A HOLISTIC APPROACH TO ADDRESS DEFORESTATION

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A HOLISTIC APPROACH TO ADDRESS DEFORESTATION

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To my beloved son Roshan and husband Kevin.

It has been a great journey with you.

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

β_0	Intercept Parameter
β	Slope Parameter
λ	Tuning Parameters
$P_\alpha(\beta)$	Elastic Net Penalty
ℓ_1	Least Absolute Deviations
ℓ_2	Least Squares Deviations
σ^2	Variance

ABREVATIONS

AIC	Akaike Information Criterion
BIC	Bayesian Information Criterion
CIESIN	Center for International Earth Science Information Network
CPR	Common Pool Resources
GPW	Gridded Population of the World
IFRI	International Forestry Resources and Institutions
LASSO	Least Absolute Shrinkage and Selection Operator
MSE	Mean Standard Error
REDD+	Reducing Emission from Deforestation and Forest Degradation
RRI	Rights and Resources Initiatives
RSS	Residual Sum of Squares
UNEP	United Nations Environment Program

USAID	United States Agency of International Development
WRI	World Resources Institute

SUMMARY

The establishments of property rights and collective actions are viewed as key strategies to support sustainable management of forests and other common pool resources. However, previous discussion of the theories either address property rights or collective actions as aggregated terms or omit the role of biophysical and socioeconomic conditions. It is not clear which property rights or collective actions are effective and under what biophysical and socioeconomic circumstance that they have effects. The dissertation analyzes how specific rights and collective actions affect deforestation in two studies based on separate sets of institutional data obtained from the World Resources Institute and International Forestry Resources and Institutions. By integrating remote-sensing, census and site survey data, a wide range of multi-disciplinary variables such as forest change and coverage, topographic, climate, soil properties, population, commercial value of the forest, forest management unit and road accessibility are integrated with the institutional data from numerous locations worldwide. Elastic Net and LASSO statistical methods are used to select significant individual variables from a large number of predictors and their interaction terms without excessive loss of information. Statistical analysis methods including linear, generalized linear and truncated normal regression analyses and cross validation are used. Both studies lead to similar conclusions. The first study analyzes data from 28,208 community forests in Cameroon, Colombia and Mexico and indicates that the effects of the alienation rights (right to lease, right to lease and collateralize, and a complete set of alienation rights) can be either positive, negative or have no correlation, when preventing deforestation and reducing deforestation are the concerns. Furthermore, the alienation rights' effects vary across locations. The second study analyzes data from 162 sites in 15 countries and indicates that the specific collective actions (existence of rules, rule congruence, monitoring and graduated sanction) and property rights (forest ownership, right to withdrawal and right to sell) perform differently, with respect to gross deforestation. The effects can be either positive, negative or show no correlation, depending on the local biophysical and socioeconomic conditions. The studies conclude that we should not assume property rights or collective actions would ultimately lead to desired forest outcomes under all local conditions. The potential effects of a specific right or action should be treated and implemented differently, and location-based solutions developed in the local biophysical and socioeconomic context may be needed to address deforestation. It is important that the decision makers, international donor organizations and academic researchers be aware of the diverse and contradictory effects of specific rights and actions, especially the associated complications of dependence on local biophysical and socioeconomic conditions.

CHAPTER 1. INTRODUCTION

1.1 Trends

1.1.1 Global Deforestation

In the past two decades, the world's forest area has declined from 281 million square kilometers in 1992 to 264 million square kilometers in 2012 (WorldBank, 2015). Remote sensing data shows that the total area deforested is much greater than the area reforested. Between 2000 and 2012, 2.3 million square kilometers of forest have been clear-cut, while only 800,000 square kilometers of land has been reforested (Hansen et al., 2013). The drivers of deforestation are a major concern to researchers, as this loss of tree cover may have negative economic climatic, and environmental consequences (Achard et al., 2002; Angelsen & Kaimowitz, 1999; Meyfroidt & Lambin, 2011). Gross deforestation, defined as the "loss in forest area over a given time period caused by conversion of forest to non-forested land" in Brown and Zarin (2013), has been identified as an indicator of the (lack of) protection of native forests.

1.1.2 Decentralization in Forest Management

Since the mid-1980s, decentralization of forest management has been the predominant trend in developing countries. Decentralization is commonly defined as the relocation of administrative functions away from a central location (e.g., government) to the closer communities or natural users (e.g., villages, tribes, etc.) (Fisher, 2001). Theoretical studies on common pool resources (CPR) have highlighted the role of decentralization in forest management—the more decentralized the forest's management, the better the forest's status (Ostrom et al., 1999; Agrawal et al., 2008; Araujo et. al, 2008; Palmer, 2011). The CPR studies suggest that a critical precondition of successful CPR management is whether or not the local actors obtain access to resources that enable their utilization and profits generated from the CPR (Agrawal, A., & Ostrom, E., 2001). Impelled by international organizations and agreements that urge better forest management in developing nations, decentralization reform coincided with demands for a greater recognition of the local communities' role in managing local forests and the desire of many governments to reduce the financial burden of forest governance (Agrawal & Hardin, 2008).

1.1.3 Variation and separation of Research Paradigms

Historically, there has been segregation of research paradigms. Traditional ecological research often excluded human impacts while the social research generally ignored biophysical drivers (Liu et al., 2007). Nevertheless, biophysical, socioeconomic and institutional factors all play roles directly or indirectly on forest as a common-pool resource (CPR). The natural generation of a forest is determined mostly by the biophysical characteristics of its location. The consumption and utilization of forests are correlated with the local socioeconomic characteristics. The management and sustainability of forests are affected by the setup of the related institutional arrangements. Furthermore, even though in some cases institutional factors do not have a direct effect, they may affect forest outcomes indirectly by shaping the socioeconomic circumstance and modifying the biophysical conditions.

1.2 Theoretical Foundations: from Hardin to Ostrom

Hardin's Tragedy of the Commons model assumes that individuals are short-term, self-interested "rational" actors, seeking to maximize their own gains. Such actors will exploit commons as long as they believe the costs to them individually are less than the benefits. The model suggests that the *laissez faire* system, leaving individuals making their own decisions, will not "as if by an invisible hand" solve the problem of the commons. Viable options include setting up formal institutions either in the form of <u>private property rights</u> to commons or enforcing constrained access to the commons as public property (Hardin, 1968). Schlager and Ostrom have further specified property rights of commons into a bundle of five rights: Access, Withdrawal, Management, Exclusion and Alienation (Schlager and Ostrom, 1992).

While acknowledging the importance of property rights as a solution to the dilemma of CRP, Dietz and Ostrom (2003) argue that Hardin’s claims were oversimplified: 1) only two institutional arrangements— centralized government and private property—were there to sustain commons over the long run; 2) resource users were trapped in a commons dilemma, unable to create solutions. He missed a possibility that the social groups may develop and maintain self-governing informal institutions or collective action to sustain the commons. Although these institutions have not always succeeded, neither have Hardin’s preferred alternatives of private or state ownership (Dietz, and Ostrom, 2003). Ostrom takes an empirical approach and finds that in many different cultures all over the world, some groups find ways to overcome the obstacles that defeated others in managing common-pool resources by creating contracts, agreements, incentives, constitutions, and signals as media to enable cooperation for mutual benefit. Ostrom’s work suggests people are trapped by the prisoner's dilemma only if they treat themselves as prisoners by passively accepting the suboptimum strategy the dilemma locks them into; but if they try to work out a contract with the other players, or find the ones most likely to cooperate, or agree on rules for sanctions or artificially change the incentive ratios, they can create an informal institution for collective action that benefits them all and hence alter the tragedy of commons (Ostrom, 1999). Ostrom specifies eight design principles for sustainable common pool resources management: clearly defined boundaries, congruence between the rules and resource environment, collective-choice arrangement and participation, monitoring, graduated sanctions, conflict resolution mechanisms, minimal recognition of rights to organize, and nested enterprises (Ostrom, 1990).

1.3 Research Goals

As a result of research paradigm separation (Liu et al., 2007) and data deficiency (Verburg, 2011; Poteete & Ostrom, 2004, 2008), forest resources data generated by various sources often come with temporal, spatial and thematic differences and inconsistency (Verburg, 2011). Incomplete model specification and omitted variables in hypothesis testing are widely observed in the CPR literature (Agrawal, 2001). Therefore, many of the theory-driven studies have not investigated the interactions between institutions and local conditions, and the complexity of coupled human-nature systems is not well understood (Liu et al., 2007).

This dissertation addresses these challenges by using data integration and data analysis methods to understand the detailed effects of specific prosperity rights and collective actions and their interactions with local biophysical and socioeconomic conditions. I integrate biophysical, socioeconomic and institutional data from a wide range of best available multiple public sources. I apply Elastic Net and LASSO statistical methods to select significant individual variables from a large number of predictors and their interaction terms in a dataset with relatively small sample size without excessive loss of information. I seek answers for a series of detailed questions: which bundles of property rights and collective actions as institutions are correlated with positive forest outcomes? To what extent do they provide such outcomes? Under what biophysical and socioeconomic circumstances would an institutional setting work or work better? Is it important to incorporate human-nature interaction into forest studies?

The bundle of five resource rights and the eight design principles for resource management provide a solid foundation and useful direction to explore the details. Based on two separate sets of institutional variable data obtained from the World Resources Institute (WRI) and the International Forestry Resources and Institutions (IFRI), the following chapters present two of my research works that aim to answer these detailed questions.

CHAPTER 2. DETAILS MATER: THE EFFECTS OF ALIENATION PROPERTY RIGHTS ON DEFORESTATION

2.1 Alienation Rights and the Tragedy of Forest Commons

Remote-sensing data show that in the past decade, we have been losing our forest at three times the speed that we are regenerating them (Hansen et al., 2013). The drivers of deforestation are a major concern to researchers, as we know that this loss of tree cover has the potential to affect temperature, cause economic losses, and create environmental havoc (Achard et al., 2002; Angelsen & Kaimowitz, 1999; Meyfroidt & Lambin, 2011). Gross deforestation, defined as the "loss in forest area over a given time period caused by conversion of forest to non-forested land" in Brown and Zarin (2013), has been used as an indicator of the loss of native forests with higher carbon/biodiversity/hydrologic-service–value, in contrast to the planting of new low-value forest. In this paper, we focus on gross deforestation and identify the prevention and reduction of gross deforestation as a desired outcome in forest management.

Schlager and Ostrom have specified property rights of commons into a bundle of five rights: Access, Withdrawal, Management, Exclusion and Alienation, to array property-rights regimes from authorized user, to claimant, to proprietor, and to owner (Table 1) (Schlager and Ostrom, 1992). Schlager and Ostrom's work provides a useful framework to analyze and understand the role of rights in the management of forest commons.

Table 1 Bundle of Rights and Resource Rights Holders

Right Holder	Bundle of Rights				Effective Use of Resources
	Access and Withdrawal	Management	Exclusion	Alienation	
Authorized User	√				Weak
Claimant	√	√			Somewhat Weak
Proprietor	√	√	√		Somewhat Strong
Owner	√	√	√	√	Strong

Source: Adapted from Schlager and Ostrom, 1992 and Coleman, 2011

Among the bundle of rights, alienation rights are believed to be crucial for the effective use of resources: "Through the sale or lease of all or part of the property rights owners hold, they can capture the benefits produced by long-term investments" (Schlager and Ostrom, 1992). Also, entitling owners to transfer their land may allow forest resources to be shifted from a less productive to a more productive use (Posner, 1973). And hence the right holders with alienation rights may have higher incentive to use the resources effectively and to improve forest outcomes. This framework has had a significant impact on academic research as well as on local, regional and global advocates. Many studies have stressed that property rights insecurity reduces the present value of forests and fosters forest conversion into other land uses (Araujo et al., 2009; Palmer, 2011). Incomplete land tenure often places greater burdens on community actors and makes local community users less flexible in responding to local diversity and change, and may contribute to deforestation (Larson and Dahal, 2012; Mendelsohn, 1994).

Because the effects of these modes of alienation rights were not differentiated by Schlager and Ostrom, the discussions of the theories often address alienation rights as an aggregated term, despite the fact that the alienation rights comprise a group of similar but still distinct modes: right to sell, right to collateralize and right to lease. Previous discussions have focused mainly on the effect of property rights as an entirety: do property rights interventions affect forest outcomes? However, framing research questions in a simplistic way could lead to problematic conclusions. Only some specific modes of forest alienation rights may be correlated with positive forest outcomes so the effects of forest rights can vary–some modes of rights might lead to positive impact and some to negative impact. Furthermore, the effects of forest property rights may also be largely constrained by the biophysical and socioeconomic circumstances.

We are interested in pursuing the details in this study: what if we break down and differentiate forest alienation rights into specific modes—the right to sell, the right to collateralize and the right to lease? We examine the correlation of these modes of ownership rights with deforestation trends in different places. Which specific right(s) link to desired or undesired forest outcomes? And to what extent do the performances of the specific rights depend on biophysical and socioeconomic circumstances? Specifically, this paper investigates the following hypotheses:

H1: The effects of the modes of alienation rights on gross deforestation are mixed.

H2: The effects of modes of alienation rights' performance on gross deforestation depend on biophysical and socioeconomic factors in the region.

2.2 Alienation Rights and Forest Commons: Theory and Empirical Evidence

Only a few countries have granted full alienation rights to their community lands. The review by the Rights and Resources Initiative shows that from the 27 countries studied, community lands in 12 countries were given some extent of the alienation right, mostly the right to lease. Only six countries allocate a right to sell community lands (RRI, 2014). The hesitation to allocate the right to sell and other alienation rights to communities has been attributed to the fear that the granting of alienation rights could result in land clearing (Larson et al., 2010).

