Titling Community Land to Prevent Deforestation: No Reduction in Forest Loss in Morona-Santiago, Ecuador

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Abstract:

Land tenure and land titling programs for forests have become a mainstay of conservation and resource management policy worldwide. They are thought to reduce deforestation by lengthening the time horizon of landholders and improving the ability of landholders to legally exclude competing users. Despite these expectations, reliable evidence about how land titling programs affect forest cover is limited because programs are targeted according to other factors that themselves influence the conversion of forests, such as indigenous status or low population density. We investigate the effect of a donor-funded land titling and management program on forest cover in Morona-Santiago, Ecuador. To estimate the impact of community land titles and management plans, we match plots in program areas with similar plots outside program areas on a variety of covariates that influence forest conversion. Based on matched comparisons, we do not find evidence that land titling or the creation of community management plans reduced forest loss in the first five years after the program. Our results are some of the first evidence about the effects of land titling programs on forests that account for spatial assignment and interactions with other institutions. More broadly, our analysis demonstrates the promise of using remotely sensed data to evaluate the effects of policies beyond normal cycles of policy and program evaluation.

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Keywords: Remote Sensing, Land Titling Programs, Forest Cover, Matching Methods

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AidData – a joint venture of the College of William and Mary, Development Gateway and Brigham Young University – is a research and innovation lab that seeks to make development finance more transparent, accountable, and effective. Users can track over $40 trillion in funding for development including remittances, foreign direct investment, aid, and most recently US private foundation flows all on a publicly accessible data portal on AidData.org. AidData's work is made possible through funding from and partnerships with USAID, the World Bank, the Asian Development Bank, the African Development Bank, the Islamic Development Bank, the Open Aid Partnership, DFATD, the Hewlett Foundation, the Gates Foundation, Humanity United, and 20+ finance and planning ministries in Asia, Africa, and Latin America.

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Contents

1. Introduction

Assigning land title to customary and collective landholders is one of the primary policies used to avoid deforestation worldwide (Davis and Wali 1994; Soule et al. 2000; Fearnside 2001; Place and Otsuka 2001; Finley-Brook 2007; ITTO 2010; Larson 2011; Larson and Dahal 2012; Robinson, Holland and Naughton-Treves *in press*). When landholders have secure, long-term access to land, backed up by the exclusion and enforcement capacity of the state, they are expected to manage resources to maximize benefits over a long time horizon. For forests, this type of management might involve less extraction of resources in early periods to ensure that a continuous stream of timber, game, forest products, or cultural amenities are available in later periods. Landholders with formal title are also expected to be more successful in excluding colonizers and extractive industries from customary lands. Upon receiving land title, landholders gain access to courts, law enforcement, and regulatory agencies that improve their ability to exclude competing users.

Based on these expectations, international aid donors, government agencies and conservation organizations have embraced land titling as a way to improve the management of forests and reduce deforestation (Tucker 1999). For example, the United States Agency for International Development (USAID) maintains an Office of Land Tenure and Resource Management, which aims to promote sustainable resource management worldwide through land titling and land tenure programs (USAID 2006). The World Resources Institute, a non-governmental organization with global reach, created the *Governance of Forests Initiative* to advise countries with large amounts of forests about land allocation and tenure. The clarification of land tenure — use and occupation rights to land that can be effectively enforced — in areas where indigenous populations reside, also aligns with donor efforts to promote minority rights, credit markets, and pluralism in politics (Liverman and Vilas 2006; Godoy et al. 1998; Robinson, Holland, and Naughton-Treves *in press*).

Additionally, land title often provides landholders with access to incentive programs that pay for ecosystem services and the maintenance of forest cover. Thus, land tenure programs are crucial prerequisites to many types of resource management policies. Indeed, as the global community debates scaling up the REDD+ program at the United Nations, international donors have made land titling a centerpiece of activities (Naughton-Treves and Day 2012). The REDD+ program has sponsored international meetings, such as the one in Rome during November 2010, to discuss strategies to improve legal tenure regimes in forest areas to support this global program at the center of international climate mitigation efforts. At the national level, incentives schemes that pay for the maintenance of forests require clearly delineated property owners who can be responsible for land management. As a consequence, payments for forest conservation, through programs like Ecuador’s flagship Socio Bosque, require landholders to secure land title for eligibility (de Koning 2011).

Despite the enthusiasm of forest managers and conservation practitioners about land tenure, given its importance for a number of areas of natural resource management policy, little reliable evidence exists about how the assignment of land title to individuals or communities affects forest cover. In a recent review of the relationship between land tenure and forest outcomes, Robinson, Holland, and Naughton-Treves note that existing research fails to isolate the direct effects of land titling programs from the background factors that are associated with selection into land titling programs (*in press*). Land titling programs are often targeted or spatially clustered on the basis of factors that independently affect forest cover, such as proximity to settlements and indigenous territory status. This non-random selection process for program siting makes it difficult to isolate the effect of land titling interventions from other factors that are present alongside land titling programs. As is the case with many spatially-explicit land management policies, this limits reliable estimates of program impacts (Joppa and Pfaff 2010).

Adding to the uncertainty, the effects of land titling programs are likely to be conditional on features of the governance environment and interactions with other programs (Barsimantov and Antezana 2012; Smith and Pinedo 2002). Recent research has moved away from estimating the effect of land tenure status as a single intervention towards analyzing how these policies interact with complex governance and geophysical factors (Mullan et al. 2011; Barsimantov et al. 2011; Paneque-Galvez et al. 2013). For example, land titles exist only in name if not backed up by institutions that enforce usage or exclusion rules and legitimize claims to them (Kerekes and Williamson 2010). This challenge requires that similar land titling programs are evaluated across areas with different supporting land management institutions.

To produce more reliable findings, we address the non-random spatial assignment of a land titling program and evaluate variations in effects when this land titling program is implemented alongside community management plans. We analyze a unique, spatial dataset of USAID-funded land titling activities for communal, indigenous, and primarily-forested areas in the province of Morona-Santiago, Ecuador. The Programa de Sostenibilidad y Unión Regional Sur (also known as Programa Sur or PSUR) was a binational border integration and development program. It was implemented from 2002-2007 in three provinces adjacent to Peru: El Oro, Loja, and Morona-Santiago. The program had a budget of $27 million and was co-implemented by CARE International and other local and international organizations (Care 2007). PSUR focused on social services, natural resource management, income generation, and the strengthening of local institutions. These activities formed USAID’s Conservation and Development Strategies with Lowland Indigenous Groups initiative (USAID 2010).

USAID and partners implemented land titling and natural resource management activities only in Morona-

Santiago and targeted Shuar indigenous territories around the Kutuku protected forest ridge. By the end of the project, PSUR claimed to have benefited more than 24,000 people and titled over 170,000 hectares of communal lands in that province, more than 80% of which included a complementary community management plan intended to enhance community natural resource management. PSUR intended to lay the groundwork to conserve the nearby and overlapping Kutukú Protected Forest area (USAID 2011; CARE et al. 2012).

Since one stated objective of PSUR was to improve local livelihoods, the program was initially evaluated only in terms of the number of direct and indirect beneficiaries residing in the three provinces — 499,420 in total for the three provinces according to a project report (Care 2007). In Morona-Santiago province, PSUR also aimed to achieve conservation goals by strengthening the management capacity of indigenous groups. USAID considered secure land tenure to be a critical basis for successful conservation of forest cover based on the assumption that securing land rights, improving living conditions and strengthening institutions would empower local groups to counter external economic and socio-political pressures that lead to deforestation. For example, a 2011 USAID report of land tenure programs in Ecuador commented that "a growing awareness of the importance of environmental issues in Ecuador provides an opportunity to bring tenure issues to the forefront, as they are closely related to conservation of biodiversity and use of natural resources including land, water and forests." Such statements, while rooted in beliefs about conservation policy, are not based on evidence from the evaluation of forest cover following titling and land management programs. Neither the environmental or social impacts have been evaluated for PSUR, including impacts realized after implementation of the program.

Indeed, it is difficult to complete evaluations that both carefully account for the non-random assignment of policies and evaluate impacts over several years following implementation. Program evaluation related to development and environmental management projects generally focuses on immediate results achieved during implementation. For many areas of policy, there is considerable uncertainty about long-term effects of programs because monitoring is not pursued after implementation (Asian Development Bank 2010; Pluye, Potvin and Denis 2004; Scheirer 2005; Stirman et al. 2012). Now that at least six years have passed since the implementation of PSUR programs, it is possible to observe whether its activities had any effect on forest cover. Using remotely sensed data on forest cover, we are able to quantify the effects of the program without costly and continuous field presence. We argue that similar techniques can be scaled up and applied in other policy areas.

Because PSUR interventions occurred in a region where similar lands remained untitled through the end of our study period, we are able to identify matched counterfactual plots that are similar to plots that received community titles and management plans. This allows us to isolate the impact of land titling programs from other factors that affect both forest outcomes and assignment to the program, a pressing and recognized research need regarding land tenure policies (Robinson et al. *in press*). After matching treatment plots to comparable control plots, we find that community land titles, whether or not coupled with community management plans, had no distinguishable average effect on loss of forest cover in the first five years after the recognition of legal status. These results raise important questions about the role of land titling and management programs in reducing deforestation and provide evidence about the effects of land tenure policies that is lacking in existing research.

2. Theory of Causation

The core mechanism by which land tenure affects resource use and land cover is *exclusion* — the ability of landholders to prevent potentially competing users from extracting value from land. Land tenure supported by formal land title makes exclusion more likely by providing landholders with access to the enforcement capabilities of the state (Fort 2008; Jacoby and Minten 2007). In a seminal article about land tenure and forests, Mendelsohn (1994) describes how the expected payoff of keeping land in forest diminishes when landholders must self-enforce claims to land. Exclusion is costly for individuals, which pushes landholders with insecure tenure to extract value from the land quickly. This often involves harvesting timber before optimal periods of growth or the conversion of forests to low-productivity agriculture (Araujo et al. 2009). Property rights granted by land title are enforced by the state, which may shift landholders away from short-term uses of forests that diminish long-term value.

The usefulness of secure land tenure for improving exclusion is reflected in empirical evidence. Jacoby and Minten (2007) find, for example, that 90 percent of farmers surveyed in Madagascar state the primary function of land titles is to guarantee access to land over competing claimants. Alston, Libecap, and Schneider (1996) find that settlers in Brazilian frontier areas with title, especially those close to a market center that offered economic opportunities, reported much higher land values. In this case, settlers with title have more opportunities to exchange land and face diminished costs in providing exclusion. More generally, improved exclusion affects the probability that forests will be converted to other uses in four ways, all of which result from managing forests for value that will be realized in later periods. Because exclusion is improved, land owners face fewer risks that competing users will appropriate valuable assets before they can be realized by the owners.

First, land titling is likely to contribute to the maintenance of forest cover to the extent that it improves the exclusion of competing users directly. Without formal title, communities are not able to easily avail themselves of legal remedies when colonizers move onto their traditional lands or extractive industries poach resources (Brasselle, Gaspart and Platteau 2002). Indigenous communities are often subjected to the expropriation of customary lands by groups who wish to extract mineral resources or convert forests to agricultural or urban uses, including the state (White and Martin, 2002). To the extent that land titles improve the ability of landholders to exclude other extractive users, land titling should be associated with the maintenance of forest cover.

