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Decentralization can help reduce deforestation when user groups engage with local government

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Policy makers around 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 study presents 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 ability of reforms 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 (a country with a much more centralized forestry policy). We find that territories with a decentralized forest governance structure have more stable forest cover, but only when local forest user groups actively engage with the local government officials. We provide evidence in support of a possible causal process behind these results: When user groups engage with the decentralized units, it creates a more enabling environment for effective local governance of forests, including more local government-led forest governance activities, fora for the resolution of forest-related conflicts, intermunicipal cooperation in the forestry sector, and stronger technical capabilities of the local government staff.

Bolivia | Peru | decentralization | forests | governance

Forests are complex systems that defy simplistic, one-size-fits-all governance approaches. Like other common-pool resources (CPRs), forests are susceptible to overuse and degradation because it is costly to exclude potential users and their use can degrade or even deplete the resource. To make governance even more challenging, forests take far longer to develop and recover than the sitting terms of parliamentarians or presidents.

For a century, governments implemented top-down, centralized forest policy, considering it to be the superior approach to ensure effective protection and use. However, many scholars and policy makers now perceive such an approach failed to sustain both forests and the livelihoods of the groups that depend on them (1, 2). Starting in the 1980's, many national governments and international donors responded to this new view by aggressively pursuing policies to decentralize the governance of forests, transferring many rights and responsibilities associated with forest governance from the central to subnational governments (3–5). Currently only a handful of developing countries have not decentralized forest governance (6–11).

The core argument behind the decentralization reforms, which international organizations have used widely, is that local authorities have better information about local forests and users, and thus can develop better policy solutions (5, 12–14). Several experts, however, have started to question the effectiveness of decentralized governance of collective goods, such as forests, suggesting such reforms may result in worse outcomes or, at best, outcomes no better than under central government control (12, 15, 16). Few robust studies exist that test this proposition: Extant work employs either qualitative case studies with a small number of observations or tends to focus on the village-level effects of the devolution of property rights to local user groups rather than on the decentralization reforms that target general-purpose, local government units, even though they are the most common targets of the decentralization policies (6, 17–20). We thus lack persuasive evidence for the effectiveness of these reforms in the very place that was the main target of the reforms: within the jurisdictions of local, general-purpose governments.

The lack of relevant and robust evidence is particularly serious for the ongoing policy efforts to curb tropical deforestation, such as the international initiative on Reducing Emissions from Deforestation and Forest Degradation. Without credible studies, policy makers can know neither the effectiveness of current policy instruments nor how to alter them to increase their effectiveness in the future (21).

Here, we draw on CPR theory (22–24) to develop an argument about the institutional conditions under which decentralization is likely to lead to improved forest governance outcomes. Specifically, we derive our argument from the work of Elinor Ostrom, who proposed eight design principles for sustaining CPRs (22). The achievement of most of these principles hinges 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 (*Measurement of Community Engagement*). This logic provides the foundation for our main proposition: When local user groups engage actively with local government officials, this engagement improves the conditions for effective CPR governance and makes it possible for decentralization to sustain forests.

To test this argument, we constructed an original database measuring decentralization policy, local governance attributes, and forest

Significance

Decentralization is one of the most important innovations in environmental policy during the past 30 years. Despite the pervasiveness and 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 hampers efforts to improve the effectiveness of current policy initiatives. Using 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 take advantage of opportunities to engage with local politicians about forestry issues.

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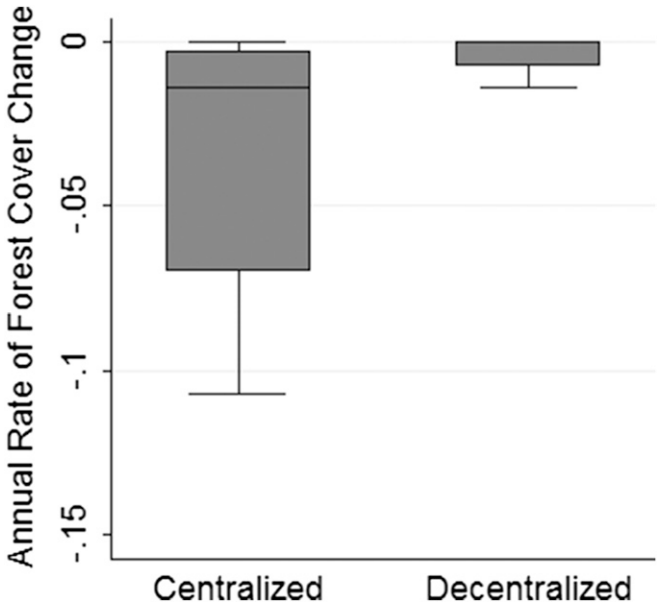

