Title of the Presentation: "Assessing the private and social benefits of forest concessions in the Maya Biosphere Reserve"

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Introduction

For resources that are not easily divisible, or may not be commercially profitable when divided due to economies of scale, establishing clearly defined and excludable property rights to a community in the form of common property resource (CPR) management systems, such as community-managed forests, can be one solution to promote the sustainable long-term use of the resource (Isaksen and Richter, 2018; Ostrom, 1990; Baland & Platteau, 1996; Bowes &Krutilla, 1989). Today, CPR management systems[1] manage some of the most ecologically vulnerable forested ecosystems in the world. They are often suggested as a way to promote sustainable development and protect forests (e.g. Ostrom, 2009; Isaken et al., 2018; Osés-Eraso and Viladrich-Grau, 2007; Agrawal, 2007). Currently, the area of land designated to be managed by communities has increased to over 500 million hectares, or nearly 16% of all forestland (Rights and Responsibilities Initiative, 2018).

A growing number of studies have provided evidence that community management is effective at forest conservation (e.g., McKean 1997; Agrawal & Chhatre, 2006; Ostrom, 2009; Blackman, 2015; Fortmann et al., 2017; Bray, 2008; Alix-Garcia, 2007, Rasolofoson et al., 2015; Takahashi & Otsuka, 2016; Robinson et al., 2017; Santika et al. 2017; Miteva et al. 2019). However, there are few large-scale empirical studies providing quantitative evidence on the impact of community forest management on community welfare.). The studies that have examined whether community management systems benefit local households find both positive and negative effects (e.g., Bocci et al., 2018; Primack et al., 1998; Richardson et al., 2011;

[1] Common property resource (CPR) management systems are systems explicitly put in place to manage common property resources. Common property resources are held in common and not divided and owned individually. In some locations CPR management systems have naturally emerged over time as a way to minimize the competition over resources and transaction costs (e.g., Olson 1965; Hardin 1965; Demsetz 1967l Taylor 1987). In contrast, in the Maya Biosphere Reserve, the legally recognized CPR management systems have been implemented through community forest management concessions as a way to secure community property rights, generate income, and protect forests.

Kumar, 2002; Adhikari et al., 2004; Adhikari, 2005; Meilby et al., 2014; Antinori 2000; Bowler et al. 2012; Burivalova et al. 2019 Alix-Garcia et al. 2005; Sims, 2010; Miteva et al. 2020; Jung et al., 2019). While these studies have examined the impact of community forest management participation on community welfare, the endogenous household decision of whether to participate in the community managed resource is often not adequately controlled for or addressed. As a result, the effect of membership may not be correctly identified.

To evaluate whether policies or approaches such as community-based, CPR management systems, promote the sustainable management of resources, it is useful to understand the trade-offs and complementarities between private economic outcomes and public ecosystem benefits. Such information can help policy makers design more effective conservation and development policies through a mix of practices and approaches. With few exceptions (e.g. Alix-Garcia et al., 2015; Burivalova, 2016; Santika et al., 2019), most studies focus on either only the private benefits or only the public benefits and have not examined how gains to communities (e.g., in the form of increased employment or income) correlate with benefits to ecosystems (e.g., avoided deforestation, carbon storage, and biodiversity). The lack of evidence about the welfare effect of CPR management systems may also undermine more widespread public support for them.

This study makes two important contributions. First, using rigorous estimation techniques and detailed, spatially explicit biophysical panel data, as well as two years of survey data from CPR management system members and non-members, we quantify the trade-offs and complementarities between the private gains that participants in a CPR management system receive from managing forests and the public conservation benefits of community-based tropical forest concessions in the Maya Biosphere Reserve in Guatemala. We find that on average the community concessions increased annual household income by about $2,204 per year per concession member household. The concessions also decreased deforestation rates by 4.2% overall from 2012 to 2017, and the carbon rental value of the avoided carbon emissions from this

decrease in deforestation is $2,472,138. The results show that the private benefits increased through higher household income, and the public benefits from avoided carbon emissions increased as well. The results suggest that higher revenues from sustainable forest management create incentives for forest conservation.

Second, in contrast to existing impact evaluation studies, we conduct a cost-benefit analysis of the community forest management system in addition to quantifying its causal impacts (Vincent 2015). To conduct the analysis, we combine the household income gained from CPR management participation with the value of the additional carbon stored by the MBR forest concessions and subtract the costs of establishing and maintaining the concessions. We find that the net value of the CPR management system in the Maya Biosphere Reserve is about $6,782,555, which is about $3.62 per hectare per year. This estimate, while positive, is likely an underestimate given that the forest concessions have a positive effect on many other ecosystem services and household-level benefits not considered by our analysis. In this way, we demonstrate that the social (public proxied by the value of avoided carbon emissions and private proxied by income) benefits of the CPR system by far outweigh to the costs of maintaining it. Thus, our results provide strong evidence that CPR systems should be continued in the MBR, and they suggest ways in which benefits of the systems can be increased.[2]

Data and Study Area

Created in 1990, the Maya Biosphere Reserve covers about 2 million hectares of the Petén department, which is about one-fifth of Guatemala's total land area. The reserve

[2] The MBR CPR management systems are typically funded through sustainable development or conservation grants. For this reason, it is important to test whether these systems provides society or local households sufficient benefits to cover costs of establishment and maintenance (Vincent 2015). A cost-benefit analysis of CPR management systems can also help justify whether existing community management contracts should be renewed.

was created as a result of international pressure on the Guatemalan government to reduce deforestation. Some of the deforestation pressures in this region include forest fires, an expanding agricultural frontier, cattle ranching, and illegal harvesting of timber and non-timber forest products. Using data from Hansen et al (2013), we calculate that the deforestation rate in the Maya Biosphere Reserve has averaged 1.1% per year, although the rate varies depending on the zone.

The Maya Biosphere Reserve is divided into three zones: the core, buffer, and multiple-use zones (Fig.1). Spanning 36% of the reserve, the core zone consists of national parks and biotopes. It is generally reserved only for low impact tourism and scientific investigation, although it has a deforestation rate of about 1.9% per year. The buffer zone is 24% of the Maya Biosphere Reserve and is located along its southern border. Created to divert land-use change pressure away from the core zone, it has a deforestation rate of about 0.75% per year. The multiple-use zone is 40% of the Maya Biosphere Reserve and has a deforestation rate of 0.14% per year. Unlike the core zone, some management and extractive use activities are permitted, such as ecotourism and the harvesting of non-timber forest products and timber. Each forest concession must also obtain Forest Sustainability Council (FSC) forest management certification.

With the financial support of USAID, in the late 1990s the concessions were granted to organized community groups by the National Council of Protected Areas, or CONAP (Radachowsky et al., 2012). To apply for a concession, communities needed to demonstrate that they could manage the forest resources sustainably and protect forests against illegal deforestation. The concession members within the communities had to partner with a non-governmental organization of their choice that helped them develop a

sustainable forest management plan and obtain forest management certification from the Forest Stewardship Council within three years of being granted the concession. Upon approval by CONAP, the concession members were granted exclusive, renewable land use rights to their forested area for 25 years (Radachowsky et al., 2012).

In the Maya Biosphere Reserve, forest concessions fall into three categories based on where the managing groups live and how long they have been in the area: nonresident, recently-inhabited, and long-inhabited (Fig. 1). There are also industrial concessions managed by private companies (Radachowsky et al., 2012; Fortmann et al., 2017) that we exclude from our analysis. Also excluded from our analysis are several of the community concessions that were canceled in 2009 due to noncompliance with the Forest Stewardship Council certification standards. Descriptive statistics about the concessions in our study area are given in Table 1.