Second, land title and any resulting security of land tenure is likely to affect land use decisions by landholders themselves. When land contains a valuable natural resource that can be extracted, such as timber, having security from outside users is likely to lengthen the time horizon for extraction and even promote investment in afforestation by the forest owners (Nguyen et al. 2010). Many times the value of forests to landholders, including timber, game, and cultural amenities, accrue over long periods of time. When landholders expect secure tenure over long periods of time, they are more likely to forego forest uses that offer short term benefits. However, these positive effects of longer time horizons may be attenuated by the relative productivity of land for agriculture or new investment opportunities in agriculture (Otsuki et al. 2002). Opportunities for alternative agricultural or pastoral uses are likely to be lowest in more remote areas (Alston et al. 1996).

Third, when landholders gain improved ability to exclude competing users, they also gain opportunities for profitable investment in the long-term productivity of their land. Secure land tenure may increase the payoff from capital investments in productive uses like agriculture (Deininger and Chamorro 2004). This is likely to increase the probability of conversion to agriculture to the extent that agriculture is both higher value and requires substantial upfront investment (see Marchand 2012). Thus, under conditions where secure title increases the payoffs to investment, conversion of forests should become more likely based on proximity and connectivity to markets, better quality soil, and greater food insecurity.

Finally, access to incentives schemes for maintaining forests is often conditional on gaining land title. Because the maintenance of forest cover often provides ecological services beyond the land itself, many incentives schemes pay owners for the value that forests provide to people beside the owners (e.g. Arriagada 2012). These schemes depend on positively identifying the individual or group that is responsible for managing a certain area so that payment can be properly directed. As the international community moves to expand payment for ecosystem service programs, such as the global REDD+ program that seeks to mitigate climate change by reducing deforestation, land titling programs often come first (Sunderlin et al. 2009; Duchelle et al. 2014). Land title can thus be a critical means of connecting landholders with other incentive schemes (e.g., de Koning et al. 2011).

It is important to note that many other factors affect incentives of landholders regarding resource extraction and the conversion of forests. Secure land tenure does not necessarily solve collective action or community management challenges that have been highlighted in the expansive literature on the commons (e.g., Agrawal 2001; Potette and Ostrom 2004; Gibson 2005). For example, Tucker (1999) argues that securing community land title only improves a community's ability to exclude external appropriators and does not necessarily deal with more challenging questions about community management of common resources.

Additionally, land titling programs are not always insulated from political influence and can themselves result in the expropriation of customary lands. Wealthy and powerful individuals can use their influence to capture disputed lands (Broegaard 2009). Because land tenure programs can set off competition for title among competing users, it is possible that land titling programs focus appropriation effort on nearby lands that remain untitled, resulting in more deforestation there (Jacoby and Minten 2007). Thus, analyses about the effects of land titling on forest cover must be careful to consider impacts on equity and other unintended consequences.

Given that past research on the effects of land tenure on forest conversion has been largely based on theoretical discussion along the lines that we outline, there exists little reliable evidence on the effect of land titling and supporting community management that accounts for selection into the program. Land title might have both positive and negative effects on forest cover, but on a net the positive benefits are thought to be substantial (Fearnside 2001; Holland et al. 2014). There also exists little research that examines the time frame over which land tenure should have an effect on forest cover. We tackle these theoretical, empirical, and conceptual challenges by examining a unique land titling program completed in southeastern Ecuador. By doing so, we test whether improved exclusion through land title changes rates of forest loss in otherwise similar lands.

2.1 Study area and land tenure context before and during PSUR

Our study area is the province of Morona-Santiago in southern Ecuador (Figure 1). The province had an estimated 2001 population of 120,487 rising to 214,786 by 2010. At 6.2 people per km^2, the population density is one of the lowest in Ecuador, far below the national average of 58.2 people per km^2. The province is dominated by tropical rainforest in the eastern and southern portion and Andean ridge mountain areas in the far west. Aside from the Andean portion in the west of the province, the majority of the province has little or no road access and the Shuar indigenous group dominates the lowland regions with 110,000 members, although its southeast corner is home to the smaller Achuar nation with 5,400 members.

The most recent Ecuadorian constitution adopted in 2008 ratifies the protections introduced in the 1998 constitution for both the environment and indigenous communal land rights. These protections are however superseded by laws and regulations that create sole and inalienable ownership of mining, gas, and oil resources for the State. This situation leaves rural populations occupying oil, mining and gas rich areas with uncertain land tenure. In addition, overlapping governance structures and jurisdictions form a complex web of land tenure institutions, especially in tropical regions where indigenous communities are prevalent (Holland et al. 2014). Chief among these competing jurisdictions are the Ministry of the Environment (MAE), which manages "hard" and "soft" protected areas, and the Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP)[1], which administers and adjudicates other rural lands. The lack of a clear legal framework delineating responsibilities between these two ministries created a patchwork of legal instruments for securing title to forest lands. As a solution, these ministries negotiated a series of inter-ministry agreements and co-management agreements with local groups as land claims arose, resulting in a changing land tenure landscape over time (Morales, Naughton-Treves and Suarez 2010).

Simplifying to the main types of legal land tenure, forested land under the MAE or MAGAP can be claimed by indigenous communities, collective associations, or individuals, but each title contains different restrictions and conditions. Each combination produces different levels of access, exclusion, security and certainty for local populations with respect to land tenure, permitted land uses, and the consequences of not meeting title requirements (Table 1).

Table 1. Usage restrictions associated with different types of forest tenure in Ecuador

	Hard Conservation Protected Areas (Environment)	**Soft Conservation** BNP / PFE forests (Environment)	**Other Rural Lands** (Agriculture)
Indigenous **-**Communal only -Cannot be sold/exchanged, sub-partitioned	Cutting forest only for subsistence (co-management agreements)	-Restricted forest extraction -Requires management plan	No limitations as long as there is no conflict with other properties
Collective and Individual	No use allowed (unless there is a co-management agreement)	-Restricted forest extraction -Requires management plan	No limitations as long as there is no conflict with other properties

Notes: SNAP is Protected Areas System; PFE and BNP are National Patrimony and Protector Forests. Source: Inter-ministry agreements, Forestry Law 1981

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[1] Originally it was the role of the Institute for Agricultural Development (INDA), whose functions were later absorbed by the Subsecretariat of Lands and Agricultural Development of MAGAP

The pre-existence of settlements prior to the establishment of “hard” protected areas has forced the MAE to devise co-management agreements rather than titles with some indigenous or “ancestral” populations residing in protected areas. In these cases, groups must demonstrate occupation and cultural links to land before the establishment of protected areas. In any other case, no human activity is allowed inside “hard” protected areas. In “soft” protected areas, only limited livelihood uses and managed forestry operations are permitted (Forestry Law 1981). In both “hard” and “soft” areas, the unauthorized extraction of forest resources and conversion of forests can lead to sanctions, including fines and in some cases annulment of the adjudication agreement that leads to a land title (Morales, Naughton-Treves and Suarez 2010).

A key feature of land tenure programs like PSUR have been management plans. Management Plans for land legalization (PMLs) are a condition for land title to be granted in any of the scenarios described in Table 1. These plans consists of a document with the following items (based on Inter-Ministry Agreements 149 which later was superseded by more explicit 098 in 2006 and 265 in 2007):

- Location of the claimed land, including clear boundaries approved by adjacent landholders;
- Existing land tenure status and the legal status of the claimants. For indigenous groups, legal recognition must precede the application for land title;
- Land management plan which includes zoning in hectares for forest protection, forest management, agriculture, pasture.

It is in this context that the PSUR program carried out land titling activities. In 2002 when the program began, jurisdictional issues between the MAE and the MAGAP were not fully resolved and the requirements for the legalization plan were not fully fleshed out. Much of the land titling effort under PSUR focused on assigning title for cases which there were no clear legalization instruments and where jurisdiction was unclear, such as areas inside protected areas claimed by indigenous groups.

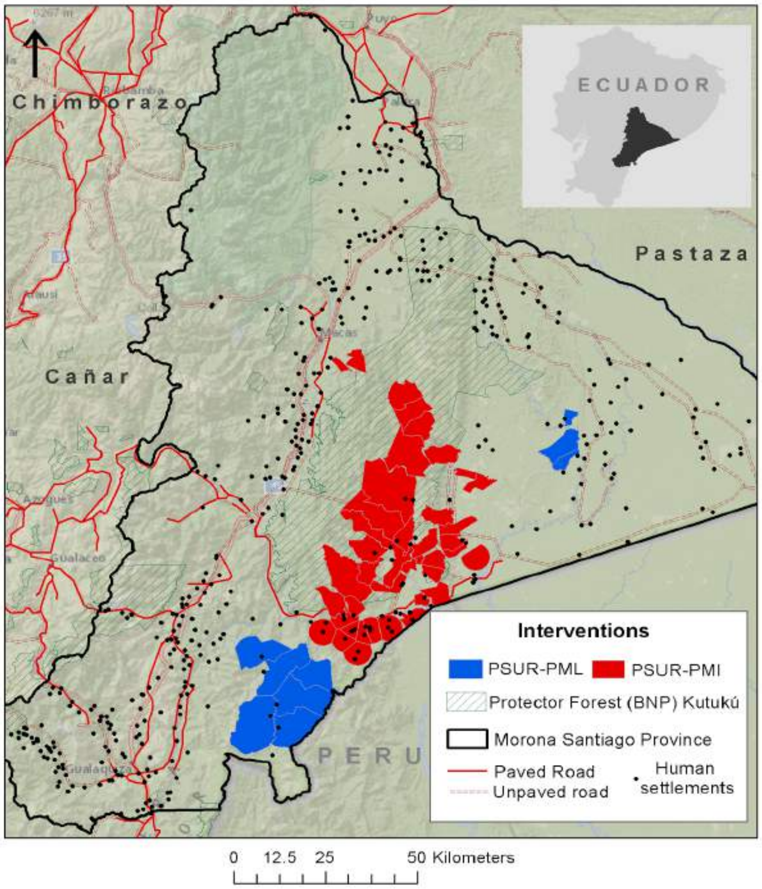
The land titling component of the PSUR program formalized traditional land rights according to the PML legalization planning process. However, later waves of the PSUR program included supplementary management activities that aimed to improve living conditions for populations in the area. Activities included micro-finance and commercial fairs for income generation, increased access to water, sanitation, and health services, natural resource management planning, evaluation, and training, and support activities for local government. Planes de Manejo Integral (PMIs), or integral management plans, were part of the PSUR natural resource management component package, but they could only be produced after the titling process and they needed Ministry of Environment approval because they implied a use of forest resources.

PMIs contained a general diagnosis of the socio-economic and environmental status of the community and a plan for managing human and natural resources, including infrastructure and zoning. PMIs were initially designed and co-implemented by non-profit partners of USAID but eventually trained local personnel from the Shuar Federation produced them. All waves of the PSUR program from 2003 onwards in Morona-Santiago included these supplementary components. This contrasts with a number of communities that received title with the assistance of CARE-Ecuador and local partner PRODEPINE with USAID PSUR funding in 2002. These nine communities out of the 52 total in the PSUR intervention area have title and a PML legalization plan, but no PMI and supplementary PSUR livelihood and natural resource management activities. The difference between these waves allows us to compare the efficacy of land titling interventions that overlap with other land management activities (Figure 1).

