Norwegian University of Life Sciences (NMBU)

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

Ryo Takahashi, Keijiro Otsuka, Mesfin Tilahun, Emiru Birhane and Stein T. Holden

Norwegian University of Life Sciences
Centre for Land Tenure Studies

Centre for Land Tenure Studies Working Paper 06/21

ISBN: 978-82-7490-297-8

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

Ryo Takahashi[a] , Keijiro Otsuka[b], Mesfin Tilahun[cd], Emiru Birhane[cd], Stein T. Holden[d]

[a] Waseda University, [b] Kobe University, [c] Mekelle University, [d] Norwegian University of Life Sciences

Abstract

In this study, we argue that while community forest management is effective in protecting forest resources as argued by Ostrom, it may fail to provide proper incentives to take care of such resources because of collective sharing of benefits of forest management. This study proposes a mixed private and community management system as a desirable arrangement for timber forest management in Ethiopia, which is characterized by communal protection of community-owned forest area and individual management of individually owned trees. 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, the treated members extracted more timber trees and forest products, which are byproducts of tree management (thinned trees and pruned branches). In contrast, the extracted volumes of nontimber forest products unrelated to tree management (fodder and honey) did not change by the intervention.

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

1. Introduction

Conservation of forest resources is critically important for developing countries (Sunderlin et al. 2005; Reed et al. 2017). As forestland and grazing land grow scarcer and rural poverty persists, however, it is imperative to recover and create forest-rich environments by growing trees and fodder grasses so as to increase and sustain stock of forest resources for both income generation and poverty reduction (Otsuka et al., 2015; Takahashi and Todo, 2014). Although secure property rights on forestlands are fundamental for sustainable forest resource management (Arnot et al., 2011; Owubah et al., 2001; Tucker, 1999), consensus on which type of property regime effectively leads to recovery of forests and their sustainable management has not been reached (Takahashi and Otsuka, 2016).

Kijima et al. (2000) found in the context of Japan after World War II that private management is more efficient than community management because individual right holders have a motivation to sustainably manage tree resources. Standard microeconomics textbook (e.g., Pindyck and Rubinfeld (2017) and Perloff (2014)) also argue that private management is more efficient. Contrary to the argument in favor of private ownership and management of forests, forest management under common property regimes (hereafter, "community forest management") is commonly adopted in developing countries (Agrawal et al., 2008; Hajjar and Oldekop, 2018), primarily due to the great contribution of Ostrom and her colleagues who advocate carefully designed community management over state ownership and management. Ostrom (1990, 2010) identified the conditions under which community management is likely to be effective in sustainable natural resource management. However, empirical evidence on the effectiveness of community forest management is mixed (Arts and De Koning, 2017; Baynes et al., 2015). Furthermore, Ostrom did not discuss how to provide incentives to take care of forest resources, even though rehabilitation of forest environments requires investments in planting and management of trees and other forest resources.

In order to achieve sustainable management of community forests, other approaches have been suggested in the recent literature. Chankrajang (2019) addresses the unique setting in Thailand, where forest property rights are shared between the communities and the state. The results showed that property rights sharing conserves forest cover and reduces forest fire incidences more effectively compared with state-owned forest area. Similarly, Holden et al. (2013) found that individual tenure was more likely to be preferred on forest land with better market access and with higher production potential in China where the government opened for communities themselves to select the preferred (restricted) property regime. They were allowed to receive individual rights to plots of forest land for 25 to 70 years. This was a result of experimentation on alternative arrangements to enhance forest management and productivity. Otsuka et al. (2015) suggested that rehabilitation of community forests growing valuable trees in developing countries can be effectively achieved by introducing a mixed management system of private and common ownership (hereafter, "mixed management system"), which is characterized by communal protection of trees and other resources and by individual management of these resources. Such a system can be realized by granting control rights of forestland to local communities and individual ownership rights of trees to community members. In 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. Otsuka et al. (2015) also argued that forest protection activity has economies of scale, as one person can oversee large areas. However, no studies have empirically investigated the effects of the mixed management system on the efficiency of forest management.

To provide new empirical insights into the debate over property regimes, this study investigates the impact of the mixed management system on forest resource management compared with that of conventional community management by conducting a randomized controlled trial in northern Ethiopia. Individual tree rights were granted to the randomly selected youth groups and their members with the permission of the local authority. Specifically, we employ three indicators to examine its impact: the number of work-days allocated to tree and forest management, the extraction of tree products, and that of other forest products. We hypothesize that community members under the mixed management system allocate more time to management of trees and extract larger volume of tree resources associated with tree management, such as thinned trees and pruned branches.[1]

The remainder of this paper is structured as follows. Based on a review of the existing studies on forest management, we propose empirical hypotheses for this study in the next section. In the subsequent sections, we describe the detail 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. Literature Review and Hypothesis

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 textbook contend theoretically that private management is more efficient than community management because individual right holders have a motivation to sustainably manage forest resources to maximize profits from own forest land. They implicitly assume, however, that common property is open access, which was envisaged by Hardin (1968). Kijima et al. (2000) found empirically that private management of timber trees is 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 an efficient and sustainable forest management system 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 and Platteau, 1997; Hayami and Godo, 2005). Ostrom (1990, 2010) identified eight principles for successful and sustainable natural resource management under common property regimes, one of which is effective monitoring to protect natural resources. Increasing population pressure, improved infrastructure, and low-cost methods of demarcating and allocating private land rights may favor desirability of private ownership and management (Deininger et al., 2008).

In general, effective monitoring is a fundamental condition to prevent excessive extraction of forest resources (Ostrom and Nagendra, 2007). Community forest management has the advantage of reducing protection costs over private forest management because the total protection costs for monitoring can be reduced by sharing or rotating monitoring activities among community members. In fact, Sakurai et al. (2004) found that the protection cost of community forestry is significantly smaller than that of private forests, which requires employing a full-time watcher for small patches of private forests. Furthermore, Rustagi et al. (2010) and Kosfeld and Rustagi (2015) conducted a field experiment in Ethiopia and indicated that cooperation among community members in monitoring was enhanced due to costly norm enforcement in the community.

Economies of scale may be present in harvesting of 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 the land to forest companies who did the harvesting. The plausible reason that individual tenure was better than community tenure in forest management was that individuals receive longer-term rights (25-70 years) while community leaders in charge of communal forests only were elected for 5 years and therefore tended to focus on their short-term rent-seeking and overharvest the forest resources when they were in power.

However, empirical evidence on the effectiveness of community tenure in forest management is mixed (Arts and De Koning, 2017; Baynes et al., 2015; Slough et al., 2021b). While many studies have reported that the introduction of community management had a positive impact on protecting forest resources compared with management under state ownership (Edmonds, 2002; Leone, 2019; Persha et al., 2011; Takahashi and Todo, 2012), recent studies based on randomized control trials (RCT) find no evidence that the introduction of community management alleviates deforestation (Christensen et al., 2021; Eisenbarth et al., 2021). Furthermore, other studies indicate that common 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 endogeneity of property rights and found that forest quality in private property areas was less degraded than in common property areas.

One potential reason for the mixed results is the heterogeneity of forests: timber or nontimber forests. To sustainably grow valuable timber trees, intensive tree management activities or silvicultural operations, such as planting, thinning, pruning, singling, and weeding, are required in the case of timber forests (Otsuka et al., 2015). Furthermore, harvesting timber trees is one of the important activities to enhance the regeneration of forest ecosystems (Karsenty and Gourlet-Fleury, 2006; Langmaier and Lapin, 2020). Thus, in addition to protection of trees, both management and harvesting efforts are essential for timber forest management.[2] In contrast, because nontimber forest resources can regrow without much care, what matters in nontimber forest management is primarily protection (Otsuka et al., 2015).