Fig. 1. Forest cover differences for matched Peruvian and Bolivian samples. Under decentralization, rates of deforestation are significantly lower (less negative). These results are shown in table form in Table S5.

cover change in 200 municipal territories in Bolivia and Peru. While sharing a number of biophysical, socioeconomic, and cultural factors, Bolivia's central government passed a forestry decentralization reform in 1996 that gave local governments (*municipios*) substantial rights, responsibilities, and resources to manage some of their forested areas (25, 26). Over the same time period, Peru kept most powers over forests under the purview of the central government (27, 28). We use matching techniques to compare outcomes in the local government territories in the decentralized setting with outcomes in similar territories in the centralized setting. With these matched observations, we then use regression techniques to evaluate the environmental impact of decentralization and the conditions under which such reforms can help stabilize forest cover.

Results

Our results show that the decentralization of forest governance to general-purpose governments is associated with lower overall rates of deforestation. This relationship disappears, however, in cases where such governments fail to build relationships with local groups who use the forest: Community engagement appears to be a necessary factor for the successful decentralization of forest governance.

The plots in Fig. 1 show differences between forest cover in carefully matched decentralized and centralized territories (details are provided in *Materials and Methods*). In terms of rates of forest cover change, decentralized territories have significantly more stable forest cover ($P < 0.05$). The average treatment effect associated with decentralization is 2.6% less forest lost per year.

We then analyzed the effects of community engagement on deforestation across decentralized and centralized municipalities to see if the effect differed between these two groups. To do so, we generated an interaction term, the product of "decentralization" and "user-group 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, the significance of coefficients in the table is not substantively meaningful; therefore, as suggested by methodologists (16), we interpret the results by examining the confidence intervals in the graph of the marginal effect of decentralization on change in forest cover, given different levels of user engagement (Fig. 2).] Fig. 2 shows a graph of the marginal effects of a change from a centralized to decentralized regime, conditional on the level of user-group engagement with the local government. The results 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. With greater community engagement, however, decentralization has a positive effect on forest cover change, leading to significantly lower rates of deforestation ($P < 0.05$).

Our results also indicate that the Peruvian government's decision to exclude forest governance rights and responsibilities from the municipal government mandate may have backfired. The regression analysis (Table S1) finds that community engagement in Peru had a negative effect on forest cover change. We attribute this result to the fact that Peruvian municipalities have no official mandate to work on forestry issues, although they do have a mandate and some public resources to facilitate agricultural development (29). Citizen engagement under such circumstances may not contribute to more and better interventions to protect forests or to promote forestry (*Background for Comparison of Forestry Policy in Bolivia and Peru*). On the contrary, it may result in higher deforestation rates because agricultural land use often competes directly with forestry and forest conservation activities.

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 in a decentralized setting is necessary for creating an enabling policy environment for the governance of CPRs, such as forests. When the local policy environment is favorable for CPR governance, deforestation rates are lower. To test this idea further, we apply Ostrom's thesis about CPR governance (22, 23) to the study of decentralization and examine empirically the extent to which Ostrom's "design principles," a set of institutional conditions that she argues help to sustain CPRs, are present in our sample of municipal territories. (We use our field observations from 2008 for this part of the analysis.) The main idea here is that the fulfillment of these design principles is more likely when user groups are