Households in the nonresident concession communities live in larger towns and cities outside of the multiple-use zone (MUZ) boundaries. Many have jobs outside of forestry and agriculture and use forest concessions as a supplemental source of income. Households in the recently-inhabited concessions typically have backgrounds in agriculture and cattle ranching; they moved into the multiple-use zone communities around the time the Maya Biosphere Reserve was established. In contrast, the households in the long-inhabited concession communities have lived within the MUZ for multiple generations. They have historically depended on harvesting timber and non-timber forest products for their livelihoods.

The main income-earning activity in the long-inhabited concession communities is forestry, while in the recently-inhabited concessions, agricultural activities, such as cattle ranching and farming, are the major income-earning activities (Table 2). In the nonresident communities, the number of workers and the amount of income earned from working in businesses or professional activities comprises a larger share of the average household income than in long-inhabited or recently-inhabited communities.

Concession members may receive a higher-than-average daily wage working in timber and non-timber forest product harvesting (Bocci et al., 2018), but also receive annual dividends from the concession. For example, in one of the long-inhabited concessions, Carmelita, the net profits in 2016 were about 3 million quetzals (about $400,000) (Cooperativa Carmelita, 2017). About 30% of the profits were paid to concession members in dividends (about 5,000 quetzals per member), regardless of whether they harvested timber or non-timber forest products. Concession members also get first priority for jobs harvesting timber in the concession. These jobs pay between 200 and 300 quetzals per day, which amounts to between 21,000 and 37,000 quetzals per year per forestry job. These jobs would not have existed if the concessions were not established, or they would only have existed until forests were converted to other uses[3].

Household Survey Data Collection

To test whether participation in community forest management benefits member households, we use a rotating panel survey dataset constructed from 2012 and 2017 household interviews in communities in the Maya Biosphere Reserve. All communities

[3] The net concession profits are from "Formato Para La Actualización del Plan de Manejo Integrado de recursos" provided by the Cooperative Carmelita concession board members. The wage and dividend information is taken from our 2012 and 2017 household panel of concession members and nonmembers.

in the sample are associated with a concession, either because they are located within the concession boundaries, or because they are located nearby in towns and cities within the Maya Biosphere Reserve. A total of 494 households in 2012 and 716 households in 2017 were interviewed using local enumerators.

The 2012 sample was constructed by taking a random sample of 20% of the households in each of the 14 villages associated with a concession from a comprehensive list of active concession members provided by CONAP. Once the households were selected, local guides were hired from each concession to take the enumerators to concession-member households in the sample. To collect data from nonmember households that were similar to concession households, the enumerators administered the survey to a next-door neighbor who was not a member of the concession (Fortmann, 2014).

In 2017 we collected a 25% sample of concession-member households. While the number of households in each community stayed roughly the same, we collected a larger sample size in 2017 to have a larger sample of households from which to construct the instrumental variable and matched regression analysis. For the 2017 survey, the local guides were asked to take the enumerators to households from the list of members and nonmembers from the 2012 survey. If the guides were unable to locate a household, the enumerators either randomly selected an alternative concession member household using an updated comprehensive list of active concession members or surveyed a nonmember household located near a randomly-sampled active concession member.

The characteristics of the members and nonmembers within the long-inhabited, recently-inhabited, and nonresident concessions as well as the statistical differences between them are shown in Table 3. The overall survey response rate for households asked to take the survey was about 99.6% in 2017 and 74% in 2012. Because two out of 716 households in 2017 given the survey did not want to participate, we selected alternative households in these cases. We also had to select alternative houses from the concession member list in about 10% of the cases because we were unable to find the respondent to ask for their participation. The majority of these cases were in nonresident communities. We were able to locate and interview 113 households surveyed both in 2012 and 2017, 104 of which are concession members and 18 of which are nonmembers[4].

Biophysical Data

We construct a geospatial panel dataset to estimate the effects of concession status on deforestation and CO_2 storage from 2012 to 2017. We use annual deforestation from 2012 to 2017 (Hansen et al. 2013), refined by the percent tree cover from the year 2000 using a 25% threshold to define forests (Sexton et al. 2015). That is, by using the threshold, we classified the 2000 percent tree cover layer into forest and non-forest. We used the latter to filter annual deforestation events that took place on cells that were not forested in 2000. Because of the high local inaccuracy of the geospatial data, we exclude reforestation from our analysis.

We focus on carbon sequestration as an ecosystem service because it can be estimated using available datasets (e.g., Baccini et al., 2012), and can be monetized using

[4] We suspect that nonmembers were more likely to leave their communities than members from 2012 to 2017 because they did not have a guaranteed source of income like the concession members.

the social cost of carbon (Nordhaus, 2017). Although community forests are likely to provide other ecosystem services (e.g., Stults, 2018; Foley et al. 2005; Pimm et al. 2014), due to data limitations we do not consider them in this analysis.

To quantify the amount of CO_2 emissions avoided by the forest conserved by the concessions, we combine the forest loss data from Hansen et al. (2013) with an aboveground woody biomass density dataset (Baccini et al. (2012)). Because the forest loss data only depicts areas of forest lost and does not detect reforestation, we assume that once an area is deforested, it remains deforested and the aboveground woody biomass density remains negligible during the 2012-2017 period. We do not include reforestation, so this approach may over-state losses due to deforestation.

We randomly sampled 30m by 30m points over the entire Maya Biosphere Reserve by first using a grid with 100m by 100m cells and overlaying the grid with the reserve boundaries in ArcGIS. Then, we dropped plots where grid lines on the map did not cross. An approximately equal proportion of pixels was selected from each concession and the control group. The purpose of the grid sampling is to help control for spatial autocorrelation by ensuring that we are not matching non-concession plots that are too close to concession plots (Blackman, 2015). We dropped plots that are in a core zone or in the buffer zone because they are under different management systems. We focused on the multiple-use zone of the Maya Biosphere Reserve because the core zone areas typically receive more conservation funding from the government and are not managed by communities, and the buffer zone contains titled land where clearing forest is a legal option for households. Within the multiple-use zone, there are tracts of land that, while still within the Maya Biosphere Reserve boundaries, are not managed as a concession or

core zone area. We used those to select points for the control group. The forests within the multiple-use zone are of the same type as in the concessions and face similar deforestation threats, such as illegal logging and slash-and-burn agriculture (Radachowsky et al., 2012).

Theory and Estimation

Large swaths of forestland exhibit economies of scale (e.g., Vega & Keenan 2014) and can accommodate a more sustainable harvesting rotation. Productivity gains can arise from increased capital utilization, reduced transaction costs, and labor. For example, individuals may become more productive because they are part of a group, especially if group effort exploits economies of scale (Holmstrom, 1982). Community management may also encourage investments in capital that increase value-added production opportunities in lumber mills, which can provide additional income to households. For this reason, granting community tenure over forests is expected to create incentives to protect forests in areas where local livelihoods are highly dependent on the forests and the forests are commercially viable (e.g., Baland & Platteau 1996; McKean 2000).

With significant pressure both inside and outside the reserve to convert land to non-forested uses, we hypothesize that the Maya Biosphere Reserve concessions generate incentives for local communities to protect forests from illegal encroachment. We hypothesize that concessions reward member households with higher incomes and sustained sources of employment. Since households can earn more income from the forest resources, concession members are incentivized to protect forests so they can benefit from the industry and maintain their land use rights through CONAP. In some

cases, in the Maya Biosphere Reserve, the land use rights have existed for generations, but in all cases, they will only continue if the communities can be self-sustaining while maintaining forest cover and avoiding illegal deforestation.

Whether forest CPRs promote both development and conservation is an empirical question. While community tenure over forests can significantly lower the government costs of forest management and protection (Ostrom, 1990), important tradeoffs often exist between conservation and development. For instance, members of CPR management systems often depend on extracting resource for their livelihoods. This in turn can cause the resource to be over-extracted under certain conditions, such as the inability to monitor and enforce restrictions, high poverty leading to short planning horizons, or unstable markets (Baland & Platteau 1996; Richardson et al., 2011). Conversely, even in a well-managed CPR management system, there is no guarantee that concession member incomes will increase. If the forests are economically inaccessible, if the concession members lack forestry knowledge or if they are unable to purchase machinery to extract timber, then concession membership may not generate member household income (Antinori 2000; Antinori and Bray, 2005).[5] Given these conflicting trends, it remains an empirical question to assess whether the Maya Biosphere Reserve forestry concessions generate income for their members and, if so, whether increased income translates into worse environmental outcomes.