We conjecture that community management works particularly for the management of nontimber forests due to a great advantage in reducing protection costs. However, under conventional community management system, the individual incentives to work for intensive tree management and harvesting activities will be 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 regard, conventional community forest management may face the social dilemmas for under-supplying management and harvesting efforts. In fact, the

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

inefficiency of community management of timber forests has been reported (Baland et al., 2010; Bhattacharya et al., 2010; Kijima et al., 2000).

This 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, mushroom, and spices), the protection cost for private forest management may be high due to the risk of illegal logging and stealing (Leipold et al., 2016; McElwee, 2004). Additionally, timber forests under private management may face the risk of accelerating deforestation through conversion to agricultural land, which results in negative environmental externalities in the locality (Angelsen, 1999). If the expected private benefit from forest conversion is higher than the private profit from forest land, forest conversion becomes a rational choice for individual landholders (Arima et al., 2007; Busch et al., 2015; Deininger and Minten, 2002; Hargrave and Kis-Katos, 2013; Marchand, 2012).

Therefore, neither private nor community management may be the optimal system. Thus, we would like to propose mixed private and community management (i.e., mixed management) as a potential solution, particularly for developing countries where the demand for forest products is high (Otsuka and Place, 2001; Otsuka et al., 2015). In the mixed management system, the protection cost is likely to be as low as community management because trees and other resources are protected jointly by the community. In contrast, individual members are fully motivated to carry out intensive management of their trees in the mixed system, because all the benefits accrue to individual tree-right holders. Furthermore, the mixed management system reduces the risk of forest conversion because the ownership of land is not granted individually and, hence, community agreement is required for conversion.[3]

Hypotheses

In order to identify whether the mixed management system can overcome two social dilemmas (i.e., under-supplying management and harvesting efforts in timber forests), we conducted a randomized experiment in Ethiopia. We randomly selected forests under

[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. It depends 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 highly demanded 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 took place and at a cost that is an order of magnitude lower than traditional land titling (Holden and Tilahun, 2020).

community management and provided tree rights to individual members to create the mixed management system. Tree rights are permanently granted with the official permission of the local authority (i.e., the Bureau of Agriculture and Natural Resources). For such treatment groups, all individual group members were allocated trees for which they received individual rights (hereafter, "individual tree-right holders"). Then, we compare the conventional community management system with the mixed management system by comparing behaviors between groups with and without individual tree-right holders. Following the above discussion, we develop testable hypotheses regarding the impact of the mixed management system on forest management.

First, introducing a mixed management system to community timber forests is expected to increase motivation for intensive management, such as thinning, pruning, watering, guarding, and planting tree seedlings. However, regarding planting tree seedlings, the mixed management system is expected to increase labor input for plantation activity in the longer term because individual tree rights holders have a motivation to maximize profits from forest products. In contrast, if individual tree rights holders already have a sufficient number of trees, they may allocate more labor to management activities of the exiting trees (i.e., thinning, pruning, and guarding). Furthermore, they may prefer to take well care of limited number of planted tree seedlings, rather than planting a large number of seedlings. Hence, in the short term, the mixed management system may not significantly affect the plantation activity of individual tree rights holders. Due to data constraints, this study can only examine the short-term impact of the mixed management system. Accordingly, we propose the following two hypotheses:

Hypothesis 1. The mixed management system stimulates tree and forest management activities, such as thinning, pruning, watering, and guarding.

Hypothesis 2. In the short term, plantation activity is not enhanced through the introduction of the mixed management system.

In addition, if the mixed management system successfully stimulates the incentives of harvesting activities, the extracted volumes of tree resources will increase. More specifically, the volumes for thinned trees, pruned branches, and extracted timber trees are expected to increase. Although it is reasonable to expect that the extracted volume of timber trees increases after the introduction of the system, it does not necessarily mean that the mixed management system causes excessive extraction of forest resources or forest degradation. As mentioned, if proper forest management practices are followed, extracting timber trees selectively is one of the important activities to enhance the regeneration of forest ecosystems (Karsenty and Gourlet-Fleury, 2006; Langmaier and Lapin, 2020). Moreover, in order to maintain the forest condition, relatively useless timber trees and densely grown trees, in particular, must be removed. Therefore, the following hypothesis is proposed:

Hypothesis 3. 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 (i.e., common property regime), it seems reasonable to assume that conventional resource extraction activities unrelated to tree management (hereafter, "non-forestry collective activities") will be continuously maintained even after the introduction of the mixed management system. One typical example of such activities is the collection of nontimber forest products, such as feed grasses, medicinal plants, honey, mushrooms, and spices. Particularly in developing countries, the motivation of continuing miscellaneous resource extraction activities after the introduction of the new system will continue to be high, simply because of the high demand for such resources. In fact, as discussed later, none of the communities investigated in this study changed rules of extraction of non-timer resources after the introduction of the mixed management system. Therefore, we expect that the introduction of the mixed management system will not affect the extracted volumes of nontimber forest products unrelated to tree management. This argument leads to the fourth hypothesis:

Hypothesis 4. The introduction of the mixed management system will not affect the collection of nontimber forest products unrelated to tree management.

3. Experimental Design and Data Collection

Description of the study area and establishment of youth groups

We selected the semi-arid Tigray region located in Northern Ethiopia as the study area importantly because it is possible to obtain official permission to grant individualized tree rights. The natural vegetation in this region is subject to annual precipitation ranging from 200 mm to 950 mm and an annual average air temperature ranging between 15° and 25° C (Birhane et al., 2011).

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

The duration of 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 period of rehabilitation, some restricted communal lands are allocated to groups of landless youth in the community (hereafter, "youth groups") (Holden and Tilahun, 2018). After registering as a formal cooperative, each youth group takes responsibility for managing demarcated forest and grazing areas sustainably. The primary motivation of communal land allocation is to provide income opportunities for landless youth and the land entitlement given to the youth group depends on performance and compliance of sustainable resource management. The youth groups establish business plans and conduct livelihood activities by utilizing common-pool resources in the allocated communal lands, such as forestry, apiculture, horticulture, mining, and livestock rearing. Similarly to other developing countries (Balana et al., 2010; Conroy et al., 2002), the benefits obtained from the youth group activities are equally shared among members.[4]

Holden and Tilahun (2018) conducted a census of 742 youth groups in five districts in Tigray and found that most groups followed the principles of collective action for sustainable natural resource management suggested by Ostrom (1990, 2010). For example, more than 97% of the groups developed bylaws, which specify the sharing of responsibilities of the group activities and equal sharing of generated income (Holden and 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.[5] Therefore, in this study, we define communal lands allocated to the

[4] Since the primary motivation of allocation was to increase income of individual landless youth members, the obtained benefits were not used for public goods purposes.
[5] According to Holden and Tilahun (2018), 3.4% of internal disputes were still unsolved by 2016.

youth groups as regulated common property areas.

To identify tree species and vegetation conditions in the allocated lands, we conducted the vegetation survey in 2018. The dominant tree species in the allocated lands are timber trees, including Acacia, Eucalyptus, Euclea, and Dodonaea angustifolia. Like other regions in Ethiopia, people depend on firewood, fodder grasses, and honey extracted from forest land in Tigray (Babulo et al., 2009; Balana et al., 2010). Therefore, the allocated land for youth groups are timber forests located in areas with high demand for both timber and nontimber products, which ensures that our study area is suitable for the purpose of this study.

