

Decentralization and Deforestation

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DRAFT

Abstract

Policy makers all over the world tout decentralization as an effective tool in the governance of natural resources. Despite the popularity of these reforms, there is limited scientific evidence on the environmental effects of decentralization, especially in tropical biomes. This paper presents new evidence on the institutional conditions under which decentralization is likely to be successful in sustaining forests. We draw on common pool resource theory to argue that the environmental impact of decentralization hinges on the reforms' ability to engage local forest users in the governance of forests. Using matching techniques, we analyze longitudinal field observations on both social and biophysical characteristics in a large number of local government territories in Bolivia (a country with a decentralized forestry policy) and Peru (which has a more centralized forestry policy). We find that territories with a decentralized forest governance structure have more stable forest cover, but only in places where local forest user groups are actively engaged with the local-government officials. We provide evidence in support of a possible causal process behind these results: when user groups are actively engaged with the decentralized units, these groups help produce a more enabling environment for the effective governance of forests, including more local government-led forest governance activities, forums for the resolution of forest-related conflicts, inter-municipal cooperation in the forestry sector, as well as improved technical capacities of the local government staff.

Keywords: Bolivia, Peru, Decentralization, Deforestation, Commons, Local Government

Significance

Decentralization is one of the most important innovations in environmental policy during the last 30 years. Despite the widespread prevalence and the large amounts of resources invested to implement these reforms, little is known about their environmental effects. Given worldwide interest in forest conservation, this lack of knowledge is a serious problem for actors interested in improving the effectiveness of current policy efforts. Employing quasi-experimental methods, we find that the environmental effects of decentralization reforms depend on how the reforms affect the conditions for user groups to govern their forests. Our findings show that decentralization to general-purpose governments may be most effective in places where forest users are well organized and take advantage of opportunities to engage with local politicians.

Introduction

Forests are complex systems that defy simplistic governance approaches. Forests can be common-pool resources, making the exclusion of potential users difficult. Forests have important externalities with regards to atmospheric, hydrological, and biological services, and they take far longer to develop and recover than the sitting terms of parliamentarians or presidents.

The last 30 years have seen significant shifts in ideas about how forests ought to be governed. Centralized, top-down forest policies—for a long time viewed as the superior approach to ensure effective governance of forests—are now perceived by many scholars and policy makers as having failed in sustaining forests and the livelihoods that depend on these resource systems [1, 2]. In response to these perceived failures of a centralized approach and supported by international donors, national governments around the world have aggressively pursued reforms to decentralize the governance of forests from the national government down to more local levels of government [3,4]. Most empirical assessments show that the results of these reforms have been very mixed, and these reports have prompted a re-examination of the question as to who authority over forests ought to be allocated [29]. The goal of this paper is to contribute to this debate by producing new empirical evidence on the conditions under which decentralization may help sustain stable forest conditions.

Several scholars argue that decentralization can promote better environmental outcomes, especially in developing countries [3, 4]. This argument has been used widely by international organizations, which have promoted and funded decentralization reforms in developing countries [5, 6]. However, some scholars have raised concerns about the effectiveness of decentralized governance, suggesting that decentralization reforms may result in worse outcomes, or at best, outcomes will be no better than under centralization [7, 8]. Some empirical evidence on the environmental impact of decentralization does exist [9, 10, 11], and the majority of these studies suggest a positive relationship: decentralized forest governance often does a better job of protecting forests than centralized governance structures. A limitation in the existing evidence base, however, is that most of the existing studies focus on localized, village-level outcomes, and not on the broader territory under the control of general-purpose local government units. These units are, by far, the most common targets of the decentralization reforms in developing countries [12, 13] and yet there is little scientific evidence on how these reforms are affecting forests governed by this type of local governments.

The absence of relevant and robust scientific evidence is particularly serious for the ongoing policy efforts to curb tropical deforestation, including the international initiative on Reducing Emissions from Deforestation and Forest Degradation (REDD+), because without better knowledge about how these policy experiments have affected forest outcomes in the past, we cannot know how existing policy instruments may be honed to become more effective [14].

Here, we draw on common-pool resource (CPR) theory [15, 16, 17] to develop an argument about the institutional conditions under which decentralization is likely to generate improved forest-governance outcomes. Specifically we derive our argument from the work of Elinor Ostrom, who proposed eight design principles for sustaining common-pool resources [15]. The achievement of most of these principles hinge directly on the degree to which local users are recognized and allowed to participate in forest-governance activities, such as rule making, monitoring, and enforcement (see SI, subsection 3). This logic provides the foundation for our

main proposition: when local user groups are actively engaged with local-government actors, this improves the conditions for effective common-pool resource governance and hence makes it possible for decentralization to work and to improve forest outcomes. In other words, we argue that resource-user engagement in the local-governance process is an enabling condition for effective decentralization reforms.

In order to test this argument, we have constructed an original database measuring decentralization policy, local governance attributes, and forest cover in 200 municipal territories in Bolivia and Peru. While sharing a number of biophysical, socioeconomic, and cultural factors, Bolivia's central government, starting in 1996, gave local governments (*municipios*) substantial rights, responsibilities, and resources to govern their forested areas; over the same time period, Peru kept most powers over forests under the purview of their central government [18, 19, 20]. We use matching techniques to compare the local-government territories in a decentralized setting to territories which share similar demographic and biophysical characteristics in a centralized regime. With these data, we employ regression techniques to evaluate the environmental impact of decentralization, and the conditions under which such reforms can help reduce deforestation and stabilize forest cover.