3. Data and Methods

We obtained spatial data on the intervention areas of all waves of PSUR from USAID Ecuador and their partners Ecolex, the Bosques y Costas Project, and Care International. These partners provided a portion of the data on titles in digital format. We digitized and georeferenced other title boundaries from PSUR documentation and maps. We approximated three community boundaries based on hardcopy and digital documentation we obtained during field visits with partners in May 2013, including management plans completed as part of the PSUR program. In the few cases when no data was available, we used existing settlement names to estimate areas around them corresponding to community lands. We compiled all data into a GIS database to produce the map shown in Figure 1.

Figure 1. The study area and locations of titling and management planning treatments



Notes: The red areas of the map indicate tenure projects with PMI land titling procedure and PSUR programs, the blue area of the map indicate tenure projects with a PML land titling procedure and minimal or no PSUR programs. The black boundary indicates the Morona-Santiago province boundaries.

To assess whether land titles and forest management plans achieved conservation goals we divided Morona-Santiago into 27,984 1 km^2 grid cells. Then we examined the amount of forest loss in each 1 km^2 plot in the five years following the PSUR treatments. We used the measure of forest loss developed by Hansen and colleagues (2013) to generate annual post-treatment and cumulative forest loss in each of our study plots over five years. The Hansen et al. data provides a measure of the conversion of forest cover to non-forest cover each year, with forest defined as vegetation reaching at least 5 meters height. In addition, we used these data to generate a measure of forest cover in each plot prior to treatment and the rate of forest loss near each plot. We used these compiled measures to ensure that matched treatment and control plots have similar baseline forest cover and rates of change prior to the initiation of the PSUR program. In the Hansen et al. data, forest loss and gain were validated using a probability-based stratified random sample of 120m blocks per biome, including tropical areas.

A major challenge when evaluating the land cover changes caused by policy interventions is the non-random spatial location of interventions (Ferraro 2009; Joppa and Pfaff 2010). Both observable and unobservable differences between treatment and control areas can confound estimates of the effects of policies or programs. When the treatment state, in this case land tenure and management status, is correlated with observed or unobserved factors that also affect the outcome, it is not possible to distinguish the effect of the intervention from the effect of the correlated factors without the additional assumption in Equation 1.

$$E[X_i , Z_i \mid T_i = 1] = E[X_i , Z_i \mid T_i = 0] \tag{1}$$

where X_i are observed covariates for each unit and Z_i are unobserved covariates for each unit that encompass all causes of the outcome Y_i other than the treatment state T_i. When X or Z have a causal relationship with the outcome of interest, then the expected untreated value of the untreated units will not be the same as the expected untreated value of the treated units, where $Y_i(0)$ is the expected value of units had they not been assigned to treatment (Equation 2). This makes it difficult to distinguish the treatment effect of the intervention from the baseline difference in expected outcomes, also referred to as the selection effect.

$$E[Y_i(T_i = 0) \mid T_i = 0] \neq E[Y_i(T_i = 0) \mid T_i = 1] \tag{2}$$

We adopt a matching framework to construct a set of control plots that have similar pre-treatment characteristics as the plots that were assigned to treatment under the PSUR program. We compile spatial data on other variables that have strong associations with forest loss in the extant literature (Table 2). We then iteratively search through sets of control observations outside the PSUR intervention area to select a set of control units that have distributions of each covariate that are not statistically different from the covariate distributions of the treatment plots.

Our first set of control variables are derivations of forest loss in pre-treatment time periods: the amount of forest cover in the subject plot and the pre-treatment rate of forest loss within 5 km^2 of the plot. As discussed with our estimation strategy below, these variables attempt to capture background rates of deforestation that cannot be explained with observable covariates.

Our second set of control variables — distances to roads, rivers, electricity grids, and disturbed lands — all account for the increased value of production and ease of colonization on lands that are more connected with built infrastructure. Within Latin America, 71% of studies in the 1980s and 83% of studies in the 1990s cite road building as a driver of tropical Amazonian deforestation (Arima et al. 2005, Rudel et al. 2009). Treatment and control plots should have similar levels of access to infrastructure and connection to settlements to generate reliable estimates of the effect of land titling. The western portion of our study region lacks access to roads and utility infrastructure, and the dominate form of transport occurs by river, so we also match on this variable. In addition, the distance to disturbed land or converted forest is one of the most important predictors of forest conversion, through population diffusion and frontier effects (Walker 2002; Geist et al. 2006). Within the tropical forests of Latin America, smallholder farm expansion is noted as a driver of deforestation in 87% of studies in the 1980s and 69% in the 1990s (Rudel et al. 2009) and this pattern likely continues throughout our analysis period of the 2000s. The majority of disturbed lands in our study area are farmlands, with some limited urban environments.

Our third set of control variables — indigenous landholding status, protected area status and population density — are demographic and institutional variables that may have impacts on rates of forest conversion. The PSUR program in Morona-Santiago was explicitly targeted to secure land title for Shuar communities. Past research has shown that ethnic backgrounds can determine land use because of cultural practices, particular skills, or institutions that govern collective action (Bray et al. 2006; Stocks et al. 2007). Likewise, protected areas are managed under different rules than non-protected areas, often with legal penalties for the conversion of forests. Because some of the Shuar communities that received land title overlap with “soft” protected areas as described above, rates of deforestation might be lower in these areas owing to additional restrictions on the use of forests. Indeed, past research has noted the success of protected areas in reducing forest conversion in many instances (Andam et al. 2008; Nelson and Chomitz 2011; Joppa and Pfaff 2011). By matching on this variable, we ensure that the treatment and control groups have the same proportion of land in protected status. Additionally, because population density is associated with the intensity of forest resource use (Laurance et al. 2002), we seek to ensure that treatment PSUR areas have the same neighborhood population density on average as the non-program areas used for comparison.

Finally, we match and control for two geophysical variables that affect the suitability of forest areas for other land uses — elevation and slope. Differing types of forest grow at differing elevations and the timber produced in the lowlands may be more or less desirable from timber extracted from the highlands. Additionally, areas of high slope are difficult to access, deforest and use for productive agriculture when compared to relatively flat areas (Yackulic et al. 2011). Hence comparison groups should have similar elevations and slope characteristics. Table 2 contains a more complete description of characteristics of the full set of variables.

Table 2. Control variables used to balance treatment and non-treatment plots

	Source	**Temporal Granularity**	**Native Resolution**
Forest Loss	Hansen et al. 2013	annual	30m
Forest Loss within 5 km^2 (*t-1*)	Hansen et al. 2013	annual	30m
Forest Cover Percent (*t-1*)	Hansen et al. 2013	annual	30m
Distance to Major Roads	OSM, VMAP1, MAE	various, 1993, 2012	vector
Distance to Electric Grid	VMAP1, MAE	1993, 2012	vector
Distance to River	VMAP1, MAE	2012	vector
Distance to Disturbed Land Classification	MOD12Q1	annual	.5 km
Indigenous Shuar Land	TNC	2012	vector
Protected Area Status	WDPA, MAE, TNC	annual	vector
Population Density within 5 km^2 (*t-1*)	Landscan	annual	1 km
Elevation / Slope	Souris, IRB	2001	30m

Before executing the matching procedure, we discard control observations that fall outside the range of values observed for treatment units on all the covariates. By removing observations from the control set that have covariate values that are never realized for the treatment observations, we reduce concerns about biased inference that might result from choosing a set of control observations have the same observable covariate distributions by selecting outliers that have no analogues in the treatment group (King and Zeng 2007).

We carry out statistical matching using a genetic algorithm that both weights and discards control plots that do not serve as comparable units to the treatment plots (for statistical derivation, see Sekhon and Mebane 2008, Sekhon 2007, Diamond and Sekhon 2013). We apply a genetic algorithm that iteratively searches through many sets of potential control plots to maximize balance on the observed covariates. Good matched sets, those that have a large *minimum p*-value on paired *t*-test for differences of means between treatment and control observations across all covariates are passed onto the next generation, along with mutated sets to ensure the full space of combinations of observations to construct the control set is explored. In our particular application, we ran the algorithm until no improvement in balance between the treatment and the 500-2000 control sets considered in each generation was observed for 20 generations. In the end, this produces a set of control plots for analysis that are close to observationally equivalent with the treatment plots, where ρ is the observed values in the selected set of treatment and control groups (Equation 3).

(3) $\rho(X_i \mid T_i = 1) \approx \rho(X_i \mid T_i = 0)$

Matching does not ensure that sets of treatment and control observations are similar for unobserved variables Z. Since we do not observe unobserved covariates, we are forced to make one additional assumption before proceeding to estimation. We assume that any unobserved variable Z that affects the outcome is captured in the pre-treatment value of the outcome variable (Equation 4), where t=0 is the pre-intervention time period and t=1 is any post-intervention time period. Matching studies are frequently able to reproduce the results of more reliable experimental studies when a pre-intervention measure of the outcome is used for matching (Cook et al. 2008). We use two derivatives of the outcome to increase the possibility that we have captured all effects of unobserved variables on forest loss and partially accounted for spatial autocorrelation: the amount of pre-treatment forest cover in the subject plot and the pre-treatment rate of forest loss within 5 km^2 of the plot.

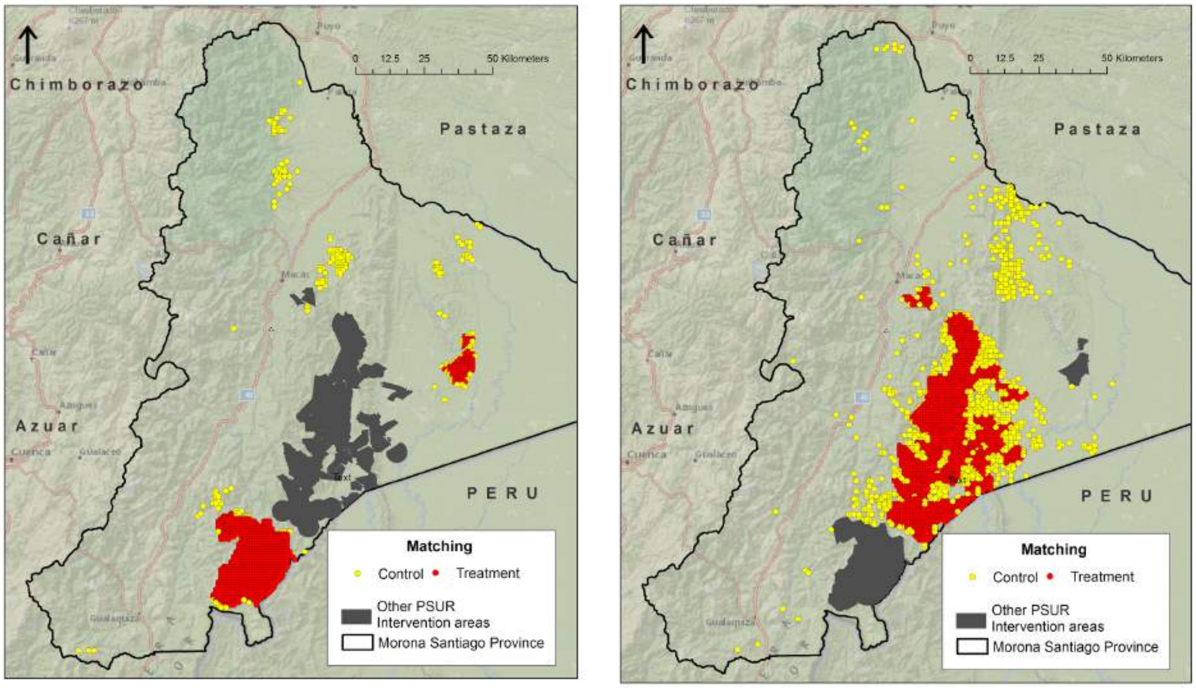
(4) $E[Y_i(t=1) \mid Y_i(t=0), X_i] = E[Y_i(t=1) \mid Y_i(t=0), X_i, Z_i]$

By ensuring that we have a comparable set of control plots with respect to observed covariates, our results are less dependent on parametric modeling assumptions that are built into regression analysis (Rubin 1973, Rubin 1979, Ho et al. 2007). The treatment and control observations that result from the genetic matching process are used to estimate the treatment effect by weighted least squares, where the weights are assigned on the basis of how often each control plot matches to a treatment plot. We examine treatment and control plots that are forested at the baseline year. We estimate difference in differences between treatment and control plots using ordinary least squares regression with aggregated forest loss over the five years following the PSUR interventions.