Provision of individual tree rights

In this study, we particularly focused on the youth groups in five districts in Tigray: Adwa, Degua Temben, Kilite Awlalo, Raya Azebo, and Seharti Samire. Between 2003 and 2016, a total of 742 youth groups were established and still existed during the 2016 census in these districts. Although communal lands are allocated to the youth groups after the rehabilitation of vegetation, most parts of allocated lands are grazing lands without any trees. As we explain later, because we provide individual tree rights for existing trees located in the allocated communal lands, we excluded the youth groups without trees in this study. Thus, we conducted the initial screening by the availability of trees in allocated communal lands, after which 68 youth groups were selected for our study.

From the selected 68 youth groups, we randomly selected 26 youth groups as the treatment groups, which received an offer to manage their community forest land under the mixed management system. The remaining 42 groups are the control groups which continued community management. Although the number of selected groups is small in this study, the sample size was almost similar with recent experimental studies on community management, ranging from 76 to 120 (Christensen et al., 2021; Eisenbarth et al., 2021; Slough et al., 2021a). Strictly speaking, randomization was applied to youth groups, 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 allocated communal lands equitably into smaller parcels based on the vegetation conditions and discussion with the group members. After reaching an agreement about the demarcation of parcels among the youth group members, property rights for trees located in each divided parcel (i.e., individual tree rights) were given to individual members who are willing to receive the rights. The average number of trees allocated to each individual was 81, while 63% of allocated trees were short trees with 5cm diameter at breast height (DBH). Although an individual tree-right holder has the ownership rights on designated trees, the entire land was continuously common property even after the introduction of the system. Therefore, individual tree-right holders may have an incentive to comply communal rules of using common-pool resources and conduct collective activities (i.e., rotating monitoring activities), which cannot be expected from simple privatization of parcels.

In this experiment, securing tree rights is fundamentally important because members' behavior related to management and investment is influenced by an insecure tenure situation (Goldstein et al., 2018). To ensure security of tree rights, we provided a paper document indicating that the official permanent permission was granted from the local authority (i.e., the Bureau of Agriculture and Natural Resources).

The provision of tree rights allows tree-right holders to extract their owned trees at any time. After the extraction, tree-right holders can continuously own trees, if they newly plant tree seedlings at the same allocated parcel. However, it is strictly prohibited to use their allocated parcel for a different purpose after the extraction, such as constructing compound and expanding agricultural land. Through our intervention, although owners of property rights on timber trees were changed from the youth group to its members, we did not change property rights owners of forest land. That is, the forest land was continuously common property for both the treatment and control groups and community agreement is required for changing land use. Furthermore, conventional resource extraction activities, such as apiculture, horticulture, and livestock rearing, continued under the control of youth group.

Before implementing tree rights provision intervention, we provided the same training program for tree and forest management for both the treatment and control groups. The training lasted one day and consisted of a lecture and field exercise of tree management activities, such as thinning, pruning, and watering, by forestry experts from Mekelle University. Therefore, knowledge of tree management between the treatment and control groups was expected to be similar.

Timeline of the experiment and characteristics of samples

Figure 1 shows the timeline of the experiment. We provided tree management training to the treatment and control groups between May and June 2018. After completing the training, we offered individual tree rights only to the members of the treatment group. The provisioning process of tree rights was completed by July and tree management activities began in August 2018. To evaluate the impact of tree rights provision on tree management efforts as well as 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.

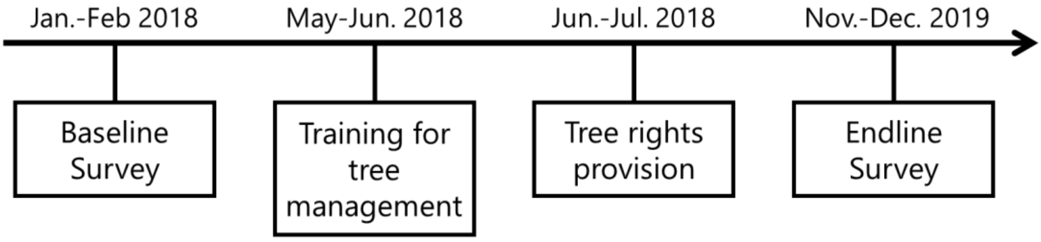


Figure 1. Timeline of the experiment

Census data shows that 728 members belong to the 68 youth groups. Although we invited all members to take the questionnaire survey, 63% of them participated in both baseline and endline surveys. Therefore, the number of observations in this study was 459, of which 197 and 262 are the potential number of observations for the treatment and control groups, respectively. Although we offered the opportunity to receive individual tree rights to all members of the treatment group, some members refused to receive tree rights (hereafter, the "non-accepters") mostly because they have the perception that group rights are preferable.[6] In our observation, a total of 25 members (12.7%) of the treatment group members did not receive the individual tree rights. Thus, among 197 members in the treatment group who were offered tree rights, 172 of them actually received the rights (i.e., tree-right holders), while 262 members who belonged to the youth groups without the offer of tree rights were the control group. Although we include the 25 non-accepters in the sample observations in the treatment group for the main analyses, we conduct robustness checks at the individual and youth group level after excluding the non-accepters from the observations in Appendix A.

The average demographic characteristics of our observations are presented in Table 1. There was no statistically significant difference in average education years, number of household members, total annual income of members, and annual income from the youth group activities of members between the treatment group (including the 25 non-accepters) and 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 members in the control group. In addition, the average distance to allocated communal land parcels from the individual residence was farther for the treatment group than the control group.

[6] Even though these members in the treatment group did not receive the tree rights, they continued to participate in the conventional collective activities.

Table 1: Average demographic characteristics

	Treatment group[a] (1)	Control group (2)	Total (3)
Number of youth groups	26	42	68
Total number of youth group members	291	437	728
Number of observations	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 member that each member belongs to	5.44	5.26	5.34
	(2.12)	(2.22)	(2.18)
Total annual income (Ethiopian Birr)[b]	8,239.22	7,430.09	7,776.86
	(13,297.84)	(8,042.72)	(10,612.52)
Annual income from the youth group activities (Ethiopian Birr)	356.38	398.70	380.57
	(690.79)	(1,087.04)	(937.26)
Distance to the allocated community land from the individual residence (km)	2.60	2.18**	2.36
	(2.63)	(1.74)	(2.17)

Note. Standard deviations in parentheses; ** indicates statistical significance (paired t- test) at the 5% level.

[a] The youth group members refused to receive tree rights (the 25 non-accepters) are included as the treatment group.

[b] The total annual income includes the annual income from the youth group activities and the annual income from other complementary sources

We obtained information related to the work efforts for tree management and the extracted volume of tree and other resources from the allocated community lands. Specifically, we asked the number of days worked for tree management activities in a year, such as thinning, pruning, guarding, watering planted tree seedlings, and planting tree seedlings. Regarding the guarding activity, we collected the data on time allocated for guarding for the allocated communal lands which is basically a collective activity and carried out usually on rotation basis. In addition, we collected the data of 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 for 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 Table 2.