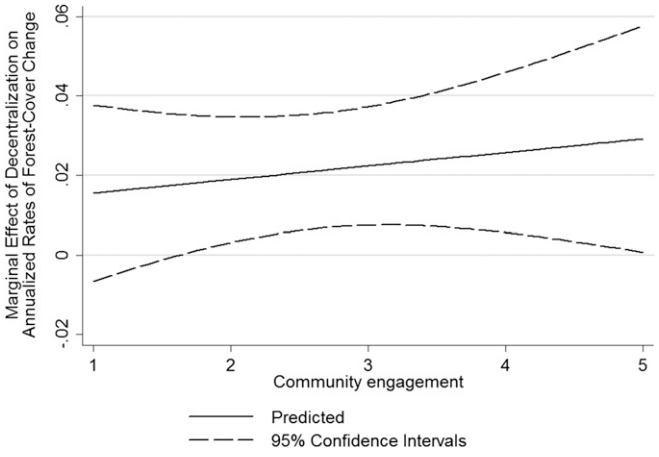

Fig. 2. Effects of decentralization, based on the GEE regression models with matched units. The difference between centralized and decentralized municipalities is not significant where engagement is weak, but the effect of decentralization is strong and significant where community engagement is stronger.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

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more actively engaged with the local government officials in decentralized entities (a more complete analysis is provided in Table S2). Of the eight principles in Ostrom's theory, we have field data on four: (*i*) existence of forums for conflict management, (*ii*) monitoring and enforcement activities by individuals who are accountable to users, (*iii*) the ability of matching solutions to local conditions, and (*iv*) the institutional nestedness of forest governance arrangements. We use our field observations to test whether these enabling conditions vary among the municipal territories in our sample.

We compare indicators for these four institutional conditions between four groups of municipal territories in Bolivia and Peru: (*i*) decentralized territories with high degrees of user-group engagement, (*ii*) decentralized territories with low user-group engagement, (*iii*) centralized territories with high user-group engagement, and (*iv*) centralized territories with low user-group engagement. Our theoretical expectation is that favorable institutional conditions exist to a greater extent in decentralized territories where user groups actively engage with local government officials. The results in Fig. 3 support this idea, showing that decentralized territories with a high degree of user engagement report consistently higher scores on our four proxy measures of Ostrom's design principles (22). [The reported results in Fig. 3 are based on Pearson χ^2 test statistics and associated P values for cross-tabulations that examine the degree of association between decentralized units (yes/no) and user engagement (high/low)].

According to Ostrom's design principles, systems that enjoy easy access to fora for conflict resolution are more likely to govern their shared resources sustainably (22). As an indicator for this condition, we calculate the proportion of local governments that report having intervened in conflicts in the forestry sector where such conflicts exist. As shown in Fig. 3, there is more frequent intervention in conflicts in decentralized territories in which local user groups are actively engaged with local governments than in the rest of the sample ($P < 0.01$).

A second design principle states that successful local governance of CPRs is more likely when the individuals responsible for monitoring and enforcement are accountable to the users (22). One of the 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 (30). Here, we examine the existence of monitoring programs in the four types of local administrations. We find that such programs are more likely to exist in decentralized units where users are activity engaged ($P < 0.01$).

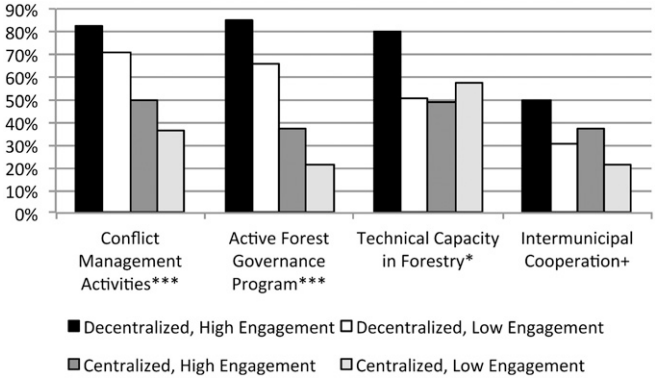

Fig. 3. Percentage of municipalities that meet four of Ostrom's design principles. In these statistical tests, we compare four groups of municipalities in our sample: 26 decentralized municipalities with high community engagement, 74 decentralized municipalities with low community engagement, 43 centralized municipalities with high community engagement, and 57 centralized municipalities with low community engagement. *P < 0.1; **P < 0.05; ***P < 0.01.