[5] We suspect this is the case with the recently-inhabited concession community group since they reside within the forest and are unable to keep their land unless they are granted a concession. However, few of the households have backgrounds in forestry and many prefer to rely on subsistence agriculture to make a living, so the people who go into forestry are likely less productive.

To empirically estimate whether there are income benefits for concession member households, we use a counterfactual analysis of what "would have happened" if the concessions did not exist, using an approach that is similar to studies that have examined the welfare effects of establishing property rights for agriculture in developing countries (e.g. Aragón, 2015; Banerjee and Weyer, 2005; Besley, 1995; Field, 2007; Galiani and Schargrodsky, 2010; Goldstein and Udry, 2008; Hornbeck, 2010; Johnson et al., 2002). As these studies have noted, it is important to carefully account for membership selection. For example, concession members likely have connections within the community that are correlated both with the likelihood the household is a concession member and with the household income. Also, while concession membership may affect income, income may affect the likelihood that a household is a concession member. Wealthier households may be more likely to become concession members, since wealthier households are typically the leaders within a community. Alternatively, households that did not earn high incomes may be more likely to join a concession for the opportunity to have a steady job.

To address the endogeneity of concession membership, we use we use a two-stage least squares (2SLS) instrumental variable approach that takes advantage of the data collected from two survey periods (2012 and 2017), and two groups (members and non-members) in various communities. An instrumental variable is constructed by matching households from the 2017 survey to households that are not part of the 113-member panel from the 2012 survey using coarsened exact matching methods (David et al, 2013; Hausman, 1996). Matched households from the 2012 survey are a good predictor of concession membership status for households in the 2017 survey because the households

from the 2012 survey are located in the same communities as the 2017 households and have similar opportunities to earn income. This instrumental variable mitigates the possibility of reverse causality because the incomes of the matched 2012 households are unlikely to determine the membership status of 2017 households. Similarly, it is unlikely that the unobserved characteristics of the 2012 matched households are going to predict the membership status or household incomes of the 2017 households in the survey. The household characteristics we use for matching are the age of the household head, the years of schooling of the household head, the gender of the household head, whether the household depends on the forest for their livelihood, the number of children under 12 in the household, whether the household head was born in the Petén, and a variable addressing trust within the household[6].

These variables are hypothesized to affect income and concession membership. For example, married participants are more likely to earn higher household incomes because more than one individual may contribute to annual income within the household. In forestry in this region, younger workers are likely to be more productive since they can better manage the physical demands of forestry. More educated participants will likely have more employment opportunities because they are more likely to have more skills and experience. The number of children under 12 is a proxy for family dependents: Households with more dependents will likely have lower incomes because more time needs to be spent on caring for the dependents, which means less time can be devoted to working. Households with land in this area are more likely to have higher incomes because they have more investment opportunities due to having assets. Intuitively,

[6] For a description of each variable used in the income effect analysis, see Table 4.

households with savings are more likely to have higher incomes, however our results suggest that this is not true in the sample. It is possible that households with more savings are not actually earning as much income because they are relying more heavily on the wealth they have accumulated instead of an annual income. Additionally, we control for whether the household depends on the forest for income, and the level of trust the respondent has in other people. Dependency on the forest and a higher level of trust imply that respondents may be more willing to cooperate with other community members, as well as the rules outlined in a sustainable forest management plan.

The coarsened exact matching method divides the 2017 data into strata. Each stratum is comprised of all of the observations that are exact matches from the 2017 to the 2012 data based on the observable covariates specified (Mishra, 2016; David et al, 2013; Hausman, 1996). All observations to which any 2017 observation does not have at least one match from the 2012 data set were dropped from the stratum. For each stratum, which are comprised of groups of (about 5) observations that are exact matches, the mean concession membership status by stratum in the 2012 sample is calculated. A new variable is then coded as 1 for each observation in the stratum (indicating the household is a member) if the stratum average is greater than 0.5, and 0 (indicating the household is not a member), if it is less than or equal to 0.5. Thus, a 2017 observation, whose matched 2012 strata have an average greater than 0.5, is given 1 for concession membership in 2017. Each 2017 observation is exactly matched with each 2012 observation and this newly coded variable, based on 2012 concession membership status, is used as the instrument for 2017 concession membership status.

The instrument is valid if it is highly correlated with the variable for which it is instrumenting and is not directly correlated with the dependent variable (Bound et al, 1995). In this study, the matched 2012 concession membership status average must be correlated with 2017 membership status and the matched 2012 membership status must not be correlated with household income in 2017. Intuitively, we have no reason to suspect these would not hold as we excluded the observations comprising the true panel from being matched to themselves. To see whether these conditions are met, we examine the first stage of the 2SLS model. The results show that the instrument is highly correlated with concession status due to the F-statistic being greater than 10 (Table A1)[7]. We cannot directly test whether the matched 2012 membership status is correlated with 2017 household income, or the exogeneity assumption, since we only have one instrument.

We estimate the 2SLS results for concession membership on income for all concession communities as well as nonresident, recently-inhabited, and long-inhabited communities separately using equations (1) and (2):

$$Income_i = \alpha + \theta C_i + X_i'\beta + \gamma + \varepsilon_i \quad (Eq.1)$$

$$C_i = \theta C_j + X_i'\beta + \gamma + \varepsilon_i \quad (Eq.2)$$

In equation (1) above, the annual income of household i is a function of C_i, which is the membership status of household i; X_i', which represents the household-level covariates for household i; γ, which represents village fixed effects; α, which represents a constant,

[7] The exception to this is for the recently-inhabited community group, which has an F-statistic of 9.73. This could be due to the relatively small number of observations compared to the nonresident and long-inhabited groups.

and the error term ε_i, which represents the standard errors. . For the models with the entire sample, we use wild t-bootstrapping to adjust for the small number of clusters. However, since the wild t-bootstrapping method may not correctly specify the error terms when the number of clusters is less than 11, the errors for the long-inhabited, recently-inhabited, and nonresident concession groups separately are robust standard errors (MacKinnon and Webb, 2018). Equation (2) is a function for the instrument used for concession membership. In equation (2), C_j represents the concession membership status of household j where household j is the match of household i. We control for variables that impact income including the age, gender, marital status, and education level of the household head as well as the amount of land owned by the household, whether the household has savings, the number of children under 12 in the household, and the education level of the spouse of the head of the household (Table 4).

As a robustness check, we used an ordinary least squares (OLS) regression using a matched sample form the households surveyed in 2017. Before estimating the regression results, we used propensity score matching to preprocess the sample and ensure overlap in the characteristics of the treatment (member) and control (non-member) households (Ho et al. 2007; Imbens & Wooldridge 2009). The observations off the common support were dropped from the analysis.[8] We also assess the effect of concession membership on income over time using a fixed effects panel of 113 households. To create the panel, we tracked households surveyed in 2012 and

[8] The results of the logistic regression used to find the predicted probability of being a concession member are shown in Table A2 in Appendix A.

interviewed them in 2017. The results, although insignificant, show that the effect of concession membership on household income is positive.

Effect of concession management on conservation outcomes

To examine the impact of concessions on deforestation rates and carbon emissions, we used a combination of matching and panel data estimators (Ho et al., 2007; Do et al., 2007; Imbens and Wooldridge, 2009; Ferraro & Miranda 2017). To preprocess the sample and ensure covariate overlap, we use propensity score nearest neighbor matching model with replacement. Estimated via a logit, the propensity score is the predicted probability that a sample unit is under concession membership[9].