There is limited empirical evidence on the effect of alienation rights. Coleman (2011) analyzed user groups in 13 countries with different bundles of rights and concluded that user groups with more complete rights, including alienation rights, are more likely to rank forest conditions favorably, and that the perceived effects of property rights also depend on the level of adaptive capacity, such as the organizational capacity of the user group and the number of rival groups. However, case studies in four locations in Nepal and India did not find alienation rights essential to maintain forest conditions (Agrawal and Ostrom, 2001). The former study measured forest outcome by user perception (whether or not the users rank their forests better than others). However, physical measurement may come out with different results, as the users may have favorable views about the forests under their management. The Agrawal and Ostrom study employed a case study approach and did not incorporate the variation of biophysical conditions into the analysis, which could potentially miss the impact of local circumstances. To the best of our understanding, none of the previous studies have looked into the effect of specific modes of alienation rights.

In addition, although studies stressed that property rights insecurity reduces the present value of forests and fosters forest conversion into other land uses (Araujo et al., 2009; Palmer, 2011), many of the theory-driven interventions (i.e. property rights) have not been investigated for their interactions with varied natural systems. Biophysical, socioeconomic and institutional factors have significant effects - directly or indirectly - on forests as they affect the value of the resource. The natural generation of a forest is determined mostly by the biophysical characteristics of the location. The consumption and utilization of a forest is correlated with local socioeconomic characteristics. The management and sustainment of a forest is affected by the setup of the related institutional arrangements. Furthermore, even though in some cases socioeconomic and institutional factors do not have a direct relationship, they may affect forest outcomes indirectly by modifying the socioeconomic and biophysical conditions.

As a result, existing local case studies have found that private property rights have had mixed outcomes (Ostrom et al., 1999; Agrawal et al., 2008; Araujo et. al, 2008; Palmer, 2011; Fisher, 1999; Anderson, 2000; Pagdee et al., 2006 ; Andersson and Ostrom, 2008). “Getting the institutions right” is a challenging and yet essentially important process, which may require detailed understanding of specific systems (Ostrom, 1990).

2.3 Land Tenure in Studied Countries

Since the 1990’s, many countries, especially those in the developing world, have introduced decentralized reforms in the forestry sector by emphasizing private property rights. The reforms have met the twin demands of recognition of the local community’s role and the desire of governments to reduce their financial burden (Agrawal et al., 2008). In Colombia, Afro-Colombian and indigenous communities hold 26% of the rural lands and own 22.1 million hectares and 5.4 million hectares of forestland, respectively (USAID, 2010). The 1991 Constitution recognized and outlined a framework for collective land rights for indigenous groups and Afro-Colombian communities. A legal change in 1995 allowed both communities to register their rights to the territories they have occupied historically (White and Martin, 2002). However, the constitution indicates that the indigenous reserves and the Afro-Colombian community lands are inalienable (Art. 63, Colombian Constitution, 1991; Art. 7, Law N° 70/1993; as cited in RRI, 2012).

In Cameroon, the 20 million hectares of forests cover 40% of the nation’s territory, in which 301 communities own over 1 million hectares (Mertens et al., 2012). The forest law provides for forest management. To register for community forests, the communities must map the boundary and inventory the forest resources (USAID, 2011), which give them some forms of excludability. By signing a Community Forest Management Agreement with the Forestry Administration, the communities are entitled with the right to access, withdrawal and management, for a period up to 15 years (RRI, 2012; USAID, 2011). But the state transfers only the right to use and benefit and maintains control over the forest ownership (Law N° 01/1994; Decree N° 531/1995; Logo 2007, 4; as cited in RRI, 2012). The community is allowed to lease the land within the limitation of the management plan (Art. 54, Law N° 01/1994; Art. 95 and 96, Decree N° 531/1995; as cited in RRI, 2012).

In Mexico, there are two types of community lands, ejidos and comunidades. These two types of community lands account for more than half of the nation’s land and 70% of the country’s forests (Larson et al., 2010). The ejidos and comunidades are lands owned by a community. Both groups are entitled with a right to lease and a right to collateralize (Article 10, 46, 59, 64, 73, 75, 107, Agrarian Law, 2008; as cited in RRI, 2012). But they are different in two aspects. First, the ejido lands are divided into parcels and each of the ejidatario have user rights to their own parcels. On the other hand, the communidades lands follow a communitarian property scheme (Robles and Peskett, 2012). Second, the ejidos are entitled with a right to sell while the communidades lands cannot be sold. The forestlands in the ejidos can be sold to the ejidatario from the same ejido as specified in the Agrarian Law reform in 1992 (Robles and Peskett, 2012). The 2008 Agrarian Law reform further lifted the constraint to allow the ejidatario to transfer common land title to commercial or civil cooperation in cases if needed for the ejido's population (Art. 75, Agrarian Law, 2008; as cited in RRI, 2012).

The community forests spatial data available in Cameroon, Colombia and Mexico allow us to explore the effects of alienation rights and their dependence on local circumstances. These countries were selected as a result of data availability. In these countries, most of the forest rights are homogenous, except the alienation rights (Table 2).

Table 2 Forest Property Rights in Studied Countries*

	Access	Withdrawal	Management	Exclusion	Alienation		
					Lease	Collateral	Sale
Cameroon	√	√	√	√	√	x	x
Colombia	√	√	√	√	x	x	x
Mexico	√	√	√	√	√	√	Ejido √ Comunidades x

**adapted from Resource Right Initiative (2014), What Future for Reform? Progress and slowdown in forest tenure reform since 2002*

2.4 Data and Data Processing

2.4.1 Data Description

Two sets of variables are included in the analysis: 1) the response variables, referring to gross deforestation; and 2) the predictive variables, which include the modes of forest alienation rights, biophysical and socioeconomic conditions. The data are collected from best available multiple public sources.

The response variable is the gross deforestation between 2000 and 2013, measured in the form of the total area of deforestation within designated boundaries. The spatial resolution of the original data is 30-meters (Hansen et al., 2013). The gross deforestation is calculated by multiplying the number of pixels within each of the community forest boundaries by 900 square meters (the size of the pixels).

Table 3 List of Data and Variables

Variables	Details
	RESPONSE VARIABLE
Gross deforestation	Gross deforestation between 2000 and 2013, measured in the form of the total area of deforestation within the boundary of the individual community forestland (Hansen, 2013)
Percentage deforestation	Gross deforestation between 2000 and 2013 divided by the forest coverage in 2000 (Hansen, 2013)
	PREDICTIVE VARIABLES
Forest Alienation Rights	
Right to sell, collateralize and lease	A binary variable indicating whether the forest owners have a complete set of alienation rights (RRI, 2014)
Right to sell and collateralize	A binary variable indicates whether the forest owners have the right to collateralize and right to sell (RRI, 2014)
Right to lease	A binary variable indicating whether the forest owners have the right to lease (RRI, 2014)
Biophysical	
Size of Forest	Forest coverage in 2000, measure in the form of total area of forest within the boundary of the individual community forestland (Hansen, 2015)
Soil productivity	Global Soil Productivity Index, range from 0 to 1 (UNEP, 2016)
Altitude	Mean altitude of the community forestland (Jarvis et al., 2008)
Temperature	Annual mean temperature (Hijmans et al., 2005)
Precipitation	Annual mean precipitation (Hijmans et al., 2005)
Socioeconomic	
Population	Total Population (GPWv4) (CIESIN, 2015)
Road Inaccessibility	Distance to main road (CIESIN, 2013)
Unit of Analysis	
Community forestlands	The spatial document outlining the boundary of the community forest (WRI, 2016)

The institutional variables include 4 modes of forest rights: a) the community forestlands in Colombia have no alienation rights; b) the community forests in Cameroon are entitled with right to lease only; 3) the communidades forestlands in Mexico have the right to collateralize and the right to lease, and; 4) the ejido forestlands in Mexico have the most complete set of alienation rights: right to sell, right to collateralize and right to lease (RRI, 2014).

The biophysical variables include altitude, temperature and precipitation. The spatial resolution of the altitude data is 90 meters (Jarvis et al., 2008). The temperature and precipitation data are available at 1-kilometers resolution (Hijmans et al., 2005). The mean altitude, temperature and precipitation are the values of average altitude, temperature and precipitation within each of the community forest boundaries, respectively. The socioeconomic variables include population and road inaccessibility. The spatial resolution of the population data is 1 kilometer (CIESIN, 2014). The total population is calculated as the sum of the number of individuals within each of the community forest boundaries. The road inaccessibility variable is generated from the Global Roads Open Access Data Set (CIESIN, 2013), calculated as the distance between the each of the community forestlands and the nearest main roads.

The unit of analysis is the individual community forest. Instead of downscaling the unit to grid cell level, we assume the forest users' activities are constrained by the land ownership boundaries. We argue that using community forest will keep the decision-making arena as the unit of analysis and the analysis will hence detect how human decisions interact with the natural system. The spatial boundaries of the community forestlands are obtained from World Resources Institute's Global Forest Watch Portal (WRI, 2015).

2.4.2 Data Processing

The data layers are overlaid and a dataset is generated for each of the community forestlands following the steps below:

Step1: Obtain the spatial file of the boundary of the study sites and link the sites to gross deforestation, institutions, and biophysical and socioeconomic variables maps

Step 2: Resample the biophysical and socioeconomic variables from 1-kilometers to 30-meters resolution

Step 3: Calculate the value of gross deforestation and the biophysical and socioeconomic variables within the land ownership boundaries

Step 4: Conduct regression analyses and hypotheses testing

Figure 1 Data Processing

2.4.3 Data Summary

To test the hypotheses, data from 28,208 community forests in the three countries are analyzed. The forests included in the study represent all community forests in the subject countries but are not a random sample of all community forests over the world. The distribution of the data shows that gross deforestation, the response variable, has two modes (Appendix: Figure 3). One mode concentrates on zero and the other follows a Gamma distribution. The two groups are analyzed separately. The summary statistics of the variables are presented by modes of alienation rights in Table 4. The data from Columbia, with no alienation rights, comes with the largest average base year forest area (426.8 square kilometers) in 2000, compared to the rest of the groups (29.9, 22.9, 5.4 square kilometers). However, group a)'s gross deforestation between 2000 and 2013 is proportionally smaller (0.6% or 2.7 square kilometers), compared to the other groups (3%, 3%, and 7% respectively). The ranges of the biophysical and socioeconomic variables are diverse.

Table 4 Summary Statistics of the Variables by Group

	Mean	**Std. Dev.**	**Min**	**Max**
a) No alienation rights (Colombia) (N=670; 3.05%)				
Deforestation 2000-2013 (square kilometers)	2.7	14.0	0.0	267.4
Forest Area in 2000 (square kilometers)	426.8	3,095.0	0.0	60,702.7
Altitude (meter)	570.8	681.4	0.0	3,279.8
Precipitation (millimeter)	3,294.5	1,740.7	0.0	9,696.3
Temperature (°C)	24.4	3.8	0.0	28.4
Soil Productivity Index	40,574.6	4,445.4	0.0	43,153.2
Population (thousand persons)	1,393.6	11,803.0	0.0	234,881.8
Road Inaccessibility (kilometer)	17.4	32.0	0.0	242.8
b) Right to lease (Cameroon) (N=339, 1.54%)				
Deforestation 2000-2013 (square kilometers)	0.9	1.6	0.0	21.8
Forest Area in 2000 (square kilometers)	29.9	16.4	0.0	69.5
Altitude (meter)	655.7	314.7	0.0	2,376.8
Precipitation (millimeter)	1,715.0	396.8	0.0	3,348.5
Temperature (°C)	23.7	2.1	0.0	28.3
Soil Productivity Index	40,847.3	2,464.1	0.0	42,101.3
Population (thousand persons)	510.7	957.5	0.0	8,221.7
Road Inaccessibility (kilometer)	1.1	2.2	0.0	13.1
c) Right to lease and to collateralize (Mexico Communidade) (N=1,608; 7.32%)				
Deforestation 2000-2013 (square kilometers)	0.7	5.0	0.0	202.4
Forest Area in 2000 (square kilometers)	22.9	110.0	0.0	4,241.1
Altitude (meter)	1,353.6	819.2	0.0	3,554.3
Precipitation (millimeter)	1,161.7	561.1	0.0	3,573.8

Table 4 Summary Statistics of the Variables by Group (continued)

	Mean	Std. Dev.	Min	Max
Temperature (°C)	19.6	4.5	0.0	29.1
Soil Productivity Index	28,448.0	4,078.0	0.0	32,372.9
Population (thousand persons)	1,077.0	2,921.0	0.0	77,457.4
Road Inaccessibility (kilometer)	1.9	3.0	0.0	24.5
d) Right to lease, to collateralize and to sell (Mexico Ejido) (N=21,981; 88.09%)				
Deforestation 2000-2013 (square kilometers)	0.4	2.5	0.0	156.4
Forest Area in 2000 (square kilometers)	5.4	24.6	0.0	1,343.5
Altitude (meter)	1,000.5	897.8	-3.3	3,713.5
Precipitation (millimeter)	1,048.8	700.8	0.0	4,653.2
Temperature (°C)	21.2	4.6	0.0	29.3
Soil Productivity Index	27,726.9	4,184.6	0.0	32,866.9
Population (thousand persons)	375.5	2,073.9	0.0	250,667.9
Road Inaccessibility (kilometer)	2.5	4.9	0.0	63.1

2.5 Statistical Methodology

The data analysis includes four steps (Figure 2): 1) Regression models to analyze the variables' relationship with deforestation 2) Outlier analysis to remove the extreme outliers; 3) Variable selection to determine the important variables correlated with deforestation; 4) model selection to select the final model based on trade-offs between the fit of the model and model complexity. The selected models are normalized in order to compare the magnitude of the parameter estimates.