(5) $a_i (Y_i(t=x) - Y_i(t=0)) = a_i (\alpha + \tau T_i + \beta X_i)$

Where Y_i is the amount of forest cover at different times, a_i is the square root of the weight for each observation, α is the regression intercept, τ is the treatment effect of the PSUR intervention, and β is a vector of coefficients for control variables. To check the assumption that the treatment indicator is statistically independent from observed covariates X, we compare estimates of treatment effects dropping the βX_i for all specifications. If the PSUR interventions have the intended effect, we will observe smaller losses in forest cover in the treatment plots than the control plots, both aggregated over several years and on a year-to-year basis.

Figure 2. Matched plots where treatment is recognized legal status and control is plot outside intervention area with no tenure.



Notes: Yellow is control and red is treatment. The left panel shows the PMI-only treatment areas and the right panel shows the PMI treatment areas.

4. Results

We first examine the results of legalization plans and titles without enhanced community management plans on the amount of forest loss during the following five years. As part of the first wave of land titling in 2002, nine Shuar communities that had worked with CARE and the local non-governmental organization PRODEPINE received titles after completing a legalization plan or PML. Although the communities are also Shuar, they did not follow the same selection criteria as the later wave of PSUR. In particular, they were not inside or adjacent to the Kutukú Protected Forest and did not receive the same support to create natural resource management plans and other project activities (Figure 2, left panel).

Difference-in-difference least-squares regression without pre-matching (Figure 3, Model a) provides an estimate of the treatment effect that legalization planning and land titling reduced the amount of deforestation as compared to plots without title during the study period, even after controlling for the other factors that drive deforestation in the area.[2] As shown in the corresponding bar (a), the aggregate effect of land titling and the legalization plan over five years is estimated to reduce more than 1000 m^2 of forest loss on average for each 1 km^2 study plot. The challenge, however, is that selection into the titling program is associated with a number of other factors that reduce deforestation. For example, PML-only plots are on average further away from major roads and more likely to have high slopes, both of which tend to decrease forest loss (Technical Appendix, Table A1). In a simple regression, this raises the possibility that estimates of treatment effects are biased by covariance between the treatment indicator and other covariates.

After matching to find plots outside of PSUR that collectively have similar observed distributions of matched covariates, we do not find any evidence that having a legalization plan and communal title reduces forest loss over the next five years. Figure 3, models (b) / (c) show that this result is consistent across post-matching models that include and do not include covariates balanced through the matching procedure. The point estimate in both models is similar and indicates higher rates of deforestation in areas following land titling, but this result is not statistically distinguishable from variation that would occur by random chance. The consistency of the point estimates in models (b) and (c) is an indication that matching has been successful in making the treatment variable observationally independent of the covariates.

Figure 3. Difference in differences over five years for PSUR plots with legalization plan (PML) and

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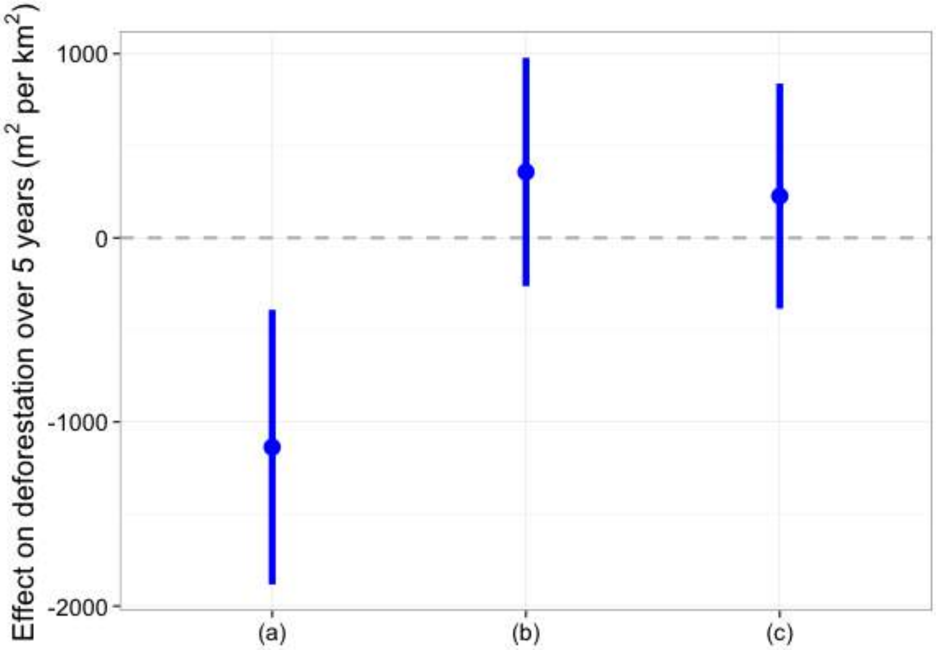
[2] Note that we do not present the coefficient estimates for the control variables in the figures below, given that our primary interest is the treatment effect of the PSUR land titling and management program. In the model estimates that use pre-matching, the coefficient estimates for the control variables have no substantive interpretation, since they are a non-representative set of the values of each control variable created after matching to isolate the effect of the treatment variable.

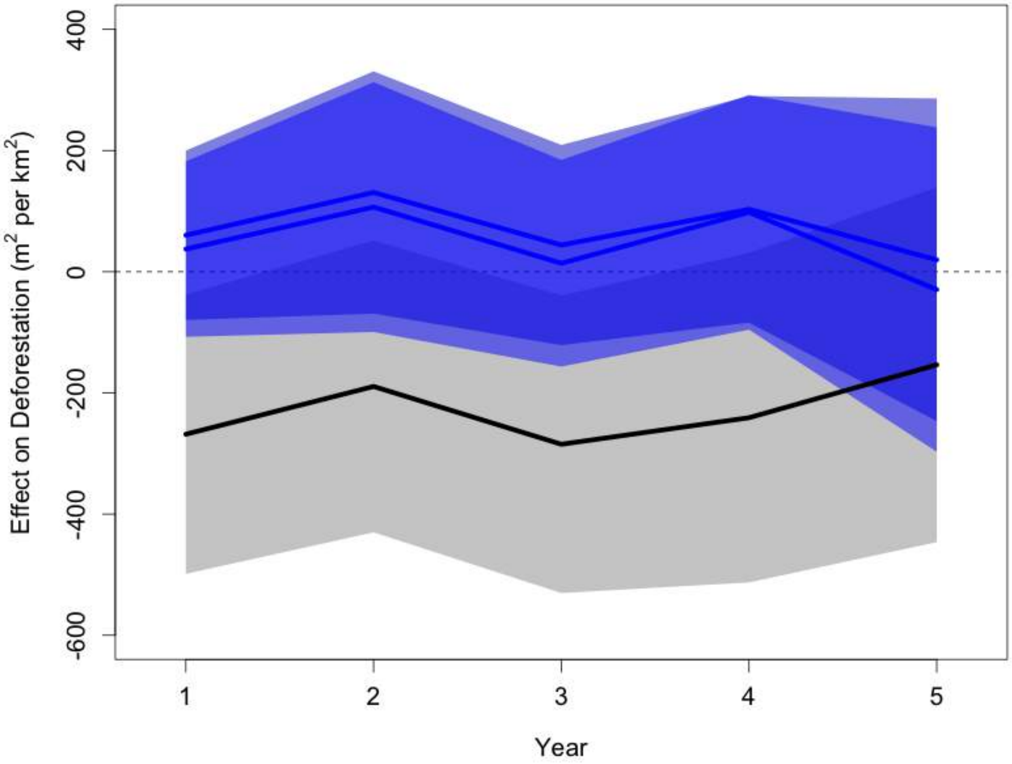
title versus non-PSUR plots with no plan or title, 2002-2012



Notes: Figure shows treatment effect of tenure status for models as follows: (a) covariates, no pre-matching; (b) no covariates, pre-matching; (c) covariates, pre-matching

We also considered the possibility that the effects of land titling could be realized at different points in time after the intervention. For example, titling might focus attention on land management immediately after the legal process, resulting in decreased deforestation only in early years. Alternatively, it may be several years until new management plans take effect given the challenges of reforming existing institutions and practices. Thus, we examine the effects of land titling in each year following the PSUR intervention, which is essentially the results presented in Figure 3 broken down into five annual periods rather than aggregated together. The results are similar to the aggregated estimates. The difference-in-differences point estimates of treatment effect without pre-matching indicate reduced deforestation, though this result is only statistically significant in two of the five years (black line). In contrast, the point estimates of the treatment effect after pre-matching, both with and without matched covariates included in the difference-in-differences regression, are never statistically distinguishable from results that are likely to be realized by random chance (blue lines). Thus, we find no evidence that land titling alone reduces deforestation within five years of the intervention when comparing treatment areas to similar areas that remain untitled.

Figure 4. PML-only effects on an annual basis following treatment



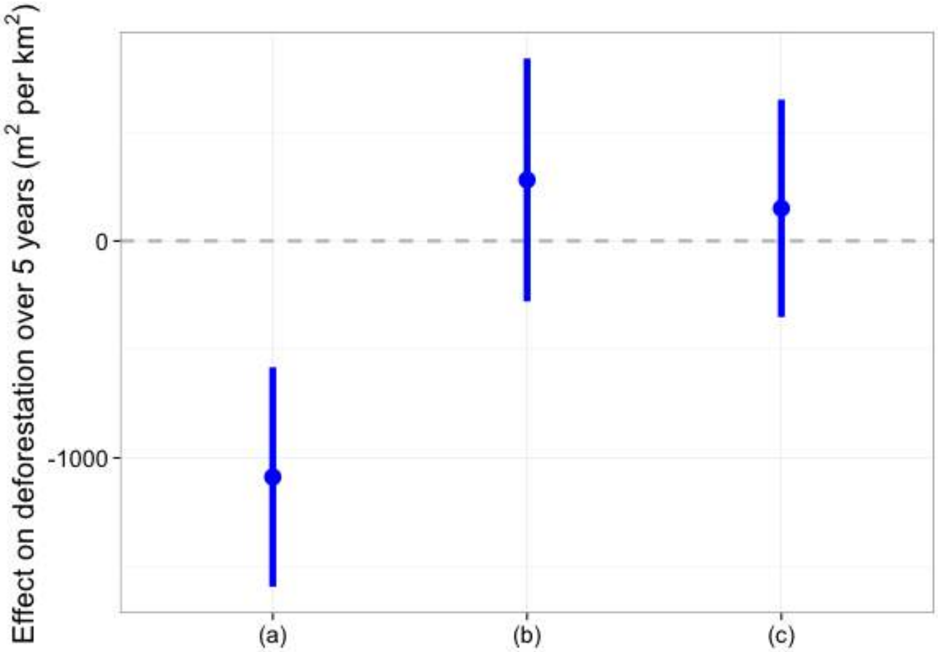
Notes: The black line / grey error bars are regression without pre-matching; The blue lines and error bars are regression estimates with pre-matching both with (dark blue) and without (light blue) covariates. The error bars show two standard errors.