Using the matched sample, we estimate the effect of being under concession management on deforestation using a panel estimator with year and concession-level fixed effects[10] as:

$$y_{it} = \alpha + \theta C_i + X_i'\beta + T + \gamma + \varepsilon_i \quad (Eq.3),$$

where y_i is equal to 1 if pixel i is deforested during the study period, C_i equals 1 if the pixel is under concession management, T represents the year fixed-effects, α represents a constant, X_i represents the characteristics of the forest land area i such as soil acidity, elevation, precipitation, distance to the nearest road, and distance to the nearest archaeological site , γ represents the concession-level fixed effects, and ε_i is an error term that represents robust standard errors. In addition to whether the pixel (30m by 30m area of land) is under concession management, we control for distance to the nearest road, distance to the nearest archaeological site, soil nutrients, elevation, and precipitation

[9] The results of the logistic regression used to calculate the predicted probability a section of land is under concession management are shown in Table B1 in Appendix B

[10] We assume the concession-level effects are correlated with the independent variables

levels (Table 5). Distance to the nearest road and distance to the nearest archaeological site are proxies for accessibility, which would likely increase the probability a pixel is deforested. Soils that are more acidic are more likely to not foster tree growth, pixels at higher elevations are less likely to be deforested through slash-and-burn agricultural methods, and pixels that receive higher level of precipitation are more likely to foster forest growth.

We use the probability of deforestation (Eq. 3) for each type to calculate the hectares of forest conserved over the five-year time span of this analysis. We first use the 2000 tree cover data described in Hansen et al. (2013) and the average annual deforestation rate for the control group, or the matched areas of the multiple-use zone not under concession management, from 2001 to 2017 (about 1.7%) to determine what the tree cover reduction would have been if the concessions did not exist. Then, we use the deforestation coefficients to determine how many of the deforested hectares were conserved because the land was under concession management.

We calculate the value of the avoided carbon emissions due to prevented deforestation by estimating the rent on the cumulative additional carbon sequestered from 2012 to 2017. To estimate the carbon rental value, we calculate annual rental rates based on the social cost of carbon from Nordhaus (2017). To calculate the annual rental for carbon, we assume $R_t = P^C_t - P^C_{t+1}/(1+r)$,[11] where r equals 5% (i.e. Tol, 2005; Interagency Working Group, 2010; Gacía-Gusano et al., 2016; Nordhaus, 2017). Using the carbon rent rather than the social cost of carbon values the carbon only for the 5-year period over

[11] For additional discussion about how the carbon rental value is calculated, see Table B2 in Appendix B.

which we have observed that it is stored. This represents a conservative estimate of carbon value because it does not include rent on carbon that was saved prior to this 5-year period as a result of the Maya Biosphere Reserve.

Results

Impact on income

Our analysis indicates that, on average, the concession members in our sample earned about 16,500 more quetzals (about $2,204) per year than nonmembers in the same area (Table 6). This result varies by community type with nonresident and long-inhabited concession members earning 21,490 (about $2,865) and 19,043 (about $2,539) more quetzals per year than nonmembers in the same communities, respectively. When compared to the average household income for each concession type (Table 2), the results imply that concession membership increased annual household income between 40% and 50% on average. The results on the impact of concession management on income for the recently inhabited concessions are not statistically significant in our sample.

The results from the robustness checks are similar to the results from the 2SLS model (Appendix A). For example, the panel regression models indicate positive coefficients, which likely due to the small sample size, are not statistically significant (Table A4). Further, the OLS regression on the matched 2017 sample indicates concession membership significantly increased income across all types of concessions (Table A3). While the magnitudes for the matched OLS regressions (Table A3) are smaller than those in the 2SLS models, the results show that concession membership has

a positive and significant effect on income for the nonresident and long-inhabited concession member households. In contrast, the effect of concession membership on income for recently-inhabited households is negative and insignificant in the 2SLS model, but positive and significant in the OLS regression on the matched sample.

Impact on forest and carbon storage

All concession types reduced the probability of deforestation during the study period, although some resulted in more avoided deforestation than others (Table 7):[12] On average, long-inhabited concessions reduced the probability of deforestation by 3.8% from 2012 to 2017. The recently-inhabited and nonresident concessions reduced the probability deforestation by 4.86% and 4.23% respectively relative to similar areas within the Maya Biosphere Reserve that are not under concession management. Interestingly, even though deforestation has remained relatively high in the recently-inhabited concessions, and several of them have been cancelled as a result, the establishment of the concessions led to a reduction in deforestation there. However, the total effect on deforestation in recently-inhabited concessions is modest because they also have a large baseline deforestation rate compared to long-inhabited and nonresident concession types.

Summed across the concessions, a total of 1,514 hectares of additional forest was preserved between 2012 to 2017 (Table B2), conserving an additional 322,503 tons of CO_2 compared to the non-concession multiple-use zone. By using the non-concession

[12] Note that, we are not comparing one concession type to another (Ferraro et al. 2013). That is, for each concession we compare the deforestation on a pixel within the concession with matched pixels within the multiple-use zone, but not under concession management. We performed a separate matching analysis for each concession classification (long-inhabited, recently-inhabited, and nonresident) separately.

multiple-use zone rather than the multiple-use and buffer zone where deforestation is more severe as the comparison group implies that our estimates are conservative.

The net value of concessions

We calculate the value of the land under concession management in the Maya Biosphere Reserve using the value of the avoided carbon emissions and household income concession member households received. Due to data constraints, we focus only on these two benefits. To calculate the private benefits of the concessions, we assume the annual household income we estimated holds for each year of the study period. Thus, the total value of household income gained from community-managed forest concessions in the Maya Biosphere Reserve is $13,424,918 and the value of the avoided carbon emissions from deforestation in the concessions is $2,380,379. The combined benefits from community forest concession management in the Maya Biosphere Reserve from 2012 to 2017 is $15,805,297 (Table 8).

The cost of implementing the community managed forest concessions is estimated by summing the costs of various organizations involved in implementing and sustaining the concessions from 2012 to 2017[13]. The organization that oversees concession management, ACOFOP, receives grant funding from the Guatemalan government and organizations such as the Inter-American Foundation, Margaret A. Cargill Foundation, Ford Foundation, ClimateWorks Foundation, and USAID and partners to foster conservation efforts and economic development of surrounding communities. ACOFOP uses these grants to manage the concessions and provide the initial investments in

[13] A more detailed list of funding is available upon request.

equipment to add value to the harvested forest products (Gray et al., 2015). Using data from the funding agencies and expenditures on forest protection efforts from the Guatemalan government, we estimate that the cost of concession management was approximately $11.375.633.30 ($726,267.75 from government and $10,649,365.56 from external grants). from 2012 to 2017. Deducting this from the benefits suggests that the net value of the concessions was $6,782,555.04 from 2012 to 2017, which is $3.62 per hectare per year.

Conclusion

This paper evaluates the tradeoffs and complementarities between conservation and development and quantifies the benefits of a CPR management system in the Maya Biosphere Reserve of Guatemala. Using a unique dataset, rigorous statistical approaches, and an instrumental variable approach, we quantify the impact of community forest concessions on member household income, forest ecosystems, and carbon sequestration. We find that while community managed forests can be an effective tool for conservation and development, the benefits depend on the type of concession. For example, the long-inhabited concessions increased annual household income for concession members by about $2,539 per year and prevented about 342 hectares of forest loss from 2012 to 2017, which stored 95,387 tons of CO_2. Similarly, the nonresident concessions increased annual household incomes for concession members by about $2,865 and decreased deforestation by 622 hectares, which conserved 205,148 tons of CO_2. In contrast, while the recently-inhabited concessions reduced deforestation by about 4.9%, equal to 66 hectares of deforestation and 21,968 tons of avoided CO_2 emissions from 2012 to 2017, there is little

statistical evidence that recently-inhabited concession members benefited from concession membership.

