Ecological Economics 236 (2025) 108658

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Community sawmills can save forests: Forest regrowth and avoided deforestation due to vertical integration of wood production in Mexican community forests

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ARTICLE INFO

Keywords:
Panel Data Estimators
Ejidos
Climate
Carbon
Biodiversity

ABSTRACT

Integrated conservation and development efforts in low- and middle-income countries have emphasized the devolution of forest management to local communities. This approach is posited to benefit both communities and conservation, but those benefits may depend on community capacity to capture value added, e.g., by processing forest products. In Mexico, most forests are under community management, but only some communities have vertically integrated their wood products supply chain through the establishment of community sawmills. The different timing of sawmill construction allows us to test the hypothesis that vertical integration of the wood products supply chain under community management is protective of forests. We use detailed, spatially explicit panel data from southern Mexico that allow us to examine impacts on land use change (deforestation and forest regrowth) separately from temporary changes in tree cover within forest areas. We find that vertical integration, as indicated by the presence of community sawmills and corroborated by a government classification of ejidos, reduced deforestation while increasing forest regrowth. Our findings, thus, have a somewhat counter-intuitive policy implication: programs that increase financial resources for communities to invest in forestry operations could improve forest protection and restoration, with regional and global benefits for climate, biodiversity, and other ecosystem services.

1. Introduction

Integrated conservation and development efforts in low- and middle-income countries have emphasized the devolution of natural resource management to local communities as a conservation strategy in recent decades (Rights and Resources Initiative, 2018a). Early syntheses of empirical work on this strategy (Bowler et al., 2010; Bowler et al., 2012; Miteva et al., 2012; Samii et al., 2014) found inconclusive and mixed evidence, based on the small number of studies that attempted to control for potential confounding variables. More recent research has suggested that community management can generate significant income to communities while protecting forests, although the impacts are heterogeneous (e.g., Alix-Garcia et al., 2015; Burivalova et al., 2016; Bocci et al., 2018; Fortmann et al., 2017; Blackman and Villalobos, 2020; Vélez et al., 2020).

Previous theoretical work has suggested that the community management of natural resources can be a successful conservation strategy under certain conditions. These include the profitability of community managed resources (as shaped by the accessibility and predictability of markets as well as the size of the resource endowment) relative to agriculture, tenure security, the ease of monitoring the resource, and characteristics of the community such as heterogeneity in terms of

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https://doi.org/10.1016/j.ecolecon.2025.108658
Received 1 November 2023; Received in revised form 14 April 2025; Accepted 25 April 2025
Available online 14 May 2025

ethnicity, religion, and collective history, and the number of decision-makers (Ostrom, 1990; Bromley, 1992; Baland and Platteau, 1996; Agrawal, 2007; Agrawal and Angelsen, 2009; Cox et al., 2010; Poteete et al., 2010). Previous work on community forestry has identified potential benefits of vertical integration including higher profits (Cubbage et al., 2015) and lower transaction costs (Antinori and Rausser, 2008; Vega and Keenan, 2014). In Mexico, the community managers of more vertically integrated CFEs are permitted to apply a wider scope of forest management activities (Antinori and Bray, 2005). Because these all make forest management more competitive with agriculture, greater vertical integration is hypothesized to reduce forest degradation and forest conversion to other uses (e.g., Molnar et al., 2008; Perez-Verdin et al., 2014; Romero et al., 2015).

There is also a small empirical literature on the relationship between vertical integration and the conservation of community forests in Mexico. Using a sample of 60 CFEs (including ejidos and comunidades)[1] in Oaxaca, Antinori (2005) finds that vertical integration is associated with larger areas for reforestation, forest conservation, and non-timber forest products. Barsimantov (2009) finds that vertical integration is associated with more forests, although there is heterogeneity across study regions. Perez-Verdin et al. (2014) find a statistically insignificant impact of vertical integration on discrete forest outcomes[2] in ejidos. Using a cross-sectional dataset of 183 ejidos, Ellis et al. (2017) find lower forest loss rates in more vertically integrated ejidos in the state of Quintana Roo. Barsimantov (2009), Perez-Verdin et al. (2014), and Ellis et al. (2017) all utilize cross-sectional data that do not allow them to account for the endogenous nature of vertical integration. Torres & Magaña (2006) model deforestation in Mexican ejidos with a generalized method of moments model including vertical integration, profits from timber and non-timber harvest, level of education, and road density within municipalities. Using a sample of 76 ejidos and data on deforestation between 1994 and 2000, they find that higher vertical integration led to lower deforestation.

We advance the empirical literature on vertical integration by applying new identification methods for panel data to estimate the effect of vertical integration on deforestation and forest regrowth across 224 forestry ejidos in the state of Quintana Roo in Mexico between 1996 and 2008.[3] We use two proxies for vertical integration- the presence of a community sawmill and a government classification based on whether communities sell stumpage, roundwood, or processed wood products. We apply recently developed panel data estimators—specifically, a synthetic difference-in-difference estimator and large-sample staggered difference-in-difference estimators as robustness checks. We find that, on average, the presence of a community sawmill reduces the fraction of forest converted to other uses and increases the fraction of forest regrowth. These patterns do not seem correlated with changes in population density.

We build upon prior studies in two main ways. First, unlike the handful of prior studies that utilized community-level multi-year panel data to estimate the impact of vertical integration on conservation outcomes, we separate longer-term forest cover loss (i.e., deforestation associated with conversion to commercial agriculture like sugarcane, soybean, and cattle pasture) from temporary forest cover loss (i.e., due to logging, fires, hurricanes, or traditional small-scale shifting agriculture). Similarly, we also consider forest regrowth on previously deforested land. Second, we employ a new generation of panel data methods suited to a context where the treatment is introduced at different times in different ejidos. Further, by using data from one of the 12 megadiverse regions in the world in terms of biodiversity (Vega and Keenan, 2014) and one of the sixth largest tropical countries in terms of natural climate solutions (NCS) mitigation potential (Griscom et al., 2020), we provide insights on interventions that can potentially be used to deliver on both local demands (for greater control over and profits from their forests) and global demands (for conservation of biodiversity and carbon rich forests).

2. Methods

2.1. Study area

2.1.1. Forestry in Quintana Roo

About 50–60 % Mexico's forests are under community management, with only about 15 % of ejidos with forest resources managing forests for timber (Bray, 2010; Cubbage et al., 2015; Madrid and Deschamps, 2014; Madrid et al., 2009). We focus on the ejidos in the state of Quintana Roo on the Yucatan Peninsula (Fig. 1). The state has been the second largest producer of valuable tropical hardwood species (e.g., Mahogany and Spanish Cedar) and the fourth in other tropical timber in Mexico (Ellis et al., 2015). About 80 % of the state's area is under forests, with approximately 62 % of the forests falling under ejido management (Ellis et al., 2015). While the forests of the Yucatan peninsula have been under *de jure* community ownership since the mid-twentieth century, logging rights and profits were largely controlled by a parastatal logging company (MIQRO) until they were conferred to communities by the 1986

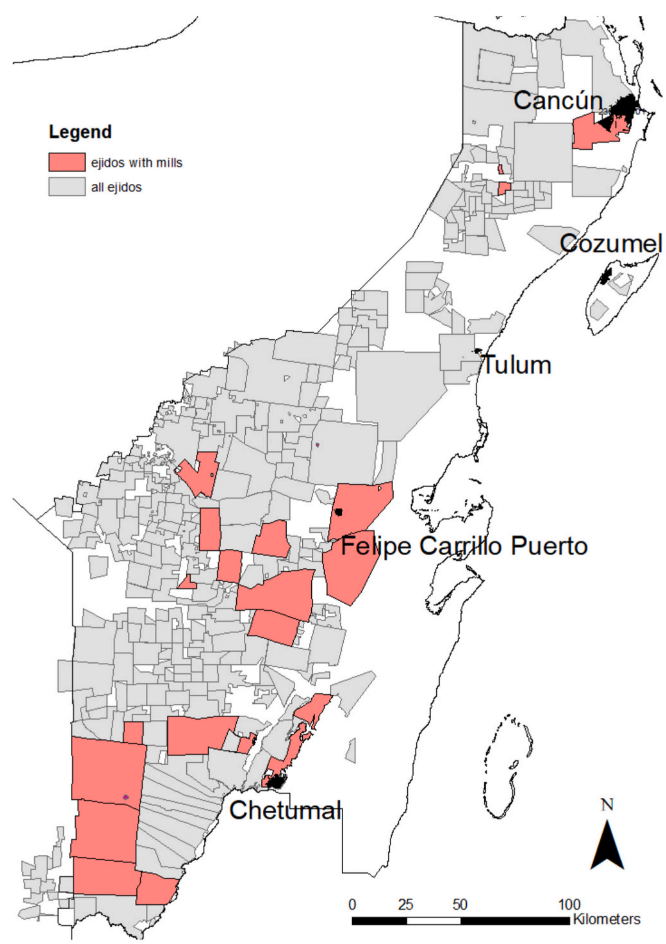

Fig. 1. Ejidos with new sawmills between 1996 and 2008.

[1] Communidades are comprised of indigenous groups and have emerged before the Spanish, whereas ejidos may be comprised of non-indigenous households, with the first ejidos settled after the passing of the 1915 Agrarian Law (USAID, 2025)

[2] The article tests the association between vertical integration and a discretized state of the forests in ejidos, specifically if the ejido is considered forested, deforested, recovered, or degraded, with each of these treated as discrete levels and not continuous variables.

[3] There are no communidades in the study area.

Forest Law (Ellis et al., 2015).

For the past several decades, the region has been characterized by clear and secure property rights over forests, land management organized at the community level (Maya, mestizo, or Mayan-mestizo communities), and the possibility of vertical integration of wood products supply chains under community control. The forests include valuable timber species like Mahogany and Spanish Cedar. There are few non-forestry employment opportunities; local and national governments and non-governmental organizations actively support forest management (Antinori and Rausser, 2008; Wilshusen, 2005; Ellis et al., 2015). These characteristics have been listed as some of the preconditions for successful community forestry management in Mexico and elsewhere (Baland and Platteau, 1996; Antinori and Rausser, 2008; Ellis et al., 2015). Unlike other parts of Mexico, very few ejidos in Quintana Roo have divided their community-managed forests into individual parcels (Barsimantov et al., 2010; DiGiano et al., 2013).[4]

2.1.2. *Vertical integration*

Since 2004, Mexico's National Forestry Commission (Comisión Nacional Forestal (CONAFOR)) has classified forestry ejidos into Type I, which are potential timber producers with sufficient forest area and timber stocks but no active forest management plan and, hence, no permit to engage in commercial forestry in a given year; Type II, which sell stumpage (rights to harvest timber) to external logging companies that harvest the trees without community participation in the harvesting operations and timber processing; Type III, which harvest and sell roundwood (e.g., logs); and Type IV, which have a timber processing mill on site or nearby[5] and sell processed roundwood (e.g., sawn wood and finished products)[6] made from the harvested timber (Ellis et al., 2015a). The classification is based on site visits by CONAFOR personnel.[7] Ten of the forestry ejidos in Quintana Roo also had voluntary Forest Stewardship Council (FSC) forest management certification at some point during the study period. The ejidos not classified by CONAFOR and not part of our sample have livelihoods based on agriculture (cattle or crops), tourism, or employment in urban areas (Barsimantov et al., 2010); we refer to these as "non-forestry ejidos" in the text. Forestry ejidos may also engage in these other activities (e.g., the ejidos of Tres Garantías, Guadalajara, Noh Bec in our sample). Pooled data from the available forest management plans active as of 2013 suggest that the more vertically integrated ejidos adopt more forest protecting practices, such as pest management, fire prevention, and directional felling (Table 1).[8] However, these data correspond to cutting cycles between 1999 and 2013 and, hence, present a limited and non-random snapshot of forest management practices of the different types of ejidos.