As mentioned earlier, the later waves of PSUR included a variety of management and training activities in addition to legalization. These included funding of the Shuar Federation operations and training its staff, supplemental income generation programs related to handicrafts, animal husbandry, and agriculture, as well as planning low-impact forestry and agroforestry operations. Many of these activities were articulated in an Integrated Management Plan (PMI), which aimed to support the success of land titling program by strengthening local institutions and complementing titles with activities that promoted sustainable use of the land.

In light of the synergy between PMIs and land titles, we pre-match and then estimate the impact of the second wave of PSUR compared to similar non-program areas that did not receive title during the study period. Like the first wave, all program areas have a PML and land title. The addition of PMIs distinguishes the second wave. Like the results we report for PML-only plots, the full PMI treatment appears to reduce forest conversion in the the difference-in-difference regression model without pre-matching (Figure 4, model a). However, like the regression model for the PML-only treatment, the plots that received title and management plans have background characteristics associated with lower levels of forest loss, including lower population densities and greater distance from disturbed land classifications (Technical Appendix, Table A1). This raises the possibility that the estimated effect is driven by collinearity with these variables, rather than an actual treatment effect.

Again, we conduct a search for a set of control plots using a genetic matching algorithm that are similar on observable covariates to the treatment plots. In the post-matching models both with and without the covariates, we estimate that the treatment effect of titling and management plans on forest loss is approximately zero (Figure 4, models b/c). Because the post-matching models with and without covariates have similar estimates, we are confident that in the post-matching dataset the treatment variable is observationally independent from the other variables that have an effect on forest loss, reducing or eliminating bias in estimates due to collinearity in the predictor variables.

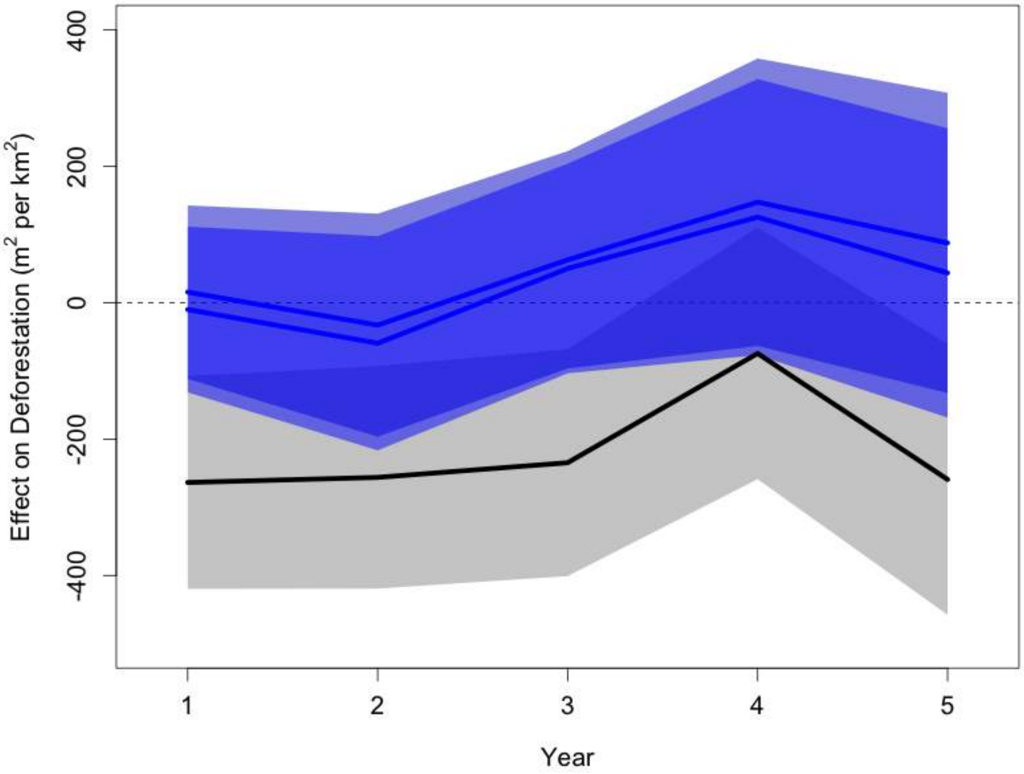
Figure 5. Difference in differences over five years for PSUR plots with title and USAID-funded management plan versus non-PSUR plots with no title, 2002-2012



Notes: Figure shows treatment effect of tenure status for models as follows: (a) covariates, no pre-matching; (b) no covariates, pre-matching; (c) covariates, pre-matching

Similar to the PML-only analysis, we disaggregate the effect of the PMI treatment and estimate treatment effects for individual years following the program. The results of this analysis mirror those reported for the PML-only analysis. The difference-in-differences point estimates of treatment effect without pre-matching indicate reduced deforestation, with a statistically significant result in four out of five years (black line). In contrast, the point estimates of the treatment effect after pre-matching, both with and without matched covariates included in the difference-in-differences regression, are never statistically distinguishable from results that are likely to be realized by random chance (blue lines). Thus, we find no evidence that land titling plus community management planning reduces deforestation within five years of the intervention when comparing treatment areas to similar areas that remain untitled, either cummulatively or annually.

Figure 6. Titling and PMI effects on an annual basis following treatment



Notes: The black line / grey error bars are regression without pre-matching; The blue lines and error bars are regression estimates with pre-matching both with (dark blue) and without (light blue) covariates. The error bars show two standard errors.

In addition to these main results, we report a number of additional results and robustness checks in a technical appendix. First, we report the balance statistics for the covariates used in the matching procedure for both the PML-only and PMI models (Technical Appendix A, Table A1). Next, we report results of the same empirical procedure reported above, but only for study plots that are inside Shuar lands as reported by the Nature Conservancy Ecuador (Technical Appendix A, Figures A1-A4). Because some of the land titling occurred in areas that are not exclusively Shuar according other datasets, we restrict our analysis to areas where titling and other datasets are in agreement about indigenous status. The basic patterns reported in the main results do not change. Finally, we add a technical appendix that describes the derivations and sources of our covariates in greater detail (Technical Appendix B).

5. Discussion and Conclusions

We find no evidence that land titling with or without management planning reduces deforestation in the five years following treatment for the PSUR program in Ecuador. This result is robust across different subsets of the data and at different periods of time following treatment. Our findings are some of the first evidence about the effects of land tenure programs on forest cover that compare program areas to similar non-program areas. Our finding of a near zero effect has important implications for a number of research programs and policy decisions.

First, no previous research that we are aware of attempts to use matching techniques to address the factors that are likely to confound the relationship between land tenure interventions and forest outcomes.[3] This has left much of the research on land tenure on weak empirical footing (Robinson, Holland and Naughton-Treves *in press*). The dangers of relying on simple regressions to estimate the effects of land tenure and community forest management on environmental outcomes are highlighted by our results. For both PML-only and PMI treatment plots, simple difference-in-difference regressions with control variables generate estimates that indicate reduced forest loss as a result of PSUR. These results are similar to other studies that do not address selection and collinearity in regression (e.g., Barsimantov and Kendall 2012). But, the PSUR intervention in our study area is implemented in areas that already have lower background rates of deforestation as compared to non-program areas. Our results speak to the need in the empirical literature to take on selection and targeting challenges more directly if reliable conclusions are to be drawn about spatially-explicit policy impacts.

Second, the literature on common property and the collective management of forests has been generally positive on the potential for secure land tenure to support customary, local institutions. The literature is filled with examples of community management institutions successfully managing land, especially when receiving formal recognition from the state (e.g., Bray et al. 2006; Ojha et al. 2009). Many of the most cited examples provide rich descriptive inference about the design and operation of community-level institutions, but do not necessarily contain explicit counterfactuals that allow for estimates of the impact of new land tenure programs. By comparing titled plots with similar plots that do not have land title or forest management plans, we have contributed to a growing body of literature that considers land tenure and community management institutions in a comparative perspective (see Agrawal 2001). Since we do not find that land titling and forest management planning reduce forest loss as compared to similar plots outside intervention areas, our results suggest that scholars must be more careful that their claims be

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[3] See Holland et al. 2014 for a discussion of the challenges of implementing matching estimators for land tenure interventions. See Alix-Garcia et al. 2012 for a study that applies a matching framework to estimate the effect of land tenure institutions on farm abandonment in post-Soviet countries.

based on explicit comparisons of areas and communities that differ on tenure status.

Third, development organizations are spending tens of millions of dollars each year on land titling programs to achieve conservation goals. Our results suggest this spending may be insufficient or perhaps even misguided if reducing the rate of forest loss is a primary goal of the program itself. More likely, these programs should carefully consider the effects of exclusion on colonization, time horizons, investment opportunities, and access to incentive schemes. As the global community scales up its support of land titling and land tenure interventions to achieve environmental and development goals, land titling programs need to be carefully considered for their connections to other processes and incentives. Future research that connects land titling programs and formal incentive schemes for maintaining forest cover offers a promising direction. In particular, geospatial impact evaluations like ours combined with behavioral experiments and field surveys might be used to link incentives, institutions, and land use decisions to outcomes such as deforestation.

Fourth, we can only speak to effects that are realized in the years immediately after the PSUR intervention. Given that other parts of southeastern Ecuador have experienced deforestation as a result of colonization and extractive industry activity (Rudel 2013), it may be the case that the PSUR program will reduce deforestation as these processes approach the intervention areas. In a political climate where program impacts need to be immediate and large, the challenge of programming for long-term benefits is pronounced. We must be careful to reinforce that just because benefits on forest cover have not been realized to this point, we take no position on whether they will be realized over a longer period of time. We intend to follow this program over time, but the challenge of measuring long-term policy effects is felt in other fields. Using remotely sensed data, we introduce the possibility of following the time path of policy effects with limited field presence and little additional cost. We expect that the use of remotely sensed data can have broad applicability to measuring the long-term impacts for agriculture, industrial development, aquaculture, and forestry policies. Thus, we advocate greater incorporation of these tools into the work of program evaluation in these fields.

