthermore, the extracted volumes of thinned trees, pruned branches, and timber were higher for the individuals in the treatment group than for those in the control group. The extracted volumes of timber were continuously zero for the members in the control group, probably due to a lack of motivation for harvesting under the conventional community management system.

The changes between pre- and post-treatment in Table 2 also clearly reveal the members in both the treatment and control groups actively planted trees. Indeed, the number of planted trees was much larger than the average number of trees whose rights were offered, which was

81. However, there is no descriptive evidence that members offered tree rights planted trees more actively.

Figure 2. Normalized youth-group-level mean differences between the treatment and control groups: pre- and post-treatment periods



Note. The figure shows the normalized mean difference and standard errors between the treatment and control groups; the mean differences for pre-treatment extracted volumes of thinned trees and timber are not visible due to both groups having a volume of zero. As for honey, the difference for pre-treatment between the groups is minimal and may be difficult to observe given the current scale of the graph; *, **, and *** indicate statistical significance (paired t-test) between the treatment and control groups at the 10%, 5%, and 1% levels, respectively.

In addition, we calculated the mean of each outcome at the youth group level (see Table A1 in Appendix A for the actual group-level mean values for the treatment and control youth groups). Figure 2 shows the normalized group mean differences between the treatment and control groups. Positive values indicate that the treatment group's average is higher than that of the control group, and vice versa for negative values. Similar to the individual-level statistics, the variables were not significantly different in the pre-treatment period; however, the group means for several outcomes become significantly different between the two groups in the post-treatment period. Specifically, the group average of the workdays for three activities (i.e., thinning, guarding, and watering) and the extracted volumes of thinned trees, pruned branches, and timber became larger for the treatment youth groups than for the control youth groups.

Although there was a significant difference in the number of workdays for thinning and watering activities, this difference was mainly due to the reduction in the control group during the post-treatment period. The decrease in the thinning activity was limited, at only 0.1 days per year. In contrast, the average workdays for watering decreased by approximately six days per year. However, the total workdays for forest management showed a negligible difference between these periods, with a reduction of only two days. These findings imply that the overall effort for forest management remained consistent in the control group, but the allocation of time to specific management activities shifted.

A similar situation was also observed for the extracted volumes of pruned branches. In this regard, there are two potential interpretations. First, as argued, this decline may be observed because the incentive for management and harvesting efforts are diluted for the members in the control group. Given that the treatment and control groups were aware of the importance of annual pruning through the training, the lack of pruning in the control group implies weak incentive to undertake such activities. Another possibility is the unobserved shocks occurred differentially across the groups. However, we believe that the latter possibility is less likely. As shown in Figure 1, our study area is extensive, with the most distant villages more than 200 kilometers apart. Although there is a possibility of small events that could affect conventional community management activities at the local level, we are unaware of any potential shocks that would have an extensive impact at the regional level during the study period.[11]

6.2 Estimation results

For the first stage of the IV estimation, as expected, we found that the random assignment dummy was significantly associated with receiving tree rights. Because the estimated *F*-statistic (421.5) is greater than 104.7, the possibility of weak instrument bias can be ruled out (Lee et al., 2022).

The effects of tree rights provision on the number of workdays allocated to tree management are reported in Table 3, while results of the number of workdays for planting are consolidated with the number of planted tree seedlings in Table 4. The results of the IV method are presented in Panel A of Table 3, while the results of offering tree rights using the ITT and group-level analyses are shown in Panels B and C, respectively (for full results see Tables A2 to A4 in Appendix A).

From the results of the IV estimation in Panel A, we found that the tree rights provision significantly increased the management index. The coefficients suggest that the total number of workdays dedicated to tree management increased by 159% through the intervention. This increase in the management index was primarily attributed to three tree management activities: pruning, guarding, and watering. The results of the ITT estimation in Panel B showed similar findings. Although the coefficients of the treatment dummy in the ITT estimation are smaller than those in the IV estimation, as expected, we found that the number of workdays allocated to pruning, guarding, and watering was significantly associated with the treatment dummy (i.e., offering individual tree rights). Moreover, positive and significant relations between the treatment dummy and the workdays allocated to the three activities can be observed in the

[11] Since 2020, armed conflict has been ranging in Tigray. However, the situation remained stable throughout the study period.

group-level estimation presented in Panel C.

The results of the planting activity, including workdays allocated to planting and the number of seedlings planted, are presented in columns 1 and 2 of Table 4, respectively. Although the coefficients of the tree rights provision dummy are positive in both cases for all estimation models, they are not statistically significant.