Table 1
Forest management practices by CONAFOR type (2013).

Forest management category	Type II		Type III		Type IV	
	N	mean (sd)	N	mean (sd)	N	mean (sd)
Total area under forest management plan (ha)	19	6171.74 (2980.29)	20	17,562.06 (17,188.01)	8	38,014.04 (22,124.73)
Area of permanent forest (ha)	19	2177.88 (1128.50)	20	5662.35 (4716.62)	8	22,565.69 (14,562.39)
Use area (ha)	19	2181.27 (994.21)	20	5420.77 (8444.75)	8	7348.38 (7334.29)
Authorized cutting volume (m^3)	19	8802.04 (5835.53)	20	28,447.80 (25,439.83)	8	57,690.96 (40,305.69)
1 if vine cutting treatment	19	0.05 (0.23)	20	0.05 (0.22)	8	0.38 (0.52)
1 if prescribed burning	19	0.05 (0.23)	20	0.25 (0.44)	8	0.25 (0.46)
1 if forest restoration treatment	19	0.53 (0.51)	20	0.40 (0.50)	8	0.63 (0.52)
1 if removal of shrubs	19	0.05 (0.23)	20	0.10 (0.31)	8	0.25 (0.46)
1 if pruning treatment	19	0.05 (0.23)	20	0.05 (0.22)	8	0.13 (0.35)
1 if thinning treatment	19	0.63 (0.50)	20	0.55 (0.51)	8	0.75 (0.46)
1 if directional felling	19	0.63 (0.50)	20	0.80 (0.41)	8	1.00 (0.00)
1 if fire prevention	19	0.74 (0.45)	20	0.95 (0.22)	8	1.00 (0.00)
1 if pest control	19	0.79 (0.42)	20	0.85 (0.37)	8	1.00 (0.00)

Note: Based on submitted Forest Management Plans (PMF) 2013. While this is a non-random sample, it captures more than half of the forestry ejidos in the study area.

2.1.3. *Ejido organization, forest management, and timber harvesting decisions*

Management and user rights to the forests are given to a fixed number of households, who are the registered members within an ejido; these are known as ejido members or ejidatarios. While the rights to the forests may also be purchased (Ellis et al., 2015), the number of ejidatarios remains constant (Barsimantov et al., 2010; Ellis et al., 2015). The ejidatarios make decisions about the management of the forest, are responsible for the monitoring and enforcement of restrictions, and directly profit from it. The rest of the households living within a forestry ejido do not have rights to harvest trees but may obtain indirect benefits in the form of public goods (such as electricity or health posts) financed by timber revenues, or training and employment in logging, wood processing, reforestation, or tree nurseries (Alix-Garcia et al., 2005; Antinori and Rausser, 2008). They may also benefit from non-timber forest products (e.g., Antinori, 2005).

To harvest timber commercially, the forestry ejidos need to apply for and obtain timber harvesting permits. Every five years, each forestry ejido must submit a forest management plan that complies with the annual maximum allowable harvest by species, determined by the forest inventory and authorized by the government (Ellis et al., 2015). While clearing forest for crops or cattle pasture without a permit is technically illegal,[9] that restriction may not be enforced (Román-Dañobeytia et al., 2014). Government subsidies for cattle ranching and farming may also encourage forest clearing (Bray and Duran-Medina, 2014).

2.1.4. *Deforestation drivers in Quintana Roo*

All forests in the study area are moist broadleaf (Ellis et al., 2015).

[4] Between 1993 and 2017 only about 2 % of the total ejido land in Quintana Roo has been formally parceled, with individual rights over forests created (RAN, 2018).

[5] Ejidos may process timber using a neighboring mill (S. Proust, *personal communication;* Reuters, 2010).

[6] Note that in this paper, we lump ejidos producing sawn wood and finished products together to correspond to the CONAFOR classification. Previous studies have suggested differences in the forest area, harvesting practices, and profitability between these two types (e.g., Antinori, 2005).

[7] Note that while the CONAFOR typology started in 2003, the categories originated under the Forest Resources Conservation and Sustainable Management Project (PROCYMAF) in the late 1990s; ejido types existed long before those—ejidos began harvesting timber in the late 70s and 80s.

[8] The management plans were authorized between 1999 and 2013 and active as of 2013. Note that this is not a random sample or a census, because some management plans were not accessible. We use the data from the management plans for illustrative purposes only.

[9] Specifically, the law prohibits removing vegetation cover spanning more than $4m^2$ of basal area without a permit or in communal forested areas outside an agricultural zone.

Forest loss can be either temporary (e.g., due to fires, hurricane damage, logging, subsistence-based shifting cultivation, called "milpa", or other subsistence agriculture) or permanent (e.g., due to urbanization, legal or illegal conversion to pastures or large-scale commercial agriculture). According to Krylov et al. (2019), most of the forest cover loss (54 %) in the Yucatan peninsula between 2000 and 2012 was temporary and attributed mostly to subsistence agriculture; 36 % was considered permanent and driven primarily by conversion to cattle pastures; the remaining 10 % was associated with fires, agricultural plantations, hurricanes, logging, and urbanization. Fires have been identified as an important driver of forest degradation in the region (Ellis et al., 2021). Logging in the study area is typically highly selective and rarely leads to detectable tree cover loss — for example, due to the construction of large log landings and roads (Ellis et al., 2015; Hernández-Gómez et al., 2019; Miteva et al., 2019).

Field studies in a few selected ejidos have found that logging damage to the forest in vertically integrated ejidos is negligible relative to the damage that external logging companies can inflict on forests (Barsimantov, 2009; Vega and Keenan, 2014; Ellis et al., 2019). While limiting damage to the remaining forest protects the future timber value of the forest, selective logging also removes valuable tree species, thereby lowering the immediate value of the remaining forest and, thus, potentially encouraging permanent conversion to agriculture. In our analysis, we focus on the permanent conversion of forest to commercial agriculture (crops and cattle pasture) and regrowth of forest in those areas, excluding temporary fluctuations in tree cover associate with logging, hurricanes, fire, or small-scale traditional shifting agriculture (milpa) (Ellis et al., 2020; Lawrence et al., 2019).

2.1.5. Theoretical model

Here we provide the intuition and testable hypotheses of the impact of vertical integration on ejido forests. We model ejido decisions as the optimal allocation of land between forest and commercial agriculture. From forests, the ejido receives benefits including income from timber or processed wood products, tourism, and non-timber forest products like honey, as well as subsistence use of those forest products and subsistence shifting agriculture. We do not model any interactions between subsistence agriculture and forestry, because our data do not allow us to distinguish changes in forest cover due to logging from changes due to subsistence agriculture. Thus, we assume a steady state in forest use. In addition to the traditional production and transportation costs, forests also entail monitoring and enforcement costs. In contrast, we assume there are no enforcement and monitoring costs associated with agriculture.

In a steady-state setting, the optimal land use allocation decision balances the marginal net benefits from forests with the marginal net benefits from commercial agriculture.[10] In other words, land remains under forest if the marginal benefit from forests exceeds the marginal benefit from land in commercial agriculture. We assume that the total land endowment, L, can be allocated to only two uses-forest (X) and agriculture (AG). We can write the net benefits from forest as

$$\Pi = p_v f(X) - C_v(f(X)) + bX - C_e(X) - [p_{AG}(L - X) - C_{AG}(L - X)] \geq 0 \quad (1)$$

where X is the area of forest and f(X) the amount of timber harvested. The timber price, p_v, and timber cost function, $C_v(.)$, vary by the level of vertical integration *v*. b is a non-timber benefit from a unit area of forest, and $C_e(.)$ is the cost of monitoring and enforcing timber harvesting restrictions. p_{AG} is the price of agricultural produce, AG -the agricultural area is equal to L-X, and $C_{AG}(.)$ – a cost function for agricultural production. We assume that timber and agricultural prices are exogenous to the ejidos. $C_v()$ includes both production (e.g., cost of labor and machinery) and transportation costs. The cost of monitoring and enforcement depends on both the forest area as well as the share of ejidatarios to non-ejidatarios (e.g., Alix-Garcia et al., 2005). The agricultural production function depends on precipitation and slope.

The first order condition becomes:

$$p_v f'(X) - C_v{}'(f(X))f'(X) + b - C_e'(X) \geq p_{AG} - C_{AG}{}'(AG) \quad (2)$$

Vertical integration increases the value of the timber products sold (e.g., Antinori, 2005; Antinori and Bray, 2005; Barsimantov, 2009; Vega and Keenan, 2014). It also reduces damage to the remaining forest, or residual stand, relative to the outcomes when stumpage is sold and harvested by external contractors relative to when the timber is processed within the ejido (e.g., Vega and Keenan, 2014). Given these, after rearranging Eq. 2 and using implicit functions, it can be seen the forest area increases with the price of timber products and the benefits from forests and decreases with the net marginal revenue from agriculture. Since the highest vertically integrated ejidos receive the highest price for timber, Eq. 2 suggests that they should have more forest, *ceteris paribus.* Because of the lower price for stumpage, we expect that the less vertically integrated ejidos will have more deforestation and less forest regrowth, *ceteris paribus.* Conversely, we expect the most vertically integrated ejidos to have the lowest level of deforestation and higher rates of forest regrowth. These are the hypotheses we test empirically.

2.2. Data

2.2.1. Sample

Our dataset includes all ejidos in the state of Quintana Roo between 1996 and 2016, with data on the CONAFOR classification of the level of vertical integration available for 2004 to 2016 and data on the establishment of timber mills available for 1996–2008. We exclude ejidos that are partially or fully spanned by protected areas (a total of 81 observations across the full panel). Most of these are Type I ($n = 20$) and non-forestry ejidos ($n = 18$). Types II, III, and IV include 7, 1, and 2 ejidos within protected areas, respectively. While excluding these ejidos reduces our sample size, it is necessary due to the potential displacement of forest cover loss from the protected to the unprotected parts of the ejidos (e.g., Miteva et al., 2019). Finally, we exclude ejido Bacalar due to its changing boundaries and the settlement of Mennonites with very different agricultural practices (Mongabay, 2023). The remaining dataset used for the analysis contains data on 281 ejidos; of these 223 can potentially produce and sell timber.