Table 2: Average individual-level characteristics: pre-treatment

	Treatment group[a] (1)	Control group (2)	Total (3)
Number of observations	197	262	459
Number of days worked for tree management activity in a year			
Thinning	0.29	0.15	0.21
	(1.38)	(0.90)	(1.13)
Pruning	0.72	0.41	0.54
	(2.87)	(1.02)	(2.04)
Guarding	19.92	18.21	18.95
	(22.79)	(19.53)	(20.98)
Watering seedlings	4.73	7.69	6.42
	(11.40)	(26.57)	(21.45)
Planting tree seedlings	2.87	2.78	2.82
	(5.80)	(4.90)	(5.30)
Number of planted tree seedlings	189.43	177.61	182.69
	(425.66)	(482.57)	(458.56)
Extracted volume of resources (kg)			
Thinned trees	0	0	0
Pruned branches	48.22	76.57	64.40
	(237.95)	(198.84)	(216.70)
Timber	0	0	0
Fodder	34.00	29.85	31.63
	(81.74)	(50.01)	(65.49)
Honey	2.45	2.35	2.40
	(5.07)	(3.72)	(4.35)

Note. Standard deviations in parentheses. There is no statistical difference between the groups.

[a] The youth group members refused to receive tree rights (the 25 non-accepters) are included as the treatment group.

We used a *t*-test to check the balance between the two groups and found that the differences in means of all variables showing days of work for tree management were insignificant. In addition, there is no statistical difference in the number of planted trees and the extracted volume of the five types of resources between the two groups. The summary statistics show that none of the members in both groups extracted timber and thinned trees from allocated communal lands. The lack of thinning activities before the tree management training is reasonable, while the absence of timber tree extraction is probably due to the lack of a management plan for timber extraction. In fact, the youth groups in both treatment and control groups did not establish the management plan including when they harvest timber before our intervention.

4. Estimation Methodology

The primary motivation of this study is to investigate the impact of individual tree rights on the 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 to receive the individual tree rights, which causes endogeneity problems (Imbens and Wooldridge, 2009). To address endogeneity, we perform 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 uses the 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 is 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 employ the Intention-To-Treat (ITT) model to estimate the treatment effects. In the ITT model, we compare the outcomes between the control group and the group assigned to treatment; in this case, 197 members belong to the treatment group who were offered individual tree rights. Because the 25 non-accepters are included in the offered group, the effects of treatment are likely to be underestimated in the ITT model (Angrist, 2006). Third, we conduct the youth-group-level analysis to identify how the random selection of treatment youth group affects the group mean of management efforts and the extracted volumes.

Furthermore, we employ 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.[7] The estimation models are as follows:

First stage: $TreeRights_i = \alpha_0 + \alpha_1 Treatment_i + u_i,$ (1)

Second stage: $\log Y_{it} - \log Y_{it-1} = \beta_0 + \beta_1 \widehat{TreeRights}_i + \varepsilon_i,$ (2)

ITT-model: $\log Y_{it} - \log Y_{it-1} = \gamma_0 + \gamma_1 Treatment_i + \omega_i,$ (3)

Group-level: $\log \overline{Y}_{jt} - \log \overline{Y}_{jt-1} = \delta_0 + \delta_1 Treatment_j + \mu_j,$ (4)

[7] There is physical distance between allocated communal lands. Thus, in this study, we did not consider about the spatial spillover effects from treated to control communities.

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, and therefore, $\log Y_{it}$ - $\log Y_{it-1}$ indicates the rate of change in the outcome between year t and t-1 (i.e., before and after the experiment). $TreeRights_i$ is a dummy variable (i.e., the individual tree rights dummy) that takes the value 1 if individual i actually receives the individual tree rights.[8] $Treatment_i$ represents a treatment dummy that takes the value 1 if individual i is 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. 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, while we employ the 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 ($\widehat{TreeRights}$) 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 whether individual member or the youth group is offered tree rights or not (*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 work-days allocated for such tree management activities as thinning, pruning, watering, and guarding. Although the groups in this study area have already adopted rotating monitoring to protect the allocated communal lands, the allocated time for guarding is expected to increase, to the extent that the protected resources become more valuable. Hence, the intervention dummies are expected to have positive coefficients in the regression equations of those activities.

In contrast, although planting new tree seedlings is an important forest management activity in the longer term, the mixed management system may not have significant effects on planting activity in the short term (Hypothesis 2). Therefore, it is possible that the coefficient of the provision dummy is insignificant or negatively significant in the regression analysis of the plantation activity, such as the number of work-days for planting tree seedlings and the number of planted tree seedlings.

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

Finally, we tested Hypotheses 3 and 4 by focusing on how the tree rights dummy in equation 2 and the treatment dummy in equation 3 affected the extracted volume of tree and other natural resources. If the provision of tree rights successfully motivates individuals to engage in harvesting activities, the extracted volumes of timber trees, thinned trees, and pruned branches are expected to increase, while the extracted volumes of nontimber resources, such as fodder and honey, remain unchanged.

5. Results

Forest management efforts and the extracted volume of natural resources after the intervention

Table 3 shows the average of the outcomes between the treatment and control groups at the individual level after the experiment. Many of the outcomes are significantly different between individuals in the treatment and control groups, even though we could not find any statistical difference in each outcome before the experiment. For example, the average number of work-days for thinning, pruning, guarding, and watering are significantly higher for the individuals in the treatment group. Roughly speaking, work-days for pruning and guarding doubled from pre- to post-treatment period for the individuals in the treatment group, whereas no such large changes are observed for the control members. More precisely, for the pruning activity, the annual work-days at the individual level increase from 0.72 to 1.41. Although it seems that the allocated days for pruning are still limited after the intervention, an increase of one day in pruning still can be expected to improve tree growth (Skovsgaard et al., 2018). Furthermore, the extracted volumes of thinned trees, pruned branches, and timber are higher for the treated individuals than the control members. The extracted volumes of timber are continuously zero for the members in the control groups, probably due to the lack of a motivation for harvesting under conventional community management.