Finally, we turn to the impact of individualized tree rights on the extracted volume (Table 5). As expected, we found that the provision of tree rights in Panel A significantly increased the extracted volumes of thinned trees, pruned branches, and timber trees. In particular, the tree-rights holders substantially increased the extracted volumes from pruning branches. While our findings consistently reveal that the introduction of individual tree rights significantly increased the extracted volumes of these three resources in the ITT estimation (Panel B), the coefficient of the treatment dummy for the volume of thinned trees in the group-level estimation shown in Panel C is insignificant ($p<0.16$). In contrast, the mixed management system did not significantly impact fodder and honey extraction in any of the models.

Table 3: Effect of the tree rights provision on the number of days worked for tree management.

The number of workdays:	Management index	Thinning	Pruning	Guarding	Watering
	(1)	(2)	(3)	(4)	(5)
Panel A: IV-estimates (n=910)					
Tree rights provision dummy	1.586***	0.009	0.348**	1.053**	0.641*
	(0.543)	(0.127)	(0.149)	(0.494)	(0.359)
Panel B: ITT-estimates (n=910)					
Offered individual tree rights	1.382***	0.008	0.304**	0.918**	0.559*
	(0.482)	(0.111)	(0.126)	(0.435)	(0.325)
Panel C: Group-level estimates (n=136)					
Offered individual tree rights	1.300**	0.016	0.188*	0.764*	0.579*
	(0.580)	(0.082)	(0.109)	(0.447)	(0.332)
Mean of unlogged dependent variable:					
at the individual-level	33.86	0.18	0.75	26.08	4.37
at the group-level	33.45	0.15	0.66	26.37	3.79

Note. Standard errors of Panels A and B are clustered at the youth group level in parentheses, while standard errors are shown in parentheses for Panel C; the tree rights provision dummy variable is instrumented by the random assignment of the treatment dummy; the variable in Panels B and C (i.e., offered individual tree rights) is a dummy variable which takes the value 1 if the individual and youth group were offered individual tree rights, respectively; *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 4: Effect of the tree rights provision on the planting activity

	Workdays for planting (1)	Planted tree seedlings (2)
Panel A: IV-estimates (n=910)		
Tree rights provision dummy	0.164	0.197
	(0.319)	(1.471)
Panel B: ITT-estimates (n=910)		
Offered individual tree rights	0.143	0.172
	(0.280)	(1.288)
Panel C: Group-level estimates (n=136)		
Offered individual tree rights	0.277	0.829
	(0.295)	(1.238)
Mean of unlogged dependent variable:		
at the individual-level	2.48	221.90
at the group-level	2.48	195.98

Note. Standard errors of Panels A and B are clustered at the youth group level in parentheses, while standard errors are shown in parentheses for Panel C; the tree rights provision dummy variable is instrumented by the random assignment of the treatment dummy; the variable in Panels B and C (i.e., offered individual tree rights) is a dummy variable which takes value 1 if the individual and youth group were offered individual tree rights, respectively; *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 5: Effect of the tree rights provision on extracted resource volumes

The number of workdays:	Thinned trees (1)	Pruned branches (2)	Timber trees (3)	Fodder (4)	Honey (5)
Panel A: IV-estimates (n=910)					
Tree rights provision dummy	0.110**	2.345***	0.352*	-0.008	0.154
	(0.051)	(0.541)	(0.196)	(0.560)	(0.164)
Panel B: ITT-estimates (n=910)					
Offered individual tree rights	0.096**	2.044***	0.307*	-0.007	0.134
	(0.045)	(0.453)	(0.172)	(0.489)	(0.145)
Panel C: Group-level estimates (n=136)					
Offered individual tree rights	0.073	1.651***	0.237**	0.238	0.038
	(0.049)	(0.530)	(0.102)	(0.616)	(0.312)
Mean of unlogged dependent variable:					
at the individual-level	0.45	45.85	1.33	52.48	17.92
at the group-level	0.37	43.56	0.84	56.55	21.64

Note. Standard errors of Panels A and B are clustered at the youth group level in parentheses, while standard errors are shown in parentheses for Panel C; the tree rights provision dummy variable is instrumented by the random assignment of the treatment dummy; the variable in Panels B and C (i.e., offered individual tree rights) is a dummy variable which takes value 1 if individual and youth group were offered individual tree rights, respectively; *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

6.3 Robustness checks and post-hoc power analysis

This section details the findings from two robustness checks, with the results tables located in Appendix A. First, after excluding the non-accepters from the observations, we estimated treatment effects at both the individual and youth group levels, as shown in Table A5 of Appendix A. The individual-level results in Panel A and the group-level results in Panel were essentially the same as the benchmark estimations.