Finally, we must recognize that our results speak only to the effects of land titling and forest planning on forest cover. It may be the case (or not) that the PSUR program had a large and positive effect on local livelihoods and income or on the ecological properties of forests that are not measurable by a categorical land conversion analysis. Our analysis cannot and does not intend to speak to these questions. Likewise, it is possible that land tenure programs will succeed in reducing forest loss in settings unlike those that we consider as part of this study. We cannot rule out this possibility until more evidence that takes selection effects seriously accumulates. Many of the implementing partners that reviewed the results of this study emphasize that PSUR increased local and national capabilities related to land management. We recognize that these effects are more difficult to quantify. For example, local paralegals trained as part of PSUR continued their work in other areas and projects. Ecuadorian NGOs gained capacity to fill legal loopholes and correct ambiguous legislation. The sense among the implementing organizations is that PSUR generated clarity in land rights generally, with spillover effects to subsequent programs. These claims, while intuitive and deeply held in the development community in Ecuador, would require very different study than we present here.

What we do offer is an empirical analysis of a land titling program that explicitly addresses selection into treatment and colinearity between the treatment factor and other background characteristics due to spatial clustering. A recent review of the land tenure literature suggests that research progress will be based on the accumulation of results from research that takes these challenges seriously (Robinson et al. *in press*). In providing an initial step in this direction, we hope to persuade the conservation and development community to improve the evaluation of land tenure interventions and consider the promise of these interventions to be testable hypotheses.

Technical Appendix A. Robustness of Model Results

We report additional results here that supplement and expand on the results reported in the manuscript. These results include balance measures for the matching analysis and reestimates of the main models within a subset of the data that are known to be inhabited by Shuar communities as delimited by the Nature Conservancy (Geoplades 2010).

As displayed in Figure 2, we searched for a set of control observations that are similar on measures of other factors that are likely to be associated with changes in forest cover. We then are able to isolate the impact of the PSUR program from these background factors. After searching for a set of control observations that improves balance on all or most of the observations, we find that we have improved balance between treatment and control groups in almost all cases, usually by very significant margins. Table A1 report pre- and post-matching balance statistics for the control variables.

Table A1. Pre- and post-matching balance summaries for covariates

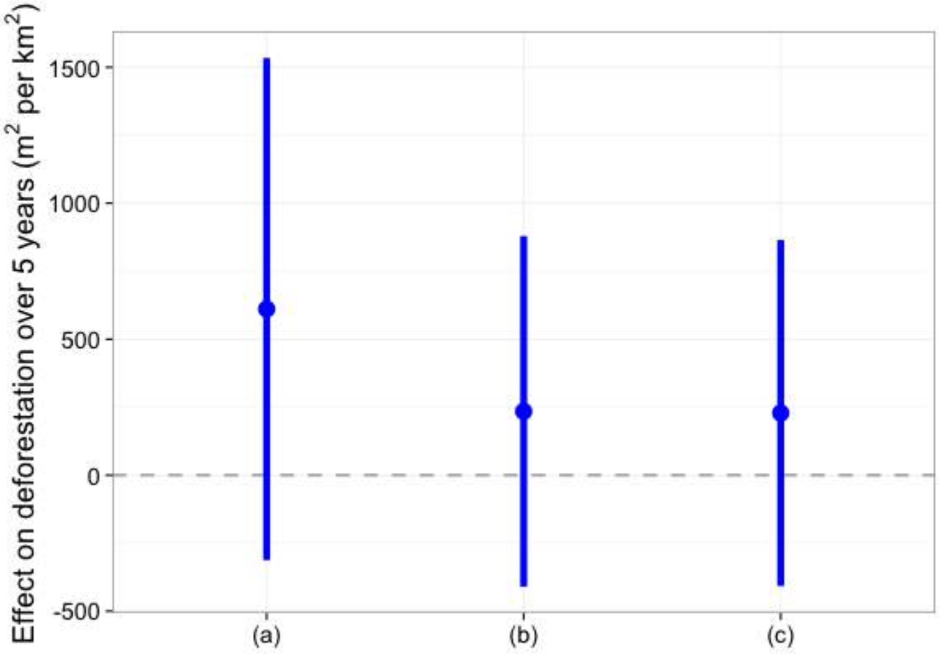
	PML-only Analysis	PMI Analysis
Forest Loss within 5 km^2 (m^2 at *t-1*)	m-t: 4261 pre-m-c: 21794 post-m-c: 3218	m-t: 9089 pre-m-c: 21794 post-m-c: 8450
Forest Cover Percent (m^2 at *t-1*)	m-t: 823861 pre-m-c: 802232 post-m-c: 826594	m-t: 840682 pre-m-c: 802232 post-m-c: 841722
Distance to Major Roads (m)	m-t: 17988 pre-m-c: 7403 post-m-c: 17473	m-t: 4064 pre-m-c: 7403 post-m-c: 4288
Distance to Electric Grid (m)	m-t: 14893 pre-m-c: 19766 post-m-c: 16322	m-t: 15209 pre-m-c: 19766 post-m-c: 14627
Distance to River (m)	m-t: 3856 pre-m-c: 3041 post-m-c: 3470	m-t: 3177 pre-m-c: 3041 post-m-c: 3121
Distance to Disturbed Land Classification (m at *t-1*)	m-t: 11464 pre-m-c: 13141 post-m-c: 10197	m-t: 16854 pre-m-c: 13141 post-m-c: 16333
Indigenous Shuar Land (binary)	m-t: 0.98 pre-m-c: 0.44 post-m-c: 0.98	m-t: 0.73 pre-m-c: 0.44 post-m-c: 0.68
Protected Area Status (binary)	m-t: 0.00 pre-m-c: 0.31	m-t: 0.57 pre-m-c: 0.31

	post-m-c: 0.00	post-m-c: 0.57
Elevation (m)	m-t: 1251 pre-m-c: 1216 post-m-c: 1337	m-t: 715 pre-m-c: 1216 post-m-c: 708
Slope (degrees)	m-t: 16.7 pre-m-c: 11.6 post-m-c: 15.7	m-t: 13.1 pre-m-c: 11.6 post-m-c: 13.0
Population Density within 5 km^2 (persons/km^2 at *t-1*)	m-t: 6.41 pre-m-c: 4.33 post-m-c: 5.73	m-t: 0.89 pre-m-c: 4.33 post-m-c: 0.92

Notes: m-t is mean of the treated group; pre-m-c is mean of the control group before matching; post-m-c is mean of the control group after matching. All unit measures are contained in column 1.

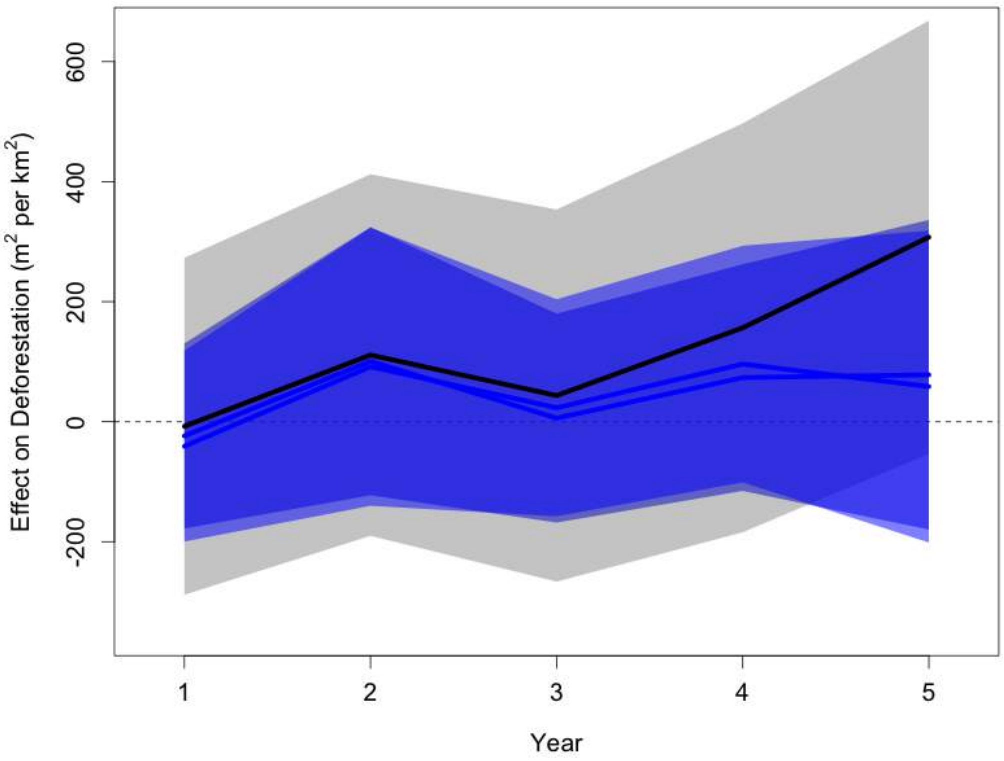
The PSUR program was formally targeted to support Shuar indigenous communities in gaining formal land title, strengthening collective decision-making, and improving access to legal institutions. According to secondary data, however, some of the PSUR programming fell outside of areas with known Shuar communities. As a consequence and to check the robustness of our models, we look only within the areas that were identified by USAID and its partners (Care 2007) as being inhabited by Shuar communities at the time. In this analysis, the main result is substantively unchanged. We do not find that the PSUR program reduced forest loss in the first five years after implementation both aggregated over five years and on a year to year basis. In the figures below, we show the results displayed in the main figures above for the subset of observations that fall within Shuar territory. Figures A1 and A2 report the results of the Shuar subset analysis for the first wave of the PSUR program that only included land titles and legalization plans (PMLs). Figures A3 and A4 report the results of the analysis on the Shuar subset for the second wave of the PSUR program that included land titles, legalization plans, and enhanced management plans (PMIs).

Figure A1. Difference in differences over five years for PSUR plots with legalization plan (PML) and title versus non-PSUR plots with no plan or title, 2002-2012



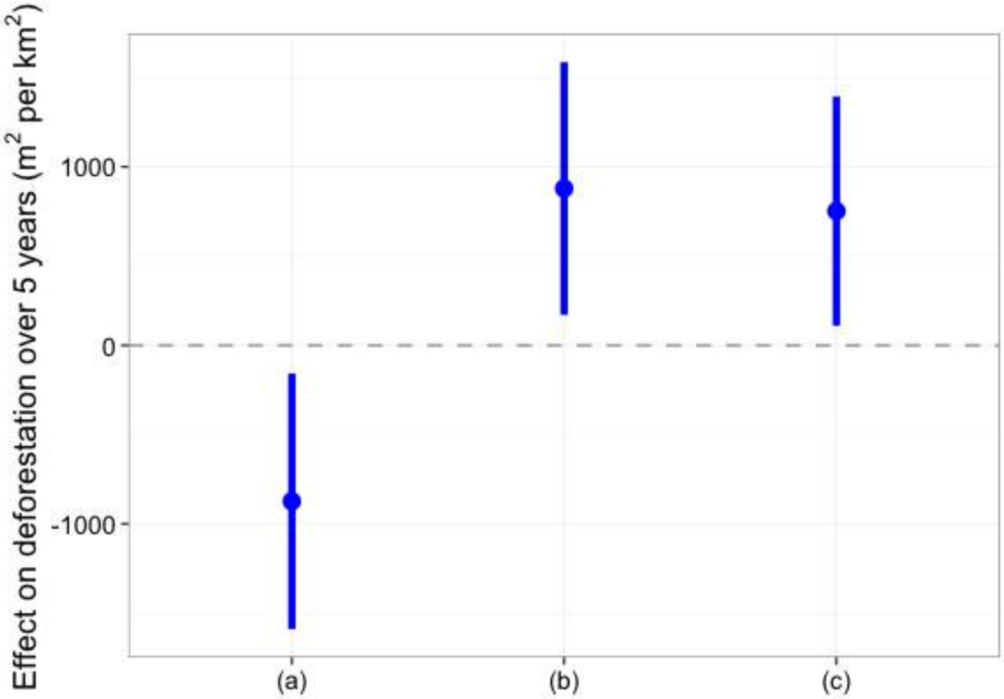
Notes: Figure shows treatment effect of tenure status for models as follows: (a) covariates, no pre-matching; (b) no covariates, pre-matching; (c) covariates, pre-matching