2.5.1 Regression Analyses

Regression analysis is performed comparing gross deforestation trends with modes of forest rights, and with the interactions with socioeconomic and biophysical variables. In the case where the base year forest is not zero but deforestation is zero, a logistic regression is applied to understand how the modes of alienation rights are associated with zero deforestation. In the case where base year forest and deforestation are both not zero, two types of models are applied to study the relationship between alienation rights and gross deforestation: 1) Truncated normal linear regression. Box-Cox transformation ($\lambda = 0.0202$ and $\lambda = 0.0101$, respectively) are made, based on Box-Cox Analysis (Appendix: Figure 4), to improve the normality of gross deforestation and percentage deforestation, the response variables; 2) Generalized linear model Gamma distribution log and inverse links, with both gross deforestation and percentage deforestation as the response variables. The final model is selected through procedures specified in section 2.5.2. – 2.5.4.

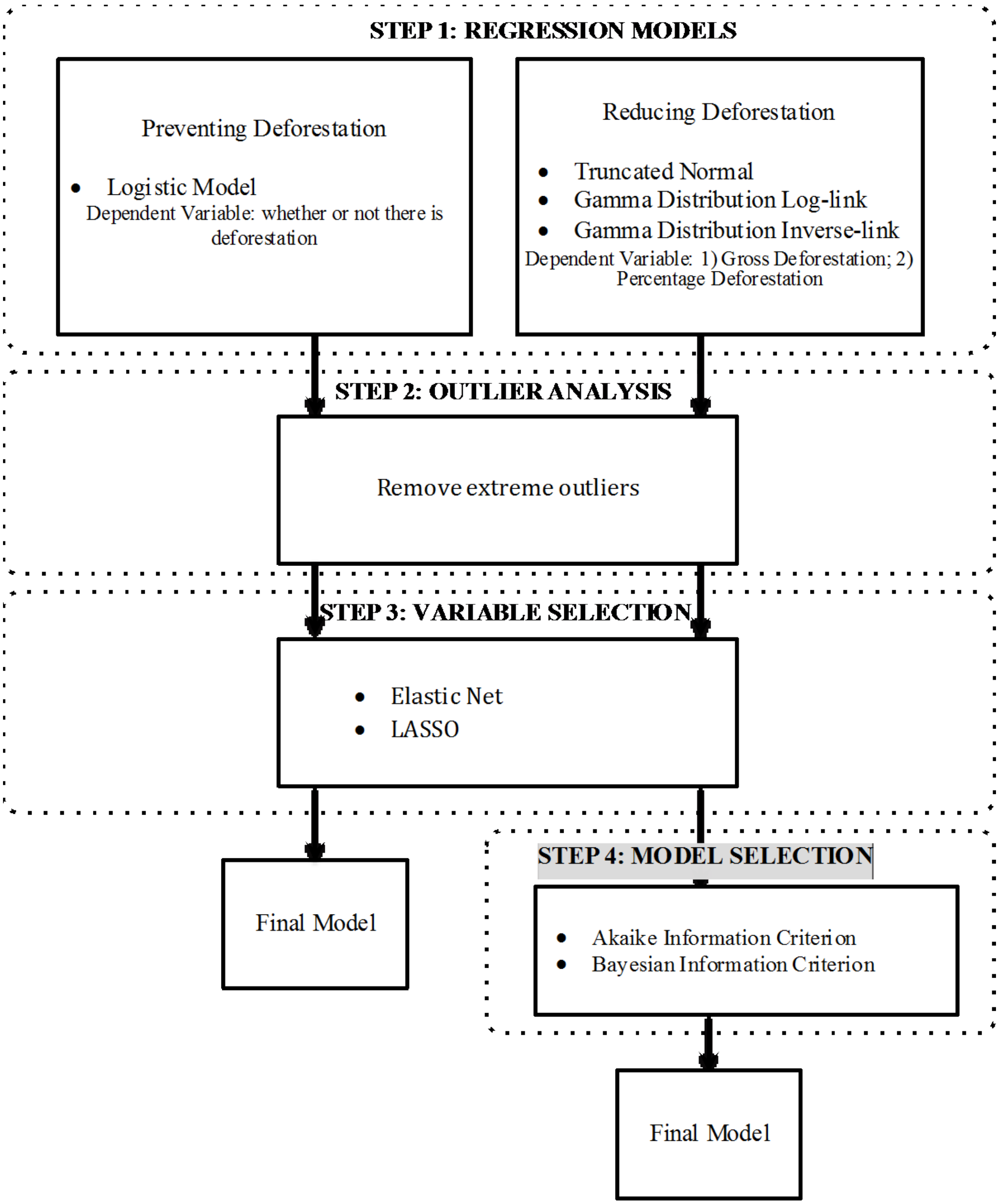


Figure 2 Data Analysis Framework

2.5.2 Outlier Analysis

The Interquartile Range rule is applied to determine the outliers. After fitting the regressions, observations with residuals that fall outside the below range are identified as outliers and are removed from the dataset (Montgomery and Runger, 2010).

$$L = Q_1 - 1.5(Q_3 - Q_1)$$
$$R = Q_3 + 1.5(Q_3 - Q_1)$$

$Q_1$and Q_3 are the first and third quartile, respectively.

2.5.3 Variable Selection

Variable selections based on LASSO and Elastic Net penalties are conducted on the models with interaction terms to determine the important variables correlated with deforestation. We use a 10-fold cross-validation for finding the tuning parameter. After variable selection, the model with the smallest Mean Standard Error (MSE) will be selected. The Elastic Net solves the below problem

$$\min_{(\beta_0,\beta)\in\mathbb{R}^{p+1}} \left[\frac{1}{2N}\sum_{i=1}^{N}\left(y_i - \beta_0 - x_i^T\beta\right)^2 + \lambda P_\alpha(\beta)\right]$$

where

$$P_\alpha(\beta) = (1-\alpha)\frac{1}{2}\|\beta\|_{\ell_2}^2 + \alpha\|\beta\|_{\ell_1}$$
$$= \sum_{j=1}^{p}\left[\frac{1}{2}(1-\alpha)\beta_j^2 + \alpha\left|\beta_j\right|\right]$$

is the elastic net penalty, a compromise between the Ridge regression penalties ($\alpha = 0$) and the LASSO penalty ($\alpha = 1$) (Friedman et. al., 2010; Zou and Hastie, 2005; Tibshirani, 1996; Hoerl and Kennard, 1970).

2.5.4 Model Selection

Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) are the general methods for model selection. AIC selects a model by making a trade-off between goodness-of-fit and complexity of model. AIC aims to minimize:

$$\text{AIC}(S) = \frac{\text{RSS}(S)}{n} + \frac{2|S|\sigma^2}{n}$$

where, RSS is the residual sum of squares, S is the number of parameters in the model, n is the number of observations and □ is the variance of the model's residuals. The first part of the equation $\frac{\text{RSS}(S)}{n}$ is an indicator of lack of fit, which measures the fit of the model. The second part of the equation $\frac{2|S|\sigma^2}{n}$ is a penalty for model complexity (Akaike, H., 1974). The model with the lowest AIC is selected.

BIC penalizes large models more harshly, compared to AIC (Schwarz, 1978). It aims to minimize:

$$BIC(S) = \frac{RRS(S)}{n} + \frac{logn|S|\sigma^2}{n}$$

2.6 Estimation and Inference

The logistic model on zero deforestation with LASSO penalty comes out with the smallest prediction error (Mean Misclassification Error = 0.014) and hence the result of LASSO penalty variable selection is chosen (Appendix: Figure 5). The analysis (Table 5) of those areas with zero deforestation shows statistically significant correlations with biophysical, socio-economic, and property rights characteristics.[1] Zero deforestation is negatively correlated with forest size and population, and positively correlated with altitude and distance to main road. Having right to lease, collateralize and sell (Mexico ejido) decreases the log likelihood of having zero deforestation. Right to lease (Cameroon) and right to collateralize in addition to right to lease (Mexico communidade) have no statistically significant correlation with the log-odds of having zero deforestation.

Having rights to collateralize and to lease in addition in areas with higher precipitation, on soil with higher productivity or in locations with more population is associated with decreased log likelihood of having zero deforestation, compared to the reference group (no alienation rights). On the other hand, having the right to lease and a complete set of alienation rights in areas with higher altitude is associated with higher log likelihood of having zero deforestation.

[1] Due to the complete/quasi separation of the logistic model problem, the coefficients of the fitted regression with LASSO penalty are reported.

By assessing the parameter estimates, we also notice that the following alienation rights-related terms have greater effects: a complete set of alienation rights (-1.36), interaction terms of right to lease and a complete set of alienation rights with altitude (3.92 and 1.13, respectively) and interaction terms of rights to collateralize and to lease with precipitation (-2.04).

Table 5 Penalized Logistic Estimates of Zero Deforestation

	Estimate (Penalized)
(Intercept)	-9.35
Forest Size (log)	-8.40
Altitude	2.24
Precipitation (log)	-
Temperature	-
Soil Productivity	-
Population (log)	-0.58
Road Inaccessibility (log)	0.46
Lease	-
Collateral+Lease	-
Sell+Collateral+Lease	-1.36
Forest Size(log) : Lease	-
Forest Size (log): Collateral+Lease	-
Forest Size(log): Sell+Collateral+Lease	-
Altitude:Lease	3.92
Altitude:Collateral+Lease	-
Altitude:Sell+Collateral+Lease	1.13
Precipitation(log):Lease	-
Precipitation(log):Collateral+Lease	-2.04
Precipitation(log):Sell+Collateral+Lease	-
Temperature:Lease	-
Temperature:Collateral+Lease	-
Temperature:Sell+Collateral+Lease	-
Soil:Lease	-
Soil:Collateral+Lease	-0.31
Soil: Sell+Collateral+Lease	-
Population (log) :Lease	-
Popualtion (log) :Collateral+Lease	-0.16
Popualtion (log) :Sell+Collateral+Lease	-
Road Inaccessibility(log):Lease	-
Road Inaccessibility(log):Collateral+Lease	-
Road Inaccessibility(log): Sell+Collateral+Lease	-

In the case where deforestation is not zero between the studied periods, after variable selection and model selection, the truncated normal model with gross deforestation as the response variable with LASSO penalty (Mean Square Error = 0.00123) has the lowest AIC and

BIC (AIC = -83,539.2; BIC = -83,286.3) (Appendix: Figure 6) and hence is chosen for further inferences. The analysis finds different results to the zero deforestation model (Table 6). Having the right to lease, having the right to collateralize and to lease and having a complete set of alienation rights are all associated with lower deforestation (λ=0.0202) (-0.46, P = 2.59E-06; -0.57, P< 2.2e-16; -0.44, P < 2.2e-16).

In addition, statistical analysis shows the alienation rights interact with biophysical and socioeconomic terms and come out with diverse outcomes. Compared to the reference group (no alienation rights), having a complete set of alienation rights in addition on larger size of forests, lands with higher precipitation, warmer temperature, higher population density, or forests far away from main roads accelerates gross deforestation. Also, having a right to lease and to collateralize in addition on forests of larger size, lands with higher precipitation, higher population density or forests far away from main roads increases gross deforestation. Having the right to lease on forests with higher precipitation increases gross deforestation but having a right to lease in addition on lands with higher soil productivity or far away from main roads decreases gross deforestation, compared to the lands without alienation rights.

By assessing the parameter estimates, we also notice the following alienation rights related terms have greater effects: a complete set of alienation rights (-0.04), the rights to collateralize and to lease (-0.06), right to lease (-0.05), interaction terms of a complete set of alienation rights with precipitation and temperature (0.04 and 0.02, respectively), and the interaction term of rights to collateralize and to lease with precipitation (0.03).

This section only presents the results of the statistical analysis and the interpretations of the inferences will be given in section 2.7.