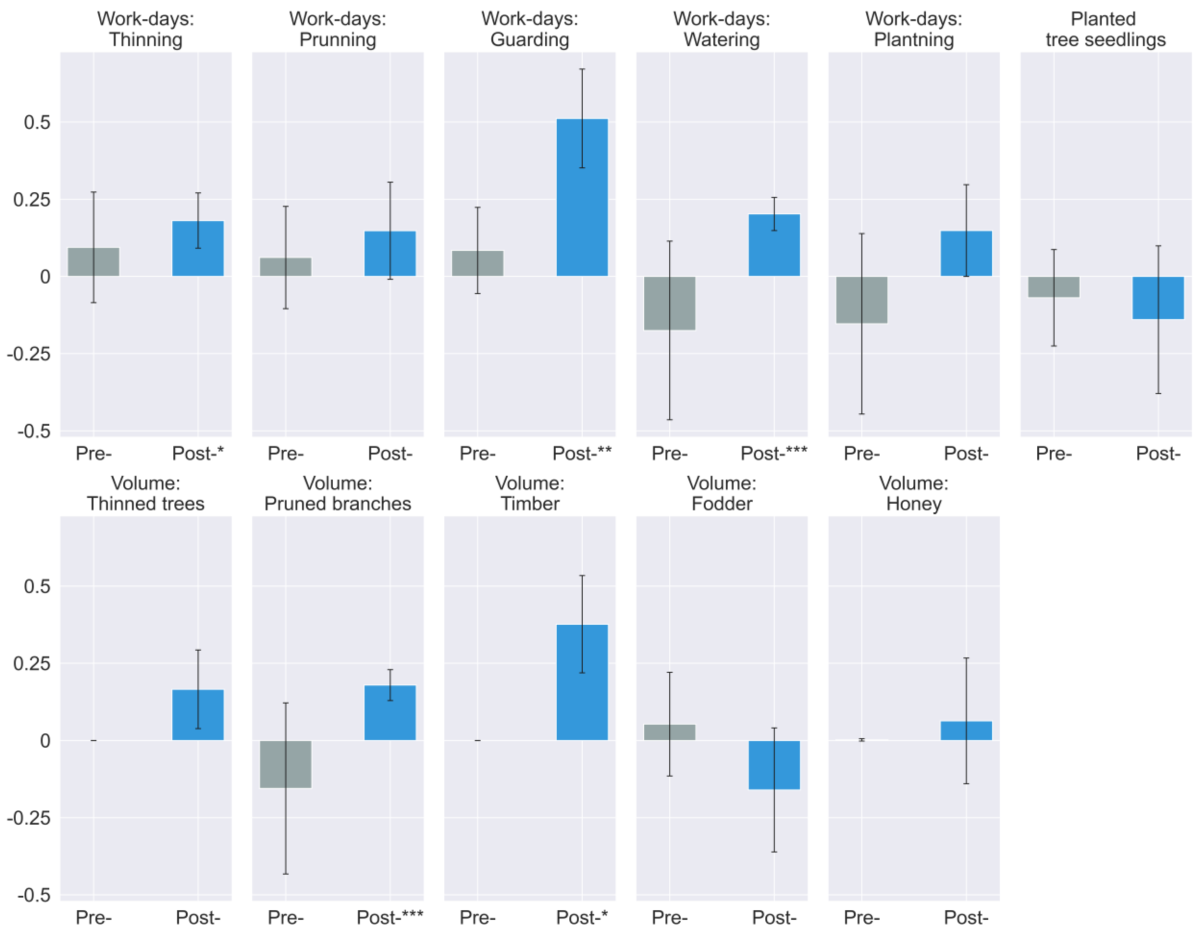
It is also clear from Tables 2 and 3 that trees were actively planted by the members in both treatment and control groups. Indeed, the number of planted trees is much larger than the average number of trees whose rights were offered, which was 81. There is, however, no descriptive evidence that members who were offered tree rights planted trees more actively.

Table 3: Average individual-level characteristics: post-treatment

	Treatment group[a] (1)	Control group (2)	Total (3)
Number of observations	197	262	459
Number of days worked for tree management activity in a year			
Thinning	0.29	0.05**	0.16
	(1.89)	(0.36)	(1.27)
Pruning	1.41	0.62***	0.96
	(2.93)	(2.12)	(2.52)
Guarding	46.29	23.37***	33.21
	(53.27)	(42.51)	(48.72)
Watering seedlings	4.19	0.92***	2.33
	(7.98)	(5.24)	(6.75)
Planting tree seedlings	2.44	1.92	2.14
	(4.66)	(3.72)	(4.16)
Number of planted tree seedlings	150.81	344.06**	261.12
	(501.04)	(1080.17)	(884.03)
Extracted volume of resources (kg)			
Thinned trees	1.79	0.23**	0.90
	(11.98)	(3.71)	(8.36)
Pruned branches	49.25	10.78***	27.29
	(88.62)	(33.11)	(65.95)
Timber	6.19	0***	2.66
	(26.61)		(17.68)
Fodder	63.64	80.63	73.34
	(91.13)	(132.22)	(116.56)
Honey	53.17	18.60	33.44
	(502.30)	(187.86)	(358.30)

Note. Standard deviations in parentheses; ** and *** indicate statistical significance (paired t- test) at the 5% and 1% levels, respectively. [a] The youth group members refused to receive tree rights (the 25 non-accepters) are included as the treatment group.

In addition, we calculate the youth-group-level mean of each outcome (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. Similar to the individual level statistics, there is no statistical difference in each variable in pre-treatment period. In contrast, the group means for several outcomes become statistically different between the two groups in post-treatment period. Specifically, the group average of the work-days for three activities (i.e., thinning, guarding, and watering) and the extracted volumes of thinned trees, pruned branches, and timber become larger for the treatment youth groups than the control youth groups.



Note. The figure shows the normalized mean difference and standard errors between the treatment and control groups (the number of observations are 26 and 42, respectively); *, **, and *** indicate statistical significance (paired t- test) between the treatment and control groups at the 10%, 5%, and 1% levels, respectively.

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

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 (Vermeir et al., 2020).

The effects of the tree rights provision, which are analyzed using the IV method on the number of days worked for tree management and the number of planted trees, are reported in Panel A of Table 4, while the results of offering tree rights using the ITT and group-level analyses are shown in Panels B and C, respectively. From the results of the IV estimation in Panel A, we found that the provision of tree rights significantly increases the number of work-days for three types of tree resource management: pruning, guarding, and watering. Particularly, the impact on guarding activity is significant and large, indicating an increase in 105.2% through the rights provision. This is likely to reflect the increased value of tree resources in the mixed management areas. Thus, maintaining communal tree protection activities seems critically important in the mixed management system. In contrast, although the work-days allocated to thinning were statistically different between the treatment and control groups according to Table 3, the coefficient on thinning is positive but insignificant in the IV regression estimation (column (1) in Table 4).

Table 4: Effect of the tree rights provision on the number of days worked for tree management and tree planting

	The number of days worked for tree management:					Planted tree seedlings
	Thinning	Pruning	Guarding	Watering	Planting	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: IV-estimates						
Tree rights provision dummy	0.024	0.344**	1.052**	0.663*	0.169	0.213
	(0.130)	(0.141)	(0.505)	(0.383)	(0.299)	(1.383)
Observations (individual-level)	459	459	459	459	459	459
Panel B: ITT-estimates						
Offered individual tree rights	0.021	0.300**	0.919**	0.579*	0.148	0.186
	(0.113)	(0.123)	(0.447)	(0.345)	(0.263)	(1.209)
Observations (individual-level)	459	459	459	459	459	459
Panel C: Group-level estimates						
Offered individual tree rights	0.024	0.188*	0.754*	0.678**	0.338	1.085
	(0.082)	(0.109)	(0.447)	(0.297)	(0.281)	(1.180)
Observations (group-level)	68	68	68	68	68	68

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% and 5% levels, respectively.

The results of the ITT estimation in Panel B also showed similar findings. Although the coefficients of the treatment dummy in the ITT estimation are smaller than the IV estimation, as expected, we found that the number of days worked for pruning, guarding, and watering were significantly associated with the treatment dummy (i.e., offering individual tree rights). Moreover, the positive and significant relations between the treatment dummy and work-days for three activities were observed in the group-level estimation presented in Panel C. Thus, it seems fair to conclude that our results largely support Hypothesis 1.

The results of the number of work-days for planting and the number of planted seedlings are presented in columns (5) and (6) of Table 4, respectively. Although the coefficient of the tree rights provision dummy is positive in both cases for all estimation models, we do not find the statistically significant coefficients. These insignificant results are not unexpected because a new plantation of tree seedlings may be enhanced more clearly in the longer run than in the short run, particularly after the extraction of existing trees. Also, it must be noted that sizable number of timber trees were planted (see Tables 2 and 3) and that they were watered more actively by the members receiving the offer of tree rights (see column (4) in Table 4), indicating that the provision of tree rights increases the incentives to take care of planted trees. Based upon the findings, the hypothesis 2 is supported.