Second, we performed the PSM-DID estimation to address imbalances between the treatment and control groups. We conducted a *t*-test to assess the mean differences of each covariate between the treatment group and the matched control group, as presented in Table A6 of Appendix A. According to post-matching analysis, we observed no statistically significant differences in demographic characteristics between the two groups. This suggests that the control group's characteristics became sufficiently similar after the matching process. After the matching procedure, we estimated the effect of the tree rights provision using PSM-DID method. The results of the PSM-DID estimation, which are given in Table A7, align with our benchmark estimation results.

Finally, due to the limited number of observations in our study, we performed post-hoc power calculations. The results suggest that, based on the observed effect size and our sample size, we achieved more than 80% power to detect statistically significant differences for most variables. However, for the variables related to the number of workdays for thinning and planting, the power was below the commonly accepted threshold of 0.8.

6.4 Discussion

We found that the provision of tree rights led to an increase in the management index. This increase is primarily due to the rise in the number of workdays allocated to pruning, guarding, and watering. In particular, the tre e right provision had a substantial effect on guarding activity, showing a doubling of guarding time among treatment group members. As shown in Table 2, the average number of workdays dedicated to guarding before the experiment was roughly 19 days in both groups. Considering that a youth group had approximately 10 members involved in collective monitoring activities, it can be inferred that they spent around half of the year guarding the allocated land before the experiment. Post-experiment feedback confirmed that this group's collective monitoring activities continued. In contrast, our findings suggest that the number of days dedicated to guarding doubled among treatment group, implying that guarding activities by treatment group were conducted every day throughout the year following the intervention to protect valuable trees. One potential reason for this increase is the risk of illegal harvesting and unauthorized grazing by outsiders. Since many of the trees provided through the experiment were small trees with a DBH of less than 5 cm, this might have led the treated members to intensify their guarding efforts to prevent damage from livestock. Another plausible explanation might be the enhanced value of tree resources in mixed management areas, emphasizing the importance of communal tree protection efforts in such systems.

Moreover, we found that watering had the second-largest coefficient after guarding, indicating an increase ranging from 56% to 64%. Given that individuals, on average, dedicated four workdays to watering, these results suggest that the intervention led to an increase in workdays to approximately seven. The heightened watering activity is likely because many of the provided trees were still young and small, requiring consistent watering to ensure their survival and growth. This finding highlights that granting tree rights improves individuals' incentives to nurture their trees.

In contrast, the coefficient on thinning activity was positive in all estimates but was not statistically significant. Table 2 shows a significant difference in the number of workdays allocated to thinning between the treatment and control groups. However, this difference was primarily due to a slight reduction in the control group (i.e., from 0.15 days to 0.05 days per member), while the average number of workdays in the treatment group remained unchanged before and after the experiment (i.e., 0.28 days per member annually). Furthermore, on average, both groups allocated less than one day per year to thinning, indicating limited efforts to thinning activity during the study periods. This might be because thinning is not a yearly requirement.

Members of the treatment group, therefore, may not have perceived a need to thin the trees, even after obtaining tree rights. For species like *Grevillea robusta*, it is recommended to conduct thinning five years after planting (Grant et al., 2006). Considering that all participants received training on proper thinning techniques, and many of the provided trees were less than four years old, members in the treatment group might have assessed that it was premature for thinning. Consequently, they might have prioritized other management activities, such as pruning, over thinning.

Regarding planting activity, we observed no significant impact on the workdays for planting or the number of tree seedlings planted. This is not unexpected, considering that planting tree seedlings is mainly determined by the rotation of forests and is not an annual activity. As both the treatment and control groups managed forests recently recovered from land degradation, the demand for new plantations was likely high in both groups. In fact, a substantial number of timber trees were planted in the treatment groups even after the intervention, averaging 150 trees per member as shown in Table 2. Therefore, the effects of new tree seedling plantations might be more pronounced in the long term rather than over a short duration, especially following the removal of pre-existing trees. Moreover, as evidenced by column 4 in Table 3, members of the treatment groups were more diligent in watering their trees. These findings suggest that providing tree rights increases individuals' incentives to care for planted trees. Given the observations above, it is reasonable to conclude that our results largely support Hypothesis 1.