Table 6 Linear Estimate of Gross Deforestation (λ =0.0202)

	Estimate	Std. Error	t-value	Pr(>|t|)	
(Intercept)	1.2910	0.0046	283.69	< 2.2e-16	***
Forest Size (log)	0.0447	0.0014	32.572	< 2.2e-16	***
Altitude	-0.0515	0.0085	-6.0464	1.5E-09	***
Precipitation (log)	-0.0217	0.0022	-9.6225	< 2.2e-16	***
Temperature	-0.0409	0.0073	-5.5708	2.E-08	***
Soil Productivity	-0.0010	0.0012	-0.9067	0.36	
Road Inaccessibility (log)	-0.0048	0.0014	-3.3935	0.0006	***
Lease	-0.0460	0.0098	-4.7007	2.6E-06	***
Collateral+Lease	-0.0567	0.0048	-11.868	< 2.2e-16	***
Sell+Collateral+Lease	-0.0439	0.0046	-9.6253	< 2.2e-16	***
Forest Size(log) : Lease	0.0027	0.0061	0.4387	0.66	
Forest Size (log): Collateral+Lease	0.0098	0.0019	5.0698	3.98E-07	***
Forest Size(log): Sell+Collateral+Lease	0.0064	0.0014	4.4874	7.2E-06	***
Altitude:Lease	-0.0036	0.0196	-0.1860	0.85	
Altitude:Collateral+Lease	0.0017	0.0091	0.1890	0.85	
Altitude:Sell+Collateral+Lease	0.0044	0.0086	0.5119	0.61	
Precipitation(log):Lease	0.0116	0.0067	1.7181	0.086	.
Precipitation(log):Collateral+Lease	0.0403	0.0027	15.058	< 2.2e-16	***
Precipitation(log):Sell+Collateral+Lease	0.0262	0.0023	11.472	< 2.2e-16	***
Temperature:Lease	-0.0091	0.0176	-0.5221	0.60	
Temperature:Collateral+Lease	0.0115	0.0080	1.4455	0.15	
Temperature:Sell+Collateral+Lease	0.0198	0.0074	2.6795	0.0074	**
Soil:Lease	-0.0067	0.0028	-2.3851	0.0170	*
Soil:Collateral+Lease	0.0023	0.0015	1.6075	0.108	
Soil: Sell+Collateral+Lease	0.0014	0.0012	1.1824	0.237	
Population (log) :None	0.0002	0.0009	0.2620	0.793	
Population (log) :Lease	0.0062	0.0048	1.2882	0.198	
Popualtion (log) :Collateral+Lease	0.0094	0.0014	6.8046	1.01E-11	***
Popualtion (log) :Sell+Collateral+Lease	0.0054	0.0003	16.355	< 2.2e-16	***
Road Inaccessibility(log):Lease	-0.0044	0.0026	-1.6843	0.0921	.
Road Inaccessibility(log):Collateral+Lease	0.0036	0.0017	2.0796	0.0375	*
Road Inaccessibility(log): Sell+Collateral+Lease	0.0039	0.0014	2.6951	0.0070	**
sigma	0.0342	0.00019	181.64	< 2.2e-16	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Log-Likelihood: 41802 on 33 Df

2.7 Analysis

When talking about alienation rights' direct effect, having the right to lease has no direct correlation with preventing deforestation (Table 7), compared to the reference group (no alienation rights). Furthermore, having the right to lease reduces deforestation. This may be because the tenants normally do not have the right to alter land use but to maintain it. Having the right to collateralize and lease has no direct correlation with the likelihood of having zero deforestation. But having the right to collateralize and to lease reduces deforestation. This may be because a collateral right doesn't translate into immediate land alteration.

It is interesting to find that when the right to sell is included, it comes out with both negative and positive effects. On one hand, having a complete set of alienation rights reduces the likelihood of zero deforestation. When local forest owners are given the right to sell, they will sometimes do so because this generates benefits greater than they could earn from timber and non-timber products in the short run, and possibly even for the long run. That may result in land use alteration for higher profit seeking and hence result in deforestation. This reconfirms Clark's economics model, which showed that when the discount rate is high and when there are alternative investment options, resource overexploitation is inevitable, even to the point of extinction (Clark, 1973). However, on the other hand, when it comes to reducing deforestation, the effect of having a complete set of alienation rights is positive - it reduces deforestation, compared to the reference group. The finding is in line with Posner and Schagler and Ostrom's model, which suggested that entitling owners to alienate their land may allow forest resources to be shifted from a less productive to a more productive use (Posner, 1975; Schagler and Ostrom, 1992). The analysis shows that either theory provides a plausible explanation for the phenomenon but neither is sufficiently precise and comprehensive.

Furthermore, the alienation rights' interaction effects with biophysical and socioeconomic variables are mixed. For instance, in the case of preventing deforestation, the effect of (a) having a right to collateralize and to lease on lands with higher precipitation, higher soil productivity or higher population is negative - it reduces the log-likelihood of having zero deforestation. However, the effect of having (b) a right to lease or having a complete set of alienation rights on lands with higher altitude is positive. In case (a), it is rational for the users to sell land with higher precipitation, higher soil productivity, more population for other land use purposes (i.e. agriculture or housing development), if such a right is granted, as that may return in higher profits compared to forests. In case (b), it is perhaps because the lands on higher latitudes are not suitable for other land use purposes than forests. Having a right to lease or a right to collateralize and to lease may encourage investment in forests.

Overall, when the right to lease has no direct correlation with preventing deforestation, its aggregated interaction effect is positive (3.916) – it further increases the log-likelihood of having zero deforestation at certain locations. The aggregated effect of the right to lease and its related interactions is positive (3.916). The right to collateralize and to lease has no direct correlation with preventing deforestation, however the sum of its interaction effects is negative (-2.510) – it accelerates the reduction of the log-likelihood of having zero deforestation under some circumstances. The aggregated effect of related terms of rights to collateral and to lease is negative (- 2.510). The direct effect of a complete set of alienation rights is negative (-1.361) but its interactions effect is positive (1.131) for some locations. The aggregated effect of related terms of a complete set of alienation rights is negative (-0.230).

Table 7 Summary of the effects of alienation rights[2]

	Preventing Deforestation (Response: log-odds of having zero deforestation)		
	Direct Effect	**Interaction**	**Aggregation**
Lease	No correlation (-)	Positive or No correlation (3.916)	Positive (3.916)
Collateralize + Lease	No correlation (-)	Negative or No correlation (-2.510)	Negative (-2.510)
Sell + Collateralize + Lease	Negative (-1.361)	Positive or No correlation (1.131)	Negative (-0.230)
	Reducing Deforestation (Response: gross deforestation λ =0.0202)		
	Direct Effect	**Interaction**	**Aggregation**
Lease	Positive (-0.046)	Mixed (0.000)	Positive (-0.046)
Collateralize + Lease	Positive (-0.057)	Negative or no correlation (0.063)	Negative (0.006)
Sell + Collateralize + Lease	Positive (-0.044)	Negative or no correlation (0.062)	Negative (0.011)

When it comes to reducing deforestation, the effects are mostly negative. Having a right to collateralize and to lease or a complete set of alienation rights on lands with higher precipitation or more population accelerates deforestation and the effects of interactions with higher precipitation are the highest among all other interaction terms. This may be because the lands with higher precipitation or more population could be more suitable for other land uses (i.e. agriculture or housing development) and hence it is rational to convert them for higher profit seeking activity. Having a right to collateralize and to lease or a complete set of alienation rights on larger forests is negative - selling the excess land to others is a better-off decision. However, the actual rationale behind these effects will have to be investigated through research in the field.

[2] * The table presents the situation when the terms increase by 1 unit

The alienation rights perform differently with regard to road inaccessibility. Road inaccessibility is directly negatively correlated with gross deforestation - the farther a land is away from a main road, the lesser the gross deforestation. However, on one hand, the effect of (a) having a complete set of alienation rights or a right to collateralize and to lease on locations far away from main road is negative - it increases gross deforestation, compared to the lands far away from main road and that have no alienation rights granted. On the other hand, the effect of (b) having a right to lease on lands far away from main road is positive - it decreases gross deforestation, compared to the reference group without alienation rights that are far away from the main road. In case (a) granting local users a complete set of alienation rights or a right to collateralize and to lease accelerates gross deforestation, even on locations difficult to access. In case (b), as land tenants normally do not have the right to alternate land uses, having only the right to lease decreases gross deforestation for locations far away from a main road, compared to lands without alienation rights.

Overall, when having a right to lease is negatively correlated with gross deforestation (-0.046), its interaction effects are mixed and cancel out (0.000). The aggregated effect of the right to lease and its related interactions is positive - it reduces gross deforestation (-0.046). Having a right to collateralize and to lease reduces gross deforestation (-0.057), however its interaction effects are negative (0.063). The aggregated effect of rights to collateralize and to lease is negative - it increases gross deforestation (0.006). A complete set of alienation rights also reduces gross deforestation (-0.044), while its interaction terms increase gross deforestation (0.062). The aggregated effect of a complete set of alienation rights is negative - increases gross deforestation (0.011).

The results suggest that we should not assume alienation rights will translate into purely negative or positive forest outcomes. Rather, each of the alienation rights behaves differently and the performance of alienation rights depends on the local biophysical and socioeconomic circumstances and the outcomes are mixed.

2.8 Limitation of the Study

We recognize an important limitation of the study. Other important forest rights, such as exclusion and withdrawal, could play a critically important role in forest conservation. Also, the country effects cannot be decoupled in three of the forest rights categories. However, data limitations preclude including these details in this assessment. We need such detailed information because these details may provide a broader understanding of the conditions under which forest degradation and regeneration may potentially occur over the long term through human-nature interactions. The results may also have implications for other common pool resources. We need to know the details of how specific aspects and modes of resource rights affect forest outcomes because these details will guide us to craft effective institutions on the ground to conserve forests and improve the welfare of local forest users, especially those in the developing world who rely on the forest for their livelihood. We urge better data accessibility and transparency on resource rights and other institutional settings.

2.9 Discussion and Conclusion

2.9.1 Implementing resource rights solutions without differentiating the potential effects of specific modes of rights and their combinations may result in varied forest outcomes

The data application of our study supports Schlager and Ostrom's analysis only for certain modes of rights. For instance, having a right to lease or a right to collateralize and to lease has no correlation with preventing deforestation but has a positive effect on reducing deforestation. A complete set of alienation rights has a negative effect on preventing deforestation but a positive effect on reducing deforestation. While Schlager and Ostrom advanced Hardin's work by differentiating property rights into specific bundles of rights, our study proves that it is necessary to further zoom into the details. This requires making Schlager and Ostrom's approach more complex by differentiating the modes of alienation rights and understanding the effect of them. Rather than analyzing the alienation rights as a general term on an aggregated level, it is critically important to assess the effects of different modes of alienation rights, if we intend to rely on property rights as a means to avoid or reduce deforestation.

Therefore, previous studies based on the assumption that the alienation rights all have the same directional effect can have misleading conclusions. And hence policies solely relying on increasing the extent of forest property rights or allocating a more complete set of rights to forest users may not prevent or reduce gross deforestation. We must be aware that allocating alienation rights to local forest users without differentiating their potential effects may result in undesired forest outcomes. When some modes of alienation rights may link to positive forest outcomes, some others may not. Furthermore, the effects of the alienation rights depend on socioeconomic and biophysical conditions.

2.9.2 Ignorance of local context may lead to undesired forest outcomes

The results show that alienation rights' effects vary across locations when it comes to preventing deforestation. For the locations analyzed in this study, the effect of having a right to lease or a complete set of alienation rights is positive on lands with higher altitude, while the effect of having a right to collateralize and to lease is negative at locations with higher precipitation, higher soil productivity and higher population. In the case of reducing gross deforestation, the integration effects are mostly negative. The results suggest that although the right to sell and to collateralize correlate with positive direct effects, allocating these rights to lands with larger forest, higher precipitation, higher population density or lands far away from main roads will turn those effects into negative impacts. These interactions will contribute to a significant amount of deforestation. Therefore, rather than addressing land tenure as a vague and general term, we urge that decision makers, international donor organizations and academic researchers be aware of the diverse and contradictory effects of specific modes of rights. It is important to be aware of these mixed effects of some modes of alienation rights and associated complications when taking into consideration their dependence on local biophysical and socioeconomic conditions.

We must therefore recognize that private property rights cannot prevent a tragedy of the commons in all conditions. Instead of relying on land tenure or property rights as a "one-size-fits-all" solution for forest commons, we urge the fostering of local institutions that can develop location-smart solutions that adapt to the local biophysical and socioeconomic context.

2.9.3 Urge the crafting of complementary and alternative solutions

One observation from the analysis is that whether or not the forest users have the right to change use of the land could be critically important. While tenants normally do not have the power to change land use but to maintain it, the right to lease does not lead to more deforestation and even reduces gross deforestation, compared to the other alienation rights categories. Furthermore, the aggregated effects of the right to lease are positive, regardless whether preventing deforestation or reducing deforestation is concerned. Therefore, entitling forest users with alienation rights, while setting up constraints to land use conversion on the demand side, could be an option for preventing and reducing deforestation. While the direct effects of the right to collateralize and lease and a complete set of alienation rights are positive when it comes to reducing deforestation, their interactions with local biophysical and socioeconomic conditions are mostly negative. And the negative effects are greater than the positive effects for preventing deforestation and for reducing deforestation. In addition, allocating a complete set of alienation rights to a community could accelerate deforestation.

In the cases where the aforementioned negative effects occur and deforestation takes place, although the local forest owners may be made better off by exercising their right to sell and their right to collateralize, society could suffer from negative externalities - losing ecosystem services such as carbon sequestration, water purification and biodiversity. While we recognize the importance of empowering local forest users with more rights, we urge the crafting of complementary solutions that will seize the positive aspects while avoiding undesirable outcomes. Options include providing forest loans to encourage forest users to delay the exercise of the alienation rights and to invest in the forest resources for higher profit in the long run; payment for ecosystem services assessment; REDD+ to invest in forests as carbon sinks; and forest certification to encourage responsible management practices. These mechanisms must be in place to may create good enough incentives for landowners to maintain their land and protect forest resources.

In summary, each mode of alienation rights performs differently when preventing and reducing deforestation are concerned. And the performances of the alienation rights depend on the local biophysical and socioeconomic circumstances. In addition, we should be aware that the negative effects of the right to collateralize and to lease or a complete set of alienation rights surpass their positive effects in preventing and reducing deforestation. Therefore, we should not assume that property rights would ultimately lead to desired forest outcomes under all local conditions. Rather, we should look into the details to understand the specific effect of each mode and their constraints under various local circumstances to develop complementary and alternative solutions on the ground to minimize the possible negative impacts and to grasp the positive ones.

CHAPTER 3. THINKING LIKE A FOREST: HOW DO FORESTS RESPOND TO SPECIFIC HUMAN INSTITUTIONS UNDER LOCAL CIRCUMSTANCES

3.1 Introduction

In this study, I use data integration and data analysis methods to explore the roles of biophysical, socioeconomic and institutional variables, using data from the International Forestry Resources and Institutions (IFRI) datasets and a wide range of best available multiple public sources. These data have a much richer set of predictors. These data provide opportunities as well as new challenges.