Figure A2. Year by year effects for PSUR plots with legalization plan (PML) and title versus non-PSUR plots with no plan or title in Shuar areas, 2000-2012



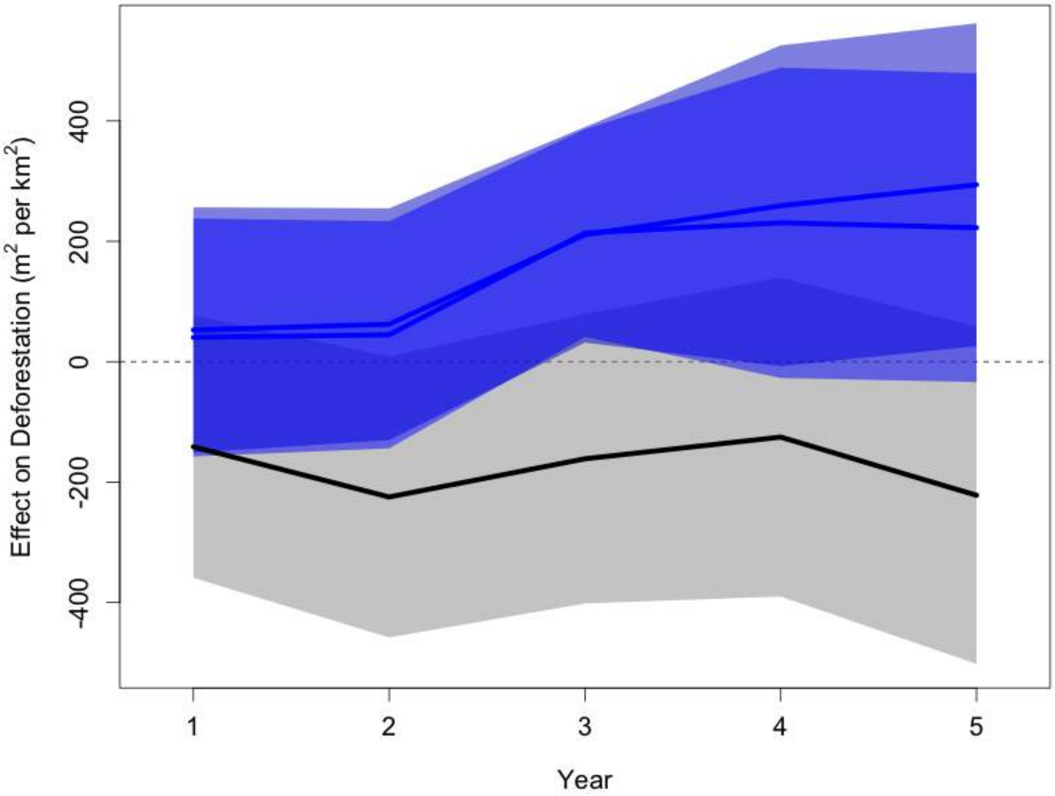
Notes: The black line / grey error bars are regression without pre-matching; The blue lines and error bars are regression estimates with pre-matching both with (dark blue) and without (light blue) covariates. The error bars show two standard errors

Figure A3. Difference in differences over five years for PSUR plots with title and USAID-funded management plan versus non-PSUR plots with no title in Shuar areas, 2002-2012



Notes: Figure shows treatment effect of tenure status for models as follows: (a) covariates, no pre-matching; (b) no covariates, pre-matching; (c) covariates, pre-matching

Figure A4. Year by year effects for PSUR plots with title and USAID-funded management plan versus non-PSUR plots with no title in Shuar areas, 2002-2012



Notes: The black line / grey error bars are regression without pre-matching; The blue lines and error bars are regression estimates with pre-matching both with (dark blue) and without (light blue) covariates. The error bars show two standard errors

Technical Appendix B. Spatial Data Layers

Hansen et. al. (2013) forest loss/gain data is available under a creative commons license at http://earthenginepartners.appspot.com/science-2013-global-forest. All other spatial data layers are provided in Google Earth format as a supplementary submission.

Data from Hansen et. al. (2013) was utilized for tree cover percentage for the year 2000. Hansen provides tree cover defined as canopy closure for all vegetation taller than 5m in height. These data are encoded as a percentage per output grid cell, in the range 0–100. We aggregated the Hansen data to 1 km^2 and converted the units from percentage to forest area per grid cell. Additionally, a focal sum process created forest density measures at the 5 km^2 neighborhood level. That is, how much forest exists per 5 km^2 for each 1 km^2 analysis cell. The native resolution is approximately 30m, the temporal resolution is annually from 2000 - 2012, and the attribute resolution is 0 - 100 as a percentage of tree cover.

Forest loss was also taken from Hansen et. al. (2013), who not only provides forest cover as a percentage in 2000 but also provides forest loss in subsequent years. Hansen's forest loss metric is a disaggregation of total forest loss to annual time scales these data are encoded as 2001 to 2012 indicating the year of loss or alternately encoded as 0 which equals no loss following 2012. Again we aggregated the Hansen data to 1 km^2 and produced a focal sum for forest loss at the 5 km^2 for each 1 km^2 analysis cell. The native resolution is approximately 30m, the temporal resolution is annually from 2000 - 2012, and the attribute resolution is 2001 - 2012 indicating year of loss.

Major roads were aggregated from vector data provided by Open Street Map, Vector Map of the World Level 1, and the official roads product from MAE within Ecuador. Road presence or absence was encoded into the 1 km^2 analysis cell. A simple euclidean distance to roads layer was then created for all 1 km^2 analysis cells that have no roads present. It should be noted that aside from the western edge of the analysis area, that did not produce matches, few if any roads exist in this area. The native data model is vector with varying temporal resolutions from 1993 to 2012.

Distance to rivers and distance to the electricity infrastructure were obtained using the same process as distance to roads outlined above but with data from MAE and Vector Map of the World Level 1 data. The native data model is vector with varying temporal resolutions from 1993 to 2012.

Disturbed land was delineated from Modis product MCD12Q (Friedl et. al 2010). MCD12Q1 provides pixel based information for 5 common land cover classification systems as well as quality information for each pixel. The data is obtained from annual composites from the Terra and Aqua systems. We utilized the

IGBP global vegetation classification scheme which allows for 17 land cover classifications (FAO 2000). We extracted classifications that relate to human disturbance such as copland and urban classifications. Once extracted a distance to these classifications was constructed utilizing a simple Euclidean distance measure. The native resolution is approximately 500m and was aggregated to the 1 km^2 pixel, the temporal resolution is annually from 2001 - 2012, and the classification system was a nominal land cover classification system.

The indigenous Shuar region and protected area status were both obtained from MAE and are current as of 2012. Both are vector products converted to binary rasters at the 1 km^2 pixel level.

Elevation and slope were derived from over 1 million elevation points derived from topographic maps. The points were interpolated into the 1 km^2 pixel with slope derived simply as rise divided by run. These data are a one-time snapshot.

Population count data was obtained at the1km^2 resolution from the Landscan data repository. The temporal resolution is 2000 to 2012. These data were converted from the 1km^2 pixel count measure to a focal density of 5km^2 using a neighborhood function.

Background map data was provided by ESRI World Topographic Map, http://www.esri.com/software/arcgis/arcgisonline/includes/basemaps/site3, and was accessed on 5/1/2014.

References

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

Alix-Garcia, J., Kuemmerle, T., & Radeloff, V. C. (2012). Prices, land tenure institutions, and geography: a matching analysis of farmland abandonment in post-socialist Eastern Europe. Land Economics, 88, 425-443.

Alston, L. J., & Libecap, G. D., & Schneider, R. (1996). The determinants and impact of property rights: land titles on the Brazilian frontier. Journal of Law, Economics, and Organization, 12, 25-61.

Andam, K. S., Ferraro, P. J., Pfaff, A., Sanchez-Azofeifa, G. A., & Robalino, J. A. (2008). Measuring the effectiveness of protected area networks in reducing deforestation. Proceedings of the National Academy of Sciences, 105, 16089-16094.

Arima, E. Y., Walker, R. T., Perz, S. G., & Caldas, M. (2005). Loggers and forest fragmentation: Behavioral models of road building in the Amazon basin. Annals of the Association of American Geographers, 95, 525-541.

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

Arriagada, R. A., Ferraro, P. J., Sills, E. O., Pattanayak, S. K., & Cordero-Sancho, S. (2012). Do payments for environmental services affect forest cover? A farm-level evaluation from Costa Rica. Land Economics, 88, 382-399.

Asian Development Bank. (2010). Post-Completion Sustainability of Asian Development Bank-Assisted Projects. Manila: Independent Evaluation Department. Report SES-OTH 2010-46.

Barsimantov, J., & Kendall, J. (2012). Community Forestry, Common Property, and Deforestation in Eight Mexican States. The Journal of Environment & Development, 21, 414-437.

Barsimantov, J., & Navia Antezana, J. (2012). Forest cover change and land tenure change in Mexico's avocado region: Is community forestry related to reduced deforestation for high value crops? Applied Geography, 32, 844-853.

Brasselle, A. S., Gaspart, F., & Platteau, J. P. (2002). Land tenure security and investment incentives: puzzling evidence from Burkina Faso. Journal of Development Economics, 67, 373-418.

Bray, David Barton, Antinori Camille, and Torres-Rojo, Juan Manuel. (2006). The Mexican model of community forest management: The role of agrarian policy and entrepreneurial organization. Forest Policy and Economics 8,470-484

Broegaard, R. B. (2009). Land access and titling in Nicaragua. Development and Change, 40, 149-169.

CARE. (2007). Programa de Sostenibilidad y Unión Regional, ¨Programa SUR¨. Available at: http://www.care.org.ec/webcare/?page_id=975 (Accessed March 2014).

CARE, Ministerio del Ambiente, Unión Europea y Tinker Foundation (2012). Plan de Manejo Actualizado y Priorizado del Bosque Protector Kutukú Shaimi, 2012-2017. Macas, Ecuador. Available at: http://www.rjb.csic.es/jardinbotanico/ficheros/documentos/pdf/pubinv/JMF/PlanManejoIntegralCutucu.pdf (Accessed May 2014).

Congreso Nacional de Ecuador (1981) Ley forestal y de Conservación de Áreas Naturales y vida Silvestre Ley No. 74. RO/ 64 de 24 de Agosto de 1981. Accessed via http://faolex.fao.org/ in April 2014.