Our estimates for income are likely to be a lower bound of the true impact on welfare because there are other benefits of concession memberships for which we were unable to account. For example, we excluded in-kind benefits concession members receive that are not quantified in the dataset, such as life insurance (payments to family members upon death), and scholarships. Further, we assume nonmembers do not benefit from concessions. If non-members do receive either in-kind, or even monetary, benefits from concessions, the welfare effect would be greater than our estimate (e.g., Alix-Garcia et al. 2005). Like many community-based resource management policies in developing countries, Maya Biosphere Reserve concessions are partially funded by international conservation and development organizations (Gray et al., 2015). This study shows that the benefits of the Maya Biosphere Reserve community concessions outweigh the costs to funding agencies.

Interestingly, the gains to member households through income are larger than the public good benefits (e.g., carbon), but this may help ensure the sustainability of the CPR management systems in this region. For example, if the private benefits are small, and the net benefit of implementing the forest concessions becomes negative, the land would be harder to protect (Baland & Platteau 1996).

In the Maya Biosphere Reserve, the long-inhabited concessions are the most valuable per hectare[14], while the recently-inhabited concessions are the least[15]. The result for recently-inhabited concessions is driven by the statistically insignificant impact of membership on income for individuals in those concessions. The impact of concession membership on income in the recently-inhabited concessions is inconclusive in part due to the relatively small sample size, as well as the collective action failures in those concessions stemming from the community location, demographics, and dynamics. For example, the recently-inhabited concessions are located near a road that runs through the center of the reserve. This location makes it especially difficult to prevent overexploitation of the forest because non-concession members have direct access to the concession through the road, making monitoring and enforcement difficult and costly. Also, individuals in the recently-inhabited communities tend not to have backgrounds in forestry, with most people having jobs in agriculture. In part, this results from the historical migration patterns, during which many of the residents in these communities came from other parts of Guatemala, in particular the highlands, with backgrounds in the agricultural sector rather than forestry (Radachowsky et al., 2012). For this reason, the concession members in these communities have been skeptical of the concession program and some favor converting the land to agriculture (Radachowsky et al., 2012). However, because individual land titles and agricultural conversion are prohibited in the Maya Biosphere Reserve, having the land as a community forestry concession is the only way for the recently inhabited communities to gain use-rights to the land. Since the

[14] Due to limited information on costs, we cannot determine how much external and government funding each specific concession receives. We assume the estimated funding concessions receive from 2012 to 2017 is divided equally among the concessions.
[15] Note that the income effect for recently-inhabited concessions is not statistically different from 0.

establishment of the Maya Biosphere Reserve, these concessions have faced significant pressure from farming, with three out of the four recently-inhabited concessions being canceled or suspended due to high deforestation levels (Radachowsky et al., 2012). Even if the land is designated as protected, there may be insufficient income from a potential carbon payments scheme to outweigh the rents gained by deforesting the land and converting it to grazing or crop land.

Our results emphasize the need to understand *why* certain common property resource management systems succeed in conserving resources. Research in political science and economics (e.g., Baland & Plattaeu 1996; Ostrom 2009) indicates that the long-inhabited concessions can be successful because members have been living together for a long time, have greater member to non-member ratios, and tend to be more homogeneous, which facilitates the emergence of social norms that foster cooperation. We suspect that the effect of concession membership on income in recently-inhabited concessions is insignificant because recently-inhabited communities are more heterogeneous in part because their families migrated to the region more recently, without having strong internal norms and governance, in addition to not having backgrounds in forestry. Thus, it appears that the concession members in recently-inhabited communities have less incentive to participate in sustainable forest management and find it difficult to cooperate with each other (Radachowsky et al., 2012). To support recently-inhabited concessions, additional interventions that foster stronger community ties and technical training in forestry could help (e.g., see Miteva, Fortmann, McNabb 2020 book chapter).

When implementing a CPR management system, it is important to consider the implications on the local communities as well as the environment. Our results suggest that involving local households in CPR management can result in significant societal welfare gains. Additionally, our results show that conservation and development objectives can be achieved simultaneously, even when the costs of implementing the CPR management system are considered. These findings are especially relevant in a developing country context where households that live near resources frequently depend on extracting the resources or using the land for their livelihoods. If successful, community CPR management has the potential to generate public and private benefits through conservation and economic development.

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Figures and Tables

Figure 1. Maya Biosphere Reserve Zones

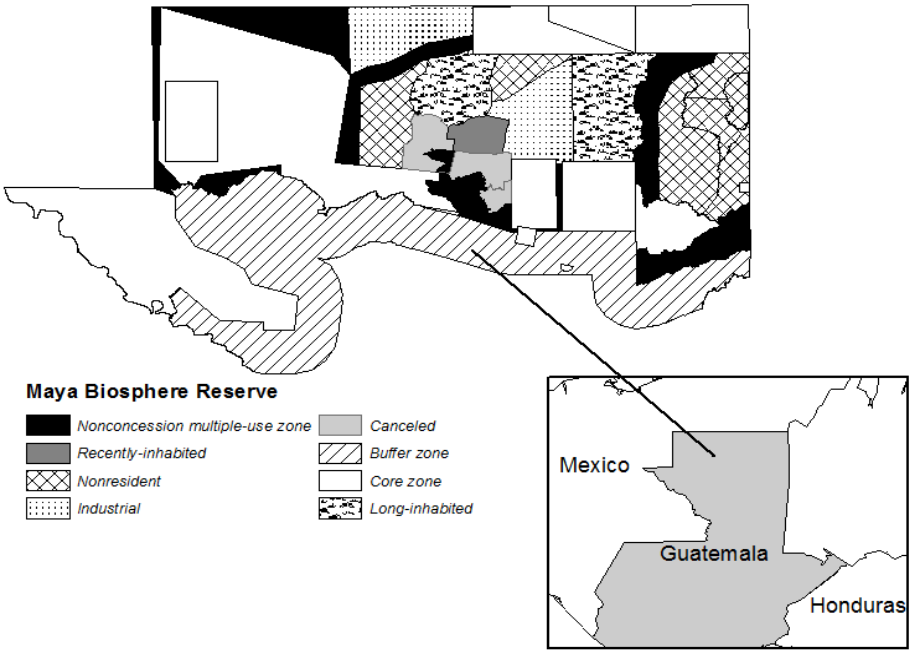

Table 1. Community Concessions in the Maya Biosphere Reserve

Concession Classification	Management Unit	Organization Name	Size (ha)	Year Formed	No. of Members
Long-inhabited	Carmelita	Cooperativa Carmelita	53,797	1997	174
	Uaxactún	Sociedad Civil Organización, Manejo y Conservación Uaxactún (OMYC)	83,558	2000	280
Recently-inhabited	Cruce a la Colorada	Asociación Forestal Cruce a la Colorada	20,469	2001	65
Canceled/ suspended	San Miguel la Palotada	Asociación Forestal San Miguel La Palotada	7,039	1994	39
	La Pasadita	Asociación de Productores La Pasadita	18,817	1997	122
	La Colorada	Asociación Forestal La Colorada	27,067	2001	48
Nonresident	Río Chanchich	Sociedad Civil Impulsores Suchitecos	12,117	1998	22
	Chosquitán	Sociedad Civil Laborantes del Bosque	19,390	2000	74
	San Andrés	Asociación Forestal Integral San Andrés	51,940	2000	170
	Las Ventanas	Sociedad Árbol Verde	64,973	2001	309
	La Unión	Sociedad Civil Custodios de la Selva (CUSTOSEL)	21,177	2002	85
	Yaloch	Sociedad Civil El Esfuerzo	25,386	2002	39
Industrial	Paxbán	GIBOR, S.A.	65,755	1999	N/A
	La Gloria	Baren Comercial Ltda.	66,548	1999	N/A