Results

Our results show that decentralization to general-purpose governments is associated with lower rates of deforestation overall. This relationship disappears, however, in cases where community engagement is weak. That is, decentralization may lead to better outcomes, but only where local user groups push local governments for improved resource governance.

The plots in Figure 1 show differences between forest cover in carefully matched decentralized and centralized territories (the matching techniques as well as the scales of the variables used are explained under the section "Materials and Methods", below). In terms of rates of forest cover change, decentralized territories have significantly more stable forest cover ($p < 0.05$). The average treatment effect (ATE) associated with decentralization was about 2.6 percent less forest lost per year.

[Figure 1 here]

We then analyzed the effects of community engagement on deforestation across decentralized and centralized municipalities to see if the effect differed. To do so, we generated an interaction term—the product of "decentralization" and "community engagement"—and included the interaction term, as well as both base terms, in a Generalized Estimation Equation (GEE) regression model with the same control variables used for the matching analysis above. Where an interaction term is included in a regression model, like the GEE models used here, the significance of coefficients in the table is not substantively meaningful, and therefore, as suggested by methodologists, we show a graph of the marginal effects of a change from a centralized to a decentralized regime, conditional on the level of user-group engagement with the local government [21, 22].

[Figure 2 about here]

The effect of decentralization on forest cover is shown in Figure 2, and provide support for this study's central hypothesis: Where community engagement is low i.e., where forest user groups

rarely meet with local government officials to express opinions regarding forestry, there is no significant effect of decentralization on forest-cover change. However, where community engagement is greater, decentralization has a positive and significant effect on forest cover change, leading to significantly lower rates of deforestation.

Discussion

What explains these results? Why is the environmental impact of decentralization contingent on user-group engagement? We propose that user-group engagement with the local government is necessary for creating an enabling policy environment for managing common-pool resources, such as forests. To test this idea further, we apply Ostrom's thesis about CPR governance [15, 16] to the study of decentralization and examine empirically the extent to which Ostrom's so-called "design principles"—which propose a set of institutional conditions that can help sustain common-pool resources—are present in our sample of municipal territories.¹ While the fulfillment of all eight design principles are more likely when user groups are more actively engaged with the local government officials (see endnote #1 above), our field data limit us to analyze four of these principles only. Specifically we focus our analysis on the following four conditions for effective local CPR governance: (1) existence of forums for conflict management²; (2) monitoring and enforcement activities by individuals who are accountable to users³; (3) the ability of matching solutions to local conditions⁴; and (4) the institutional nestedness of forest-governance arrangements.⁵

For our sample of municipal territories, we compare indicators for these institutional conditions between two groups: (1) decentralized territories in which local user groups are actively engaged with local governments and (2) all other territories, decentralized or centralized, where user groups are less engaged with their local governments. Figure 3 shows the results of the comparative analysis, showing statistically significant differences between the two types of local government units for all four indicators:

First, according to Ostrom's design principles for local CPR governance, systems that enjoy easy access to forums for conflict resolution are more likely to govern their shared resources sustainably. As an indicator for this condition, we draw on responses to our field surveys to calculate the proportions of local governments that told us that they have intervened in conflicts in the forestry sector where such conflicts exist. As shown in Figure 3, decentralized territories in which local user groups are actively engaged with local governments, representatives of these local-governments intervene in conflicts almost twice as frequently (84% vs. 46%) and this difference is statistically significant ($p < 0.05$).

[Figure 3 about here]

Second, the local governance of CPRs is more likely to be successful if the individuals who are responsible for monitoring and enforcement are accountable to the resource users [15]. One of the formally mandated responsibilities of democratically-elected local governments in decentralized Bolivia is the monitoring and enforcement of rule compliance in the forestry sector, but the extent to which local governments perform these duties depends in part on how committed the local politicians are to forest governance and how much of a political priority such forest governance activities represent. Here, we examine the existence of locally-funded forest-governance programs in the two types of local administrations. We find that active

municipal forest-governance programs are almost twice as prevalent in decentralized units where users are activity engaged (84% vs. 46%) and this difference is statistically significant ($p < 0.05$).

Third, and according to another of Ostrom's design principles [15], successful CPR governance is more likely to work when the institutional arrangements match the local context. We propose that in order for a local governance system to be able to match solutions to the specific local circumstances, the system needs to have technically competent personnel with a strong local presence. This means that the units responsible for the creation and enforcement of rules about forest use need to have "boots on the ground". As a proxy for this condition, we use a variable from our field data that measures the number of local-government employees who had earned a degree in forestry or related fields. The results in Figure 3 show that the decentralized units with high user engagement, tend to have better technical capacity, as indicated by having more employees with formal technical training in forestry ($p < 0.05$).

Finally, we look at a fourth condition that may help promote effective local governance of forests: Ostrom's eight design principle states that the effective local governance of CPRs, and especially large ones, will benefit from a nested governance system, in which local user groups and their institutional arrangements are nested within governance units that operate at broader spatial scales. Our proxy indicator for this principle is the existence of formal inter-municipal cooperation agreements in the forestry sector. According to our interviews with local government representatives in the two countries, such cooperation between local governments exists at a much higher rate in the decentralized units with high user engagements, although this difference is only statistically significant at the level of $p < 0.1$.