Next, we will examine hypotheses 2 and 3 based on the impact of tree rights provision on the extracted volume of timber and non-timber forest products. First, among the three timber products, the impact of tree rights provision on pruned branches was the most significant, with coefficients varying from 165% to 235%. However, as shown in Table 2, the difference between the treatment and control groups is primarily due to reduced extracted volume in the control groups. A potential explanation for this could be the absence of tree ownership rights in the control groups, which may have reduced the incentive for intensively pruning branches.

Moreover, the extracted volume of timber trees is positively and significantly associated with tree rights provision, showing an increase ranging from 24% to 35%. The increase in the extracted volume of timber trees does not necessarily imply that the mixed management system causes excessive extraction of forest resources or forest degradation. As mentioned before, because most allocated trees for tree-rights holders were short trees, removing short trees from dense tree areas can be a part of timber forest management. The average volume of extracted timber is 1.3 kg per member, which means that an increase of 24 to 35% corresponds to an increment of less than 500 grams per member. Additionally, the tree-rights holders continuously planted a sizable number of tree seedlings (150 trees per member annually on average), indicating an actual increase in the total number of trees. While our study was limited to a short-term investigation, the mixed management system could potentially promote sustainable forest management.[12] In sum, the findings of this study favor Hypothesis 2.

Finally, we found that the tree rights provision did not stimulate the extraction of non-timber resources, such as fodder and honey (columns 4 and 5 in Table 5). These results imply that non-timber resource extraction activities are continuously conducted in the youth group

[12] Unfortunately, information other than the extracted volume of timber trees in kg was not obtained. It would be useful to know which timber species and for what reasons trees are extracted from forests under the mixed management system.

receiving tree rights, probably because the communal rules of extracting non-timber forest products were unchanged by the introduction of the mixed management system. Hence, Hypothesis 3 is supported.

7 Conclusion

In this study, we proposed that a mixed private and community management system would be a potential institution for recovering timber forests in developing countries and empirically investigated its impact on forest management activities. Consequently, we introduced a mixed management system by providing individual tree rights to randomly selected communities and their members in Ethiopia. We found that introducing the mixed management system significantly stimulated intensive forest management, as evidenced by the increased number of workdays allocated to pruning, guarding, and watering tasks. In particular, it is noteworthy that the number of workdays allocated for collective guarding activity in the community forestland roughly doubled under the rights provision. In addition, members of the mixed management system extracted more timber trees and forest products related to tree management, such as thinned trees and pruned branches. In contrast, the extracted volumes of forest products unrelated to tree management (i.e., fodder and honey) did not change through the intervention.

These results provide useful information for sustainable forest management. Because of the considerable efforts of Ostrom and her colleagues (Ostrom 1990, 2010; Ostrom and Nagendra 2007), community forest management has been adopted globally (Agrawal et al., 2008; Hajjar & Oldekop, 2018). However, because community forest management does not provide a clear incentive for conducting intensive tree management tasks, it may be difficult to achieve reforestation of degraded timber forests under such a system. The results of this study suggest that introducing a mixed management system may motivate community members to allocate more efforts toward sustainable forest management while maintaining the advantages of community forest management in protecting forest resources.

In practice, developing countries can adopt mixed management systems for timber forests by granting individualized property rights for timber trees on community forestlands. A prominent challenge lies in bridging the knowledge gap around the mixed management system, a concept not well-known to many in developing countries. Without a clear understanding of the mixed management system, community members might lean more towards community forest management, as highlighted by He et al. (2020). Thus, it is essential to grasp the distinctions between mixed management and conventional private ownership systems, as well as their respective economic benefits. This study reveals that, while a small portion of people prefer to be non-accepters, the majority were willing to adopt the mixed management system after receiving comprehensive explanations, highlighting its significant practical potential.

Overall, our estimation results suggest that the mixed management system successfully increases individuals' incentives for engaging in effective forest management tasks. However, this study has a couple of limitations. First, this study shows only the short-term impact of the mixed management system, leaving its long-term implications uncertain. In particular, the effects on tree plantations are expected to change over the longer term. In addition, since certain tree management activities, especially thinning, are not conducted annually, our findings might reflect the short-run variations. Furthermore, how individual tree-rights holders will act in the future is unclear, particularly when observing their peers tree harvesting behaviors. Thus, whether the mixed management system motivates community members to sustainably engage in intensive forest management by planting timber trees in the longer term is a major remaining empirical question.

Second, while most variables demonstrated sufficient statistical power, the number of workdays dedicated to thinning and tree planting did not. Consequently, the lack of significance in these two variables could be attributed to our sample size. Future research should, therefore, seek to validate these effects using a larger dataset.