2.2.2. Treatment

We use two definitions of vertical integration: the CONAFOR classification (Bray and Duran-Medina, 2014) and the presence of community sawmills located within an ejido or immediately adjacent to a given ejido. During the study period, the CONAFOR criteria used to classify ejidos into each of the vertical integration categories remained virtually unchanged. Most of the ejidos (~66 % of the sample) in Quintana Roo are listed as potential producers or Type I (SI Table 2). Type II and III comprise about ~13 % and 15 % of the sample, respectively, whereas Type IV—only about 4 %. Most ejidos did not change their CONAFOR types during the study period.

[10] The first order conditions from a dynamic optimization model yield qualitatively the same predictions. That is, we define the Hamiltonian as $H = p_v u - c_v(u) + bX - c_e(X) + p_{ag}AG - c_{AG} + \lambda(G(X) - u - d(u) - AG$, where u is the amount harvested, G(X) is an intrinsic forest growth function, and d() is a forest damage function; the rest of the parameters are defined as in the static model. We normalize the value of the forest damage for the other ejidos relative to those selling stumpage: that is, for the other two types of vertical integration, we assume that the damages to the forest are negligible *relative to Type II* (e.g., Vega and Keenan, 2014). The first order conditions become $(p_v - c_v'(u))/(d_v'(u)) = p_{AG} - C_{AG}{}'(AG)$. These also imply higher conversion to agriculture in less vertically integrated ejidos.

Fifty-one ejidos changed their CONAFOR type at least once between 2004 and 2016. Of these, 9 ejidos moved from Type II to Type I, 4 ejidos-from Type III to Type I, 2 ejidos from Type III to Type II, and 1 ejido from Type IV to Type I. Five ejidos switched from Type I to Type II and 7-from Type I to Type III. Only 1 ejido transitioned from Type II to Type III and 1-ejido-from Type III to Type IV. The rest of the ejidos ($n = 21$) changed categories more than once. The number of non-forestry ejidos remained the same throughout the study period.

We also use the presence of community sawmills, considering sawmills located in an ejido or any immediately adjacent ejido as a proxy for vertical integration. We utilize data, spanning 1996 to 2008, on the year of establishment of new sawmills. Our data do not include mobile sawmills which may also be used to process timber (Flachsenberg and Galetti, 1998).[11] We consider an ejido "treated" if it had a timber processing mill within its boundaries or was immediately adjacent to an ejido with a mill (SI Table 3).

2.2.3. Outcomes

To calculate forest areas, we employ the dataset by Vancutsem et al. (2021). Spanning 1990 to 2020, the dataset provides at 30-m resolution annual information on degraded forest (forest that is cleared for 2.5 years or less and then allowed to recover), deforestation (forests that remain as another land use for more than 2.5 years), forest regrowth (areas deforested for at least 2.5 years and allowed to regrow after), and undisturbed tropical forests. We focus on deforestation and forest regrowth regardless of whether they occur in areas zoned for agriculture or forestry in the ejido (Bray et al., 2004; Ellis and Porter-Bolland, 2008). We exclude degradation as it captures both traditional slash-and-burn agriculture and temporary changes in the forest due to logging and logging road construction, fires, and hurricanes. Similarly, we exclude the "undisturbed forest" category as the forests in the area have been logged for a very long time (Snook, 1998).

We calculate the outcomes used in the estimation as the deforested area in a given year divided by the total forest area 1996; we construct an analogous variable for regrowth. We define total forest in 1996 as the sum of the four forest categories in Vancutsem et al. (2021).

2.2.4. Covariates

We consider covariates impacting the profitability of forests like the proximity to markets (proxied by the distance to ports and large urban areas), ejido area, average slope within ejidos, tourism potential (proxied by the distance to archaeological sites) as well as the area under water within an ejido. We use Euclidean distances as we do not have time-varying data on logging and paved roads; the area is also flat with no major physical barriers. The data sources for the variables are given Appendix Table S1.

2.2.5. Estimation

In our case, the propensity to vertically integrate is a function of an ejido's characteristics, including its resources, proximity to markets, and institutional arrangements. The timing of vertical integration is also affected by idiosyncratic exogenous factors, such as the supply chain for equipment and biophysical conditions like rainfall that affect the profitability of forestry relative to agriculture.

Because of the limited temporal variability in the CONAFOR typology, we cannot use large-sample panel data estimators to obtain the causal impact of vertical integration on forests. For this reason, we first estimate a random effects model with year fixed effects using suitable covariates that are not collinear with each other: total ejido area and the water area within an ejido, mean slope, proximity to ports and archaeological sites, and year fixed effects.[12] The reason we exclude collinear variables is the loss of degrees of freedom and larger standard errors. We also exclude ejidos that permanently or temporarily switched their CONAFOR typologies during the study period as well as potential producers (Type I) and non-forestry ejidos. While not necessarily causal without additional assumptions, the model presents a useful first step.

To estimate the causal impact of vertical integration, we use two different treatments: the adjacency to timber processing mills and the CONAFOR typologies for ejidos that experienced permanent change. In the first case, we define the treatment as 1 for ejidos either having a mill or being immediately adjacent to an ejido with one in a given year and 0 otherwise. Since the mills were built in different years, the treatment is staggered. Because we do not have data on whether mills ceased operation during the study period, our treatment is weakly increasing: That is, the number of ejidos with treatment = 1 increases over time as new mills are built. Our sample consists of 78 ejidos that received the treatment over time and 145 forestry ejidos that were never treated during the study period (SI Table 3).

As an alternative treatment, we utilize the ejidos that permanently switched to a higher CONAFOR type during 2004–2016 and compare them to ejidos of the same initial type that did not change their CONAFOR typology. In Quintana Roo, only two met this criterion: one ejido that transitioned from Type II to Type III and one-to Type III to Type IV, respectively. For these, we consider two sets of analyses: In one, the control group consists of Type II ejidos that did not change their CONAFOR type; we examine the impact of switching to Type III relative to Type II. Analogously, we consider the impact of a Type III ejido switching to Type IV, relative to other Type III ejidos that did not change their CONAFOR type during the study period.

Because the treatment group is small regardless of whether we use the presence of mills or CONAFOR type as the time-varying treatment, we apply a synthetic difference-in-difference estimator (Arkhangelsky et al., 2021). The estimator can be used for both small and large sample sizes. The average treatment effect on the treated (ATT) is given by

$$\text{ATT} = arg\ min_{\mu,\tau,\alpha,\beta}\left\{\sum_{i=1}^{N}\sum_{t=1}^{T}(Y_{it}-\mu-\alpha_i-\beta_t-D_{it}\tau)^2\widehat{\omega_i}\widehat{\lambda_t}\right\}, \quad (3)$$

where the outcome for ejido i at time t is given by Y_{it}, the binary treatment -by D_{it}, and the average treatment effect-by τ. α_i and β_t are ejido and time fixed effects, respectively, and μ is a constant. $\widehat{\omega_i}$ is an ejido-level weight that aligns the pre-exposure trends in the outcome for the treatment and control observations. $\widehat{\lambda_t}$ is a time weight that balances pre- and post-exposure time periods. N is the total sample size and T-the number of time periods. More weight is given to similar (based on past outcomes) observations; similarly, more weight is given to periods that are, on average, similar to the treatment group pre-trends. The weights are estimated from the data to ensure balanced pre-trends in the outcomes of the treatment and control observations. Note that without the weights $\widehat{\omega_i}$ and $\widehat{\lambda_t}$, the estimator collapses to a Two-Way Fixed Effects (TWFE) model (Arkhangelsky et al., 2021).

The weights are calculated from the sample. With a staggered treatment, the estimator performs a series of TWFE regressions for each year of the treatment. For example, given observations that were treated in 1997 and others-in 1998, the synthetic difference-in-difference estimator will run two weighted regressions, comparing the observations treated in 1997 to untreated observations and observations treated in

[11] Based on the authors' personal observations from Quintana Roo: Portable sawmills are not considered as productive as a standing sawmill. The band saw blades do not function well with tropical hardwood and once they are damaged, people stop using them.

[12] We use a Value Inflation Factor (VIF) of 10 as a cutoff for multicollinearity. We also exclude covariates that have pairwise Pearson correlations>0.5 with those already included in the model. The exclusion of relevant covariates due to multicollinearity may lead to biased and inconsistent estimates in a random effects model. However, in our data, the sign and significance of the estimated coefficients remain the same when the potentially multicollinear variables are included.

1998 to untreated observations. The ATT is an average of individual treatment year effects. Because the estimator requires a balanced panel and no treated observations at the baseline, we exclude from the sample the 10 ejidos with mills in 1996.

The synthetic difference-in-difference estimator allows for only time-varying exogenous covariates to be included in the model. The only covariate that meets this criterion is precipitation. We present results with and without that covariate.

Because of the small sample size of the treatment group, we use a placebo estimator to calculate the standard errors under the assumption of homoscedasticity (Arkhangelsky et al., 2021). For the presence of mills treatment, we also present results from a bootstrap procedure that independently resamples ejidos (Arkhangelsky et al., 2021). In all specifications based on the presence of mills as the treatment, we use 1000 replications; for the CONAFOR typologies-we use 500. We use the *sdid* package in Stata (Clarke et al., 2023). In all specifications, we cluster the standard errors at the ejido level (Abadie et al., 2022).

For the two treatments based on the CONAFOR typologies, we present the results from a synthetic control estimation (Abadie and Gardeazabal, 2003). It differs from the synthetic difference-in-difference model in the lack of time weights only (Arkhangelsky et al., 2021). We are not aware of other recent estimators appropriate for very small treatment groups.

Vertical integration may arise to improve efficiency by minimizing transaction costs and maximizing investment (e.g., Williamson, 1971; Williamson, 2010). This means that vertical integration is endogenous (i.e., driven by the characteristics of the ejidos and, hence, non-random). Previous studies have highlighted the role of biophysical and social factors like the forest endowment and ejido governance in determining the degree of market insertion and vertical integration (Wilshusen, 2005; Forster et al., 2014). Proximity to markets (population centers), mechanical expertise, parastatal history as well as the area and quality of forests for timber harvesting have been highlighted as crucial based on empirical work (Antinori, 2005; Antinori and Rausser, 2008). The internal organization of ejidos is believed to be correlated with the size of forest endowment: Larger and more commercially viable ejidos are more likely to have incentives to foster strong internal governance related to forests, with stronger governance likely to emerge over longer time periods, *ceteris paribus* (e.g., Baland and Platteau, 1996). In Quintana Roo, the larger and more vertically integrated ejidos were established prior to 1945 with the intent of rubber tapping, whereas the smaller ones-post 1964 with the intent of agriculture and cattle ranching (Forster et al., 2014). Because the characteristics of the ejidos are unlikely to vary significantly over time and the CONAFOR criteria remained unchanged during the study period, we model this potential endogeneity as a time invariant omitted variable that is controlled for by fixed effects. Further, the estimators we use rely on parallel trends for the treatment and control ejidos. In other words, in our estimation the propensity of an ejido to become vertically integrated is a function of pre-determined time-invariant characteristics; we estimate the effect of idiosyncratic variation in the timing of mill establishment, which is effectively random.