For all of these proxy indicators, the decentralized regime where users are more actively engaged appears to experience better conditions for effective forest governance compared to those local government territories where users are not as engaged. Taken together, these results suggest that a possible process through which decentralized systems can maintain more stable forest cover is that these units are organized in a way that can make involvement with forest users more meaningful (but not necessarily more prevalent) and when this happens it provides superior conditions for sustaining common pool resources, such as forests.

An alternative explanation to our results is the possibility of reverse causality. According to such a logic, areas with better forest condition or lower deforestation rates might somehow be more likely to have been decentralized. In this study, this is not a likely course of events since the decentralization reform in Bolivia was homogeneously implemented—all local governments were given the same formal mandate to govern forests in their territories [20]. A more subtle possibility of endogeneity is that forest user groups might be more likely to engage with local government officials in places where the forest is in relatively superior conditions. This suspicion is not well founded because environmental governance research has demonstrated that local forest user groups are *more* likely to engage in resource-governance when the resource is salient, scarce, and perceived to be under threat, not when it is abundant and in good condition [23, 24]. In addition, the careful matching of similar municipalities and the controlled longitudinal analysis that we use here increase our confidence in the inferences that we draw from our analytical results.

Conclusion

Our results show that decentralization is not a panacea. Decentralization will not automatically lead to more stable forests because the outcomes will likely depend on how local politicians

choose to interact with other members of the local-governance system. Our findings do suggest that the interactions between local forest users and local politicians are particularly important because such interactions can strengthen the political incentives for politicians to take action in the forestry sector, and can help to make such action more effective. When local politicians perceive political incentives to take policy action in the forestry sector—to support and monitor local people’s interactions with the local forests—decentralization stands a better chance to succeed in stabilizing forest cover. That said, even when local government units experience reduced deforestation rates, this does not necessarily mean that people’s livelihoods are improved or that social justice is served. It is entirely possible that the local user groups that engage with the local government administration are in relatively privileged positions and push for a more active forest-governance program in order to strengthen their own narrow self-interested objectives in the forestry sector. Such processes of elite capture, which previous studies have reported to be a common outcome of decentralization reforms [25, 26], cannot be ruled out on the basis of our results.

Forest-user engagement with local government officials allows both these parties to gather useful information about how local problems and issues may be addressed, and this information exchange has implications for downward accountability. Consistent with the findings from literature on democratic decentralization [27, 28, 29] with more frequent community engagement, local politicians can more easily gather information about community needs, preferences, and conditions, making it easier for them to be effective in responding to local needs and in this way seek the support of their constituents. Strong user group engagement also allows community members—voting constituents—to gather information about the performance of local politicians, making it easier for community members to reward effective politicians with re-election, and to punish ineffective and corrupt leaders by voting against them in local-government elections [30, 31]. Ultimately, the decentralization of formal authority to govern forests seems to be a necessary but not sufficient condition for effective local forest governance.

In sum, our findings do not show that decentralization is performing well, but rather that it can, under certain conditions, perform better than the centralized regime. This conclusion has implications for efforts to slow down tropical deforestation beyond the two countries in our study. For example, one governance characteristic shared by most countries that participate in the REDD+ pilot activities, is the relatively weak institutional arrangements for implementing forest protection policies at the central-government level. Forest governance in several of these countries is given a low political priority relative to other land use options—such as mining, agriculture, and cattle raising—which tend to bring in higher revenues for national governments (at least in the short term) [32, 33]. Our results suggest that when the centralized governance regime is dysfunctional, decentralizing some of the rights, resources, and responsibilities associated with forest governance from the national down to the more local-level, general-purpose governments may effectively introduce improved conditions for governing forests, but only when forest users are taking an active role in the local governance process.

Materials and Methods

There are four major data sources for this study: (1) surveys of local governance actors (2000 and 2007), (2) census/archive data (2000, 2007), (3) satellite images (1993, 2000, and 2007), and (4) digital elevation models of Peru and Bolivia. In each of 200 selected municipalities, we interviewed the elected mayor in two waves: 2000/1 and again in 2007/8. In addition, we

interviewed municipal forestry officials and community leaders in order to triangulate responses in 2007/8. Survey enumerators completed a survey instrument (258 questions) with municipal officials which was designed to elicit information regarding the interviewee's policy priorities, staff, relationship with central and non-governmental agencies, and relationship with citizens. We checked several interview responses with archival data and found the survey instrument to be highly reliable. We also use government statistics from both countries for some of our key variables (as noted below).

Biophysical data was generated from two sources: (1) digital elevation models to create topographic data, and (2) forest cover data that were generated using remote-sensing techniques (Landsat™ satellite imagery and aerial photography). We use digital elevation models to generate estimates of altitude and the percentage of land in each municipality above a 12% grade—that is, the slope above which commercial, large-scale agricultural production is not feasible. We also hired remote-sensing analysts in Peru and Bolivia to estimate forest cover change for our sample of 100 local government territories in Bolivia for the period 1993-2008, and for 35 Peruvian municipalities in the period 1990-2008. The methods used to calculate the dependent variable, forest-cover-change, are described in detail in section 2 of the SI.