According to Ostrom (22), the success of CPR governance depends on matching institutional arrangements with the local context. We propose that in order for a local governance system to match solutions to the specific local circumstances, the system needs to have technically competent personnel in the local government administration. Consequently, the units responsible for the creation and enforcement of rules about forest use need to have some technical knowledge about forestry. As a proxy for this condition, we calculate the number of local government employees with formal training in forestry or agricultural sciences. The results in Fig. 3 show that the decentralized units with high user engagement have a higher proportion of employees with technical training ($P < 0.05$).

Finally, Ostrom's eighth design principle states that effective local governance of large-scale CPRs 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 agreements between local governments to cooperate on forest governance activities. Our comparison shows that such cooperation exists at a higher rate in the decentralized units with high user engagement ($P < 0.1$).

The results of these comparisons of proxy indicators suggest that the decentralized territories where users are more actively engaged experience better conditions for effective local forest governance compared with territories where users are not as engaged. Taken together, these results suggest that a possible process through which decentralized systems can maintain more stable forests is by organizing their work in ways that make involvement with forest users both possible and meaningful.

Given the inherent uncertainties associated in all comparative analyses, we consider the possibility of unobserved differences that may explain the variation in deforestation rates between the local territories of the two countries. As plausible alternative explanations for our results, we consider three differences between Bolivia and Peru: (*i*) central government policies, (*ii*) political history, and (*iii*) market opportunities. Detailed tests and discussions of these three possible explanations can be found in *Alternative Explanations to the Observed Results*. Our conclusion from our analysis of these alternative explanations, however, is that our comparative analysis provides a stronger explanation of the observed patterns. All three alternative explanations imply that there might be unobserved differences in government policies, political history, and/or market incentives that would make deforestation more likely in Peruvian territories regardless of any decentralized policy. According to this logic, one would expect to see one or more of these contextual factors generating decisions and actions in Peru that lead to high anthropogenic pressure on forests and a resultant increase in deforestation rates in the aggregate (or at least higher than in Bolivia). One would also expect that such differences could be identified by examining deforestation rates (before the time of the Bolivian reform) in each of Peru's local territories in our study.

Such expectations, however, are not consistent with empirical data at either the national or local level. First, data on aggregate deforestation rates show the opposite: Peru has experienced lower overall deforestation rates at the national level than Bolivia during this period (31). Second, because our comparative analysis between local territories in Bolivia and Peru controls for historical deforestation rates, along with a number of other proximate drivers of deforestation in each territory, we can be more confident that the results of our analysis are not driven primarily by these differences.

Reverse causality may also threaten our explanation (i.e., that areas with better forest condition or lower deforestation rates might somehow be more likely to have been decentralized in

Bolivia). Such reverse causality is not the case, however; every local government in the country received the same rights and responsibilities over the forests simultaneously (26). A subtler endogeneity concern is that user groups would be more likely to engage with local governments in areas with more abundant and stable forest resources, but such an explanation is not supported by theory. A core finding by researchers examining local environmental governance is that forest user groups are more likely to engage in a resource's management when it is salient, scarce, and perceived to be threatened, not when it is abundant and in good condition (30, 32).

All comparative analyses warrant caution when interpreting the results. Although it is impossible to control for all contextual differences between territories, our design uses the careful matching of similar areas and longitudinal data, which increase our confidence in the inferences we draw from the analyses.

Conclusion

Our results show that decentralization is not a panacea. Decentralization does not automatically lead to more stable forests because outcomes likely depend on how local politicians choose to interact with other members of the local governance system. Our findings suggest that the interactions between local forest users and local politicians are particularly important because this relationship can strengthen the 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.

Forest user engagement with local government officials is also important because it allows 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 the literature on democratic decentralization (5, 9, 33) with more frequent communication, local politicians can gather information about community needs and preferences, making it feasible to respond to local needs and, in this way, strengthen the support of their constituents and their chances for reelection. Strong user-group engagement also allows community members (voting constituents) to gauge the performance of local politicians, making it possible for community members to reward effective politicians with reelection and to punish ineffective or corrupt leaders by voting against them (21, 34).

Even when local government territories experience more stable forest cover, however, it does not necessarily mean that people's livelihoods are improved or that some form of distributive 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 to strengthen their own narrow, self-interested objectives in the forestry sector. Such processes of elite capture, which several studies report to be a common byproduct of decentralization reforms (35, 36), cannot be ruled out on the basis of our results.