Lastly, although conducting intensive management activities is expected to promote timber forest rehabilitation, whether the mixed management system, in fact, promotes forest rehabilitation was not directly investigated in this study because of the short study time interval available after granting the individualized tree rights. Using remote sensing to gauge forest quality changes accurately, as was done by (Burgess et al., 2012; Takahashi & Todo, 2013, 2017), further studies should be conducted to assess the effect of the mixed management system on forest quality changes over a longer period.

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Appendix A: Additonal Tables

Average group-level characteristics in pre- and post-treatment periods

To conduct the group-level estimation shown in Equation 4, we calculated the mean of each outcome at the youth-group-level in both the pre- and post-treatment periods. The 25 non-accepters were included in the treatment youth groups when the mean values were calculated. Table A1 shows the group-level mean values for the treatment and control youth groups: columns 1 and 2 show the group-level means in the pre-treatment period and columns 3 and 4 indicate the post-treatment means. After normalizing the mean values for each outcome, we estimated the differences between the two groups, which are illustrated in Figure 2.

Estimations after excluding the non-accepters from the treatment group.

As mentioned, 25 members in the treatment group (approximately 12.7%) did not accept the offer of individual tree rights. To incorporate endogeneity related to these non-accepters, we performed three regression models: the IV, ITT, and group-level estimations. As robustness checks, we conducted additional regression analyses at the individual and youth group levels after excluding the 25 non-accepters from the observations. The effects of tree rights provision at the individual and group levels, are presented in Panels A and B of Table A5, respectively. The results of the robustness checks are consistent with the results of the benchmark estimations.

Table A1: Average group-level characteristics: pre- and post-treatment

	Pre-treatment		Post-treatment	
	Treatment youth group (1)	Control youth group (2)	Treatment youth group (3)	Control youth group (4)
Number of observations	26	42	26	42
Number of days worked for tree management activity in a year				
Thinning	0.22	0.11	0.28	0.06**
	(1.14)	(0.64)	(0.66)	(0.19)
Pruning	0.47	0.32	1.09	0.75
	(2.22)	(0.87)	(1.61)	(1.34)
Guarding	23.09	19.88	43.75	24.23***
	(25.22)	(18.64)	(27.66)	(22.26)
Watering seedlings	3.85	6.66	3.99	0.75***
	(8.42)	(22.64)	(4.90)	(2.12)
Planting tree seedlings	2.58	3.31	2.35	1.64
	(3.61)	(6.51)	(3.02)	(2.72)
Number of planted tree seedlings	147.54	196.22	147.98	246.63
	(342.00)	(492.26)	(439.99)	(785.52)
Extracted volumes (kg)				
Thinned trees	0	0	1.35	0.36
			(3.92)	(2.32)
Pruned branches	49.88	74.88	40.12	11.23***
	(184.74)	(175.22)	(46.78)	(18.71)
Timber	0	0	4.73	0**
			(12.89)	
Fodder	39.00	33.86	67.27	82.78
	(84.24)	(49.99)	(69.12)	(82.83)
Honey	2.82	2.31	50.72	34.55
	(4.41)	(3.45)	(245.46)	(179.51)

Note. Standard deviations in parentheses. ** and *** indicate statistical significance (paired t-test) between the treatment and control youth groups at the 5% and 1% levels, respectively.

Table A2: Full results of the effect of the tree rights provision using the instrumental variable method.