2.2.6. Robustness checks

For the presence of mills treatment, we compare the results from the synthetic difference-in-difference estimator with the estimators proposed by de Chaisemartin & D'Haultfœuille (2024) and Callaway & Sant'Anna (2021). The first estimator generally employs a series of 2 by 2 TWFE models and aggregates impacts; it computes analytical standard errors (de Chaisemartin and D'Haultfœuille, 2024). Identification there is based on the number of ejidos that switch into the treatment, with the control group being ejidos not treated in a given year. We report the results from the non-normalized event study estimator, in order to be able to compare the results with the rest of the models.[13] The second estimator combines regression adjustments and inverse probability weighting. Specifically, it uses time-invariant characteristics to construct a propensity score, the inverse of which is used to weigh observations in a series of weighted regression models corresponding to each year of the treatment adoption (Callaway and Sant'Anna, 2021). For the untreated observations for a given period, the estimator also regresses on the baseline covariates the difference in outcomes at the baseline and a given time period. Finally, the estimator combines the inverse probability weighting with the differences in the outcomes between the treated and never treated observations and the differences from the regression model. The advantage of the doubly robust estimator is that the estimated coefficients are unbiased even if either the propensity score, or outcome equation is mis-specified (Callaway and Sant'Anna, 2021). The control group we use is the forestry ejidos that did not switch their treatment throughout the study period. In both models, we improve the pre-trends by using the average slope within ejidos, the distance to archaeological sites, distance to ports, the ejido area (highly correlated with baseline forest area ($\rho = 0.88, p < 0.001$) as well as the area under water within an ejido. We exclude the covariates that are correlated with the ones we retained. In these models we do not use precipitation as the mean precipitation for 1996–2008 is highly correlated with the distance to ports variable included in the model ($\rho = -0.50$, $p < 0.001$).[14]

Finally, we present the results from a two-period TWFE model using only 1996 as the baseline and 2008 as the end year. We modify the adjacency to mills treatment to equal 1 if an ejido built a mill or became adjacent to an ejido with a mill during our study period. The control group includes ejidos that were not adjacent to mills throughout the study period.

As in the main specifications, we cluster the standard errors at the ejido level for all robustness checks (Abadie et al., 2022).

2.2.7. Examining changes in population density as a potential rival explanation

In general, changes in forest cover may be due to improved timber management practices and reduced conversion to agriculture or out-migration decreasing the demand for agricultural land. Further, monitoring and enforcement costs depend on the share of the ejidatarios relative to non-ejidatarios. Given that the former is constant, changes in the population density can change the monitoring and enforcement costs. For example, a significant influx of new migrants is likely to severely diminish the capacity of an ejido to monitor and enforce restrictions (e.g., Baland and Platteau, 1996; Alix-Garcia et al., 2005).

To examine correlations between changes in the population density and vertical integration, we use the same the synthetic difference-in-difference estimators as well as the estimators by de Chaisemartin & D'Haultfœuille (2024) and Callaway & Sant'Anna (2021). We obtain the annual data on population density from the LANDSCAN datasets (Bright et al., 2009). The data are available annually from 2000 to 2017 at a resolution of approximately 1 km. Because the mills data were available until 2008, we limit the analysis to 2000–2008 for that treatment.

3. Results

3.1. Descriptive statistics

On average, the ejidos with sawmills present (in or immediately adjacent) are larger and have a larger forest area, suggesting that vertical integration is associated with economies of scale (Gnych et al., 2020) (Table S5). While these ejidos had a larger absolute area of forest loss during the study period, it represented a smaller fraction of the total forest. These ejidos also experienced a net forest growth, whereas the

[13] The normalized estimator reports the average causal impact divided by the number of periods a unit has been treated (de Chaisemartin and D'Haultfœuille, 2024).

[14] However, the models with precipitation yield very consistent results.

ejidos not adjacent to a sawmill, an overall net decrease in the forest area between 1996 and 2008.

Results from the pooled regression model suggest that CONAFOR Type IV ejidos are associated with significantly lower deforestation relative to the ejidos selling stumpage (Type II) (Table 2). While the coefficient for the ejidos selling roundwood is negative as expected, it is not statistically significant. In terms of forest regrowth, the coefficient on Type IV ejidos was positive but statistically insignificant. The coefficient on the Type III ejidos was negative but also statistically insignificant.

3.2. Results from synthetic difference-in-difference estimation

3.2.1. Presence of sawmills as treatment

We consider the results from the synthetic difference-in-difference model with a placebo variance estimator and no covariates (i.e., precipitation[15]) to be our main model (Table 3 top row). The pre-trends of the treated and control observations appear parallel (Fig. 2 & 3). There are few influential observations for a few of the treatment years (Figs. S1 &S2). The assumption of homoskedasticity of the error terms appears supported (Fig. S3).

Our preferred model indicates that, on average, the adjacency to mills reduced deforestation by about 3.6 percentage points relative to similar control ejidos. The average impact is significant at the 5 % level. The presence of mills also increased forest regrowth by about 0.3 percentage points, significant at the 1 % level.

The results appear consistent with the large-sample estimators we use as a robustness check. For the deforestation outcome, all coefficients are negative but are statistically significant only with the synthetic difference-in-difference and the de Chaisemartin & D'Haultfœuille (2024) estimators. There are two potential explanations for the increased standard errors and resulting statistical insignificance: First, these estimators assume a large sample, with sufficiently large group of treated observations. The small number of treated observations is likely to lead to lower statistical power. Second, not all estimators appear to balance the pre-trends between treated and control observations. For example, the Callaway & Sant'Anna (2021) estimator did not result in parallel trends for all of the pre-treatment years (Fig. S5). Further, in the TWFE model we could not test for parallel pre-trends. The unbalanced parallel trends are likely to introduce bias (Roth, 2022; Rambachan and Roth, 2023).

Table 2

Pooled regression estimates for the relationship between CONAFOR type and deforestation/total forest (column (1) and new forest/total forest (columns 2) for 2004–2016 (standard errors in parentheses). The comparisons are relative to Type II; the data exclude potential producers (CONAFOR Type I), non-forestry ejidos as well as ejidos that changed their CONAFOR type between 2004 and 2016. Both models include covariates that did not result in multicollinearity: total ejido area and the water area within an ejido; proximity to urban centers, towns, archaeological sites, and large roads; variability in the slope; and year fixed effects.

CONAFOR Type	[1]	[2]
Type III	−0.01 (0.06)	−0.001 (0.005)
Type IV	−0.24*** (0.08)	0.00008 (0.008)
Outcome	Forest loss/forest in 1996	Forest regrowth/forest in 1996
N	816	816
#ejidos	84	84

Significance levels: *** 1 %, **5 %, *10 %.

Table 3

Summary of the causal estimates from various estimators for the proximity to mills treatment (standard errors in parentheses). The forest variables are calculated as the area in a given year divided by the forest area in 1996 (our baseline). Unless specified otherwise, the standard errors are clustered at the ejido level. Negative values of the coefficients indicate a reduction, and positive-an increase in the outcome due to the presence of sawmills. The population density specifications use data from 2000 to 2008 only.

Estimator	Deforestation	Reforestation	Population density
Synthetic difference-in-difference, placebo standard errors, no covariates	−0.036** (0.016)	0.003*** (0.0004)	−0.74 (0.97)
Synthetic difference-in-difference, bootstrap standard errors	−0.036*** (0.010)	0.003*** (0.001)	- 0.71** (0.32)
Callaway & Sant'Anna (2021)	-−0.026 (0.03)	0.003** (0.001)	−1.75*** (0.65)
Synthetic difference-in-difference, placebo standard errors, precipitation as covariate	−0.036** (0.016)	0.003*** (0.0004)	−0.71 (0.97)
de Chaisemartin & D'Haultfœuille (2024)	−0.023*** (0.008)	0.002*** (0.0005)	−0.66** (0.30)
Before-After TWFE	−0.014 (0.018)	0.004*** (0.001)	−0.69 (0.99)

Significance levels: ***1 %, **5 %, *10 %.

For the reforestation outcome, all estimators yield comparable in magnitude and significance results. While there are few influential observations (Fig. S2), the parallel trends assumption appears supported in all specifications (Figs., S4B, S5B).

While the average impact on deforestation is negative, there appears to be some heterogeneity of the impacts based on when the sawmills were established. For example, ejidos adjacent to mills established in 2002 and 2005 had higher deforestation than control ejidos (Fig. 2). Similarly, while the average impact on reforestation is positive, we find heterogeneity based on when mills were established, with mills established in 2002 and 2005 having lower levels of reforestation than control ejidos (Fig. 3). The event-study estimators by Callaway & Sant'Anna (2021) and de Chaisemartin & D'Haultfœuille (2024) also suggest heterogeneity though time (Figs. S4&5, Tables S7 &8), but these effects are not directly comparable with the plots in Figs. 2 & 3.

3.2.2. CONAFOR typologies as treatment

We find a consistent negative coefficient on the impact of advancing the CONAFOR type on deforestation: The average treatment effects on the treated (ATTs) are −0.02 (st. error = 0.07) and − 0.07 (st. error = 0.11) for the switch from Type II to Type III and Type III to Type IV, respectively (Table S9). However, neither of these estimates is statistically significant. The ATTs on reforestation are negative but also insignificant: −0.002 (st. error = 0.04) and − 0.01 (st. error = 0.02).

There are two likely explanations for the insignificant results–statistical power and heterogeneity through time. For example, the estimation using the switch from Type II to Type III uses 16 control and 1 treated ejido. Similarly, the estimations using the switch from Type III to Type IV uses 24 control and 1 treated ejidos. Further, there appear to be a few very influential observations (Fig. S6). For this reason, while consistent with the main results, these should be interpreted with caution. Second, for the deforestation outcome, it appears that the impacts are increasing over time, with avoided deforestation increasing as the time since treatment increases (Fig. 4 left panels). Similarly, reforestation seems to increase a few years after the switch to a Type III ejido (Fig. 4 top right panel), but the average increase during the study period is statistically insignificant because of the temporal heterogeneity. Reforestation in the Type IV ejido seems to be increasing, but less than in similar control ejidos. However, the estimate is based on four very influential observations (Fig. S6 bottom right panel).