Table 2. Sample-level Income and wage-earning activities

Nonresident				
	2017		2012	
	Income	Jobs	Income	Jobs
Forestry	33,130.00	90	14,631.25	8
Agriculture	16,575.41	96	21,346.30	65
Tourism	34,575.00	9	11,991.43	7
Business	33,994.73	201	25,151.08	96
Professional Careers	50,202.54	111	47,811.42	75
Other	36,634.67	136	22,025.60	153
Average annual income per job	34,637.41	107	27,125.68	67
Average income per household	48,172.35	---	45,878.35	---
Long-inhabited				
	2017		2012	
	Income	Jobs	Income	Jobs
Forestry	36,782.55	125	10,288.47	17
Agriculture	34,965.33	26	572.00	4
Tourism	52,747.96	25	6,000.00	2
Business	27,565.30	38	16,969.23	13
Professional Careers	41,509.14	37	37,358.36	11
Other	35,121.39	53	8,627.75	20
Average annual income per job	37,073.58	50.67	14,825.21	11.17
Average annual income per household	46,660.50	---	31,601.98	---
Recently-inhabited				
	2017		2012	
	Income	Jobs	Income	Jobs
Forestry	21,034.50	58	48,000.00	1
Agriculture	33773.36	63	8,647.28	47
Tourism	N/A	0	63,000.00	1
Business	9,900.00	12	18,022.67	24
Professional Careers	22,392.00	3	23,408.75	8
Other	33,953.25	12	12,665.00	30
Average annual income per job	26,629.31	24.67	13,668.34	18.5
Average annual income per household	36,176.18	---	23,346.88	---

Income values are in quetzals. Average income is the average, nominal income for each job type weighted by the number of annual jobs in each category. Average income per household is the average annual income per household, which often includes income from more than one person working. The "Professional Careers" category refers to jobs that require a University degree or a special skill.

Table 3. Sample characteristics for the concession members and nonmembers by community type

All Households				
	2017		2012	
	Concession Members	Nonmembers	Concession members	Nonmembers
Household Head Age	50.45***	42.46***	49.64***	44.27***
Household Head Education	6.54**	7.07**	4.37	4.27
Born in the Petén (%)	63%	63.33%	53.18%	49.57%
Land owned (manzanas)	11.15***	5.85***	20.66	16.4
Forest dependent	0.80***	0.60***	0.53***	0.26***
Household head gender	1.20**	1.26**	1.12*	1.17*
Savings	1.84	1.85	1.82	1.82
Spouse education	5.98**	6.40**	4.65*	4.26*
Married	0.82*	0.78*	0.76*	0.81*
Under 12	1.04***	1.33***	1.49*	1.69*
Trust	0.31	0.34	0.09	0.11
Observations	356	360	267	226
Nonresident				
	2017		2012	
	Concession Members	Nonmembers	Concession members	Nonmembers
Age	54***	44.97***	49.63***	44.57***
Education	6.91**	7.62**	5.14	5.07
Born in the Petén (%)	57*	65.79*	59.73	58.33
Land owned (manzanas)	12.43***	3.51***	15.17***	8.63***
Forest dependent	0.72***	0.48***	0.53***	0.32***
Household head gender	1.16***	1.31***	1.10**	1.20**
Savings	1.81	1.80	1.76	1.79
Spouse education	6.13**	6.82***	4.80	4.57
Married	0.85***	0.71***	0.74	0.80
Under 12	0.87***	1.18***	1.36*	1.60*
Trust	0.31	0.27	0.08	0.12
Observations	209	190	149	144

Table 3 (cont.)

Recently-inhabited				
	2017		2012	
	Concession Members	Nonmembers	Concession members	Nonmembers
Age	38.94	42.92	49.17***	36.41***
Education	6.26*	5.5*	3.51	3.55
Born in the Petén (%)	61.70%**	35.90%**	49.06%	50.00%
Land owned (manzanas)	12.77	9.18	36.92	28.36
Forest dependent	0.94	0.87	0.26	0.36
Household head gender	1.26***	1.03***	1.10	1.09
Savings	1.94	1.97	1.94*	1.77*
Spouse education	5.50	5.09	4.88	4.72
Married	0.85**	1.00**	0.74	0.82
Under 12	1.17**	1.87**	1.52*	2.27*
Trust	0.34*	0.54*	0.10	0.09
Observations	47	39	31	22
Long-inhabited				
	2017		2012	
	Concession Members	Nonmembers	Concession members	Nonmembers
Age	48.51***	35.43***	48	N/A
Education	5.94***	7.26***	4.12	N/A
Born in the Petén (%)	74.75%*	86.96%*	46.38%	N/A
Land owned (manzanas)	7.58	6.41	9.09	N/A
Forest dependent	0.93	0.91	0.79	N/A
Household head gender	1.25	1.30	1.18	N/A
Savings	1.87	1.88	1.90	N/A
Spouse education	5.91*	6.62*	4.45	N/A
Married	0.75	0.80	0.79	N/A
Under 12	1.34	1.42	1.66	N/A
Trust	0.38	0.34	0.11	N/A
Observations	99	69	61	0

Table 3 (cont.)

	Non-concession			
	2017		2012	
	Concession Members	Nonmembers	Concession members	Nonmembers
Age	N/A	41.77	N/A	N/A
Education	N/A	6.13	N/A	N/A
Born in the Petén (%)	N/A	46.67%	N/A	N/A
Land owned (manzanas)	N/A	9.13	N/A	N/A
Forest dependent	N/A	0.58	N/A	N/A
Household head gender	N/A	1.2	N/A	N/A
Savings	N/A	1.92	N/A	N/A
Spouse education	N/A	5.68	N/A	N/A
Married	N/A	0.82	N/A	N/A
Under 12	N/A	1.23	N/A	N/A
Trust	N/A	0.23	N/A	N/A
Observations	0	60	N/A	N/A

Note, *,**,*** indicate that the t-test result is statistically different across members and nonmembers at the 90%,95%, and 99% confidence levels respectively. T-test results are not shown for long-inhabited communities in 2012 due to the lack of nonmember observations. For non-concession communities, the only data available is for 2017 nonmembers. For a detailed description of each variable, see Table 4.

Table 4. Variable description for income analysis

Variable name	Description
Household income	The total amount of reported income earned by the household in quetzals. This includes income earned from forestry and non-forestry activities as well as dividends earned from forest concessions and ecotourism.
Concession membership	Indicates whether the household is a member of a community forest concession in the Maya Biosphere Reserve. This variable is equal to 1 if the household is a member of a community forest concession and 0 if it is not
Household head age	Represents the age of the household head of the survey participant.
Household head education	Represents the highest level of education obtained by the household head.
Forest dependent	Constructed from a Likert scale question on the 2012 and 2017 surveys that asked to what extent the respondent agrees with the statement "We depend on the forest resources for our livelihood." This variable is equal to 1 if the participant responded "agree" or "strongly agree" and 0 if the participant responded "strongly disagree," "disagree," or "neutral."
Household head gender	Observed based on the observed gender of the participant and their relationship to the head of the household. This variable is equal to 1 if the participant is a male and 2 if they are a female.
Savings	Indicates whether the household has savings. This variable is equal to 1 if the household has savings and 0 if it does not.
Born Petén	Indicates whether the participant was born in the Petén. This variable is equal to 1 if the participant was born in the Petén and 0 if they were not.
Spouse education	Represents the highest level of education obtained by the spouse of the household head.
Married	Indicates whether the household head has a spouse or long-term partner. This variable is equal to 1 if the participant responded "married" or "unified" and 0 if the participant responded "divorced," "single," or "widowed."
Under 12	Indicates the number of children under 12 that live in the household.
Trust	Indicates the participant's response to the question "Do you think that you can trust the majority of people?" This variable is equal to 1 is the participant responded "You can trust some people" or "You can trust the majority of the people." This variable is equal to 0 is the participant responded "You need to be very careful with everyone," "You have to be somewhat careful with everyone," "It's possible that you should be careful," "We don't know," or if the participant refused to answer.
Own Land	Indicates the amount of land in manzanas owned by the household.