	Management index	The number of days worked for tree management: Thinning	Pruning	Guarding	Watering	Planting	Planted tree seedlings	Extracted volumes: Thinned trees	Pruned branches	Timber trees	Fodder	Honey
Effect of tree-rights	1.586***	0.009	0.348**	1.053**	0.641*	0.164	0.197	0.110**	2.345***	0.352*	-0.008	0.154
	(0.543)	(0.127)	(0.150)	(0.494)	(0.359)	(0.319)	(1.472)	(0.051)	(0.541)	(0.196)	(0.560)	(0.164)
Treatment dummy	-0.177	0.047	-0.023	0.078	0.111	-0.006	0.160	-0.003	-0.800**	-0.003	-0.465	-0.139
	(0.375)	(0.103)	(0.158)	(0.339)	(0.285)	(0.216)	(0.832)	(0.003)	(0.379)	(0.013)	(0.422)	(0.201)
Time dummy	-0.216	-0.013	0.042	0.296	-0.515**	-0.223	-0.613	0.016	-0.652*	-0.000	0.362	-0.112
	(0.271)	(0.036)	(0.058)	(0.284)	(0.196)	(0.180)	(0.888)	(0.016)	(0.363)	(0.000)	(0.357)	(0.089)
Average age	0.006	0.002	-0.001	0.001	0.006	-0.001	-0.016	0.001	0.010	0.004	0.031*	0.032***
	(0.012)	(0.001)	(0.002)	(0.015)	(0.008)	(0.007)	(0.029)	(0.001)	(0.014)	(0.004)	(0.016)	(0.010)
Average education	0.003	0.003**	0.005	-0.023	0.013	0.014	0.038	0.004	-0.008	-0.002	0.044	0.008
year	(0.022)	(0.001)	(0.009)	(0.025)	(0.013)	(0.014)	(0.060)	(0.003)	(0.023)	(0.003)	(0.035)	(0.014)
Number of household	-0.015	0.002	0.000	-0.023	0.011	0.019	0.073	0.001	0.000	-0.001	0.094**	0.048**
member	(0.035)	(0.004)	(0.011)	(0.028)	(0.015)	(0.019)	(0.082)	(0.003)	(0.035)	(0.010)	(0.046)	(0.022)
Average total income	0.000	-0.000	-0.000	0.000	-0.000	-0.000	-0.000*	-0.000	0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Average distance to	-0.003	0.003	0.001	0.009	-0.017	-0.005	-0.010	-0.002	0.004	-0.013*	0.012	0.024
the community land	(0.037)	(0.004)	(0.011)	(0.035)	(0.022)	(0.019)	(0.083)	(0.004)	(0.033)	(0.007)	(0.040)	(0.022)
Constant term	2.408***	-0.045	0.208	1.999***	0.473	0.726**	3.659**	-0.047	0.968	-0.070	0.734	-0.505
	(0.522)	(0.038)	(0.156)	(0.610)	(0.305)	(0.322)	(1.521)	(0.033)	(0.788)	(0.121)	(0.754)	(0.346)

Note. For all estimates, the number of observations is 910. The variable "Effect of tree-rights" is an interaction term between the treatment dummy and time dummy. Standard errors are clustered at the youth group level in parentheses; * and ** indicate statistical significance at the 10% and 5% levels, respectively.

Table A3: Full results of the effect of the tree rights provision using the intention-to-treat model.

	Management index	The number of days worked for tree management: Thinning	Pruning	Guarding	Watering	Planting	Planted tree seedlings	Extracted volumes: Thinned trees	Pruned branches	Timber trees	Fodder	Honey
Effect of tree-rights	1.382***	0.008	0.304**	0.918**	0.559*	0.143	0.172	0.096**	2.044***	0.307*	-0.007	0.134
	(0.482)	(0.111)	(0.126)	(0.436)	(0.325)	(0.280)	(1.289)	(0.046)	(0.453)	(0.172)	(0.489)	(0.145)
Treatment dummy	-0.170	0.033	0.008	0.110	0.103	-0.028	0.065	-0.012	-0.815**	-0.010	-0.512	-0.211
	(0.366)	(0.097)	(0.162)	(0.335)	(0.295)	(0.233)	(0.890)	(0.012)	(0.377)	(0.019)	(0.466)	(0.189)
Time dummy	-0.216	-0.013	0.042	0.296	-0.515**	-0.223	-0.613	0.016	-0.652*	-0.000	0.362	-0.112
	(0.272)	(0.037)	(0.058)	(0.284)	(0.197)	(0.180)	(0.890)	(0.016)	(0.364)	(0.001)	(0.356)	(0.090)
Average age	0.003	0.001	0.001	-0.001	0.007	0.003	0.013	0.002	0.014	0.006	0.016	0.011**
	(0.014)	(0.001)	(0.003)	(0.015)	(0.007)	(0.005)	(0.022)	(0.002)	(0.010)	(0.004)	(0.015)	(0.005)
Average education	-0.005	0.005**	0.009	-0.023	0.012	0.015	0.043	0.005	0.021	0.001	0.042*	0.021*
year	(0.021)	(0.002)	(0.009)	(0.022)	(0.012)	(0.011)	(0.047)	(0.005)	(0.017)	(0.003)	(0.025)	(0.012)
Number of household	-0.027	0.002	0.002	-0.032	0.013	0.020	0.095	0.003	-0.003	-0.002	0.058	0.020
member	(0.032)	(0.003)	(0.013)	(0.025)	(0.014)	(0.019)	(0.079)	(0.003)	(0.033)	(0.008)	(0.043)	(0.020)
Average total income	-0.000	-0.000	-0.000	0.000	-0.000	-0.000	-0.000	-0.000	-0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Average distance to	-0.003	-0.001	0.005	0.009	-0.017	-0.001	0.026	-0.002	-0.003	-0.011	-0.005	-0.015
the community land	(0.037)	(0.005)	(0.011)	(0.036)	(0.020)	(0.017)	(0.071)	(0.005)	(0.035)	(0.007)	(0.040)	(0.022)
Constant term	2.583***	-0.006	0.107	2.133***	0.434*	0.614**	2.579**	-0.077	0.809	-0.135	1.419**	0.310
	(0.555)	(0.061)	(0.182)	(0.602)	(0.257)	(0.253)	(1.192)	(0.067)	(0.642)	(0.089)	(0.663)	(0.208)