We present two independent variables of interest: *de jure* decentralization reforms and degree of community engagement on forest cover change (deforestation) over time. *De jure* decentralization is a dummy variable that identifies whether the municipality was located in a formally decentralized regime, therefore this variable is coded 0 in both time periods for Peru, and 0 in period 1 for Bolivia (2001), and 1 in the second time point for Bolivia (2008). Decentralization was coded in this way because we believe that the 1996 decentralization reforms would not have had a substantial impact on policy and forest cover by 2001, but would have begun to have an effect by 2008. However, to ensure the robustness of our results, we tested all of the models presented here with an alternative coding, in which Bolivia is coded 1 in both time periods. Although this changed the balance of our matching sample significantly, the direction and significance of our results did not vary when using this alternate coding.

Community engagement is a variable that denotes the degree to which a local government is connected through frequent interactions about forestry with community-based organizations. This variable is drawn from one of our survey questions, which asks respondents how often community-based organizations expressed opinions regarding forestry to municipal government officials on a range from 1 (“never”) to 5 (“very frequently”). We averaged the responses from surveys with mayors, local forestry officials, and community-based organization leaders in each municipality to generate an overall measure of the degree of community engagement on forestry issues within a municipality.

Our empirical tests employ two multivariate techniques: (a) Mahalanobis matching with propensity scores, and (b) GEE regression using Mahalanobis matching with propensity scores as a pre-processing technique to eliminate non-comparable observations.

It is not practical to carry out randomized trials of decentralization reforms by randomly granting municipal governments legal authority and resources. And though decentralization reforms in forest policy have been applied to municipalities in Bolivia and not in Peru, a simple comparison between Bolivian and Peruvian municipalities in terms of land cover change and other forestry-related outcomes (the so-called difference in difference approach) is not appropriate. This is

because we are likely to confuse differences between Peru and Bolivia with the effects of decentralization [35, 36, 37].

Instead, we use multivariate matching techniques to examine the effects of decentralization. Specifically, we use a matched sample in which municipalities in a decentralized setting are matched with non-decentralized municipalities which share several key characteristics. Spatial autocorrelation is not a major concern for this analysis because in our matched sample of local government territories it is rare that these territories share boundaries with one another.

We use Mahalanobis matching in this study [38]. This approach matches observations (in this case, several treatment cases for each control) according to the “Mahalanobis distance” between them. The Mahalanobis distance is the distance between observations in a multi-dimensional space, in which each dimension is a control variable (a variable upon which the matching is to be based). These include annual rate of deforestation (lagged), the proportion of municipal area with a slope over 12% (the percent above which most mechanized agriculture is impossible), road density (km. per square km., ln), population (ln), municipal budget size (millions of \$US, ln) and municipal area (ha, ln). By using this technique, it is possible to generate a set of matched cases in which treatment and control cases are not significantly different on observables, except for the treatment. In essence, then, the technique, like other matching techniques, generates a “treatment” and “control” group that are statistically not significantly different on important observable control variables [39, 40, 41]. We also use propensity scores to improve the balance of our matched samples, such that “control” (centralized) cases are more comparable to “treatment” (decentralized) cases, as suggested by statistical methodologists [39, 41]. We generate propensity scores using several the control variables listed above. These propensity scores are then used as a matching variable in our Mahalanobis matching models, in addition to other control variables. After generating a matched sample based on control variables and propensity scores, we used two-sample t-tests to confirm that our matched samples did not significantly differ in terms of the mean values of the centralized (control) and decentralized (treatment) variables. In order to generate apples-to-apples comparisons, we eliminated poorly-matching observations from the sample. In the end, we were able to generate a strong sample of cases with no significant differences in terms of the control variables in our model.

Multivariate matching techniques enjoy a number of advantages over regression techniques, the standard approach in the social sciences. First, statistical tests using matching do not assume a linear, additive effect. Second, because we use statistical tests to ensure a balanced sample, extreme values of control variables cannot drive spurious results [42, 43].

At the same time, matching is not useful when examining the interactive effects of multiple independent variables on a single dependent variable. Therefore, we use regression techniques to test hypotheses involving interactions between community and decentralization. In these models, we also control for the biophysical variables listed above. In post-estimation tests, we examined regression models with both matched and unmatched samples, and found that regression models produced different results, suggesting that this standard approach problematic in the case of decentralization because they may tend to compare incomparable cases. Our approach—using regression models after pre-processing data with matching models—addresses this problem [40]. The regression technique we use here—GEE regression—is used to address potential temporal autocorrelation in panel data [44-49].

¹ We use our field observations from 2008 for this part of the analysis.

² Ostrom (1990) design principle #6

³ Ostrom (1990) design principle #4

⁴ Ostrom (1990) design principle #2

⁵ Ostrom (1990) design principle #8

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Figure 1: Forest cover differences between unmatched (left box) and matched (right box) Peruvian and Bolivian samples. Under decentralization, rates of deforestation are lower (less negative), but differences are smaller than those suggested by a naïve comparison between Peru (centralized) and Bolivia (decentralized)