First, many forest commons studies based on the IFRI dataset used user perception to measure the forest outcomes, rather than using the physical measurements of forest conditions (i.e. deforestation, reforestation, biodiversity). For instance, Andersson and Agrawal (2011) measured forest outcomes by asking local households their perception of forest conditions. Physical measures of forest outcomes could provide different results, as local households may have positively-skewed views about the forest under their management. Besides, the user perception may not solely align with physical forest outcomes such as gross deforestation. Instead, it could include a wider range of concerns, such as the livelihood and welfare generated from the forest. There are good reasons behind the approach of using user perception to measure the forest outcomes, as forest coverage inventory from the ground is time consuming and labor intensive and hence may not be feasible when the dataset cover a wide range of countries globally. However, analysis based on potentially biased or unspecified forest outcomes could lead to misleading interpretations and conclusions.

Forest outcomes measured by user perception can be replaced by physical gross deforestation data. In addition, a wide range of biophysical variables such as topographic, climate, soil conditions, population and road accessibility can be incorporated into the model. Instead of preselecting a relatively small variable set or create index system to reduce the number of variables, I apply Elastic Net and LASSO statistical methods to select significant individual variables from the large number of predictors and their interaction terms in a dataset with relatively small sample size without excessive loss of information. Details of the data integration and data analysis methods are specified in section 3.2 and 3.3.

Also, given the complexity of the system, a large number of factors can be critical to the sustainability of common pool resources. The necessity to incorporate the interaction terms (increase the number of variables) when studying a highly interactive system would make the situation even more challenging. In addition, studies tend to create additive indexes, either with or without weighting. For instance, a) Andersson and Agrawal creates collective action index by adding up five binary variables on collective action related activities (Andersson and Agrawal, 2011); b) Coleman (2011) developed a weighted organizational capacity index to incorporate a series of user group activities related to collective actions based on principle component analysis. This approach may be useful to reduce number of variables with relatively small sample size. However, an index system can be misleading. In case a), the presumption that all activities have positive effects might not hold true with equal weighting. In case a) and b), adding up the individual variables may result in neglecting important detailed effects of the individual variables.

3.2 Data and Data Processing

3.2.1 Data Description

Two sets of variables are included in the analysis: 1) the response variables, referring to gross deforestation between 2000 and 2013; 2) the predictive variables, which include forest property rights and collective action, biophysical and socioeconomic conditions. The data are collected from best available multiple public sources. Details of the variables are summarized in Table 8.

In the study sites of the International Forestry Resources and Institutions (IFRI), more than one user-group uses and manages the forests at the same time, under diverse management schemes. There is no clear boundary of the forests for the users. In this case, we assume that people's activities are constrained by their ability to travel and the local circumstances such as slope and altitude. Hypothetical boundaries within travel distance (i.e. 1, 2 or 5 kilometers) are drawn from the center of the settlement, as data statistics indicate the households live within 1 to 5 kilometers from the forests they rely on, with an average value of around 2 kilometers. The area within the boundaries will be the unit of analysis.

The response variable is the gross deforestation between 2000 and 2013, measured in the form of the total area of deforestation within the hypothetical boundaries. The spatial resolution of the original data is 30-meters (Hansen et al., 2013). The gross deforestation is calculated by multiplying the number of pixels within each of the hypothetical boundaries by 900 square meters (the size of the pixels).

Table 8 Summary of Data

Variables	Details
	RESPONSE VARIABLE
Gross deforestation	Gross deforestation between 2000 and 2013, measured in the form of the total area of deforestation within 1, 2 and 5 kilometers radius from the center of the study sites (Hansen, 2013)
	PREDICTIVE VARIABLES
Property Rights	
Right to exclude	A categorical variable indicating whether the forests is under community, government, private ownership or is openly accessed (IFRI, 2015)
Right to withdrawal	A dichotomous variable indicating whether or not the local users have the right to withdrawal timber and non-timber products from the forests, data available (IFRI, 2015)
Right to alienate	A dichotomous variable indicating whether or not the local users have the right to sell their forests (IFRI, 2015)
Collective Actions	
Existence of rules	The number of rules adopted to restrict usage, maintenance and management of the forests (IFRI, 2015)
Congruence between rules and local conditions	A dichotomous variable indicating whether the forest users consider the type of conversion measures adopted in relation to the forests is at the right level (IFRI, 2015)
Monitoring	A dichotomous variable indicating whether the harvesters of forest products from different user groups readily observed by each other while harvesting (IFRI, 2015)
Graduated sanction	A dichotomous variable indicating whether there are graduated sanctions for rule breakers (IFRI, 2015)
Biophysical	
Altitude	Mean altitude of the community forestland (Jarvis et al., 2008)
Temperature	Annual mean temperature between 2000 and 2010 (Hijmans et al., 2005)
Precipitation	Annual mean precipitation between 2000 and 2010 (Hijmans et al., 2005)
Size of forest	Forest coverage in 2000, measure in the form of total area of forest within 1, 2 and 5 kilometers radius from the center of the study sites (Hansen, 2015)
Soil productivity	Global Soil Productivity Index, range from 0 to 1 (UNEP, 2016)
Soil texture	Categorical variables indicating whether the top- (0-30cm) and subsoil (30-100cm) texture is coarse, medium or fine (Batjes, 2012)
Soil pH level	The pH levels of the soil in top- and sub soil. (Batjes, 2012)
Soil organic carbon level	The organic carbon level in top- and sub soil. (Batjes, 2012)
Soil base saturation level	Sum of exchangeable cations (nutrients) Na, Ca, Mg and K as a percentage of the overall exchange capacity of the top- and subsoil.(Batjes, 2012)
Road accessibility	Distance to main road (CIESIN, 2013)
Socioeconomic	
Population	Mean population of 2000, 2005 and 2010 (GPWv4) (CIESIN, 2015)
Commercial value of the forest	A categorical variable indicating whether the commercial value of the forest is below normal, normal or above normal (IFRI, 2015)
Forest management unit	A dichotomous variable indicating whether the forest has been divided into management units
Unit of Analysis	
Hypothetical boundaries within travel distances	The spatial document outlining the buffer zone 1, 2 and 5 kilometers from the center of the sites

The institutional variables are collected from a site-specific survey questionnaire, which includes three forest property rights: a) forest ownership; b) right to withdrawal and c) right to sell, and four collective action variables: a) existence of rules; b) congruence between rules and local conditions; c) monitoring; and d) graduated sanction. (IFRI, 2015) The institutional variables are calculated as either the mean or majority of the data value in the original dataset, depending on whether the variable is continuous or categorical. These variables are selected based on relevance to theoretical frameworks and data availability.

The biophysical variables include altitude, temperature, precipitation, forest coverage in 2000, and five soil properties: a) productivity; b) texture; c) pH level; d) organic carbon and e) base saturation level. The spatial resolution of the altitude data is 90-meters (Jarvis et al., 2008). The temperature and precipitation data are available at 1-kilometers resolution (Hijmans et al., 2005). The resolution of the forest coverage data is 30-meters (Hansen et al., 2013). The resolution of the soil properties data is 1-kilometers (Batjes, 2012). The mean altitude, temperature and precipitation are the values of average altitude, temperature and precipitation within each of the hypothetical boundaries, respectively. The forest coverage in 2000 is calculated by multiplying the number of pixels within each of the hypothetical boundaries by 900 square meters. The soil properties are either the mean or majority of the original dataset, depending on whether the variable is continuous or categorical.

The socioeconomic variables include population, road inaccessibility, commercial value of the forest and forest management unit. The spatial resolution of the population data is 1 kilometer (CIESIN, 2014). The total population is calculated as the sum of the number of individuals within each of the community forest boundaries. The road inaccessibility variable is generated from the Global Roads Open Access Data Set (CIESIN, 2013), calculated as the distance between the sites and the nearest main roads. The commercial value of the forest and forest management unit are calculated as the majority of the value of the variables in the original dataset

3.2.2 Data Processing

The data layers are overlaid based on coordinates and a dataset is generated for each of the hypothetical boundaries, following the steps below:

Step1: Obtain the coordinates of the study sites and link the sites to forest change, biophysical and socioeconomic variables maps

Step 2: Draw buffer zone of 1, 2 and 5 kilometers radius from the center of the study sites

Step 3: Calculate the area of forest change, average or majority of the biophysical and socioeconomic variables within the buffer zones

Step 4: Apply statistics techniques to analyze the data

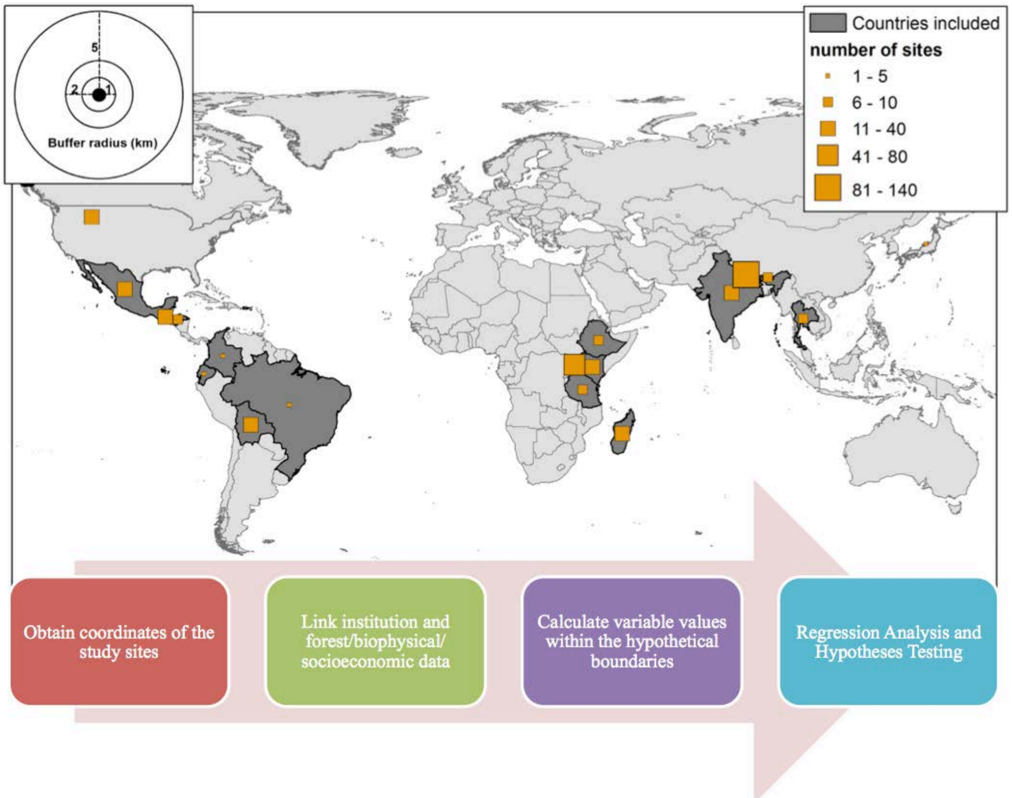


Figure 3 Linking site-specific survey data with spatial data

3.2.3 Data Summary

After data integration, data from 162 sites in Bhutan, Bolivia, Colombia, Ecuador, Ethiopia, Guatemala, Honduras, India, Kenya, Madagascar, Mexico, Nepal, Tanzania, Thailand and Uganda are analyzed. The summary statistics of the variables are presented in Table 9. The valid number of observations is 82 within 1-kilometer radius, 93 within 2-kilometer radius and 99 within 5-kilometer radius. Between 2000 and 2013, the average gross deforestations are 0.1 square kilometers, with a standard deviation of 0.2 square kilometers within 1-kilometer radius, 0.5 square kilometers, with a standard deviation of 0.9 square kilometers within 2-kilometer radius and 2.4 square kilometers, with a standard deviation of 2.4 square kilometers within 5-kilometer radius. In terms of forest property rights, 65.1% of the forest users have the right to withdrawal of timber and non-timber products from the forests but only 30.2% of them have the right to sell the forests. The majority (81.1%) of the forests are under community ownership. Among the rest, 1.9% is owned by government, 6.6% is under private ownership and 10.4% is open access. For collective actions, the average number of forest rules is 4.1. The forest users in 54.7% of the sites believe these forest rules are congruent with local conditions, the forest harvesting activities in 57.5% of sites are under monitoring, and 39.6% of the sites apply graduated sanction to the rule breakers. The ranges of the biophysical and socioeconomic variables are diverse.