[15] The model with precipitation as a time-varying covariate yields very similar results (Table 3).

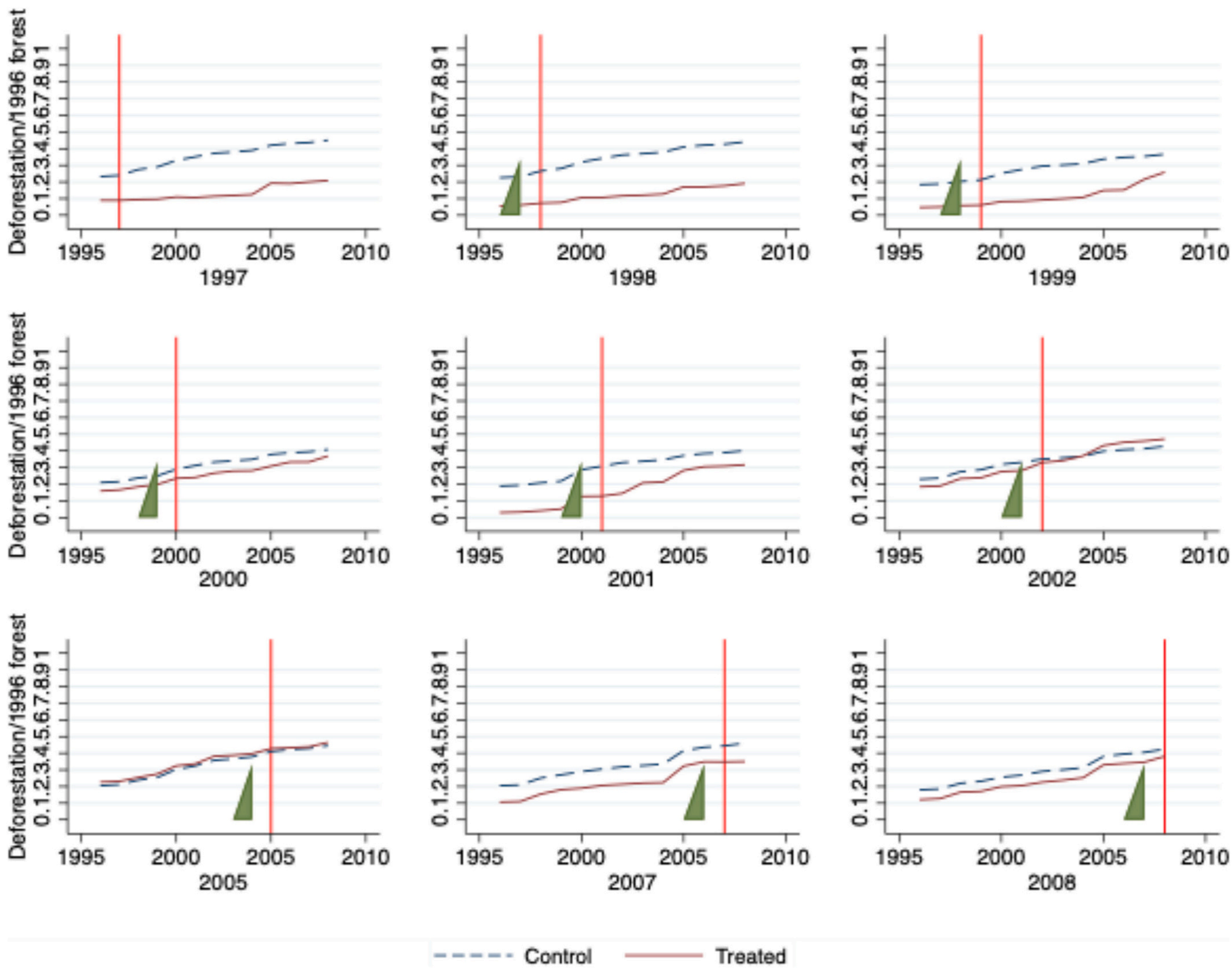

Fig. 2. Impact of adjacency to mills on deforestation expressed as the area of forest lost in a given year/forest area in 1996. Note that the estimator groups ejidos with mills established in the same year as a treatment group and estimates the impacts for each treatment group separately. The green triangles represent time weights used to construct parallel pre-trends. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The results from the synthetic control estimation are consistent, with ATTs equal to −0.001 (st. error = 0.08) and − 0.01 (st. error = 0.11) for the switch from Type II to Type III and Type III to Type IV, respectively, and deforestation as the outcome. For reforestation, the ATTs become −0.03 (st. error = 0.03) and − 0.02 (st. error = 0.02) the switch from Type II to Type III and Type III to Type IV, respectively. However, these are based on a smaller set of control observations, with a few influential observations (Fig. S7).

3.2.3. Changes in population density as a potential explanation

In our preferred specification (Table 3 top row), we find a negative but insignificant coefficient on population density. This suggests that the decreased deforestation and increased forest regrowth do not seem correlated with a decline in population relative to observationally similar controls. The coefficients on most models we use as a robustness check are consistent in magnitude but differ in statistical significance. The reason is that the variance in these models assumes large samples, which is not the case here. The coefficient from the Callaway & Sant'Anna (2021) estimator is much larger than the rest but it appears it is driven by unbalanced pre-trends (Fig. S5C).

4. Discussion and conclusions

Previous work has highlighted local governance quality and demand for cleared land in shaping the impact of timber harvesting permits on forest cover in Mexico (Blackman and Villalobos, 2020). Building on these insights, we test another mechanism: vertical integration that allows communities to capture more value added from their timber. We find robust empirical support that vertical integration was protective of forests in Quintana Roo between 1996 and 2008, suggesting that government and non-governmental organizations (NGO) support for this strategy can potentially deliver on both local demands (for greater control over and profits from their forests) and global demands (for conservation of biodiversity and carbon rich forests).

The global scaling potential of such findings is large. Avoided forest conversion is the largest natural climate solution in the tropics, with nearly 3 $GtCO_2$ yr^{-1} of cost-effective potential (Griscom et al., 2020). Much of this potential occurs in the 521 million hectares of forests (~15 % of the world's forests) legally titled to indigenous peoples and local communities, often located at the forest frontier (Rights and Resources Initiative, 2018a, 2018b), as well as the larger areas with traditional community rights that are not yet legally titled. Under community forest tenure regimes, communities have management and extractive rights for

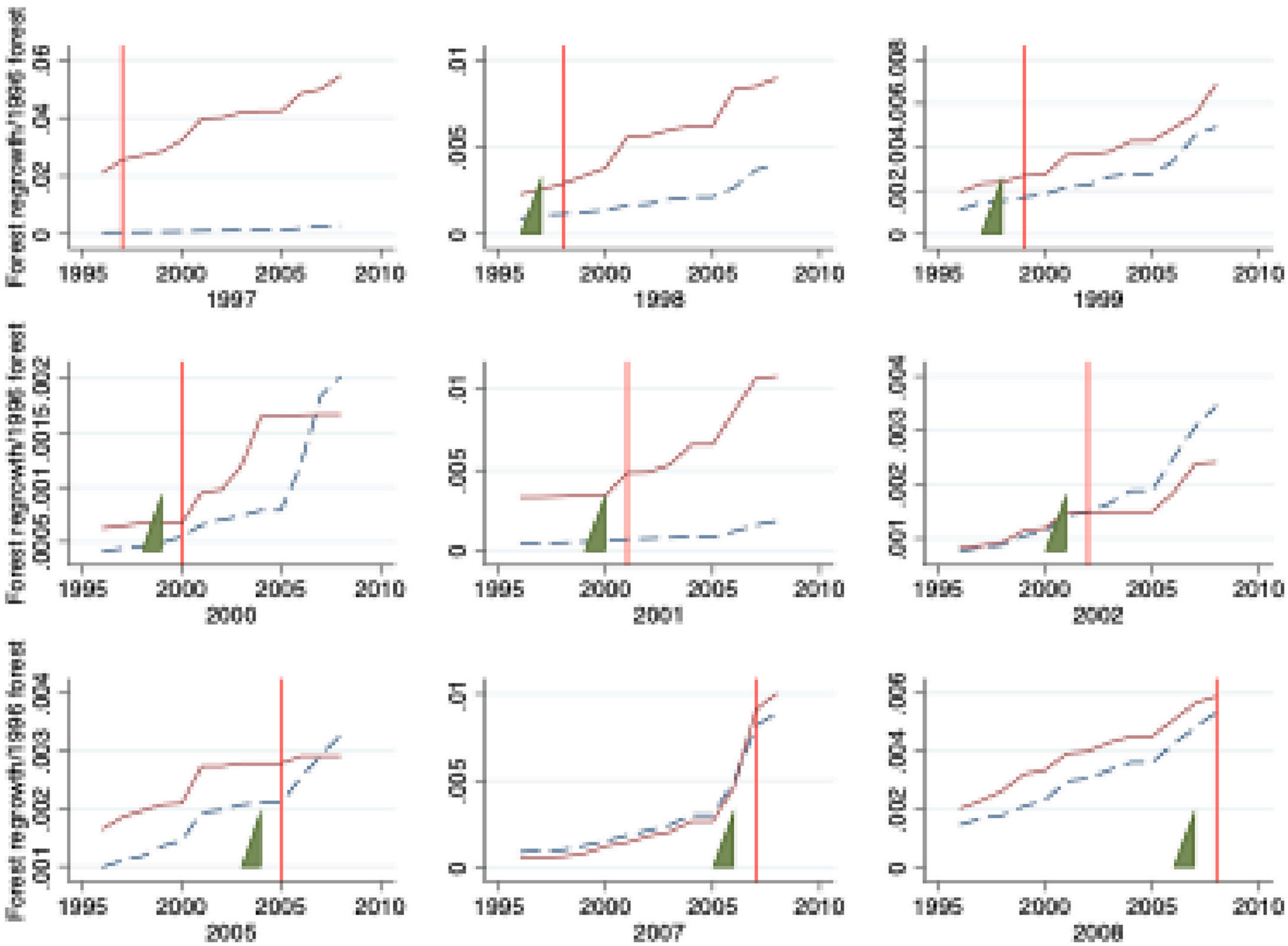

Fig. 3. Impact of adjacency to mills on reforestation expressed as the area of forest regrowth in a given year/forest area in 1996. Note that the estimator groups ejidos with mills established in the same year as a treatment group and estimates the impacts for each treatment group separately. The green triangles represent time weights used to construct parallel pre-trends. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

timber and non-timber forest products that support over 1.5 billion people in rural economies (FAO, 2018). The links between the large climate mitigation potential of protection, restoration, and improved management of ecosystems and a range of sustainable development goals have been much discussed and debated (Smith et al., 2019; Griscom et al., 2019); however, robust evidence of specific interventions that cause sustained positive links between local human well-being, biodiversity conservation, and enhanced ecosystem carbon storage are limited (Burivalova et al., 2016; Jayachandran et al., 2017; Pagiola et al., 2016).