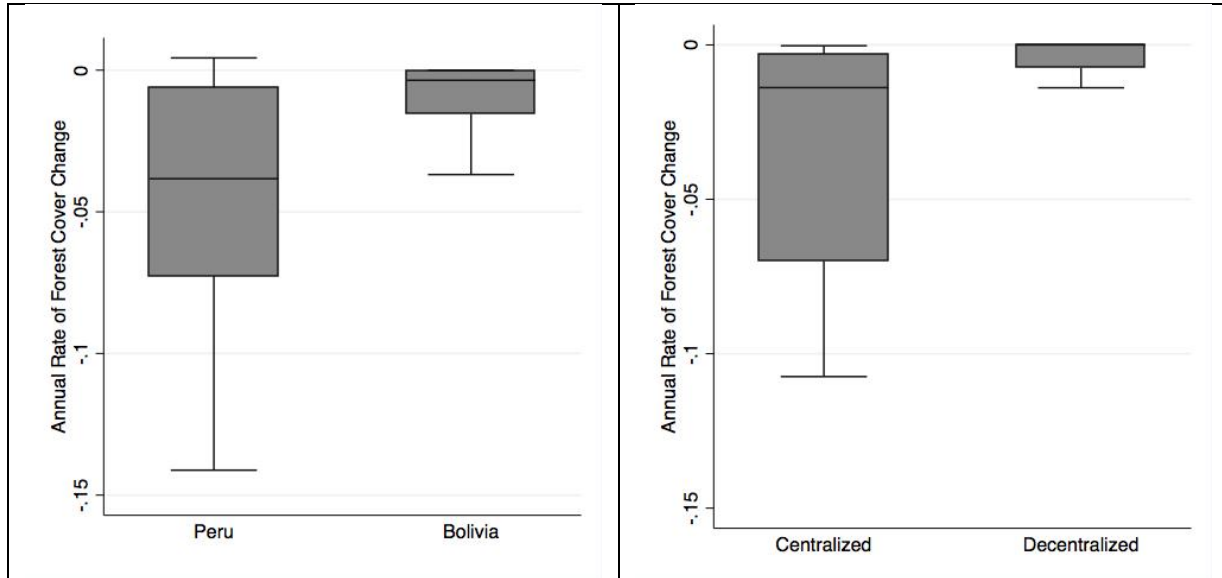


Figure 2. The effects of decentralization, based on the GEE regression models with matched units. The difference between centralized and decentralized municipalities is not significant where engagement is weak, but the effect of decentralization is strong and significant where community engagement is stronger. Dashed lines represent 95% confidence intervals.

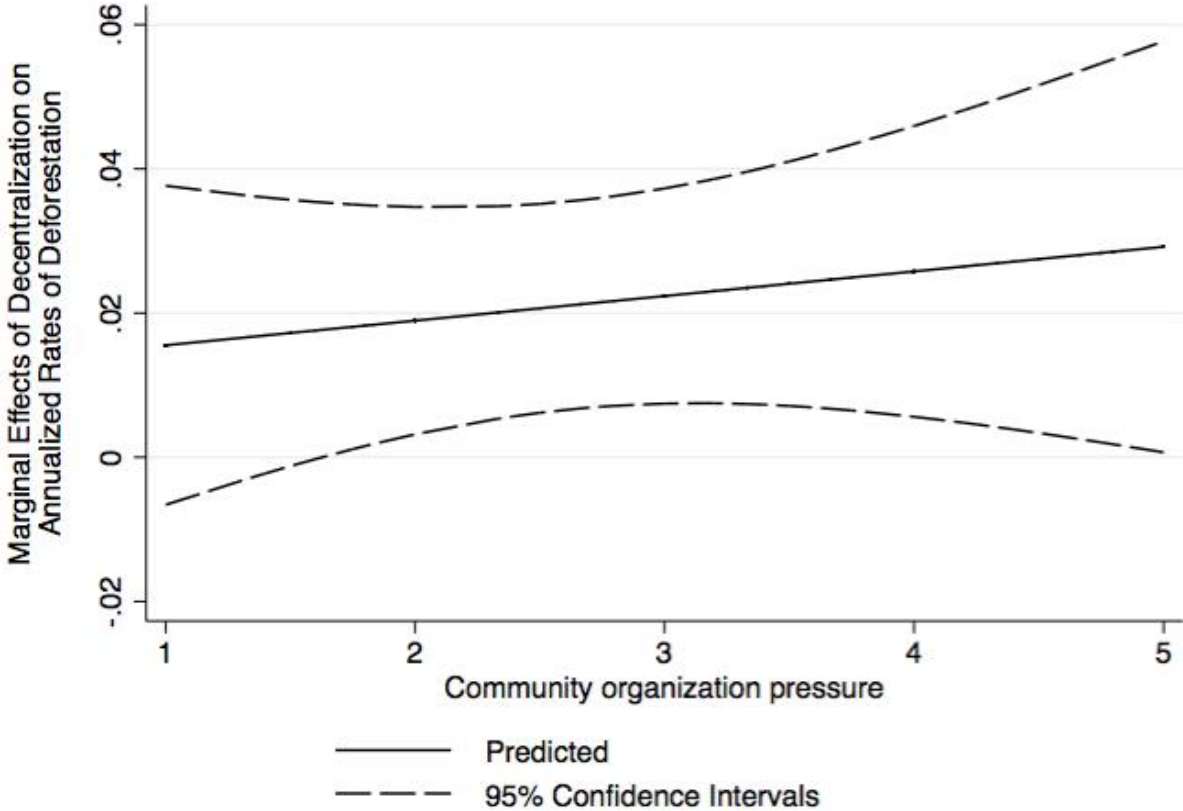
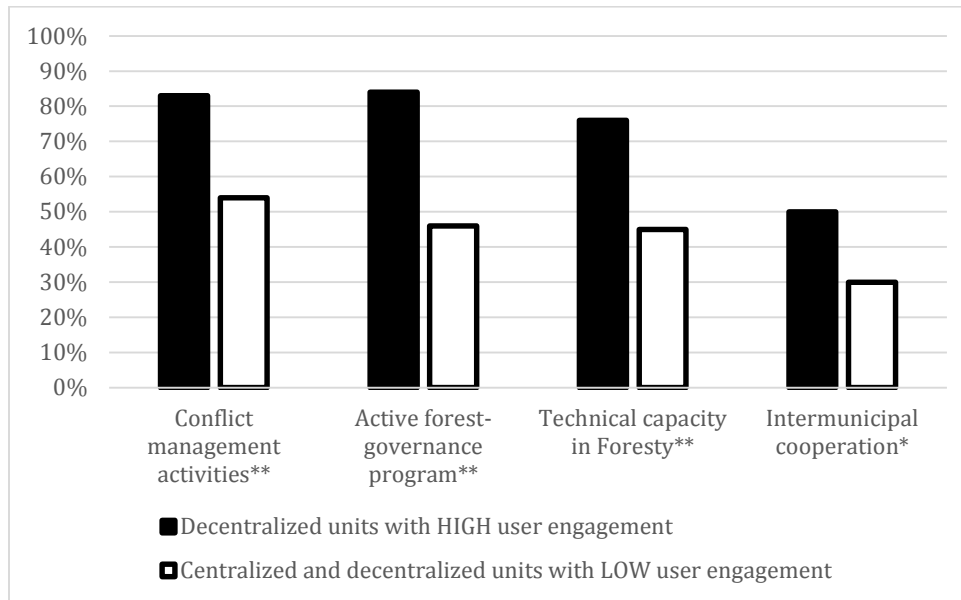