Table 9 Summary Statistics of the Variables

	1-kilometer		2-kilometer		5-kilometer	
	Mean/ %	**Std. Dev.**	**Mean/ %**	**Std. Dev.**	**Mean/ %**	**Std. Dev.**
Number of observations	82		93		99	
RESPONSE VARIABLE						
Gross deforestation (square kilometers)	0.1	0.2	0.5	0.9	2.4	4.5
PREDICTIVE VARIABLES						
Property Rights						
Right to withdrawal	65.1%	-	65.1%	-	65.1%	-
Right to alienate	30.2%	-	30.2%	-	30.2%	-
Forest ownership community	81.1%	-	81.1%	-	81.1%	-
Forest ownership government	1.9%	-	1.9%	-	1.9%	-
Forest ownership private	6.6%	-	6.6%	-	6.6%	-
Forest ownership open Access	10.4%	-	10.4%	-	10.4%	-
Collective Actions						
Congruence between rules and local conditions	54.7%	-	54.7%	-	54.7%	-
Number of rules	4.1	-	4.1	-	4.1	-
Monitoring	57.5%	-	57.5%	-	57.5%	-
Graduate sanction	39.6%	-	39.6%	-	39.6%	-
Biophysical						
Size of forest (km^2)	1.2	1.1	5.0	4.2	30.4	24.0
Altitude (m)	918.8	676.4	918.3	674.1	933.9	687.7
Precipitation (mm/yr)	1,462.8	573.4	1,463.2	571.0	1,454.6	552.5
Temperature (°C)	22.1	3.7	22.1	3.7	22.0	3.8
Soil productivity Index	4.0	0.9	4.0	0.9	4.0	0.9
Topsoil texture coarse	24.5%	-	26.4%	-	24.5%	-
Topsoil texture medium	52.8%	-	50.9%	-	50.9%	-
Topsoil texture fine	22.6%	-	22.6%	-	24.5%	-
Subsoil texture coarse	17.0%	-	18.9%	-	17.9%	-
Subsoil texture medium	33.0%	-	31.1%	-	31.1%	-
Subsoil texture fine	50.0%	-	50.0%	-	50.9%	-
Topsoil pH level	6.1	1.1	6.1	1.1	6.1	1.2
Subsoil pH level	4.9	2.4	4.9	2.3	4.9	2.3
Topsoil organic carbon level	1.6	1.9	1.6	1.9	1.5	1.9
Subsoil organic carbon level	0.5	0.4	0.5	0.4	0.5	0.4
Topsoil base saturation level	68.1	26.8	68.6	26.2	68.7	25.4
Subsoil base saturation level	51.6	33.6	51.6	32.5	50.8	30.9
Road inaccessibility (km)	3,500.5	4,845.8	3,500.5	4,845.8	3,500.5	4,845.8
Socioeconomic						
Population within radius	481.0	869.0	1,812.0	2,960.0	10,472.9	17,344.1
Commercial value of the forest above normal	52.8%	-	52.8%	-	52.8%	-
Commercial value of the forest normal	31.1%	-	31.1%	-	31.1%	-
Commercial value of the forest below normal	16.0%	-	16.0%	-	16.0%	-
Forest management unit	44.3%	-	44.3%	-	44.3%	-

3.3 Statistical Methodology

A four-step analysis is implemented to answer the research questions (Figure 4). Linear regression models are applied to analyze the variables' relationship with deforestation. By elastic net and LASSO variable selection, correlated variables are selected from the existing 29 first-order predictors and 180 second-order predictors, with relatively small number of observations

(82, 93 and 99 at 1, 2 and 5 kilometer radius, respectively). The number of predictors is largely reduced without excessive information loss. Finally, by applying cross validation on model selection, the prediction errors of models with and without interactions are compared to understand the role of interaction effects. The models are normalized in order to compare the magnitude of the parameter estimates. Log transformation is made wherever necessary to improve the normality of the concerned variables.

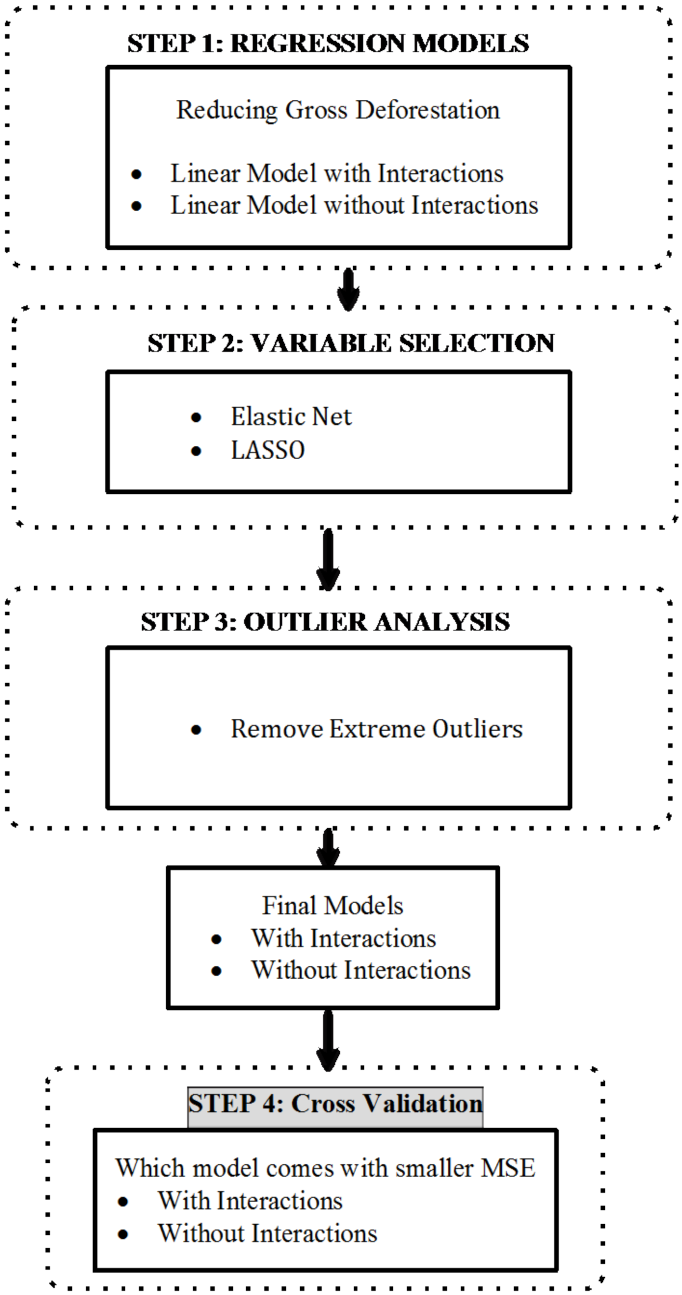


Figure 4 Data Analysis Framework

3.3.1 Regression Analysis

Considering the distribution of the dependent variable (log transformation of gross deforestation), linear regression models are applied in the study. The models assume a wide variety of location variables or their proxies could lead to different forest outcomes.

3.3.2 Variable Selection

Variable selections based on LASSO and Elastic Net penalties are conducted on the models with interaction terms to determine the important variables correlated with deforestation. We use a 10-fold cross-validation for finding the tuning parameter. After variable selection, the model with the smallest Mean Standard Error (MSE) will be selected. The Elastic Net solves the below problem

$$\min_{(\beta_0,\beta)\in\mathbb{R}^{p+1}}\left[\frac{1}{2N}\sum_{i=1}^{N}\left(y_i-\beta_0-x_i^T\beta\right)^2+\lambda P_\alpha(\beta)\right]$$

where

$$P_\alpha(\beta)=(1-\alpha)\frac{1}{2}\|\beta\|_{\ell_2}^2+\alpha\|\beta\|_{\ell_1}$$
$$=\sum_{j=1}^{p}\left[\frac{1}{2}(1-\alpha)\beta_j^2+\alpha\left|\beta_j\right|\right]$$

is the elastic net penalty, a compromise between the Ridge regression penalties ($\alpha = 0$) and the LASSO penalty ($\alpha = 1$) (Friedman et. al., 2010; Zou and Hastie, 2005; Tibshirani, 1996; Hoerl and Kennard, 1970).

3.3.3 Outlier Analysis

The Interquartile Range rule is applied to determine the outliers. After fitting the regressions, observations with residuals that fall outside the below range are identified as outliers and are removed from the dataset (Montgomery and Runger, 2010).

$$L = Q_1 - 1.5(Q_3 - Q_1)$$
$$R = Q_3 + 1.5(Q_3 - Q_1)$$

Q_1 and Q_3 are the first and third quartile, respectively.

3.3.4 Cross Validation

Cross-validation is applied to compare the prediction error of the models with and without interaction terms. Cross-validation involves randomly splitting the data into two pieces: the training set T and the validation set V. The prediction error is estimated by validating the training set with the validation set. In this way an unbiased estimate of how well future data are predicted could be obtained. The classifier h is constructed from the training set and the prediction error is estimated by below formula, where *n* is the size of the validation set (Kohavi, 1995). A 10-fold cross validation is applied in the study.

$$PE(\hat{f}) = E\left[\frac{1}{n}\sum_{i=1}^{n}\left(y_i' - \hat{f}(x_i)\right)^2\right]$$

3.4 Estimates and Inferences

The Elastic Net penalty (MSE = 3.31) variable selection on the model with interaction terms and the LASSO penalty on the model without interaction terms (Mean Square Error = 2.87) have the lowest MSE at 1-km radius. The LASSO penalty (MSE = 2.98) on the model with interaction terms and the Elastic Net penalty (MSE = 3.38) on the models without interaction terms have the lowest MSE at 2-km radius. The Elastic Net penalty (MSE = 2.84) on model with interaction term and the LASSO penalty (MSE = 3.02) on the model without interaction terms have the lowest MSE at 5-km radius (Appendix: Figure 9). These models are chosen for further inferences. The results of models with interaction terms (Table 10) show that none of the forest rights variables and collective action variables are directly correlated with gross deforestation, at 1-kilometer, 2-kilometer or 5-kilometer radius. However, the forest property rights and collective actions variables interact with biophysical and socioeconomic terms and come out with diverse outcomes. Having a right to withdrawal on lands with higher topsoil base saturation at 2-km radius or forests with above normal commercial value at 5-km radius decreases gross deforestation (-0.88, P = 0.07 and -2.48, P = 0.00, respectively), compared to the reference group (no withdrawal right on lands with lower topsoil base saturation and no withdrawal right on forests with above normal commercial value, respectively). Having the right to sell on lands with higher precipitation accelerates reduction of gross deforestation at 1-km, 2-km and 5-km radius (-1.21, P = 0.01; -0.96, P=0.01 and -1.39, P = 0.01, respectively), compared to the reference group (without right to sell on lands with lower precipitation). However, having the right to sell on lands with fine topsoil texture accelerates gross deforestation at 1-km radius (1.88, P = 0.07).

For collective actions, having rules congruent with local conditions on fine topsoil texture accelerates gross deforestation at 1-km and 2-km radius (1.75, P = 0.04; 1.66, P=0.00), compared to the reference group (no rule congruence on lands with coarse topsoil texture). Having rules congruent with local conditions on fine subsoil texture accelerates gross deforestation at 1-km and 10-km radius (1.20, P = 0.05; 1.07, P =0.04). Having monitoring on lands with higher precipitation accelerates gross deforestation at 1-km radius (0.78, P =0.01). On the other hand, having rule congruence on lands with medium subsoil texture decreases gross deforestation at 2-

km radius (-1.11, P = 0.00). Having more forest management rules on medium topsoil texture and fine subsoil texture decreases deforestation at 1-km radius (-1.42, P =0.04; -1.16, P = 0.04), compared to the reference group (having less forest management rules on coarse topsoil texture, coarse subsoil texture or forests not divided into management unit). Having more forest management rules on forests divided into management units also decreases gross deforestation at 1-km and 2km radius (-0.70, P = 0.09; -0.93, P =0.00).

Table 10 Linear Estimate of Gross Deforestation (log) with Interaction Terms[3]

	1-km			2-km			5-km		
	Estimate	**Pr(>|t|)**		**Estimate**	**Pr(>|t|)**		**Estimate**	**Pr(>|t|)**	
(Intercept)	10.47	0.00	***	11.83	0.00	***	14.98	0.00	***
Forest coverage	0.06	0.94		0.06	0.92		-1.00	0.56	
Altitude	-0.02	0.92							
Subsoil texture fine							0.02	0.99	
Subsoil texture medium							-0.53	0.66	
Topsoil Organic Carbon (log)	-0.29	0.66		-0.13	0.63				
Subsoil Organic Carbon (log)	-0.20	0.77							
Topsoil pH							0.04	0.93	
Topsoil base saturation							-0.89	0.06	.
Subsoil base saturation	0.18	0.75							
Forest ownership government				-0.25	0.79		-2.15	0.26	
Forest ownership private							-0.93	0.62	
Right to sell							0.26	0.55	
Number of rules	0.88	0.10							
Graduated Sanction							-0.08	0.85	
Right to withdraw: Topsoil texture medium	-0.78	0.16							
Right to withdraw: Topsoil pH	0.06	0.94		0.35	0.42				
Right to withdraw: Topsoil base saturation				-0.88	0.07	.			
Right to withdraw: Subsoil base saturation	-1.22	0.17							
Right to withdraw: Forests Commercial Value Above Normal							-2.48	0.00	***
Right to withdraw: Forests Commercial Value Normal							0.60	0.18	
Forest ownership government: Forest Coverage	1.01	0.27		0.78	0.11		2.01	0.25	
Forest ownership community: Altitude				-0.34	0.53				
Forest ownership private: Altitude				1.99	0.48				
Forest ownership private: Temperature	-1.87	0.40							
Forest ownership community: Topsoil texture fine	-0.33	0.86		0.34	0.82				
Forest ownership private: Topsoil texture fine	-2.08	0.20							
Forest ownership community: Subsoil texture fine							0.85	0.72	
Forest ownership government: Topsoil Organic Carbon (log)	-0.54	0.32		-0.46	0.17				
Forest ownership community: Topsoil pH							-0.10	0.91	
Forest ownership government: Subsoil base saturation	-0.22	0.69							

[3] Due to the length issue (209 predictors when interactions are taken into account), the table only presents variables selected in at least one of the models.