Questions remain. First, we need to understand why some ejidos decide to integrate vertically whereas others do not, as well as what motivates some ejidos to switch vertical integration categories year to year. Previous work based on a handful of case studies from Mexico has suggested the fluctuation in vertical integration may be due to challenges with the internal organization of ejidos, including raising the money to operate a mill, timber prices, and the type of buyers (e.g., Wilshusen, 2005).

NGOs may play important roles in helping ejidos become and *remain* vertically integrated successfully (Vega and Keenan, 2014; Miteva et al., 2022). For example, (Barsimantov, 2010) claims that NGOs that promote community development and provide technical assistance with timber harvesting are crucial for vertical integration; strong internal governance in the ejidos by itself is necessary, but often not sufficient. NGOs can help ejidos with voluntary forest management certification and increase the demand for certified timber (Miteva et al., 2022). Government initiatives can also provide technical and monetary assistance to ejidos (e.g., Wilshusen, 2005).

Second, it is important to understand *why* and *through what channels* vertical integration reduces forest loss. Our analysis suggests no statistically significant reduction in the population density in ejidos due to vertical integration. This result suggests that the impacts on forests are likely due to improved forest management and avoided conversion to agriculture. However, future work needs to provide rigorous evidence on how forest management changes with vertical integration. Previous studies have emphasized the importance of understanding transaction costs as a factor determining the level of vertical integration and forest outcomes (e.g., Antinori, 2005).

Third, it remains to be seen how generalizable and scalable the results are to other locations. Relative to other areas in Mexico, the ejidos in Quintana Roo are characterized by more or less existing and stable markets for timber, native forests with valuable timber resources, secure tenure and rights to the forest, high legal levels of timber extraction, topography contributing to easy harvesting, market accessibility, political stability, low levels of ejido parcelization, and high political and NGO support (Ellis et al., 2015; Bray et al., 2004). Therefore, the ejidos in Quinata Roo may represent an outlier in low- and middle-income countries. For this reason, we cannot easily extrapolate our results to

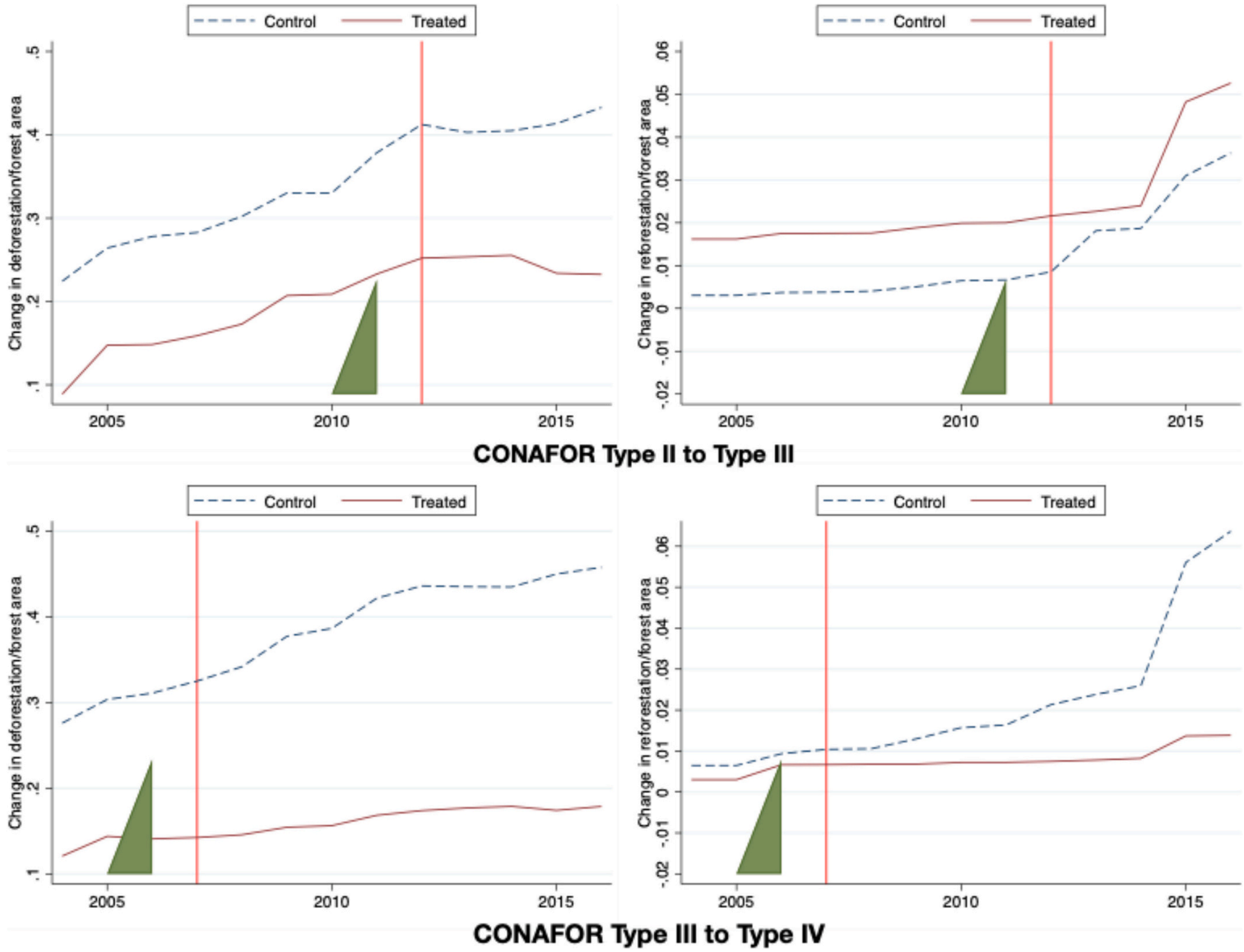

Fig. 4. Impact of advancing the CONAFOR typology on deforestation (left panels) and reforestation (right panels). The top panels present the impact of the ejido switching from Type II to Type III relative to Type II ejidos that did not switch, whereas the bottom panels-the impact of switching from Type III to Type IV, relative to Type III ejidos that did not switch. The green triangles represent weights used to align the pre-trends. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

other locations in Mexico and beyond. The issue of scalability and generalizability needs to be examined in future work.

Fourth, it remains unclear how the level of vertical integration interacts with forest benefits and policies like agricultural subsidies, policies aimed at reducing transportation costs, and payments for ecosystem services (PES). For example, there are ongoing efforts to improve connectivity between cities on the Yucatan Peninsula by expanding the railroad network (Tren Maya, 2025). The expanded railroad is likely to reduce transportation costs for timber but may increase the demand for urban or agricultural land. Which effect is likely to dominate needs to be addressed by future work.

Previous work has suggested that agricultural subsidies may increase forest conversion to livestock and commercial maize production (Ellis et al., 2017). The provision of forest ecosystem services is likely to reduce forest cover loss. The available data on forest management plans from 2013 indicates that ejido Types III and IV also may derive additional benefits like non-timber forest products (NTFP) and charcoal: For example, none of the Type II ejidos reported the production of charcoal in 2013, whereas 45 % and 25 % of Types III and IV, respectively, reported the production of charcoal. Forty-two percent of the Type II ejidos reported the collection of NTFP, while the percentage for Type IV ejidos was 63 %.

We only have data on the Payments for Ecosystem Services (PES) allocated to ejidos between 2008 and 2011. Within that time period, on average, 23 ejidos received PES each year. Most of the instances involved ejidos with CONAFOR Type I (potential producers, $n = 56$) and II (selling stumpage, $n = 18$), while there are only 11 instances of Type III and 3 Type IV ejidos receiving PES, during the entire 4-year period. Consistent with our model, we expect that PES make the forest more valuable and, thus, are likely to deter forest loss (Gnych et al., 2020). Because of the temporal mismatch between the available mills and PES data, we do not control for PES in the estimation. However, previous work has suggested that the impact of PES in the Yucatan peninsula may be short-lived (Le Velly et al., 2017).

Our study provides rare empirical evidence on the effects of vertical integration in forest products using rigorous statistical methods and detailed geospatial data. We find robust evidence that vertical integration can help avoid deforestation in, at least, one middle-income country setting. Our findings suggest that communities are more likely to protect and restore forests when they are more directly engaged in the harvest and when they capture more value added from forest products. Our findings, thus, have a somewhat counter-intuitive policy implication: Programs that increase financial resources for communities to invest in forestry operations could improve forest protection and restoration, with regional and global benefits for climate, biodiversity, and other ecosystem services.[16]

CRediT authorship contribution statement

Daniela A. Miteva: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Edward A. Ellis:** Writing – review & editing, Writing – original draft, Resources, Data curation, Conceptualization. **Peter W. Ellis:** Writing – original draft, Resources, Funding acquisition, Conceptualization. **Erin O. Sills:** Writing – review & editing, Writing – original draft, Resources, Methodology, Conceptualization. **Bronson W. Griscom:** Writing – review & editing, Writing – original draft, Resources, Funding acquisition, Conceptualization. **Dawn Rodriguez-Ward:** Writing – review & editing, Writing – original draft, Resources. **Colette Naples:** Resources, Data curation. **Claire Uematsu:** Resources, Data curation.

Funding

The work was funded by The Nature Conservancy and The Ohio State University. Neither institution has influenced the analysis in this manuscript.

Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2025.108658.

Data availability

Data will be made available on request.

References

Abadie, Alberto, Gardeazabal, Javier, 2003. The economic costs of conflict: a case study of the Basque Country. Am. Econ. Rev. 93 (1), 113–132. https://doi.org/10.2307/3132164.

Abadie, Alberto, Athey, Susan, Imbens, Guido W., Wooldridge, Jeffrey M., 2022. When should you adjust standard errors for clustering? Q. J. Econ. 36. https://doi.org/10.1093/qje/qjac038.

Agrawal, Arun, 2007. Forests, governance, and sustainability. Int. J. Commons 1 (1).

Agrawal, A., Angelsen, A., 2009. Using community Forest management to achieve REDD + goals. In: Angelsen, A., Brockhaus, M., Kanninen, M., Sills, E., Sunderlin, W.D., Wertz-Kanounnikoff, S. (Eds.), Realising REDD+: National Strategy and Policy Options. CIFOR, Bogor, Indonesia.

Alix-Garcia, Jennifer, de Janvry, Alain, Sadoulet, Elisabeth, 2005. A tale of two communities: explaining deforestation in Mexico. World Dev. 33 (2 SPEC. ISS), 219–235. https://doi.org/10.1016/j.worlddev.2004.07.010.

Alix-Garcia, Jennifer M., Sims, Katharine R.E., Yañez-Pagans, Patricia, 2015. Only one tree from each seed? Environmental effectiveness and poverty alleviation in Mexico's payments for ecosystem services program. Am. Econ. J. Econ. Pol. 7 (4), 1–40. https://doi.org/10.1257/pol.20130139.