Figure 3: Comparing Indicators for Enabling the Local Governance of Common-Pool Resources



** $p < 0.05$

* $p < 0.10$

Table 1. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Decentralization	472	0.21	0.41	0	1
Community engagement	422	2.99	1.18	1	5
Community Engagement *					
Decentralization	422	0.65	1.29	0	5
Central government engagement	375	2.47	1.51	1	5
Annual forest change (pct.)	256	-0.02	0.03	-0.14	0.13
Forest cover (pct., lagged)	268	17.83	27.57	0	100
Slope (pct. > 12%)	465	46.32	31.8	0	94.8
Road density (ln)	249	-2.47	1.7	-9.21	0.47
Municipal size (ha, ln)	465	11.08	1.62	7.18	15.79
Population (ln)	405	8.27	1.48	3.67	12.63
Budget (\$US millions, ln)	423	-0.93	1.67	-8.19	5.22

Table 2. The effects of decentralization, matching results.

Matching Results						
Dependent Variable	Treatment Cases	Control Cases	Total Cases	ATE	ATU	ATT
Annual forest change (pct.)	43	59	102	0.03	0.03	0.02 (2.47)*
T-statistic in parentheses						
* significant at the $p < .05$ level; ** significant at the $p < .01$ level						

Table 3. GEE results: Effect of community engagement with local officials across centralized and decentralized regimes. Note that methodologists suggest that regression tables like these are not helpful in the case of interaction models [6, 14, 15].

	GEE Regression
Decentralization	0.012 (0.373)
Community engagement	-0.011 (0.000)**
Community engagement * Decentralization	0.003 (0.521)
Slope	0.000 (0.817)
Road density (ln)	-0.003 (0.241)
Population (ln)	0.004 (0.063)+
Municipal size (ha., ln)	0.005 (0.032)*
Budget (\$US millions, ln)	0.010 (0.000)**
Forest cover (lagged, ln)	0.000 (0.984)
Constant	-0.099 (0.001)**
Observations	101
Number of municipalities	79
p values in parentheses + significant at 10%; * significant at 5%; ** significant at 1%	

Supplemental Information

In this supplement to the paper, we provide more in-depth discussion of four methodological aspects of the paper. The purpose of this discussion is to provide sufficient detail on the methodological choices made in the study so that other researchers are able to replicate the study should they wish to do so. The supplement consists of five sections: (1) Background information on the study sites in Bolivia and Peru; (2) Measurement of forest-cover change; (3) Measurement of user-group engagement; (4) Methodological choices about matching and regression analysis, and (5) Description of data files available for download (which we are making available to reviewers as well as eventual readers).

(1) Background information on the comparative study of forestry policy in Bolivia and Peru

The cases of Bolivia and Peru provide an excellent comparison through which to examine the effects of decentralization and community engagement in the forest sector. While the two neighboring countries share a number of essential biophysical, socio-economic, historical and cultural characteristics, they differ on the variable of theoretical interest to this study: decentralization. Starting in 1996, Bolivian local governments were given substantial rights, responsibilities and resources from the central government to govern forest areas within their territories, while Peruvian local governments have no formal mandate to for forest governance [18,19].