Note. For all estimates, the number of observations is 910. The variable "Effect of tree-rights" is an interaction term between the treatment dummy and time dummy. Standard errors are clustered at the youth group level in parentheses; *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A4: Full results of the effect of the tree rights provision at the group level

	Management index	The number of days worked for tree management:					Planted tree seedlings		Extracted volumes:			
		Thinning	Pruning	Guarding	Watering	Planting		Thinned trees	Pruned branches	Timber trees	Fodder	Honey
Effect of tree-rights	1.300**	0.016	0.188*	0.764*	0.579*	0.277	0.829	0.073	1.651***	0.237**	0.238	0.038
	(0.580)	(0.082)	(0.109)	(0.447)	(0.334)	(0.295)	(1.241)	(0.049)	(0.532)	(0.102)	(0.603)	(0.307)
Treatment dummy	-0.376	0.028	-0.045	-0.001	0.054	-0.086	-0.118	0.004	-0.648*	0.017	-0.627	-0.125
	(0.425)	(0.060)	(0.110)	(0.407)	(0.243)	(0.215)	(0.904)	(0.036)	(0.387)	(0.074)	(0.440)	(0.224)
Time dummy	-0.369	-0.008	0.114	0.187	-0.493**	-0.345*	-1.175	0.024	-0.637*	0.000	0.319	-0.025
	(0.354)	(0.050)	(0.092)	(0.341)	(0.204)	(0.180)	(0.758)	(0.030)	(0.325)	(0.062)	(0.369)	(0.187)
Average age	0.010	0.003	0.001	0.002	0.019	-0.000	-0.007	-0.000	0.031	0.003	0.062**	0.068***
	(0.025)	(0.004)	(0.007)	(0.027)	(0.016)	(0.014)	(0.060)	(0.002)	(0.026)	(0.005)	(0.029)	(0.015)
Average education	0.032	0.007	0.022	-0.066	0.029	0.056	0.188	-0.002	-0.037	-0.007	0.147**	-0.027
year	(0.067)	(0.010)	(0.018)	(0.066)	(0.039)	(0.035)	(0.147)	(0.006)	(0.063)	(0.012)	(0.071)	(0.036)
Number of household	-0.084	-0.005	0.026	-0.145	-0.008	0.055	0.152	-0.008	-0.033	0.016	0.343**	0.160**
member	(0.133)	(0.019)	(0.034)	(0.126)	(0.075)	(0.067)	(0.280)	(0.011)	(0.120)	(0.023)	(0.136)	(0.069)
Average total income	0.000	0.000	0.000	-0.000	0.000	0.000	0.000	-0.000	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Average distance to	0.042	0.001	-0.000	0.099	-0.030	-0.047	-0.141	-0.003	-0.010	-0.038	-0.003	0.048
the community land	(0.145)	(0.020)	(0.037)	(0.139)	(0.083)	(0.073)	(0.308)	(0.012)	(0.132)	(0.025)	(0.150)	(0.076)
Constant term	2.411**	-0.065	-0.142	2.812***	0.009	0.214	1.752	0.089	0.559	-0.058	-2.107*	-1.786***
	(1.031)	(0.146)	(0.267)	(0.987)	(0.590)	(0.521)	(2.194)	(0.087)	(0.940)	(0.180)	(1.067)	(0.543)

Note. For all estimates, the number of observations is 136. The variable “Effect of tree-rights” is an interaction term between the treatment dummy and time dummy. Standard errors are in parentheses; *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A5: Effect of the tree rights provision on the number of days worked for tree management and resource volumes without the non-accepters.