Table 10 Linear Estimate of Gross Deforestation (log) with Interaction Terms (continued)

	1-km			2-km			5-km		
	Estimate	Pr(>|t|)		Estimate	Pr(>|t|)		Estimate	Pr(>|t|)	
Forest ownership community: Population (log)				-0.15	0.74				
Forest ownership community: Inaccessibility (log)				-0.28	0.62		0.42	0.71	
Forest ownership government: Inaccessibility (log)	-0.19	0.43					-0.51	0.01	*
Forest ownership community: Forests Commercial Value Normal	1.95	0.04	*						
Forest ownership community: Forest management unit	-0.67	0.66							
Right to sell: Forest Coverage				0.75	0.03	*	0.54	0.34	
Right to sell: Precipitation	-1.21	0.01	*	-0.96	0.01	**	-1.39	0.01	**
Right to sell: Topsoil texture fine	1.88	0.07	.	-0.05	0.95				
Right to sell: Subsoil texture fine	-0.88	0.20							
Right to sell: Topsoil Organic Carbon (log)				-0.03	0.95				
Right to sell: Subsoil base saturation:	0.53	0.30		0.20	0.57				
Right to sell: Forest management unit	0.33	0.69		0.84	0.20				
Rule Congruence: Forest Coverage	0.15	0.70		0.42	0.18				
Rule Congruence: Soil productivity	0.47	0.26							
Rule Congruence: Topsoil texture fine	1.75	0.04	*	1.66	0.00	**			
Rule Congruence: Subsoil texture fine	1.20	0.05	*				1.07	0.04	*
Rule Congruence: Subsoil texture medium				-1.11	0.00	**	-0.33	0.60	
Rule Congruence: Subsoil texture coarse							0.94	0.40	
Rule Congruence: Topsoil base saturation:	-0.09	0.81							
Rule Congruence: Forests Commercial Value Above Normal	-0.86	0.26							
Number of rules: Precipitation	-0.20	0.46							
Number of rules: Soil productivity	0.10	0.72							
Number of rules: Topsoil texture medium	-1.42	0.04	*						
Number of rules: Subsoil texture fine	-1.16	0.04	*						
Number of rules: Subsoil Organic Carbon(log)							0.11	0.68	
Number of rules: Topsoil pH	0.55	0.42							
Number of rules: Subsoil pH							-0.10	0.67	
Number of rules: Topsoil base saturation	-0.60	0.40		-0.14	0.44				
Number of rules: Forest management unit	-0.70	0.09	.	-0.93	0.00	***			
Forest Coverage: Monitoring							-0.39	0.42	
Precipitation: Monitoring	0.78	0.01	*						
Soil productivity: Monitoring							-0.41	0.31	
Topsoil Organic Carbon (log):Monitoring	0.10	0.85							
Subsoil Organic Carbon (log):Monitoring	-0.32	0.64							
Topsoil pH: Monitoring				-0.01	0.96		0.06	0.90	
Monitoring: Population (log)				-0.08	0.74				
Monitoring: Inaccessibility (log)	-0.42	0.17							
Monitoring: Forests Commercial Value Above Normal	-0.17	0.81							
Forest Coverage: Graduated Sanction				0.16	0.61		0.34	0.43	
Soil productivity: Graduated Sanction							-0.16	0.68	
Topsoil texture fine: Graduated Sanction	-1.09	0.17		0.82	0.12				
Graduated Sanction: Forest management unit	-0.63	0.29							
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1									
Multiple R-squared/Adjusted R-squared	0.846/0.672			0.799/0.712			0.784/0.632		

By assessing the parameter estimates, we found that the following forest property-right-related-terms have greater effects: interaction terms of community forest ownership and forests with normal commercial value (1.95), right to sell with fine topsoil texture (1.88) and rule congruence with fine topsoil texture (1.75) at 1-km radius; rule congruence with fine topsoil texture (1.66) and with medium subsoil texture (-1.11), right to sell with precipitation (-0.96) and number of rules with forest management unit (-0.93) at 2-km radius; right to withdraw and forests with above normal commercial value (-2.48), right to sell with precipitation (-1.39) and rule congruence with fine subsoil texture (1.07).

The results of models without interaction terms (Appendix: Table 13) show that none of the forest property rights and collective action variables is correlated with gross deforestation, at 1-km, 2-km and 5-km radius. Gross deforestation is determined by the biophysical and socioeconomic variables only.

Cross validation on models with and without interaction terms show that the models without interaction terms at 1-km and 5-km radius have smaller prediction errors (MSE = 2.93 and 2.82, respectively). However, the model with interaction terms at 2-km radius comes with smaller prediction error (MSE = 2.28).

Table 11 Cross Validation on models with and without interaction terms

	MSE		
	1-km	**2-km**	**5-km**
With Interactions	6.26	2.28	3.33
Without Interactions	2.93	2.31	2.82

This section only presents the results of the statistical analysis and the interpretations of the inferences will be given in section 3.5.

3.5 Analysis

It is interesting to find that the model with interaction terms provides better prediction of gross deforestation only at 2-km radius, while the models without interaction terms predict better at 1-km and 5-km radius. The results suggest that the influence of institutional arrangements is constrained by the local users' range of forest-related activities. At 1-km radius from the sites, the areas may be largely occupied by residential buildings and agricultural lands, rather than the forests. At 5-km radius, the forests are far away from the settlements. The local users might not travel for such a long distance to those forests on a daily basis and hence institutional arrangement could play a less significant role. In either case, although institutional arrangements do interact with local conditions, gross deforestation is better explained by biophysical and socioeconomic conditions directly, such as soil properties and road accessibility. Nevertheless, at 2-km radius, the average distance from the villages to nearby forest, institutional arrangements do play an important role through interactions with local biophysical and socioeconomic circumstances.

By looking into the 2-km model[4], analysis finds that none of the forest property rights variables, right to withdraw, forest ownership and right to sell, has direct correlation with gross deforestation, compared to the reference groups (no right to withdrawal, open access and no right to sell). Neither do any of the collective actions arrangements - rule congruence, number of rules, and monitoring and graduated sanction - have direct correlation with gross deforestation, compared to the reference group (no rule congruence, less number of rules, no monitoring and no graduated sanction) (Table 12). The findings suggest that the institutional variables do not have direct impact on gross deforestation.

When the interaction terms are taken into account, the forest property rights, a) right to withdrawal interacts with topsoil base saturation and b) right to sell interacts with precipitation, and both are negatively correlated with gross deforestation. However, c) the interaction terms of forest ownership again show no correlation with gross deforestation. The case a) implies that when local users are granted the right to withdraw and can rely on forests for their livelihood activities, they tend to maintain the forest, rather than clear-cutting them for other land use purposes (e/g. agricultural activities). Furthermore, such an effect gets accelerated when the right to withdraw is granted on lands with higher topsoil base saturation - the lands better for forests and forest products development (having higher nutrient availability and greater buffering against soil acidification). The finding of case b) is in line with Posner and Schagler and Ostrom's model, which suggested that entitling owners to alienate their land may allow forest resources to be shifted from a less productive to a more productive use (Posner, 1975; Schagler and Ostrom, 1992). Having the right to sell on the lands with higher precipitation (higher forest productivity) could further encourage such land ownership transfer and hence result in less gross deforestation. The finding is consistent with our previous work on forest alienation rights (Liu et. al, 2017). The

[4] The 1-km and 5-km models are not discussed since: a) the models without interaction terms come with better prediction outcomes, however; b) none of the institutional variables are correlated with gross deforestation in the models without interaction terms. In both situations, gross deforestation is better explained by local biophysical and socioeconomic conditions rather than institutional arrangements-the variables of interest in the study.

case c) shows that forest ownership has no correlation at all with gross deforestation, either directly or indirectly. These findings suggest that the formal ownership of the forests does not matter when reducing gross deforestation is the concern. Rather, it is the specific resources rights granted that are having the impact.

The effects of the interaction terms on collective action arrangements are diverse. On one hand, a) when local forest users believe the forest conservation rules are at an appropriate level at locations with fine topsoil texture, gross deforestation is accelerated, compared to the reference group (local users believe forest conservation rules are not at appropriate level and locations with coarse topsoil texture). On the other hand, b) when local forest users believe the forest conservation rules are at an appropriate level at locations with medium subsoil texture, gross deforestation is further reduced. The case a) and b) suggest that the local forest users' interpretation of appropriateness of forest rules does not necessarily align with forest outcomes. Instead, user interpretations of appropriateness could reflect a wider range of considerations, such as the livelihood and welfare of the local users. The case a) implies that at locations with fine topsoil texture (good for nutrients and water retention and supply, compared to medium and coarse soil textures, and hence higher forest productivity), local users may tend to extract more forest resources and possibly lead to overexploitation. While in case b) where forest productivity is at medium level on medium subsoil texture, local users may tend to maintain forests for a more sustainable livelihood. In addition, c) having more rules on forests with divided management units decreases gross deforestation. The result suggests that when forest management unit is defined and rules are clearly specified, gross deforestation can be reduced effectively.

Overall, when none of the institutional variables has a direct effect on gross deforestation at 2-km, the aggregated indirect effects of significant forest property right variables are positive. The aggregated interaction effects of right to withdrawal (-0.88) and of right to sell (-1.01) are both positive, in terms of reducing gross deforestation. The aggregated indirect effects of significant collective action arrangements variables are mixed. The aggregated interaction effects of rule congruence are negative (0.55) and the aggregated interaction effects of number of rules are positive (-0.93), when reducing gross deforestation is concerned.

Table 12 Summary of the effects of institutional variables at 2-km radius

	Reducing Deforestation (Response: gross deforestation (log) at 2-km Radius)	
	Direct Effect	**Interaction**
Right to withdraw	No correlation (-)	Positive (-0.88)
Right to sell	No correlation (-)	Positive (-1.01)
Forest ownership community	No correlation (-)	No correlation (-)
Forest ownership government	No correlation (-)	No correlation (-)
Forest ownership private	No correlation (-)	No correlation (-)
Rule Congruence	No correlation (-)	Negative (0.55)
Number of rules	No correlation (-)	Positive (-0.93)
Monitoring	No correlation (-)	No correlation (-)
Graduated Sanction	No correlation (-)	No correlation (-)

3.6 Limitations of the Study

Although the study was intended to incorporate a wide range of critical variables, I had to drop a few potentially important predictors, including collective choice arrangement and participation, conflict resolution mechanisms, minimal recognition of rights to manage and nested enterprises. This was largely due to missing data, as well as data spatial and thematic inconsistency when integrating site survey data with spatial data. In the IFRI data set, only the coordinates of the study sites, rather than the boundary and location of the forests, are available to link the site survey data with spatial data. As a result, the study has to rely on the study sites as the unit of analysis. However, the original dataset obtained from IFRI uses forests around the study sites as the unit of analysis. As the number of forests (442) is greater than the number of sites (323), the number of observations shrank substantially after data integration (162), especially after missing coordinates and accuracy of the coordinates are taken into account. This leaves not much room to incorporate the important variables with the relatively larger number of missing values. In addition, missing information regarding how far the sites are away from individual forests makes it impossible to better incorporate individual forests status into the final dataset based on location information. Instead, simple aggregation methods such as taking majority or mean of the variables are applied. The accuracy of the model estimates could be significantly improved, if aforementioned information were available.

3.7 Discussion and Conclusion

3.7.1 Specific actions matter: need to assess the effect of collective actions individually

The findings of the study only supports Ostrom's theory partially. First, not all design principles are effective as expected. For instance, two critical variables, monitoring and graduated sanction, show no correlation with gross deforestation either directly or indirectly. Despite whether or not graduated sanction and monitoring exist, deforestation can still take place in various locations with different biophysical and socioeconomic conditions. Second, in the case when institutional design variables, such as number of rules and rule congruence, show significant correlation with gross deforestation, their effects are either positive or negative, depending on the local biophysical and socioeconomic conditions. The design principles are useful guidelines for forest resources management, however the results suggest their effects could vary when it comes to implementation.

The finding is contradictory to previous studies, which suggest all eight principles are well supported empirically (Cox et al., 2010). As discussed in section 2, three possible reasons could explain the contradiction: a) Many of the forest commons studies rely on the IFRI dataset for analysis and hence use user perception to measure forest outcomes; such indicators may not be accurate or specific enough and could lead to misleading results and conclusions. b) Studies creating an additive index to aggregately measure collective actions can provide important theoretical and practical findings. However, an index system measuring collective actions aggregately comes at a cost of omitting the unaggregated effects of specific actions. Even though the collective actions show positive effect in aggregate, their individual performance could vary. c) Due to segregation of disciplinary research and data deficiency, previous studies were not able to include biophysical and socioeconomic variables in the models. As a result, the institutional variables' dependence on local biophysical and socioeconomic conditions is neglected. Introducing the interaction terms between institutional variables and biophysical/socioeconomic variables into the models will lead to different results and conclusions.

The results suggest that we should not assume collective actions will ultimately lead to desired forest outcomes under all local conditions. Rather, we should look into the details to understand the specific effect of each action and their constraints under various local circumstances to guide us to design specific participatory mechanism on the ground to minimize the possible negative impacts and to grasp the positive ones.

3.7.2 Specific rights matter: Decentralization reform should recognize the limited understanding of property rights' effects

The data application of the study shows that none of the manners of forest ownership are correlated with gross deforestation, either directly or indirectly. However, the right to withdrawal and right to sell interact with local soil and climate conditions and the interaction effects are positive, in term of reducing gross deforestation. The results suggest that formal arrangements such as land ownership might not be as effective as expected. Rather, the specific rights are the ones that matter. Superficial interpretation of Hardin's model as simply setting up formal institutions in the form of private property rights to the commons (Hardin, 1968) might not tackle the substance of the problem of the commons. After all, vague and general terms of land ownership or participatory management could vary widely without specification of details on rights and actions associated.

Therefore, the forest reforms centered on decentralization of land ownership might not be relevant, if reducing gross deforestation is the concern. Instead of transferring land ownership from government to local users - believing that deforestation would be halted automatically through such transfer - the reforms might be reoriented towards granting specific rights to local users in order to induce desired outcomes. Nevertheless, we should also be aware of the dependence of rights and actions' on local circumstances and their possible diverse outcomes.

3.7.3 Local context matters: Impacts of institutional solutions vary with local context

The results show that the effects of forest property rights and collective actions depend on local circumstances. While none of the property rights and collective action variables is directly correlated with gross deforestation, their indirect effects are significant through the interactions with soil, climate and socioeconomic variables. Through the analysis, two possible scenarios are observed.