Finally, let us 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 and pruned branches. Particularly, the tree-right holders substantially increased the extracted volumes from pruning branches. Although we found that offering individual tree rights significantly increased the extracted volumes of thinned trees and pruned branches 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 was insignificant ($p<0.16$).

Moreover, the extracted volume of timber trees shown in column (3) is positively and significantly associated with the tree rights provision. The coefficient suggests that tree-right holders extract 34.8% more timber trees than those without tree rights. Consistently, the treatment dummy in Panels B and C is positively correlated with the extracted volume of timber trees. The increase in the extracted volume of timber trees does not necessary mean that the mixed management system causes excessive extraction of forest resources or forest degradation. As mentioned before, because the majority of allocated trees for tree-right holders were short trees of 5cm DBH or less, removing short trees where trees are densely grown can be a part of timber forest management. Additionally, the tree-right holders continuously planted sizable number of tree seedlings, which suggests that the total number of trees actually increases. Although only a short-term investigation is possible at this point, sustainable forest management might be achieved through the mixed management system.[9] In sum, the findings of this study favor Hypothesis 3.

In contrast, there is no significant impact on fodder and honey extraction for all models. These results imply that non-timber resource extraction activities are continuously carried out in the youth group receiving the tree rights, probably because communal rules of extracting nontimber forest products are unchanged by the introduction of the mixed management system. Hence, Hypothesis 4 is clearly supported.

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

	Thinned trees (1)	Pruned branches (2)	Timber trees (3)	Fodder (4)	Honey (5)
Panel A: IV-estimates					
Tree rights provision dummy	0.109*	2.357***	0.348*	0.000	0.139
	(0.064)	(0.568)	(0.187)	(0.519)	(0.222)
Observations (individual-level)	459	459	459	459	459
Panel B: ITT-estimates					
Offered individual tree rights	0.095*	2.058***	0.303*	0.000	0.122
	(0.057)	(0.463)	(0.165)	(0.453)	(0.194)
Observations (individual-level)	459	459	459	459	459
Panel C: Group-level estimates					
Offered individual tree rights	0.068	1.602***	0.237**	0.113	-0.025
	(0.047)	(0.529)	(0.101)	(0.487)	(0.189)
Observations (group-level)	68	68	68	68	68

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.

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

6. Conclusion

In this study, we proposed mixed private and community management system as a desirable institution for timber forest management in developing countries and empirically investigated its impact on forest management activities. For this purpose, we introduced a mixed management system by providing individual tree rights to randomly selected communities and their members in Ethiopia. We found that the introduction of the mixed management system significantly stimulated intensive forest management, as evidenced by the increased number of work-days for pruning, guarding, and watering. Particularly, it is noteworthy that the number of work-days allocated for collective guarding activity in the community forest land roughly doubled through 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, while 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 and Oldekop, 2018). However, because community forest management does not provide a clear incentive for conducting intensive tree management, it may be difficult to achieve reforestation of degraded timber forests under such system. The results of this study suggest that introducing a mixed management system may motivate community members to allocate efforts for sustainable forest management, while maintaining the advantage of community forest management in protecting forest resources. Practically, the mixed management system can be adopted for timber forests in developing countries by granting individualized property rights for timber trees on the community forest lands.

Overall, our estimation results strongly suggest that the mixed management system successfully increases the incentive for engaging with effective forest management. However, this study has a couple of limitations. First, while this study showed only the short-term impact of the mixed management system, the long-term impact is unclear. Particularly, the effects on the tree plantation are expected to change in the longer term. Thus, whether the mixed management system motivates community members to engage in intensive forest management sustainably by planting timber trees in the longer term is a major reaming empirical question. Second, although conducting intensive management activities is expected to promote the rehabilitation of timber forests, whether the mixed management system in fact promotes forest rehabilitation is not directly investigated in this study because of the short lapse of time after granting individualized tree rights. Using remote sensing to accurately gauge forest quality changes, as was done by (Burgess et al., 2012; Takahashi and Todo, 2013, 2017), further studies should be carried out to assess the effect of the mixed management system on forest quality changes in the longer run.

Acknowledgements:

This study was supported by the Inamori Foundation, the Mitsui & Co. Environment Fund (Number: R17-0006), the SEI Group CSR Foundation, and the Sumitomo Foundation (Number: 163044). The initial baseline data collection was funded under the NORAD NORHED I "Climate Smart Natural Resources Management and Policy" (CLISNARP) project.

References

Agrawal, A., 2001. Common property institutions and sustainable governance of resources. World Dev. 29 (10), 1649-1672.

Agrawal, A., Chhatre, A., Hardin, R., 2008. Changing governance of the world's forests. Science 320 (5882), 1460-1462.

Angelsen, A., 1999. Agricultural expansion and deforestation: modelling the impact of population, market forces and property rights. Journal of Development Economics 58 (1), 185-218.

Angrist, J.D., 1990. Lifetime earnings and the Vietnam era draft lottery: evidence from social security administrative records. Am. Econ. Rev. 80 (3), 313-336.

Angrist, J.D., 2006. Instrumental variables methods in experimental criminological research:

what, why and how. J. Exp. Criminol. 2 (1), 23-44.

Araujo, C., Bonjean, C.A., Combes, J.-L., Combes Motel, P., Reis, E.J., 2009. Property rights and deforestation in the Brazilian Amazon. Ecological Economics 68 (8), 2461-2468.

Arima, E.Y., Simmons, C.S., Walker, R.T., Cochrane, M.A., 2007. Fire in the Brazilian Amazon: A spatially explicit model for policy impact analysis. Journal of Regional Science 47 (3), 541-567.

Arnot, C.D., Luckert, M.K., Boxall, P.C., 2011. What is tenure security? Conceptual implications for empirical analysis. Land Economics 87 (2), 297-311.

Arts, B., De Koning, J., 2017. Community forest management: An assessment and explanation of its performance through QCA. World Dev. 96, 315-325.

Babulo, B., Muys, B., Nega, F., Tollens, E., Nyssen, J., Deckers, J., Mathijs, E., 2009. The economic contribution of forest resource use to rural livelihoods in Tigray, Northern Ethiopia. For. Policy. Econ. 11 (2), 109-117.

Balana, B.B., Mathijs, E., Muys, B., 2010. Assessing the sustainability of forest management: An application of multi-criteria decision analysis to community forests in northern Ethiopia. J. Environ. Manage. 91 (6), 1294-1304.

Baland, J.-M., Bardhan, P., Das, S., Mookherjee, D., 2010. Forests to the people: Decentralization and forest degradation in the Indian Himalayas. World Dev. 38 (11), 1642-1656.

Baland, J.M., Platteau, J.P., 1997. Wealth inequality and efficiency in the commons part I: The unregulated case. Oxford Economic Papers 49 (4), 451-482.

Baynes, J., Herbohn, J., Smith, C., Fisher, R., Bray, D., 2015. Key factors which influence the success of community forestry in developing countries. Glob. Environ. Change. 35, 226-238.

Bhattacharya, P., Pradhan, L., Yadav, G., 2010. Joint forest management in India: Experiences of two decades. Resour. Conserv. Recycl. 54 (8), 469-480.

Birhane, E., Aynekulu, E., Mekuria, W., Endale, D., 2011. Management, use and ecology of medicinal plants in the degraded dry lands of Tigray, Northern Ethiopia. Journal of Medicinal Plants Research 5 (3), 308-319.