Antinori, Camille, 2005. Ch. 11. Vertical integration in the community forestry enterprises of Oaxaca. In: The Community Forests of Mexico. University of Texas Press (muse.jhu.edu/book/3090).

[16] We conducted a literature review in Google Scholar and Web of Science using jointly as key words "vertical integration" "community", "forests", and "deforestation" as well as reviewed the studies citing the ones we identified as relevant.

Antinori, Camille, Bray, David Barton, 2005. Community Forest enterprises as entrepreneurial firms: economic and institutional perspectives from Mexico. World Dev. 33 (9 SPEC. ISS), 1529–1543. https://doi.org/10.1016/j.worlddev.2004.10.011.

Antinori, Camille, Rausser, Gordon C., 2008. Ownership and control in Mexico's community forestry sector. Econ. Dev. Cult. Chang. 57 (1), 101–136. https://doi.org/10.1086/590459.

Arkhangelsky, Dmitry, Athey, Susan, Hirshberg, David A., Imbens, Guido W., Wager, Stefan, 2021. Synthetic difference-in-differences. Am. Econ. Rev. 111 (12), 4088–4118. https://doi.org/10.1257/aer.20190159.

Baland, Jean-Marie, Platteau, Jean-Philippe, 1996. Halting degradation of natural resources. Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/x5316e/x5316e00.htm.

Barsimantov, James, 2009. What makes community forestry work? A comparable case study in Michoacan and Oaxaca, Mexico. [Doctoral dissertation, University of California Santa Cruz]. http://www.ccmss.org.mx/wp-content/uploads/2014/10/What_makes_community_forestry_work._A_comparative_case_study_in_Michoacan_and_Oaxaca_Mexico.pdf.

Barsimantov, James A., 2010. Vicious and virtuous cycles and the role of external non-government actors in community forestry in Oaxaca and Michoacán, Mexico. Hum. Ecol. 38 (1), 49–63. https://doi.org/10.1007/s10745-009-9289-3.

Barsimantov, James, Racelis, Alex, Barnes, Greeville, DiGiano, Maria, 2010. Tenure, tourism and timber in Quintana Roo, Mexico: land tenure changes in Forest Ejidos after agrarian reforms. Int. J. Commons 4 (1), 293–318.

Blackman, Allen, Villalobos, Laura, 2020. Use forests or lose them? Regulated timber extraction and tree CoverÂ loss in Mexico. J. Assoc. Environ. Resour. Econ. https://doi.org/10.1086/710837.

Bocci, Corinne, Fortmann, Lea, Sohngen, Brent, Milian, Bayron, 2018. The impact of community Forest concessions on income: an analysis of communities in the Maya biosphere reserve. World Dev. 107 (July), 10–21. https://doi.org/10.1016/j.worlddev.2018.02.011.

Bowler, D.E., Buyung-Ali, L., Healey, J.R., Jones, J.P.G., Knight, T., Pullin, A.S., 2010. The Evidence Base for Community Forest Management as a Mechanism for Supplying Global Environmental Benefits and Improving Local Welfare. In: Environmental Evidence CEE review 08–011 (SR48). Centre for Evidence-Based Conservation – SENRGY, Bangor University, Bangor, UK. www.environmentalevidence.org/SR48.html.

Bowler, Diana E., Buyung-Ali, Lisette M., Healey, John R., Jones, Julia P.G., Knight, Teri M., Pullin, Andrew S., 2012. Does community Forest management provide global environmental benefits and improve local welfare? Front. Ecol. Environ. 10 (1), 29–36. https://doi.org/10.1890/110040.

Bray, David, 2010. Toward 'post-REDD+ landscapes': Mexico's community forestry enterprises provide a proven pathway to reduce emissions from deforestation and Forest degradation. CIFOR Infobriefs 30.

Bray, David, Duran-Medina, Elvira, 2014. Options for Reducing Carbon Emissions in Forest Management in the Oaxaca and Chihuahua Áreas de Acción Temprana REDD + (AATR). Alianza México Para La Reducción De Emisiones Por Deforestación Y Degradación.

Bray, David Barton, Ellis, Edward A., Armijo-Canto, Natalia, Beck, Christopher T., 2004. The institutional drivers of sustainable landscapes: a case study of the 'Mayan zone' in Quintana Roo, Mexico. Land Use Policy 21 (4), 333–346. https://doi.org/10.1016/j.landusepol.2003.11.001.

Bright, Edward, Coleman, Phillip, King, Amy, Rose, Amy, Urban, Marie, 2009. LandScan Global 2008. Oak Ridge National Laboratory, Oak Ridge, TN. https://doi.org/10.48690/1524204. [dataset].

Bromley, Daniel (Ed.), 1992. Making the Commons Work: Theory, Parctice, and Policy. Institute for Contemporary Studies, San Francisco, CA.

Burivalova, Zuzana, Hua, Fangyuan, Koh, Lian Pin, Garcia, Claude, Putz, Francis, 2016. A Critical Comparison of Conventional, Certified, and Community Management of Tropical Forests for Timber in Terms of Environmental, Economic, and Social Variables Forest Certification. Conserv. Lett. 0 (March), 1–11. https://doi.org/10.1111/conl.12244.

Callaway, Brantly, Sant'Anna, Pedro H.C., 2021. Difference-in-differences with multiple time periods. J. Econ. 225 (2), 200–230. https://doi.org/10.1016/j.jeconom.2020.12.001.

Clarke, Damian, Pailañir, Daniel, Athey, Susan Carleton, Imbens, Guido W., 2023. Synthetic difference-in-differences estimation. SSRN Electron. J. https://doi.org/10.2139/ssrn.4346540.

Cox, Michael, Arnold, Gwen, Tomás, Sergio Villamayor, 2010. A review of design principles for community-based natural resource management. Ecol. Soc. 15 (4), art38. https://doi.org/10.5751/ES-03704-150438.

Cubbage, Frederick W., Davis, Robert R., Paredes, Diana Rodríguez, Mollenhauer, Ramon, Elsin, Yoanna Kraus, Frey, Gregory E., González, Ignacio A., Hernández, Humberto Albarrán, Hurtado, Anita Mercedes, Cruz, Salazar, Salas, Diana Nacibe Chemor, 2015. Community forestry Enterprises in Mexico: sustainability and competitiveness. J. Sustain. For. 34 (6–7), 623–650. https://doi.org/10.1080/10549811.2015.1040514.

de Chaisemartin, Clement, D'Haultfœuille, Xavier, 2024. Difference-in-Differences Estimators of Intertemporal Treatment Effects.

DiGiano, Maria, Ellis, Edward, Keys, Eric, 2013. Changing landscapes for Forest commons: linking land tenure with Forest cover change following Mexico's 1992 agrarian counter-reforms. Hum. Ecol. 41 (5), 707–723. https://doi.org/10.1007/s10745-013-9581-0.

Ellis, Edward A., Porter-Bolland, Luciana, 2008. Is community-based Forest management more effective than protected areas?. A comparison of land use/land cover change in two neighboring study areas of the Central Yucatan peninsula, Mexico. For. Ecol. Manag. 256 (11), 1971–1983. https://doi.org/10.1016/j.foreco.2008.07.036.

Ellis, Edward A., Kainer, Karen, Sierra-Huelsz, José, Negreros-Castillo, Patricia, Rodriguez-Ward, Dawn, DiGiano, Maria, 2015. Endurance and adaptation of community Forest Management in Quintana Roo, Mexico. Forests 6 (11), 4295–4327. https://doi.org/10.3390/f6114295.

Ellis, Edward A., Montero, José Arturo Romero, Gómez, Irving Uriel Hernández, 2017. Deforestation processes in the state of Quintana Roo, Mexico: the role of land use and community forestry. Tropical Conserv. Sci. 10 (January). https://doi.org/10.1177/1940082917697259, 194008291769725.

Ellis, Edward A., Montero, Samaria Armenta, Gómez, Irving Uriel Hernández, Montero, José Arturo Romero, Ellis, Peter W., Rodríguez-Ward, Dawn, Reyes, Pascual Blanco, Putz, Francis E., 2019. Reduced-impact logging practices reduce Forest disturbance and carbon emissions in community managed forests on the Yucatán peninsula, Mexico. For. Ecol. Manag. 437 (April), 396–410. https://doi.org/10.1016/j.foreco.2019.01.040.

Ellis, Edward A., Navarro Martínez, A., García Ortega, M., Hernández Gómez, I.U., Chacón Castillo, D., 2020. Forest cover dynamics in the Selva Maya of central and southern Quintana Roo, Mexico: deforestation or degradation? J. Land Use Sci. 15 (1), 25–51. https://doi.org/10.1080/1747423X.2020.1732489.

Ellis, Edward A., Navarro-Martínez, Angélica, García-Ortega, Martha, 2021. Drivers of Forest cover transitions in the Selva Maya, Mexico: integrating regional and community scales for landscape assessment. Land Degrad. Dev. 32 (10), 3122–3141. https://doi.org/10.1002/ldr.3972.

FAO, 2018. The State of the World's Forests. Rome. https://openknowledge.fao.org/items/28896bfc-567c-4e4e-a1b2-d28e78867028.

Flachsenberg, H., Galetti, Hugo, 1998. Forest Management in Quintana Roo, Mexico. In: Timber, Tourists, and Temples: Conservation and Development in the Maya Forest of Belize, Guatemala, and Mexico. https://ethz.ch/content/dam/ethz/special-interest/usys/ites/ecosystem-management-dam/documents/EducationDOC/EM_DOC/1997%20Brokaw%20et%20al%20Toward%20sustainable%20forestry%20in%20Belize.pdf#page=83.

Forster, R.A., Guemes-Ricalde, F.J., Zapata, J.L., 2014. Market insertion of Forest communities in southeastern Mexico: the relevance of Forest endowment and organization. Eur. Sci. J. 10 (34), 20.

Fortmann, Lea, Sohngen, Brent, Southgate, Douglas, 2017. Assessing the role of group heterogeneity in community Forest concessions in Guatemala's Maya biosphere reserve. Land Econ. 93 (3), 503–526. https://doi.org/10.3368/le.93.3.503.

Gnych, Sophia, Lawry, Steven, McLain, Rebecca, Monterroso, Iliana, Adhikary, Anukram, 2020. Is community tenure facilitating Investment in the Commons for inclusive and sustainable development? Forest Policy Econ. 111 (February), 102088. https://doi.org/10.1016/j.forpol.2019.102088.

Griscom, Bronson W., Lomax, Guy, Kroeger, Timm, Fargione, Joseph E., Adams, Justin, Almond, Lucy, Bossio, Deborah, et al., 2019. We need both natural and energy solutions to stabilize our climate. Glob. Chang. Biol. 25 (6), 1889–1890. https://doi.org/10.1111/gcb.14612.