The data were collected from 2012 and 2017 household-level surveys in Maya Biosphere Reserve communities.

Table 5. Variable description for conservation analysis

Variable name	Description
Forest loss	This variable is constructed from the Global Forest Change data set described in Hansen et al. (2013). It represents the forest loss in each year from 2012 to 2017. The variable is equal to 1 if the 100m by 100m pixel was deforested in a given year. A pixel is "deforested" if the amount of forest on the pixel drops below 25%.
Carbon	This variable is constructed from the Aboveground live woody biomass density layer from Global Forest Watch. The data is at a 30-meter resolution for the year 2000. The CO_2 value per hectare is estimated from this layer as 50 percent of biomass density values multiplied by the ratio of the molecular weight of carbon and CO_2 (44/12) (Baccini et al., 2012; GlobalForestWatch, 2018).
Current Concession	This variable is equal to 1 if the 100m by 100m pixel is under concession management and 0 if it is not. The separate variables for each type of concession used in this analysis are nonresident, long-inhabited, and recently-inhabited.
Distance to road	Indicates the Euclidean distance of each pixel to the nearest road in meters.
Distance to archaeological site	Indicates the Euclidean distance of each pixel to the nearest archaeological site in meters. The archaeological sites considered are el Mirador, Tikal, and Yaxha-Nakum-Naranjo, which are the three most visited archaeological sites in the Maya Biosphere Reserve.
Soil Nutrients	An index for the amount of nutrients in the soil ranging from 1, meaning no or few limitations, to 7, meaning water bodies, or non-soil areas.
Elevation	Taken from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM), which is a product of METWe and NASA. The resolution is 70m and the unit is meters with 0 meters being at sea level.
Precipitation	Taken from monthly rainfall data from NASA. Represents the average annual rainfall in millimeters for each pixel for each year from 2012 to 2017.

Unless otherwise mentioned, the data are at the 30 by 30-meter pixel resolution. Observations that are non-soil areas or bodies of water were dropped from the analysis.

Table 6. Two-stage least squares results for the effect of concession membership on income

	All Communities	Long-inhabited	Recently-inhabited	Nonresident
Concession membership	2,204**	2,539***	-1,405	2,865***
	(1,163)	(578.8)	(2,062)	(927.2)
Household head age	-3.39	-39.20***	37.85	5.11
	(21.96)	(5.84)	(45.81)	(22.32)
Household head education	117.3	186.9	-178.5	177.3**
	(106.6)	(198.1)	(246.0)	(90.5)
Forest Dependent	90	1,557***	-954.133	-21.0267
	(925.6)	(97.6)	(2,009)	(800.9)
Household Head Gender	817.6	1,373***	1,684	1,547***
	(763.9)	(300.4)	(1,870)	(486.9)
Savings	-1,095	-2,480***	750.4	-985.9
	(977.7)	(629.5)	(2,785)	(627.2)
Born Petén	-232.8	-1,257**	2481.2	-229.333
	(732.1)	(616.0)	(1,700)	(724.1)
Spouse education	216.5	274.0*	216.0	172.7*
	(132.4)	(163.7)	(321.7)	(103.1)
Married	1,588**	851.3	186.3	2,278***
	(866.1)	(1,495)	(2,354)	(567.6)
Under 12	272.4	615.7***	-125.4	1.11
	(194.9)	(32.47)	(471.7)	(207.6)
Trust	-959.6	-378.1**	503.1	-1,793***
	(652.7)	(181.3)	(1,369)	(382.0)
Own Land	34.69*	44.76***	46.92**	25.25
	(16.61)	(3.17)	(23.39)	(18.31)
Constant	1,683	4,543	3,021	-240.1
	(1,816)	(4,782)	(7.089)	(1,991)
Observations	642	166	86	390
R-squared	0.11	0.211	0.104	0.132

*** p<0.01, ** p<0.05, * p<0.1. The standard errors for the "all communities" regression were generated using wild cluster bootstrapping and the standard errors for the long-inhabited, recently-inhabited, and nonresident concession groups separately are robust standard errors. All values are adjusted for inflation and are reported in U.S. dollars. 1 USD is equal to approximately 7.5 quetzals. Results include village fixed effects. Observations that were unmatched and that reported income above 300,000 quetzals a year were dropped from the analysis. The first stage results are in Appendix A.

Table 7. Effect of concession management on deforestation

	All communities	Long-inhabited	Recently-inhabited	Nonresident
Current Concession	-0.0420***	-0.0379***	-0.0486***	-0.0423***
	(0.000253)	(0.000506)	(0.00127)	(0.000355)
Distance to road	-2.29e-06***	-3.87e-06***	-7.38e-06***	-3.25e-06***
	(4.09e-08)	(7.99e-08)	(1.42e-07)	(6.59e-08)
Distance to archaeological site	9.56e-08***	1.00e-07***	3.70e-07***	3.10e-07***
	(9.74e-09)	(1.88e-08)	(2.49e-08)	(1.42e-08)
Soil Nutrients	0.00675**	0.00817*	-0.00059	0.01140***
	(0.00312)	(0.00440)	(0.00537)	(0.00381)
Elevation	6.07e-05***	0.000139***	0.000213***	0.000169***
	(1.89e-06)	(4.06e-06)	(6.50e-06)	(3.50e-06)
Precipitation	3.03e-06***	5.10e-06***	-3.40e-07	3.35e-06***
	(2.60e-07)	(5.84e-07)	(7.52e-07)	(3.38e-07)
Constant	0.0142***	-0.0115**	-0.0147**	-0.0190***
	(0.00326)	(0.00481)	(0.00605)	(0.00408)
Observations	4,208,562	1,997,364	1,311,114	2,504,610
Number of Pixels	701,427	332,894	218,519	417,435

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors are inside the parenthesis. The "number of pixels" represents the number of land parcels in the analysis and the "observations" row represents the total number of observations over the entire time period. For a description of each variable used, see Table 5.

Table 8. Cumulative value of land under concession management from 2012 to 2017

	All Community Types	Long-inhabited	Recently-inhabited	Nonresident
Average annual income effect per household	$2,590.77	$2,539.04	-	$2,865.29
Concession member households	$1,218.00	$454.00	$65.00	$699.00
Cumulative Income effect (2012-2017)	$15,777,809.35	$5,763,615.00	-	$10,014,191.00
Cumulative carbon rents (2012-2017)	$2,380,379.00	$832,416.00	$169,171.00	$1,470,551.00
Cumulative value (income and carbon rents)	$18,158,188.35	$6,596,031.00	$169,171.00	$11,484,742.00
Hectares	$374,944.00	$134,978.00	$20,445.00	$348,686.00
Gross value per hectare	$48.43	$48.87	$8.27	$32.94
Guatemalan government funding	$726,267.75			
External funding from grants	$10,649,365.56			
Total net value	$6,782,555.04			
Total net value per hectare	$18.09			
Total annual net value per hectare	$3.62			

The income in the "All community types" column is calculated using the average income earned from being a concession member across all concession classifications. Recently-inhabited concession members were assumed to not receive an income benefit from the concessions since the income effect for recently-inhabited concessions is not statistically different from 0. All income values are adjusted for inflation. The quetzal to USD exchange rate used is 7.5. The carbon sequestration rental value is calculated using a 5% discount rate (García-Gusano et al., 2016). The values for cumulative carbon rents are the sum of the annual carbon rental values for each year from 2012 to 2017. The values for all community types represent the average values among the community concession classifications. Due to limited information on external funding, we cannot accurately report the external funding for each concession classification.