In sum, our findings show that decentralized regimes can, under certain conditions, perform better than centralized regimes. Achieving such improvements involves making sure that forest users have ample opportunities to participate in the decentralized governance process. Previous studies show an important role for external organizations in supporting such participation (37, 38). For example, inclusive governance is more likely when central governments require local governments to conduct participatory planning and budgeting activities and mandate the establishment of local committees to oversee local government spending (28, 39), as well as when nongovernmental organizations support user groups to strengthen their organizational capabilities (40, 41). Such interventions, in combination with forestry decentralization, can improve the governance of the world's forests.

Materials and Methods

There are four major data sources for this study: (*i*) surveys of local governance actors (2001 and 2008), (*ii*) census/archive data (2000 and 2007), (*iii*) satellite images (1993, 2000, and 2008), and (*iv*) digital elevation models of Peru and Bolivia. In each of 200 selected municipalities, we interviewed the elected mayor in two waves: 2001/2002 and again in 2008. In addition, we interviewed municipal forestry officials and community leaders to triangulate responses. 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 nongovernmental agencies, and relationship with citizens.

Biophysical data were generated from two sources: (*i*) digital elevation models to characterize steepness of terrain, and (*ii*) data on forest cover that were generated using remote-sensing analysis (Landsat Thematic Mapper satellite imagery and aerial photography). We used digital elevation models (30-m Shuttle Radar Topography Mission) to generate measures of surface slope to identify 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 performed remote-sensing analysis of satellite images acquired to estimate forest cover change for our sample of 100 local government territories in Bolivia and for 35 Peruvian municipalities in the period. The methods used to calculate the dependent variable, forest cover change, are described in *Measurement of Forest Cover Change*.

Decentralization is perhaps our most important independent variable of interest. At the time our data were collected, Bolivia had experienced a country-wide process of decentralization of forest governance. In 1994, the Congress of Bolivia passed the *Ley Participación Popular*, the "Popular Participation Law," essentially a package of decentralization reforms that granted substantial authority and 20% of national tax revenues to municipal governments. The enactment of this law was followed by the 1996 *Ley Forestal 1700*, which 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 citizens by creating new jurisdictions for the communal management of local forest resources (26, 42). Most importantly, it granted municipalities the power to monitor forestry operations and enforce forestry rules and regulations related to forest clearings within their territory (42).

Unlike Bolivia, forestry decentralization had not yet touched the forestry sector in Peru at the time of our last survey wave in 2008. Although the Peruvian national government began to devolve power to local government (both regional and municipal governments) in the early 2000s, forest governance remained in the hands of national government agencies (28, 43). Forestry decentralization did eventually affect Peru (decentralization reforms were implemented shortly after our second, and final, wave of surveys was gathered), but even when these reforms took place, forestry governance was not devolved to municipalities, instead being granted to regional governments (roughly equivalent to states in the United States or departments in Bolivia) (29).

In practice, the absence of decentralization reforms in Peru does not mean that local governments were never engaged in forest governance activities. Peruvian municipal governments do have a well-institutionalized system for citizen input in municipal politics (including nationwide municipal participatory budgeting processes and extensive advisory roundtables, in addition to a thick network of civil society organizations), but these institutions are rarely involved in systematic forest governance activities. Since the early 2000s, the Peruvian national government did, however, begin handing over more responsibilities for public services related to agricultural land uses (43).

We present two independent variables of interest: decentralization reforms and degree of community engagement on change in forest cover (deforestation) over time. Decentralization is a dummy variable that identifies whether the municipality was located in a formally decentralized regime at the time when the survey data were collected for that municipality. Because Peru did not experience a decentralization reform during this period, this variable is coded 0 (meaning centralized) for both survey waves in Peru (2001 and 2008). For Bolivia, we coded decentralization as 0 (centralized) during the first wave (2001) and as 1 (decentralized) during the second wave (2008) of data collection. Decentralization was coded in this way because we believe, supported by policy literature in Bolivia, that the 1996 forestry decentralization reforms experienced a significant policy lag: a significant amount of delay in the efforts to implement the new regime, integrating municipal governments functionally