Bolivia and Peru are neighbors, have high-mountain, and lowland Amazon jungle geographies. The two countries both have large indigenous populations, including Quechua- and Aymara-speaking highland indigenous peoples and multiple lowland indigenous groups. Both are middle-income countries with high levels of inequality and a great deal of rural poverty. Both countries share a history of Spanish colonial domination and unstable, authoritarian regimes in the post-independence period. More recently, both countries experienced similar waves of neoclassical or “neoliberal” economic liberalization. And both countries have recently emerged from periods of authoritarian rule and now host vibrant, contentious, though often corrupt democratic national governments. The democratization processes strengthened the customary land rights of indigenous populations in both countries. It also introduced democratic election procedures for political leadership positions within local level, multi-purpose governments (*municipios* in Bolivia and *distritos* in Peru) [19]. When it comes to forest governance, however, Bolivia and Peru differ significantly on their degrees of decentralization. This makes it possible to compare municipalities on the Peruvian side of the border to similar municipalities on the Bolivian side to examine the effects of decentralization. In addition, longitudinal data makes it possible to compare pre-decentralization Bolivian municipalities to similar municipalities after decentralization was implemented.

In 1990, the Congress of Bolivia passed the 1994 *Ley Participación Popular*, the “Popular Participation Law”—essentially a package of decentralization reforms which granted substantial authority and 20% of national tax revenues to municipal governments, and the 1996 *Ley Forestal 1700* decentralized substantial control over forests to local governments. The *Ley Forestal 1700* lengthened the tenure of leases to forestry firms for timber exploitation, made these leases renewable, and improved the security of tenure for the forest-dependent poor by creating new jurisdictions for the communal management of local forest resources [30]. Most importantly, it granted municipalities the power to monitor forestry operations and enforce forestry rules and regulations within their territory [18, 20, 30].

Unlike Bolivia, decentralization had not yet touched the forestry sector in Peru at the time of our last visit in 2008. While the Peruvian national government began to devolve power to the regional level of government (not to the municipal governments) in the early 2000s, during the presidency of Alejandro Toledo, resource governance remained in the hands of national government agencies [21, 22].

(2) Measurement of forest-cover change

The forest cover our data used to calculate the rates of change for each of the municipal territories for the three time periods come from Hansen et al (2013). The authors estimate the overall accuracy of these data for tropical forests to be 99.5% ($\pm 0.1\%$) (Hansen et al 2013, SM: 17). Although these data have been criticized for not distinguishing between planted and natural forests (cit) and for limited capabilities of detecting forest degradation (cit), we chose to use these data because they lend themselves to comparable analysis. The authors' well-documented and consistent methods used to quantify forest-cover change, not just across the Bolivian and Peruvian sites in our study but across the planet, make these data useful for the purposes of our study.

We used these data to calculate our dependent variable: the compound rate of forest-cover change. We calculate this for three time periods: 2000-2002; 2002-2008, and 2008-2012. The first period represents the forest conditions just prior to our first wave of field survey data. The second period represents the forest change trend for the period after our first survey wave (circa 2002) but before our second survey wave (circa 2008), and the third period captures forest cover change during the time after our second survey wave.

The first step of calculating the dependent variables was to create municipal territory maps for each of the 13 years (2000-2012) in the Hansen (2013) data set. For each of the municipal territories, we calculated the compound annual rate (CAR) of forest cover change for all municipal territories and for the three periods of interest:

$$CAR \text{ of forest cover change} = \left(\frac{\text{Ending Value}}{\text{Beginning Value}} \right)^{\left(\frac{1}{\# \text{ of years}} \right)} - 1$$

(3) Measurement of community engagement

We measure the degree of engagement between representatives from community-based organizations and the officials from the local government administration. The ordinal measure is described under the Material and Methods section above. Here we discuss the theoretical importance of this variable and why it works as a proxy measure for a series of institutional conditions that are considered to support decentralized governance of common pool resources.

User-group engagement is a good proxy measure for a host of institutional conditions that the literature on decentralized resource governance describes as conducive to effective governance of common pool resources [15, 16, 51]. More precisely, to achieve the institutional conditions described by most, if not all, of Ostrom's design principles [15] in the context of decentralized forest governance, active user-group engagement with local government decision makers is

necessary. In the absence of repeated interactions between local users and local government authorities, who are the targets of the decentralization reforms, it seems improbable to observe most, if not all, of Ostrom's eight principles [16]. What follows is an analysis of how each of the eight principles depend, to various degrees, on active user-group engagement: (1) Clearly defined physical and social boundaries: without engagement from users how will local decision makers know the boundaries of de facto property rights?); (2) Rules regarding the appropriation and provision of common resources that are adapted to local conditions (resources users know local conditions best); (3) Collective-choice arrangements that allow most resource appropriators to participate in the decision-making process (this cannot happen without some engagement of users); (4) Effective monitoring by monitors who are part of or accountable to the appropriators (relies on active engagement by users, both in monitoring activities as well as in holding monitors accountable); (5) A scale of graduated sanctions for resource appropriators who violate community rules (unless users and local government officials interact regularly, community rules will not be known to the government authorities); (6) Mechanisms of conflict resolution that are cheap and of easy access (user-group engagement will help communicate to governmental authorities what constitutes cheap and easy access to them); (7) Self-determination of the community recognized by higher-level authorities (this may happen in the absence of user group engagement, but when such rights are not recognized by the highest levels of authority, active community engagement with local government officials is likely to increase the likelihood of achieving such recognition), and (8) In the case of larger common-pool resources, organization in the form of multiple layers of nested enterprises, with small local CPRs at the base level (to create such nested governance, requires both communication and coordination among multiple governance actors, especially between local user groups and the governance actors immediately above in the national hierarchy of forest governance).