Deininger, K., & Chamorro, J. S. (2004). Investment and equity effects of land regularisation: the case of Nicaragua⋆. Agricultural Economics, 30, 101-116.

de Koning, F., Aguinaga, M., Bravo, M., Chiu, M., Lascano, M., Lozada, T., Suarez, L. (2011) Bridging the gap between forest conservation and poverty alleviation: the Ecuadorian Socio Bosque program. Environmental Science & Policy, 14, 531-542.

Diamond, A., & Sekhon, J. S. (2013). Genetic Matching for Estimating Causal Effects: A General Multivariate Matching Method for Achieving Balance in Observational Studies. Review of Economics and Statistics 95: 932-945.

Duchelle, A. E., Cromberg, M., Gebara, M. F., Guerra, R., Melo, T., Larson, A., ... & Sunderlin, W. D. (2014). Linking forest tenure reform, environmental compliance, and incentives: lessons from REDD+ initiatives in the Brazilian Amazon. World Development, 55, 53-67.

FAO Forestry Department (2000). Forest Cover Mapping with NOAA-AVHRR & Other Coarse Spatial Resolution Sensors. Working Paper 29 Rome 2000: 1-42.

Fearnside, P. M. (2001). Land-tenure issues as factors in environmental destruction in Brazilian Amazonia: the case of southern Pará. World Development, 29, 1361-1372.

Ferraro, P. J. (2009). Counterfactual thinking and impact evaluation in environmental policy. New Directions for Evaluation, 2009, 75-84.

Finley-Brook, M. (2007). Indigenous land tenure insecurity fosters illegal logging in Nicaragua. International Forestry Review, 9, 850-864.

Fort, R. (2008). The homogenization effect of land titling on investment incentives: evidence from Peru. NJAS-Wageningen Journal of Life Sciences, 5, 325-343.

Friedl, M. A., Sulla-Menashe, D., Tan, B., Schneider, A., Ramankutty, N., Sibley, A., and Huang, X. (2010). MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. Remote Sensing of Environment, 114, 168–182.

Geist, H., McConnell, W., Lambin, E. F., Moran, E., Alves, D., & Rudel, T. (2006). Causes and trajectories of land-use/cover change. In Land-use and land-cover change (pp. 41-70). Springer Berlin Heidelberg.

GEOPLADES-Geografía, Planeación y Desarrollo (2010). Estudio Multitemporal de Cobertura Vegetal y Uso del Suelo entre los Años 1990, 2010 y Proyección al 2030 a Escala 1:50.000 para el Centro y Sur Oriente de la Amazonía Ecuatoriana y Sistematización de la información sobre los aspectos socio-económicos y culturales para facilitar la toma de decisiones en proyectos de desarrollo y conservación. Documento realizado para y con aportes de The Nature Conservancy & The Wildlife Conservation Society. Quito, Ecuador.

Gibson, C. C. (2005). Local enforcement and better forests. World Development, 33(2), 273-284.

Godoy, R., Jacobson, M., De Castro, J., Aliaga, V., Romero, J. and Davis, A. (1998). The Role of Tenure Security and Private Time Preference in Neotropical Deforestation. Land Economics 74, 162-170.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., ... & Townshend, J. R. G. (2013). High-resolution global maps of 21st-century forest cover change. Science, 342, 850-853.

Ho, D. E., Imai, K., King, G., & Stuart, E. A. (2007). Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference. Political Analysis, 15, 199-236.

Holland, M. B., de Koning, F., Morales, M., Naughton-Treves, L., Robinson, B. E., & Suárez, L. (2014). Complex tenure and deforestation: implications for conservation incentives in the Ecuadorian Amazon. World Development, 55, 21-36.

International Tropical Timber Organization [ITTO] (2010). Tropical Forest Tenure Assessment: Trends, Challenges and Opportunities. Washington, D.C.: Rights and Resources Initiative.

Kerekes, C. B., & Williamson, C. R. (2010). Propertyless in Peru, even with a government land title. American Journal of Economics and Sociology, 69, 1011-1033.

Jacoby, H. G., & Minten, B. (2007). Is land titling in Sub-Saharan Africa cost-effective? Evidence from Madagascar. The World Bank Economic Review, 21, 461-485.

Joppa, L., and Pfaff, A. (2010). Reassessing the forest impacts of protection. Annals of the New York Academy of Sciences, 1185, 135-149.

Joppa, L. N., & Pfaff, A. (2011). Global protected area impacts. Proceedings of the Royal Society B: Biological Sciences, 278, 1633-1638.

King, G., & Zeng, L. (2007). When can history be our guide? the pitfalls of counterfactual inference. International Studies Quarterly, 51, 183-210.

Larson, A. M. (2011). Forest tenure reform in the age of climate change: Lessons for REDD+. Global Environmental Change, 21, 540-549.

Larson, A. M., & Dahal, G. R. (2012). Forest tenure reform: New resource rights for forest-based communities?. Conservation and Society, 10, 77.

Laurance, W. F., Albernaz, A. K., Schroth, G., Fearnside, P. M., Bergen, S., Venticinque, E. M., & Da Costa, C. (2002). Predictors of deforestation in the Brazilian Amazon. Journal of Biogeography, 29, 737-748.

Liverman, D. M., & Vilas, S. (2006). Neoliberalism and the environment in Latin America. Annu. Rev. Environ. Resour., 31, 327-363.

Marchand, S. (2012). The relationship between technical efficiency in agriculture and deforestation in the

Brazilian Amazon. Ecological Economics, 77, 166-175.

Mendelsohn, R. (1994). Property rights and tropical deforestation. Oxford economic papers, 750-756.

Morales, M. Naughton-Treves, L., & Suarez, L. (Eds.) (2010) Seguridad en la tenencia de tierras e incentivos para la conservación de los bosques 1970-2010. Quito, Ecuador. ECOLEX,

[MAE] Ministerio del Medio Ambiente 2003. Acuerdo Ministerial 149. Accessed via http://faolex.fao.org/ in April 2014

[MAE] Ministerio del Medio Ambiente 2006. Acuerdo Ministerial 098. Accessed via http://faolex.fao.org/ in April 2014.

[MAE] Ministerio del Medio Ambiente 2007. Acuerdo Ministerial 265. Accessed via http://faolex.fao.org/ in April 2014.

Mullan, K., Grosjean, P., & Kontoleon, A. (2011). Land Tenure Arrangements and Rural–Urban Migration in China. World Development, 39, 123-133.

Naughton-Treves, L. and Day, C., Eds. (2012). Lessons about land tenure, forest governance and REDD+. Madison: UW-Madison Land Tenure Center.

Nelson, A., & Chomitz, K. M. (2011). Effectiveness of strict vs. multiple use protected areas in reducing tropical forest fires: a global analysis using matching methods. PLoS One, 6, e22722.

Nguyen, T. T., Bauer, S., & Uibrig, H. (2010). Land privatization and afforestation incentive of rural farms in the Northern Uplands of Vietnam. Forest policy and economics, 12, 518-526.

Ojha, H., Persha, L., & Chhatre, A. (2009) Community forestry in Nepal: a policy innovation for local livelihoods. International Food Policy Research Institute-IFPRI. Discussion Paper 913.

Otsuki, T., Hardie, I. W., & Reis, E. J. (2002). The implication of property rights for joint agriculture–timber productivity in the Brazilian Amazon. Environment and Development Economics, 7, 299-323.

Paneque-Gálvez, J., Mas, J. F., Guèze, M., Luz, A. C., Macía, M. J., Orta-Martínez, M., ... & Reyes-García, V. (2013). Land tenure and forest cover change. The case of southwestern Beni, Bolivian Amazon, 1986–2009. Applied Geography, 43, 113-126.

Pluye, P., Potvin, L., & Denis, J. L. (2004). Making public health programs last: conceptualizing sustainability. Evaluation and Program Planning, 27, 121-133.

Poteete, A. R., & Ostrom, E. (2004). Heterogeneity, group size and collective action: the role of institutions in forest management. Development and change, 35, 435-461.

Robinson, B.E., Holland, M.B., Naughton-Treves, L. (in press). Does secure land tenure save forests? A meta-analysis of the relationship between land tenure and tropical deforestation. Global Environmental Change.

Rudel, T. K., Defries, R., Asner, G. P., & Laurance, W. F. (2009). Changing drivers of deforestation and new opportunities for conservation. Conservation Biology, 23, 1396-1405.

Rudel, T. K., & Horowitz, B. (2013). Tropical Deforestation: Small Farmers and Land Clearing in Ecuadorian Amazon. Columbia University Press.

Rubin, D. B. (1973). Matching to remove bias in observational studies. Biometrics, 29, 159-183.

Rubin, D. B. (1979). Using multivariate matched sampling and regression adjustment to control bias in observational studies. Journal of the American Statistical Association, 74, 318-328.

Saleska, S.R., Didan, K., Huete, A.R., da Rocha, H.R. (2007) Amazon Forests Green-Up During 2005 Drought. Science, 318, 612.

Scheirer, M. A. (2005). Is sustainability possible? A review and commentary on empirical studies of program sustainability. American Journal of Evaluation, 26, 320-347.

Sekhon, J. S. (2007). Multivariate and propensity score matching software with automated balance optimization: The Matching package for R. Journal of Statistical Software.

Sekhon, J. S., & Grieve, R. (2008). A new non-parametric matching method for bias adjustment with applications to economic evaluations. In: University of California, Berkeley.

Souris, M., (2008). Ecuador, in: Souris, M. (Ed.), Ecuador. School of Engineering and Technology, Asian Institute of Technology Pathumthani,Thailand.

Stirman, S. W., Kimberly, J., Cook, N., Calloway, A., Castro, F., & Charns, M. (2012). The sustainability of new programs and innovations: a review of the empirical literature and recommendations for future research. Implementation Science, 7, 17.

Stocks, A., McMahan, B., & Taber, P. (2007). Indigenous, colonist, and government impacts on Nicaragua's Bosawas Reserve.Conservation Biology, 21, 1495-1505.

Sunderlin, W. D., Larson, A. M., & Cronkleton, P. (2009). Forest tenure rights and REDD. Realising REDD, edited by A. Angelsen, 139-150.

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

USAID / ARD, Inc. (2006). The role of property rights in natural resource management, good governance, and empowerment of the rural poor. USAID Contract No. PCE-I-00-99-00001-00, Task No. 13.

USAID / ECUADOR ECODIT LCC. (2010). Evaluation of conservation and Development Strategies with Lowland Indigenous Groups. Task Order No. EPP-1-09-06-00010-00. http://pdf.usaid.gov/pdf_docs/pdacs415.pdf

USAID. (2011). Property Rights and Resource Governance: Ecuador. Washington, D.C.: USAID. Available at: http://usaidlandtenure.net/sites/default/files/country-profiles/full-reports/USAID_Land_Tenure_Ecuador_Profile.pdf (Accessed April 2014).

Walker, R., Perz, S., Caldas, M., & Silva, L. G. T. (2002). Land use and land cover change in forest frontiers: The role of household life cycles. International Regional Science Review, 25, 169-199.

White, A., & Martin, A. (2002). Who owns the world's forests. Forest Trends, Washington, DC.

Yackulic, C. B., Fagan, M., Jain, M., Jina, A., Lim, Y., Marlier, M., ... & Uriarte, M. (2011). Biophysical and Socioeconomic Factors Associated with Forest Transitions at Multiple Spatial and Temporal Scales. Ecology & Society,16.