	Management index	The number of days worked for tree management: Thinning	Pruning	Guarding	Watering	Planting	Planted tree seedlings	Extracted volumes: Thinned trees	Pruned branches	Timber trees	Fodder	Honey
Panel A:												
Individual-level												
(n=860)												
Effect of tree-rights	1.431***	0.032	0.308***	0.982**	0.674**	0.203	0.462	0.111*	2.009***	0.318*	-0.011	0.147
	(0.487)	(0.109)	(0.114)	(0.453)	(0.316)	(0.247)	(1.176)	(0.063)	(0.476)	(0.183)	(0.469)	(0.208)
Panel B:												
Group-level												
(n=136)												
Effect of tree-rights	1.283**	0.016	0.190*	0.754*	0.651**	0.349	1.162	0.069	1.612***	0.228**	0.217	-0.020
	(0.581)	(0.082)	(0.111)	(0.451)	(0.298)	(0.279)	(1.182)	(0.048)	(0.532)	(0.100)	(0.498)	(0.189)

Note. Standard errors of Panel A are clustered at the youth group level in parentheses, while standard errors are shown in parentheses for Panel B; the 25 non-accepters were excluded from the observations; the variable "Effect of tree-rights" is an interaction term between the treatment dummy and time dummy; *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A6: Balancing tests

	Mean after matching:		
	Treatment group	Control group	*t*-statistics
	(1)	(2)	(3)
Number of observations	188	248	
Age	29.57	29.36	0.28
Education year	5.62	5.59	0.10
Number of household member	5.42	5.61	-1.14
Total annual income	7702.6	7769.0	-0.09
Distance to the community land	2.40	2.43	-0.20

Note: There is no statistically significant difference in any variable between the groups after matching.

Table A7: Effect of the tree rights provision using PSM-DID

	The number of days worked for tree management:					Planted	Extracted volumes:				
	Thinning	Pruning	Guarding	Watering	Planting	tree seedlings	Thinned trees	Pruned branches	Timber trees	Fodder	Honey
Effect of tree-rights	0.009	0.300**	0.966**	0.570*	0.157	0.244	0.100**	1.921***	0.318*	0.031	0.123
	(0.116)	(0.130)	(0.432)	(0.335)	(0.289)	(1.334)	(0.047)	(0.426)	(0.178)	(0.491)	(0.136)
Treatment dummy	0.034	0.018	0.051	0.108	-0.017	0.091	-0.012	-0.708*	-0.012	-0.538	-0.208
	(0.101)	(0.162)	(0.330)	(0.300)	(0.234)	(0.895)	(0.012)	(0.354)	(0.021)	(0.462)	(0.183)
Time dummy	-0.014	0.035	0.317	-0.524**	-0.226	-0.632	0.017	-0.552*	0.000	0.389	-0.092
	(0.038)	(0.058)	(0.283)	(0.204)	(0.185)	(0.923)	(0.017)	(0.322)	(0.001)	(0.366)	(0.085)
Average age	0.002	0.001	-0.001	0.006	0.003	0.014	0.002	0.021**	0.007*	0.016	0.012*
	(0.001)	(0.003)	(0.016)	(0.008)	(0.005)	(0.021)	(0.002)	(0.010)	(0.004)	(0.015)	(0.006)
Average education year	0.005**	0.011	-0.023	0.011	0.016	0.046	0.005	0.038**	0.002	0.043*	0.024**
	(0.002)	(0.009)	(0.022)	(0.013)	(0.011)	(0.046)	(0.005)	(0.015)	(0.003)	(0.023)	(0.011)
Number of household member	0.002	0.005	-0.036	0.015	0.023	0.105	0.003	0.003	-0.001	0.061	0.022
	(0.003)	(0.013)	(0.026)	(0.016)	(0.019)	(0.081)	(0.003)	(0.032)	(0.008)	(0.043)	(0.020)
Average total income	-0.000	-0.000	-0.000	0.000	-0.000	-0.000	-0.000	-0.000	0.000	-0.000	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Average distance to the	0.003	0.005	0.008	-0.007	0.004	0.047	-0.001	0.005	-0.011	0.003	-0.026
community land	(0.008)	(0.012)	(0.045)	(0.025)	(0.021)	(0.086)	(0.006)	(0.044)	(0.008)	(0.048)	(0.026)
Constant term	-0.035	0.087	2.150***	0.427	0.557**	2.415**	-0.102	0.345	-0.179*	1.403**	0.256
	(0.070)	(0.170)	(0.619)	(0.270)	(0.230)	(1.100)	(0.084)	(0.531)	(0.104)	(0.629)	(0.208)

Note. For all estimates, the number of observations is 872. The variable "Effect of tree-rights" is an interaction term between the treatment dummy and time dummy. Standard errors are in parentheses; * and ** indicate statistical significance at the 10% and 5% levels, respectively.