Burgess, R., Hansen, M., Olken, B.A., Potapov, P., Sieber, S., 2012. The political economy of deforestation in the tropics. Q. J. Econ. 127 (4), 1707-1754.

Busch, J., Ferretti-Gallon, K., Engelmann, J., Wright, M., Austin, K.G., Stolle, F., Turubanova, S., Potapov, P.V., Margono, B., Hansen, M.C., 2015. Reductions in emissions from deforestation from Indonesia's moratorium on new oil palm, timber, and logging concessions. Proc. Natl. Acad. Sci. U.S.A. 112 (5), 1328-1333.

Chankrajang, T., 2019. State-community property-rights sharing in forests and its contributions to environmental outcomes: Evidence from Thailand's community forestry. J. Dev. Econ. 138, 261-273.

Christensen, D., Hartman, A.C., Samii, C., 2021. Citizen monitoring promotes informed and inclusive forest governance in Liberia. Proceedings of the National Academy of Sciences 118 (29),

Conroy, C., Mishra, A., Rai, A., 2002. Learning from self-initiated community forest management in Orissa, India. Forest Policy and Economics 4 (3), 227-237.

Deininger, K., Ali, D.A., Holden, S., Zevenbergen, J., 2008. Rural land certification in Ethiopia: Process, initial impact, and implications for other African countries. World development 36 (10), 1786-1812.

Deininger, K., Minten, B., 2002. Determinants of deforestation and the economics of protection: An application to Mexico. American Journal of Agricultural Economics 84 (4), 943-960.

Edmonds, E.V., 2002. Government-initiated community resource management and local resource extraction from Nepal's forests. Journal of Development Economics 68 (1), 89-115.

Eisenbarth, S., Graham, L., Rigterink, A.S., 2021. Can community monitoring save the commons? Evidence on forest use and displacement. Proceedings of the National Academy of Sciences 118 (29),

Godoy, R., Jacobson, M., De Castro, J., Aliaga, V., Romero, J., Davis, A., 1998. The role of tenure security and private time preference in neotropical deforestation. Land Economics, 162-170.

Goldstein, M., Houngbedji, K., Kondylis, F., O'Sullivan, M., Selod, H., 2018. Formalization without certification? Experimental evidence on property rights and investment. Journal of Development Economics 132, 57-74.

Hajjar, R., Oldekop, J.A., 2018. Research frontiers in community forest management. Curr. Opin. Environ. Sustain. 32, 119-125.

Hargrave, J., Kis-Katos, K., 2013. Economic causes of deforestation in the Brazilian Amazon: A panel data analysis for the 2000s. Environmental and Resource Economics 54 (4), 471-494.

Hayami, Y., Godo, Y., 2005. Development economics: From the poverty to the wealth of nations. Oxford University Press, New York, USA.

Holden, S.T., Tilahun, M., 2018. The importance of Ostrom's Design Principles: Youth group performance in northern Ethiopia. World Dev. 104, 10-30.

Holden, S.T., Tilahun, M., 2020. Farm size and gender distribution of land: Evidence from Ethiopian land registry data. World Development 130, 104926.

Holden, S.T., Yi, Y., Jiang, X., Xu, J., 2013. Tenure security and investment effects of forest tenure reform in China, In: Holden ST, Otsuka K, Deininger K (Eds), Land tenure reform in Asia and Africa. Springer: New York City, USA, pp. 256-282.

Imbens, G.M., Wooldridge, J.M., 2009. Recent developments in the econometrics of program evaluation. Journal of Economic Literature 47 (1), 5-86.

Karsenty, A., Gourlet-Fleury, S., 2006. Assessing sustainability of logging practices in the Congo Basin's managed forests: the issue of commercial species recovery. Ecology and Society 11 (1),

Kijima, Y., Sakurai, T., Otsuka, K., 2000. Iriaichi: Collective versus individualized management of community forests in postwar Japan. Economic Development and Cultural Change 48 (4), 867-886.

Kosfeld, M., Rustagi, D., 2015. Leader punishment and cooperation in groups: Experimental field evidence from commons management in Ethiopia. American Economic Review 105 (2), 747-783.

Langmaier, M., Lapin, K., 2020. A systematic review of the impact of invasive alien plants on forest regeneration in European temperate forests. Frontiers in Plant Science 11, 1349.

Leipold, S., Sotirov, M., Frei, T., Winkel, G., 2016. Protecting "First world" markets and "Third world" nature: The politics of illegal logging in Australia, the European Union and the United States. Glob. Environ. Change. 39, 294-304.

Leone, M., 2019. Women as decision makers in community forest management: Evidence from Nepal. J. Dev. Econ. 138, 180-191.

Marchand, S., 2012. The relationship between technical efficiency in agriculture and deforestation in the Brazilian Amazon. Ecological Economics 77, 166-175.

McElwee, P., 2004. You say illegal, I say legal: The relationship between 'illegal'logging and land tenure, poverty, and forest use rights in Vietnam. J. Sustain. For. 19 (1-3), 97-135.

Mekuria, W., Veldkamp, E., Haile, M., Nyssen, J., Muys, B., Gebrehiwot, K., 2007. Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. J. Arid Environ. 69 (2), 270-284.

Mekuria, W., Yami, M., Haile, M., Gebrehiwot, K., Birhane, E., 2019. Impact of exclosures on wood biomass production and fuelwood supply in northern Ethiopia. J. For. Res. 30 (2), 629-637.

Nelson, G.C., Harris, V., Stone, S.W., 2001. Deforestation, land use, and property rights: Empirical evidence from Darien, Panama. Land Economics 77 (2), 187-205.

Nyssen, J., Poesen, J., Moeyersons, J., Deckers, J., Haile, M., Lang, A., 2004. Human impact on the environment in the Ethiopian and Eritrean highlands—a state of the art. Earth-Sci. Rev. 64 (3-4), 273-320.

Ostrom, E., 1990. Governing the commons: The evolution of institutions for collective action. Cambridge University Press,

Ostrom, E., 2010. Beyond markets and states: Polycentric governance of complex economic systems. Am. Econ. Rev. 100 (3), 641-672.

Ostrom, E., Nagendra, H., 2007. Tenure alone is not sufficient: Monitoring is essential. Environ. Econ. Policy Stud. 8 (3), 175-199.

Otsuka, K., Place, F.M., 2001. Land tenure and natural resource management: A comparative study of agrarian communities in Asia and Africa. International Food Policy Research Institute, Washington D.C., USA.

Otsuka, K., Takahashi, R., Pokharel, R., 2015. In search of optimum institutions for forest management. Journal of Sustainable Forestry 34 (3), 300-314.

Owubah, C.E., Le Master, D.C., Bowker, M.J., Lee, J.G., 2001. Forest tenure systems and sustainable forest management: The case of Ghana. Forest Ecology and Management 149 (1), 253-264.

Perloff, J.M., 2014. Microeconomics. Pearson, New York City, NY, USA.

Persha, L., Agrawal, A., Chhatre, A., 2011. Social and ecological synergy: local rulemaking, forest livelihoods, and biodiversity conservation. Science 331 (6024), 1606-1608.

Pindyck, R., Rubinfeld, D., 2017. Microeconomics. Pearson, New York City, NY, USA.

Rustagi, D., Engel, S., Kosfeld, M., 2010. Conditional cooperation and costly monitoring explain success in forest commons management. Science 330 (6006), 961-965.

Sakurai, T., Rayamajhi, S., Pokharel, R.K., Otsuka, K., 2004. Efficiency of timber production in community and private forestry in Nepal. Environment and Development Economics 9 (4), 539-561.