Appendix A

Table A1. 2SLS first stage results for the instrumental variable (matched concession membership status) on concession membership

	All Community Types	Long-inhabited	Recently-inhabited	Nonresident
Household head age	.00198*	.0034372**	-.0007313	.0030943**
	(.0010421)	(.0016409)	(.0029711)	(.0014465)
Household head education	-.0015469	.0017412	.0106537	-.0002937
	(.0052684)	(.0089562)	(.0156759)	(.0069655)
Forest Dependent	.0620899*	-.0091771	.0875065	.0663322*
	(.0326653)	(.078037)	(.1285354)	(.0383067)
Household Head Gender	.0258014	.015648	.2372176**	-.0205991
	(.0364279)	(.0589938)	(.1155193)	(.0482929)
Savings	-.0551528	-.0413343	-.266616	-.0183232
	(.0372151)	(.0659855)	(.1809424)	(.0456959)
Born Petén	.0811459**	-.0029377	.2395872**	.0532374
	(.0338238)	(.0578347)	(.1024261)	(.0444288)
Spouse education	-.003583	.0030468	-.0168345	-.0009576
	(.0057784)	(.0096554)	(.0212621)	(.0074645)
Married	.0260778	-.0397788	-.1298929	.0623913
	(.0383753)	(.0594423)	(.1477859)	(.0504363)
Under 12	-.0096468	.001789	-.0066814	-.0153684
	(.0105877)	(.0137944)	(.0302241)	(.0166224)
Trust	.0103392	-.0478751	-.1112285	.0428471
	(.0287561)	(.0452531)	(.0836104)	(.0398554)
Own Land	.0003596	-.0002579	-.0005975	.0013487
	(.00062)	(.00106)	(.0015215)	(.0008568)
Observations	646	167	86	393
F-statistic	33.99	31.57	9.73	21.14
R-squared	0.58	0.73	0.62	0.56

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors are inside the parenthesis. For a complete description of each variable, see Table 4

Table A2. Logistic regression results for likelihood of being a concession member

	Logit results	Odds Ratio
Household Head Age	0.0171**	1.017267**
	(0.00721)	.(007332)
Household head education	0.00669	1.006716
	(0.0371)	(.0373664)
Born Petén	0.284	1.32832
	(0.226)	(.3008249)
Constant	-0.0726	.9300165
	(0.524)	(.4875009)
Observations	488	

*** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parenthesis.

Table A3. Matched ordinary-least squares regression results for the effect of concession membership on income

	All Communities	Long-inhabited	Recently-inhabited	Nonresident
Concession membership	1,744***	1,802*	2,580 **	2,026**
	(510.1)	(141.6)	(166.7)	(113.3)
Household head age	-0.9	-28.0	3.5	14.2
	(14.69)	(4.15)	(5.53)	(4.12)
Household head education	152.0***	91.3	-85.8	243.9
	(93.12)	(23.75)	(28.05)	(19.83)
Forest Dependent	156.1	1,611.2	-3,751.9**	296.3
	(813.1)	(221.6)	(234.3)	(111.2)
Household Head Gender	1,094.7	1,803.9	-2,221.9	1,673.9
	(542.8)	(163.8)	(195.6)	(137.9)
Savings	-412.1***	-2,196.8*	1,387.5	-78.5
	(622.5)	(167.9)	(333.3)	(127.7)
Born Petén	-333.3	-1,192.1	-1,421.3	220.1
	(350.7)	(146.6)	(201.3)	(128.9)
Spouse education	190.0	349.7*	160.8	103.3
	(80.85)	(26.17)	(36.25)	(20.65)
Married	1,886.4	1,149.3	330.0	2,732.3***
	(632.1)	(162.6)	(236.9)	(140.1)
Under 12	229.6	598.3**	-129.5	-65.1
	(150.7)	(33.33)	(54.77)	(47.69)
Trust	-792.8	138.5	773.5	-1,548.9*
	(566.0)	(114.5)	(163.0)	(112.0)
Own Land	36.8**	44.9**	17.3	35.4*
	(8.91)	(2.47)	(2.69)	(2.41)
Constant	-261.7	1,935.3	5,088.7	-3,455.7
	(359.1)	(551.8)	(803.3)	(516.9)
Observations	482	122	66	294
R-squared	0.140	0.221	0.223	0.141

*** p<0.01, ** p<0.05, * p<0.1. Results are in USD. 1 USD is equal to approximately 7.5 quetzals. The standard errors for the "all communities" regression were generated using wild cluster bootstrapping and the standard errors for the long-inhabited, recently-inhabited, and nonresident concession groups separately are robust standard errors. 233 households were unmatched and dropped from the analysis. All values are adjusted for inflation. The matching method we used was a propensity score, nearest neighbor matching method.

Table A4. Panel results for effect of concession membership on income

	All Communities	Nonresident	Long-inhabited
Concession membership	1,731.5	1,874.0	579.3
	(203.6)	(290.6)	(295.1)
Household head age	-34.7	-67.6	-13.7
	(3.83)	(7.43)	(4.11)
Household head education	28.0	2.6	251.5
	(20.01)	(31.53)	(26.03)
Forest Dependent	631.2	1,992.4	-79.0
	(135.8)	(219.9)	(162.2)
Household Head Gender	-312.7	24.3	728.7
	(174.1)	(250.1)	(264.7)
Savings	142.9	749.6	-1,035.7
	(132.6)	(189.3)	(162.8)
Born Petén	1,124.3	1,882.9	264.4
	(102.4)	(166.4)	(118.8)
Spouse education	54.2	-21.7	14.5
	(18.73)	(30.03)	(23.31)
Married	-828.5*	-1,028.0	-303.6
	(59.36)	(91.93)	(70.41)
Under 12	273.6	-208.9	571.3***
	(32.85)	(74.24)	(28.27)
Trust	-208.1	-1,364.1	1,726.3*
	(119.0)	(189.9)	(133.0)
Own Land	-7.1	-30.7	19.0
	(2.23)	(3.03)	(3.83)
Constant	2,553.5	2,175.9	6,764.3
	(513.5)	(839.0)	(612.6)
Observations	224	118	83
Number of Households	113	63	46

*** p<0.01, ** p<0.05, * p<0.1. The results are in USD. 1 USD is equal to approximately 7.5 quetzals. The panel includes only observations that were interviewed in both 2012 and 2017. Results include village fixed effects. Observations that reported income above 300,000 quetzals a year were dropped from the analysis. All values are adjusted for inflation.

Appendix B

Table B1. Logistic regression results for likelihood of concession placement

	Logit results	Odds Ratio
Distance to road	0.000191***	1.00019***
	(1.04e-06)	(1.04e-06)
Distance to archaeological site	-5.05e-05***	.99995***
	(2.18e-07)	(2.18e-07)
Elevation	-0.00106***	.99894***
	(4.20e-05)	(4.20e-05)
Soil nutrients	-0.04450***	.95649***
	(0.00036)	(0.00036)
Constant	758.00***	---
	(6.05)	(6.05)
Observations	783,480	783,480

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors are inside the parenthesis.

Table B2. CO_2 values

	Additional forest conserved (ha)	Average tons of CO_2 per ha	Total tons of CO_2 gained	Value of CO_2	CO_2 rental value (2012-2017)
Long-inhabited	342.05	278.87	95,387	$2,956,997	$832,416
Recently-inhabited	65.63	334.72	21,968	$681,008	$169,171
Nonresident	621.53	330.07	205,148	$6,359,588	$1,470,551
Total for active concessions	1513.92		322,503	$9,997,593	$2,472,138

The additional forest conserved in this table and the CO_2 rental values are accumulated from 2012 to 2017. The annual carbon rental value is calculated using the formula R=[P-(P/(1+i))]. R is the annual rental rate, P is the carbon price, or $31. R times the tones of CO2 conserved each year is the annual total rental. This is summed over the period 2012 to 2017 to obtain the cumulative total rental. The value of CO_2 is calculated using $31 as the social cost of carbon (Nordhaus, 2017). The average tons of CO_2 per hectare are calculated by concession classification (long-inhabited, recently-inhabited, and nonresident).