Griscom, Bronson W., Busch, Jonah, Cook-Patton, Susan C., Ellis, Peter W., Funk, Jason, Leavitt, Sara M., Lomax, Guy, et al., 2020. National mitigation potential from natural climate solutions in the tropics. Philos. Trans. R. Soc. B 375 (1794), 20190126. https://doi.org/10.1098/rstb.2019.0126.

Hernández-Gómez, Irving, Cerdán, Carlos, Navarro-Martínez, Angélica, Vázquez-Luna, Dinora, Armenta-Montero, Samaria, Ellis, Edward, 2019. Assessment of the CLASlite Forest monitoring system in detecting disturbance from selective logging in the Selva Maya, Mexico. Silva Fennica 53 (1). https://doi.org/10.14214/sf.10012.

Jayachandran, Seema, de Laat, Joost, Lambin, Eric F., Stanton, Charlotte Y., Audy, Robin, Thomas, Nancy E., 2017. Cash for carbon: a randomized trial of payments for ecosystem services to reduce deforestation. Science 357 (6348), 267–273. https://doi.org/10.1126/science.aan0568.

Krylov, Alexander, Steininger, Marc K., Hansen, Matthew C., Potapov, Peter V., Stehman, Stephen V., Gost, Allison, Noel, Jacob, et al., 2019. Contrasting tree-cover loss and subsequent land cover in two Neotropical Forest regions: sample-based assessment of the Mexican Yucatán and argentine Chaco. J. Land Use Sci. February, 1–16. https://doi.org/10.1080/1747423X.2019.1569169.

Lawrence, Ted J., Morreale, Stephen J., Stedman, Richard C., 2019. Distant political-economic forces and global-to-local pathway to impacts on forests of Ejido landscapes across Yucatán, México. Land Degrad. Dev. 30 (17), 2021–2032. https://doi.org/10.1002/ldr.3400.

Le Velly, Gwenole, Sauquet, Alexandre, Cortina-villar, Sergio, Land Economics, 2017. PES Impact and Leakages over Several Cohorts: The Case of the PSA-H in Yucatan, Mexico PES Impact and Leakages over Several Cohorts: The Case of the PSA-H in Yucatan, Mexico. Land Econ. 93 (2), 230–257. https://doi.org/10.3368/le.93.2.230.

Madrid, L., Deschamps, P., 2014. Sustainable rural landscape Management in Central Mexico. In: Chavez-Tafur, Jorge, Zagt, Roderick J. (Eds.), Towards Productive Landscapes. Tropenbos International, Wageningen, the Netherlands, pp. 66–73. https://www.researchgate.net/profile/Eduard-Merger/publication/269688103_Certified_timber_production_and_landscape_governance/links/549d76260cf2b803713a76ec/Certified-timber-production-and-landscape-governance.pdf#page=8.

Madrid, L., Núñez, J.M., Quiroz, G., Aldabe, Y.R., 2009. La Propiedad Social Forestal En México. Investiga. Ambiental Ciencia y Política Pública 1 (2).

Miteva, Daniela A., Pattanayak, Subhrendu K., Ferraro, Paul J., 2012. Evaluation of biodiversity policy instruments: what works and what doesn't? Oxf. Rev. Econ. Policy 28 (1), 69–92. https://doi.org/10.1093/oxrep/grs009.

Miteva, Daniela A., Ellis, Peter W., Ellis, Edward A., Griscom, Bronson W., 2019. The Role of Property Rights in Shaping the Effectiveness of Protected Areas and Resisting Forest Loss in the Yucatan Peninsula. Edited by Laura C. Schneider. PLoS One 14 (5), e0215820. https://doi.org/10.1371/journal.pone.0215820.

Miteva, Daniela A., Fortmann, Lea, McNab, Roan, 2022. Beyond the Traditional: Voluntary Market-Based Initiatives to Promote Land Tenure Security. In: Land Tenure Security and Sustainable Development. Palgrave-Macmillan, pp. 269–290. https://library.oapen.org/bitstream/handle/20.500.12657/57897/1/978-3-030-81881-4.pdf#page=293.

Molnar, Augusta, Gomes, Denyse, Sousa, Romier, Vidal, Natalia, Hojer, Rene Forster, Arguelles, Luis Alfonso, Kaatz, Stefanie, et al., 2008. Community Forest Enterprise Markets in Mexico and Brazil: new opportunities and challenges for legal access to the Forest. J. Sustain. For. 27 (1–2), 87–121. https://doi.org/10.1080/10549810802225259.

Mongabay, 2023. Deforestation on the rise in Quintana Roo, Mexico as Mennonite communities move in. https://news.mongabay.com/2023/03/deforestation-on-the-rise-in-southern-mexico-as-mennonite-communities-move-in/. (Accessed 30 August 2023).

Ostrom, Elinor, 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge.

Pagiola, Stefano, Honey-Rosés, Jordi, Freire-González, Jaume, 2016. Evaluation of the Permanence of Land Use Change Induced by Payments for Environmental Services in Quindío, Colombia. Edited by Chris T. Bauch. PLoS One 11 (3), e0147829. https://doi.org/10.1371/journal.pone.0147829.

Perez-Verdin, G., Marquez-Linares, M.A., Salmeron-Macias, M., 2014. Spatial heterogeneity of factors influencing Forest fires size in northern Mexico. J. For. Res. 25 (2), 291–300. https://doi.org/10.1007/s11676-014-0460-3.

Poteete, A.R., Janssen, M.A., Ostrom, E., 2010. Working Together: Collective Action, the Commons, and Multiple Methods in Practice. Princeton University Press.

Rambachan, Ashesh, Roth, Jonathan, 2023. A more credible approach to parallel trends. Rev. Econ. Stud. 90 (5), 2555–2591. https://doi.org/10.1093/restud/rdad018.

RAN, 2018. https://datos.gob.mx/busca/dataset/datos-historicos-derivados-de-la-certificacion-de-la-propiedad-social-por-destino-de-la-tierra. (Accessed 16 March 2018).

Reuters, 2010. Mexico eyes climate funds for locally run forests. https://www.reuters.com/article/us-climate-forests-mexico/mexico-eyes-climate-funds-for-locally-run-forests-idUSTRE6AO3PD20101125. (Accessed 1 July 2024).

Rights and Resources Initiative, 2018a. At a Crossroads: Consequential Trends in Recognition of Community-Based Forest Tenure from 2002–2017. Washington, DC.

Rights and Resources Initiative, 2018b. Uncertainty and Opportunity: The Status of Forest Carbon Rights and Governance Frameworks in over Half of the World's Tropical Forests. Washington, DC. https://rightsandresources.org/publication/uncertainty-opportunity-status-forest-carbon-rights-governance-frameworks-half-worlds-tropical-forests/.

Román-Dañobeytia, Francisco, Levy-Tacher, Samuel, Macario-Mendoza, Pedro, Zúñiga-Morales, José, 2014. Redefining secondary forests in the Mexican Forest code: implications for management, restoration, and conservation. Forests 5 (5), 978–991. https://doi.org/10.3390/f5050978.

Romero, Claudia, Putz, Francis E., Guariguata, Manuel R., Sills, Erin, Maryudi, Ahmad, Ruslandi, 2015. The Context of Natural Forest Management and FSC Certification in Indonesia, 9786023870028. http://www.cifor.org/publications/pdf_files/OccPapers/OP-126.pdf.

Roth, Jonathan, 2022. Pretest with caution: event-study estimates after testing for parallel trends. Am. Econ. Rev.: Insights 4 (3), 305–322. https://doi.org/10.1257/aeri.20210236.

Samii, Cyrus, Lisiecki, Matthew, Kulkarni, Parashar, Paler, Laura, Chavis, Larry, 2014. Effects of decentralized Forest management (DFM) on deforestation and poverty in low- and middle-income countries: a systematic review. Campbell Syst. Rev. 10 (1), 1–88. https://doi.org/10.4073/csr.2014.10.

Smith, Pete, Adams, Justin, Beerling, David J., Beringer, Tim, Calvin, Katherine V., Fuss, Sabine, Griscom, Bronson, et al., 2019. Land-management options for greenhouse gas removal and their impacts on ecosystem services and the sustainable development goals. Annu. Rev. Environ. Resour. 44 (1), 255–286. https://doi.org/10.1146/annurev-environ-101718-033129.

Snook, L., 1998. Sustaining harvests of mahogany (Swietenia Macrophylla King) from Mexico's Yucatán forests: Past, present, and future. In: Timber, Tourists, and Temples: Conservation and Development in the Maya Forest of Belize, Guatemala, and Mexico. Island Press, Washington, D.C.

Torres, R.J.M., Os Magaña, T., 2006. Management of Mexican Community Forests with timber production objectives. J. For. Res. 177 (3/4). https://www.researchgate.net/profile/Juan-Torres-Rojo/publication/286534129_Management_of_Mexican_community_forests_with_timber_production_objectives/links/5b76ea494585151fd119b28d/Management-of-Mexican-community-forests-with-timber-production-objectives.pdf.

Tren Maya, 2025. Rutas del Tren Maya. https://www.trenmaya.gob.mx. (Accessed 17 December 2024).

USAID, 2025. The Social Property in Mexico. n.d. https://www.nass.usda.gov/mexsai/Papers/socialpropertyp.pdf. (Accessed 13 April 2025).

Vancutsem, C., Achard, F., Pekel, J.-F., Vieilledent, G., Carboni, S., Simonetti, D., Gallego, J., Aragão, L.E.O.C., Nasi, R., 2021. Long-Term (1990–2019) Monitoring of Forest Cover Changes in the Humid Tropics. Sci. Adv. 7 (10), eabe1603. https://doi.org/10.1126/sciadv.abe1603.

Vega, Dora Carias, Keenan, Rodney J., 2014. Transaction cost theory of the firm and community forestry enterprises. Forest Policy Econ. 42 (May), 1–7. https://doi.org/10.1016/j.forpol.2014.01.006.

Vélez, Maria Alejandra, Robalino, Juan, Cardenas, Juan Camilo, Paz, Andrea, Pacay, Eduardo, 2020. Is collective titling enough to protect forests? Evidence from afro-descendant communities in the Colombian Pacific region. World Dev. 128 (April), 104837. https://doi.org/10.1016/j.worlddev.2019.104837.

Williamson, Oliver E., 1971. The vertical integration of production: market failure considerations. Am. Econ. Rev. 61 (2), 112–123.

Williamson, Oliver E., 2010. Transaction cost economics: the natural progression. Am. Econ. Rev. 100 (3), 673–690. https://doi.org/10.1257/aer.100.3.673.

Wilshusen, Peter, 2005. Community adaptation or collective breakdown? The emergence of "'work groups"' in two forestry Ejidos in Quintana Roo, Mexico. In: The Community Forests of Mexico: Managing for Sustainable Landscapes. University of Texas Press (muse.jhu.edu/book/3090).