Skovsgaard, J.P., Markmann, J.J.M., Attocchi, G., Talbot, B., 2018. High-pruning of European beech (Fagus sylvatica L.) and pedunculate oak (Quercus robur L.): Work efficiency for target pruning as a function of tree species, pruning height, branch characteristics, pole saw type and operator. Scand. J. For. Res. 33 (5), 511-517.

Slough, T., Kopas, J., Urpelainen, J., 2021a. Satellite-based deforestation alerts with training and incentives for patrolling facilitate community monitoring in the Peruvian Amazon. Proceedings of the National Academy of Sciences 118 (29),

Slough, T., Rubenson, D., Rodriguez, F.A., Del Carpio, M.B., Buntaine, M.T., Christensen, D., Cooperman, A., Eisenbarth, S., Ferraro, P.J., Graham, L., 2021b. Adoption of community monitoring improves common pool resource management across contexts. Proceedings of the National Academy of Sciences 118 (29),

Solomon, N., Birhane, E., Tadesse, T., Treydte, A.C., Meles, K., 2017. Carbon stocks and sequestration potential of dry forests under community management in Tigray, Ethiopia. Ecol. Process. 6 (1), 1-11.

Takahashi, R., Otsuka, K., 2016. Determinants of Forest Degradation under Private and Common Property Regimes: The Case of Ethiopia. Land Economics 92 (3), 450-467.

Takahashi, R., Todo, Y., 2012. Impact of Community-Based Forest Management on Forest Protection: Evidence from an Aid-Funded Project in Ethiopia. Environmental Management 50 (3), 396-404.

Takahashi, R., Todo, Y., 2013. The impact of a shade coffee certification program on forest conservation: A case study from a wild coffee forest in Ethiopia. Journal of

Environmental Management 130, 48-54.

Takahashi, R., Todo, Y., 2014. The impact of a shade coffee certification program on forest conservation using remote sensing and household data. Environmental Impact Assessment Review 44, 76-81.

Takahashi, R., Todo, Y., 2017. Coffee certification and forest quality: Evidence from a wild coffee forest in Ethiopia. World Development 92, 158-166.

Takahashi, R., Todo, Y., Funaki, Y., 2018. How Can We Motivate Consumers to Purchase Certified Forest Coffee? Evidence From a Laboratory Randomized Experiment Using Eye-trackers. Ecological Economics 150, 107-121.

Tilahun, M., Olschewski, R., Kleinn, C., Gebrehiwot, K., 2007. Economic analysis of closing degraded Boswellia papyrifera dry forest from human interventions—a study from Tigray, Northern Ethiopia. For. Policy. Econ. 9 (8), 996-1005.

Tucker, C.M., 1999. Private versus common property forests: Forest conditions and tenure in a Honduran community. Human Ecology 27 (2), 201-230.

Vermeir, I., Weijters, B., De Houwer, J., Geuens, M., Slabbinck, H., Spruyt, A., Van Kerckhove, A., Van Lippevelde, W., De Steur, H., Verbeke, W., 2020. Environmentally sustainable food consumption: a review and research agenda from a goal-directed perspective. Frontiers in psychology 11, 1603.

Wang, W., Ida, T., Shimada, H., 2020. Default effect versus active decision: Evidence from a field experiment in Los Alamos. Eur. Econ. Rev. 128, 103498.

Welemariam, M., Kebede, F., Bedadi, B., Birhane, E., 2018. Exclosures backed up with community-based soil and water conservation practices increased soil organic carbon stock and microbial biomass carbon distribution, in the northern highlands of Ethiopia. Chem. Biol. Technol. Agric. 5 (1), 1-11.

Yayneshet, T., Eik, L., Moe, S., 2009. The effects of exclosures in restoring degraded semi-arid vegetation in communal grazing lands in northern Ethiopia. J. Arid Environ. 73 (4-

5), 542-549.

Appendix A: Robustness Checks

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

To conduct the group-level estimation shown in equation 4, we calculate the youth-group-level mean for each outcome in pre- and post-treatment periods. The 25 non-accepters are included in the treatment youth groups when the mean values are calculated. Table A1shows the group-level mean values for the treatment and control youth groups, with columns 1 and 2 showing the group-level means in pre-treatment period and columns 3 and 4 indicating the post-treatment ones. After normalizing the mean values for each outcome, we estimated the differences between the two groups which are illustrated in Figure 2.

Estimations by excluding the non-accepters from the treatment group

As mentioned, the 25 members in the treatment group (approximately 12.7%) did not accept the offer of individual tree rights. To incorporate endogeneity related to non-accepters, we performed the three regression models, such as the IV, the ITT, and the group-level estimations. As robustness checks, we conducted additional regression analyses at the individual and youth group level after excluding the 25 non-accepters from the observations.

The effects of the tree rights provision on the number of days worked for tree management and the number of planted trees are reported in Table A2, while the results for the extracted volume are shown in Table A3. Panels A and B in both tables show the effects of receiving individual tree rights without the non-accepters at the individual and group level, respectively. We found that the provision of individual tree rights was significantly associated with the numbers of work-days for pruning, guarding, and watering for both individual and group level estimations (Panels A and B of Table A2). Moreover, the results of the individual level estimation shown in Panel A of Table A3 suggest that individual members increase the extracted volumes of thinned trees, pruned branches, and timber trees after receiving individual tree rights. Consistently, although the results of the group-level estimation indicate the significant effects of the provision of tree rights on the volumes of pruned branches and timber trees (Panel B of Table A3), the coefficient becomes insignificant for the extracted volume of thinned trees. Overall, the results of 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 volume (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: Effect of the tree rights provision on the number of days worked for tree management without the non-accepters

	The number of days worked for tree management:					Planted tree seedlings
	Thinning	Pruning	Guarding	Watering	Planting	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Individual-level						
Tree rights provision dummy	0.032	0.308***	0.982**	0.674**	0.203	0.462
	(0.109)	(0.114)	(0.453)	(0.316)	(0.247)	(1.176)
Observations (individual-level)	434	434	434	434	434	434
Panel B: Group-level						
Tree rights provision dummy	0.016	0.190*	0.754*	0.651**	0.349	1.162
	(0.082)	(0.111)	(0.451)	(0.298)	(0.279)	(1.182)
Observations (group-level)	68	68	68	68	68	68

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 tree rights provision dummy in Panels A and B is a dummy variable which takes value 1 if individual and youth group, respectively, receive individual tree rights; * and ** indicate statistical significance at the 10% and 5% levels, respectively.

Table A3: Effect of the tree rights provision on resource volume without the non-accepters

	Thinned trees	Pruned branches	Timber trees	Fodder	Honey
	(1)	(2)	(3)	(4)	(5)
Panel A: Individual-level					
Tree rights provision dummy	0.111*	2.009***	0.318*	-0.011	0.147
	(0.063)	(0.476)	(0.183)	(0.469)	(0.208)
Observations (individual-level)	434	434	434	434	434
Panel B: Group-level					
Tree rights provision dummy	0.069	1.612***	0.228**	0.217	-0.020
	(0.048)	(0.532)	(0.100)	(0.498)	(0.189)
Observations (group-level)	68	68	68	68	68

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 tree rights provision dummy in Panels A and B is a dummy variable which takes value 1 if individual and youth group, respectively, receive individual tree rights; * and ** indicate statistical significance at the 10% and 5% levels, respectively.