(4) Methodological choices about matching and regression analysis

Ideally, to test the effects of decentralization on forest-related outcomes such as deforestation, we would use a randomized, controlled experimental approach, in which decentralization reforms would be applied to randomly selected jurisdictions such as municipalities, while other jurisdictions would not receive the decentralization "treatment". If decentralization were applied randomly to municipalities in Bolivia and/or Peru, for example, it would be possible to examine the effects of decentralization, by comparing the average changes in forest cover in decentralized municipalities to changes in forest cover in cases which have not been "treated" with decentralization.

Such an approach is not practical because decentralization reforms were applied uniformly to all municipal territories throughout Bolivia and not at all in Peru. Instead, we attempt to use multivariate matching techniques to approximate randomization. Specifically, we use a matched sample in which municipalities in a decentralized setting are matched with non-decentralized municipalities which share key characteristics.

We use Mahalanobis matching in this study. This approach matches observations (in this case, several treatment cases for each control) according to the “Mahalanobis distance” between them. The Mahalanobis distance is the distance between observations in a multi-dimensional space, in which each dimension is a control variable (a variable upon which the matching is to be based). By using this technique, it is possible to generate a set of matched cases in which treatment and control cases are not significantly different on observables, except for the treatment. In essence, then, the technique, like other matching techniques, generates a “treatment” and “control” group that are statistically not significantly different on important observable control variables [14-16]

Quantitative methodologists suggest that the use of a propensity score as a matching criterion is helpful in improving the balance of matched samples, such that “control” (centralized) cases are more comparable to “treatment” (decentralized) cases [15, 16, 35-39]. We generate propensity scores—effectively, the likelihood that a municipality with the observed characteristics of a given sample municipality will appear in the treatment (decentralized) group—using several key biophysical variables, including annual rate of deforestation (lagged), the proportion of municipal area with a slope over 12% (the percent above which most mechanized agriculture is impossible), road density (km. per square km., ln), population (ln), municipal budget size (millions of \$US, ln) and municipal area (ha, ln). These propensity scores are then used as a matching variable in our Mahalanobis matching models, in addition to other control variables.

After generating a matched sample based on control variables and propensity scores, we used two-sample t-tests to confirm that our matched samples did not significantly differ in terms of the mean values of the centralized (control) and decentralized (treatment) variables. Where statistically significant differences between samples occurred, these differences indicated that our matched samples were not good comparisons. That is, we were, to some extent, comparing apples to oranges. Therefore, in order to generate apples-to-apples comparisons, we eliminated poorly-matching observations from the sample, by eliminating matches with significantly differing propensity scores. In the end, we were able to generate a strong sample of cases with no significant differences in terms of the control variables in our model. In short, our matched sample does appear to be a good apples-to-apples comparison.

Matching enjoys certain advantages over regression, but is not useful when examining the interactive effects of multiple inputs on a single outcome. To deal with this shortcoming, as noted above, we use regression models to test hypotheses involving interactions between community and decentralization. Because the data is cross-sectional, time-series data, we use a population-averaged Generalized Estimating Equation (GEE) time-series approach. GEE models are extensions of generalized linear models like Poisson and logit regression, but which allow analysts to compensate for serial autocorrelation by assuming a “working” within-unit correlation matrix and adjusting errors accordingly [35-39]. All the models here were tested in regressions which assume a range of different within-unit correlation matrices, with no substantive differences in our results.

The presence of many poorly-matching cases in our matching analysis suggests that regression results would include the inappropriate comparison of cases which are different—an apples-to-oranges comparison. In our tests, we examined regression models with both matched samples and unmatched samples, and found that these tests produced different results, suggesting that regression models are inaccurate in the case of decentralization because they may tend to compare incomparable cases. The approach of using regression models after pre-processing data with matching models addresses this problem and allows us to enjoy some of the advantages of

regression-based techniques while also comparing similar cases through matching pre-processing [6, 19].

Besides the results we report here, we also conducted a number of robustness checks on our regression results. These included the following: (a) re-testing our models after removing observations with high deviance residuals and high leverage cases, (b) including a fuller set of controls, including a range of mayoral characteristics such as gender, ethnicity, and years in office, indigenous population, human development index (HDI) and HDI squared terms, total municipal size (natural logarithm, square kilometers), total forest size (natural logarithm, square kilometers), and total number of municipal employees, and (c) including and excluding these in a series of sensitivity tests. Using these tests, we were never able to change the direction or significance of our independent variables of interest.

The models shown here use “percentage of municipality covered in forest” as a control as a measure of the relative availability of forest resources. However, we also tested all the models shown here with a measure of absolute forest size (forest cover in square kilometers, ln). Both control variables produce the same substantive results.

Table 1 shows descriptive statistics for the variables used in the statistical models presented here, Table 2 shows our matching results, and Table 3 shows our GEE regression results. The substantive meaning of these matching and regression tables is explicated in the text of the paper.

[Table 1, 2, and 3 about here]

(5) Description of data files for download

The data used in the analysis is available for download. To facilitate replication, the table below serves as a codebook for the data file. [provide link for download]

Variable name	Description	Comment
Unique identifier		
Muni		
Dept		
Country		
DV_2000		
DV_2008		
etc		