into the new governance regime (44, 45). Our explanation is that there would be a policy lag that delayed the impact of the newly implemented governance regime on rates of deforestation. Over time, as the new decentralized governance regime took hold, we would expect a cleaner signal of a relationship between decentralization and deforestation to emerge. To ensure our results are robust to an alternative coding of decentralization, we ran all of the models presented here in which Bolivia is coded as 1 (postdecentralization) in both survey waves (2001 and 2008). This alternative coding represents a test of an outcome where there is a near-immediate impact of the new decentralization regime on a reduction in deforestation (shorter policy lag). Although this alternative coding changed the balance of our matching sample significantly, the direction and significance of our results did not vary when using this alternative coding: Decentralization still reduces forest cover loss significantly ($P < 0.05$).

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"), which is a variable that has been shown to predict the extent to which democratically elected local governments involve citizens in both policy decisions and implementation (38). 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 use two multivariate techniques: (*i*) Mahalanobis matching with propensity scores and (*ii*) GEE regression using Mahalanobis matching with propensity scores as a preprocessing technique to eliminate noncomparable observations.

Descriptive statistics for all of our values are included in Table S3, and a code book for these variables is included in Table S4. For the datasets used in this paper, see Datasets S1 and S2. The cases of Bolivia and Peru provide an opportunity to use comparative analysis to study the effects of decentralization and community engagement on forest outcomes. Even 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 in this case because we are likely to confuse differences between Peru and Bolivia with the effects of decentralization (46–51).

Instead, we draw on recent studies in program evaluation to create a quasi-experimental research design that enables an approximation to a counterfactual analysis (52, 53). Through this research design, we compare what happened after the reform in Bolivia with a counterfactual scenario of what is likely to have happened in the absence of the decentralization reform. Because such a scenario does not exist in Bolivia, because all local governments were given the same rights and responsibilities through the reform, we use Peruvian local government territories as surrogates for the unobservable counterfactual scenario in Bolivian territories.

Using Peru as a surrogate counterfactual scenario for Bolivia constitutes a hard "test case" because at the national aggregate level, Peru experienced slightly lower deforestation rates than Bolivia during the 2000–2010 period (31). This finding means that the comparative analysis of local governance outcomes is biased against Bolivian territories, and that Bolivian local governments face an uphill battle to exhibit lower deforestation rates than their Peruvian counterparts.

Following this design, we use multivariate matching techniques to ensure that the Peruvian territories that represent the surrogate for a Bolivian counterfactual scenario are as similar as possible to the Bolivian territories when it comes to several contextual variables, such as population densities, topography, road densities, forest cover, and historical deforestation rates (before the implementation of the Bolivian reform). Despite carefully developed comparisons, using multivariate matching techniques, there is still a great deal of uncertainty associated with the inferences drawn from comparative analyses, especially when such comparisons cross national borders. (Spatial autocorrelation is not a major concern for this analysis because in our matched sample of local government territories, municipalities are generally located at great distances from one another.) Because of the uncertainties associated with all comparative work, it is important to consider alternative explanations of the observed patterns and how unobservable differences might have affected the results. Three such alternative explanations are discussed in *Alternative Explanations to the Observed Results*.

The Mahalanobis matching method matches observations (in this case, several treatment cases for each control) according to the "Mahalanobis distance" between them (49). The Mahalanobis distance is the distance between observations in a multidimensional space, in which each dimension is a control variable (a variable upon which the matching is to be based). These control variables include annual rate of deforestation (lagged), the proportion of municipal area with a slope over 12% (the percentage above which most mechanized agriculture is impossible), road density [kilometers per square kilometer, natural logarithm (ln)], population (ln), municipal budget size ($US million, ln) and municipal area (hectares, 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" group and a "control" group that are statistically not significantly different on important observable control variables (49, 50, 54, 55). 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 (50, 51, 56). We generate propensity scores using several of 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. 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 (54, 55).

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 engagement 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 is problematic because it tends to compare incomparable cases. Our approach, using regression models after preprocessing data with matching models, addresses this problem (56). The regression technique we use here, GEE regression, is used to deal with potential temporal autocorrelation in panel data (57–60).

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