First, institutional variables measured through local users' perception such as rule congruence (appropriateness of forest conservation rules) may be affected by local circumstances such as soil conditions. Local users' interpretation of appropriateness of forest conservation rules includes a wider range of concerns (e.g. welfare or economic returns), in addition to forest outcomes. When the land is fertile (fine topsoil texture), the abundance of forest resources could lead to over-extraction from the forest. However, for land with medium level fertility (medium subsoil texture), the local users might not be overly extractive, in order to ensure sustainability of forest and livelihoods.

Second, even if institutional variables remain constant, they may only have effects on gross deforestation through their interactions with specific local conditions. For instance, the right to withdrawal negatively correlates with gross deforestation only when it is allocated to lands with higher topsoil base saturation. The right to sell negatively correlates with gross deforestation when it is allocated on lands with higher precipitation. Number of rules negatively correlates with gross deforestation only when forest management unit is clearly defined.

We should also notice that the effects of forest property rights and collective actions are constrained by the local users' range of forest-related activity. Only at 2-km radius, the average distance from the villages to nearby forests, does the model with institutional variables' interaction terms with biophysical and socioeconomic conditions predict better than the one without. This result suggests that, in forest commons studies, it is important and necessary to incorporate the interaction of institutional variables with local biophysical and socioeconomic variables for better understanding of the complex human-nature system.

We must therefore recognize that forest property rights and collective actions may not all perform as desired in all biophysical and socioeconomic conditions. We need to study and understand the diverse effects of individual actions in implementation, under various biophysical and socioeconomic circumstances. We need to understand such details, because only details will provide us with sufficiently specific information to guide actions on the ground in an effective way to conserve forests to improve the welfare of local forest users, as well as the global community.

CHAPTER 4. CONCLUSION

The studies, based on two separate sets of data, lead to conclusions pointing in the same direction. In chapter 2, the available data from 28,208 community forests in Cameroon, Colombia and Mexico indicate that the right to lease or the right to collateralize and to lease has a positive direct effect on reducing gross deforestation. A complete set of alienation rights has a negative direct effect on preventing deforestation (decreases the log-likelihood of zero deforestation) but a positive direct effect on reducing deforestation (reduces gross deforestation). Furthermore, the linkage of alienation rights to deforestation may also depend on local biophysical and socio-economic conditions. The interaction effects of the right to lease can be positive, negative or no correlation depending on locations and on whether preventing or reducing deforestation is concerned. When the right to sell and to collateralize or a complete set of alienation rights directly correlate with positive impact on reducing gross deforestation, allocating these rights to a certain location correlates with negative impacts. The aggregated effects of the right to lease are positive on both preventing and reducing deforestation but the aggregated effects of having a right to collateralize and to lease or a complete set of alienation rights are negative with regard to either preventing or reducing deforestation. This study indicates that alienation of property rights can have varying effects on deforestation, depending on both the specifics of the alienation rights and local factors.

Similarly in chapter 3, analysis of data from 162 sites in 15 countries indicates that the specific collective actions (existence of rules, rule congruence, monitoring and graduated sanction) and property rights (forest ownership, right to withdrawal and right to sell) perform differently with respect to gross deforestation. When looking into collective actions, not all actions are as effective as expected. Two critical variables, monitoring and graduated sanctions, show no correlation with gross deforestation either directly or indirectly. Number of rules and rule congruence show significant correlation with gross deforestation. Depending on the local biophysical and socioeconomic conditions, the effects are either positive or negative. With respect to property rights, none of the manners of forest ownership are correlated with gross deforestation, either directly or indirectly. However, the right to withdrawal and right to sell interact with local soil and climate conditions and the interaction effects are positive, in term of reducing gross deforestation.

The results suggest that we should not assume property rights or collective actions will ultimately lead to desired forest outcomes under all local conditions. Rather, we should look at the details to understand the specific effect of each action and right, and their constraints under various local circumstances in order to develop complementary and alternative solutions on the ground, and to minimize the possible negative impacts and to achieve the positive ones. Only such details will provide us with sufficiently specific information to guide actions on the ground in an effective way to conserve forests to improve the welfare of local forest users, as well as the global community.

The studies have potential to contribute to the common-pool resources theory development. First, the alienation rights study presented in Chapter 2 bridges Schlager and Ostrom's alienation rights model with Clark's. Schalger and Ostrom's alienation rights model suggests entitling alienation rights to forest owners could introduce desired forest outcomes by allowing forest resources to be shifted from a less productive to a more productive use (Posner, 1975; Schagler and Ostrom, 1992). Clark's economics of overexploitation model shows that even when property rights are in place, the forest outcome can be undesired, if the discount rate is high and when there are alternative investment options (Clark, 1973). The two models may seem contradictory, but the results of this study show that both Clark's and Schagler and Ostrom's models can explain forest outcomes, depending on what forest outcome is measured. When zero-deforestation is used as measurement, the negative correlation between alienation rights and zero-deforestation can be explained by Clark's model; On the other hand, when gross deforestation is used as measurement, the positive correlation between alienation rights and gross deforestation can be explained by Schagler and Ostrom's model.

Second, the property rights and collective actions study presented in Chapter 3 complements Hardin's tragedy of common model and Schlager and Ostrom's alienation rights model. Chapter 3 shows that none of the manners of forest ownership are correlated with gross deforestation, but the right to withdrawal and right to sell's interaction effects are positive. The result suggest that superficial interpretation of Hardin's model as simply setting up formal institutions in the form of private property rights to the commons (Hardin, 1968) might not tackle the substance of the problem of the commons. We should instead look into the details of the bundles of rights specified by Schlager and Ostrom (Schagler and Ostrom, 1992). Furthermore, the results of Chapter 3 indicate that when analyzing the specific rights, local conditions must be taken into consideration, as the specific rights' performance can be either positive or of no correlation, depending on the local circumstances.

Third, the study enhances Ostrom's eight design principles for common pool resources management. Chapter 3 shows that the design principles may not all come out with desired forest outcomes in all biophysical and socioeconomic conditions. The effects of the design principles can be either positive, negative or of no correlation, depending on local circumstances. Furthermore, the results clarify that the effects of collective actions are constrained by the local users' range of forest-related activity. Instead of presuming all design principles would lead to desired forest outcomes, one should understand the local conditions when implementing the design principles on the ground.

There are many interesting research topics to explore beyond this dissertation. The first one would be assessing the institutional variables and their interaction terms' correlation with gross reforestation. Property rights and collective actions may perform differently on gross reforestation, compared to their effects on gross deforestation. For instance, when the forest property right approach sets up a boundary in the forests, it could play a more significant role in reducing gross deforestation by excluding other users' from one's territory. However, it may not create an incentive for reforestation activities. On the other hand, collective actions may be more effective in increasing gross reforestation, as the actions on the ground would encourage local users to invest in maintenance and regeneration of the forests. However, without the right to exclude other users, the effects on reducing gross deforestation would be limited. Both mechanisms could be complementary to each other in sustainability of the forests. The existing literatures have yet not made such distinctions.

A second topic is to evaluate how changes in specific institutions (i.e. more decentralized positive change, no change or less decentralized negative change) have affected forests in the past decade. We should not assume all positive changes in institutions (i.e. a more decentralized property rights scheme or a more participative local collective action mechanism) would lead to desired forest outcomes. It is highly possible that a more decentralized property rights scheme and the disturbance introduced by the change of schemes may lead to unexpected decisions with undesired outcomes, such as clear-cutting or selling forests on one's own territory in order to catch the policy change. Similarly, it is also possible that a more participative local collective action mechanism and the disturbance of the change could lead to collective decisions of undesired outcomes, as local forest users may just collectively decide to overexploit forest resources in the short-run when more users are introduced into the system. Understanding how forests respond to a changing world will have both theoretical and practical implications. After all, we are living in a diverse dynamic world, not a uniformly static one.

APPENDIX

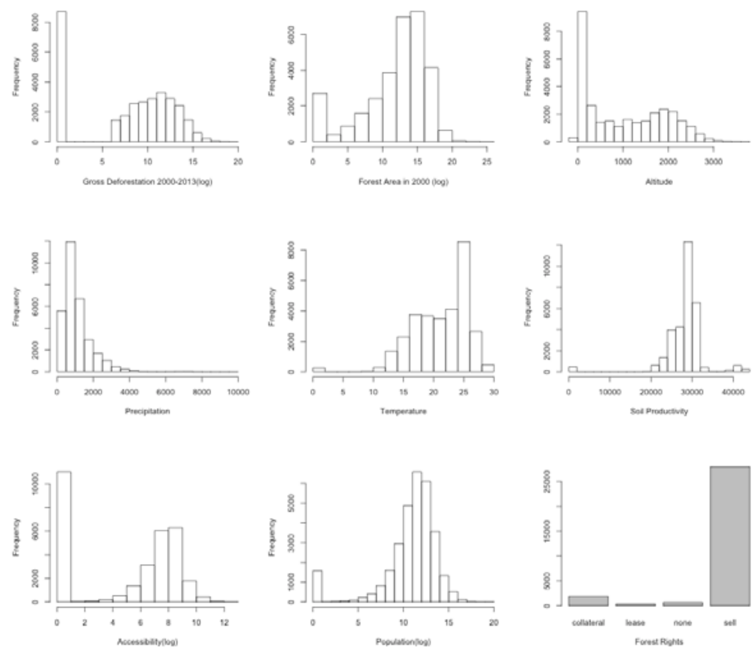
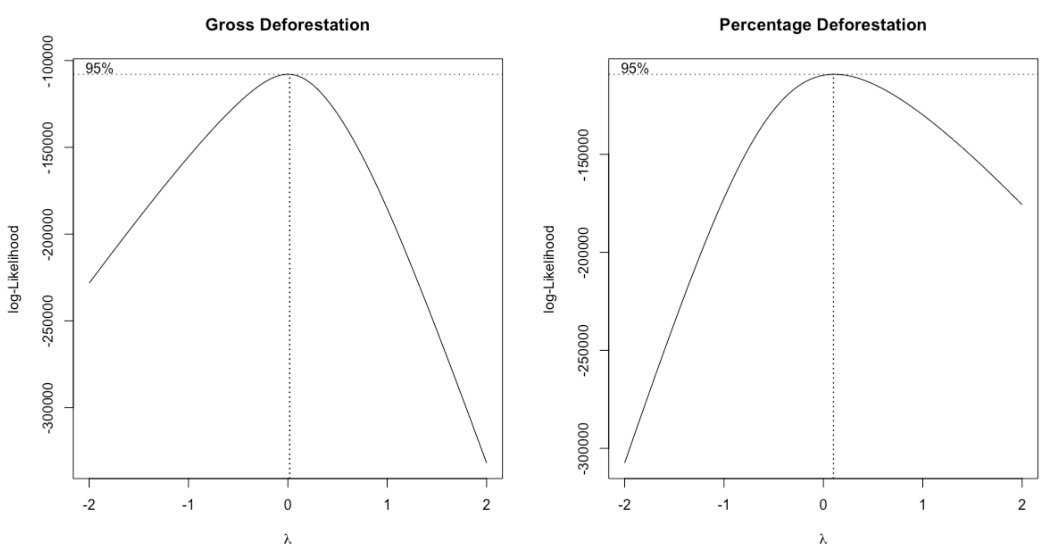
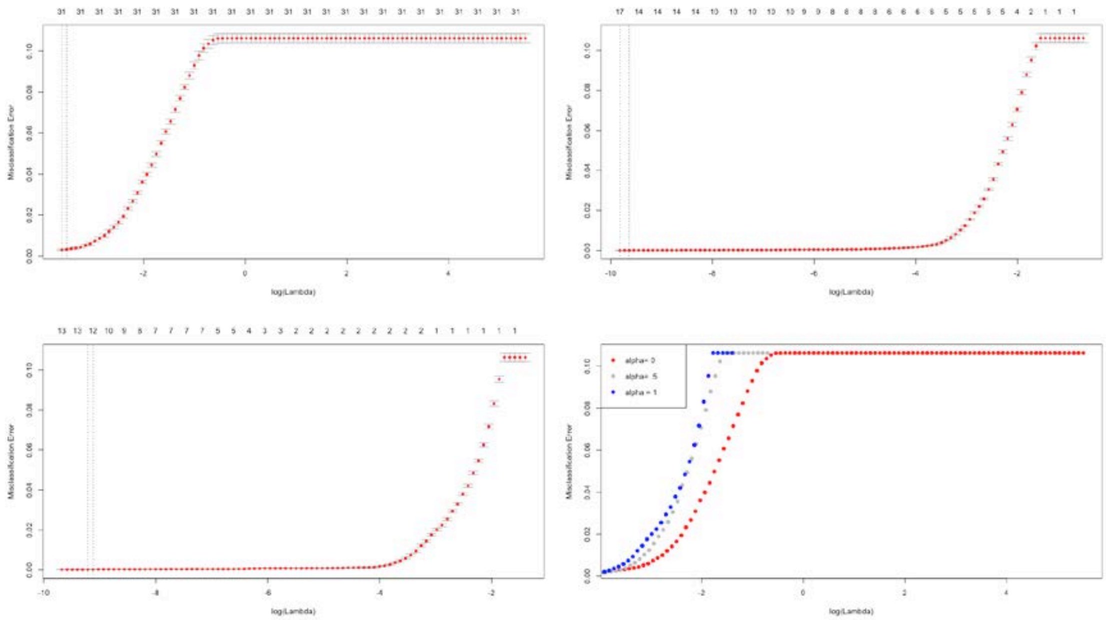


Figure 5 Distribution of Variables



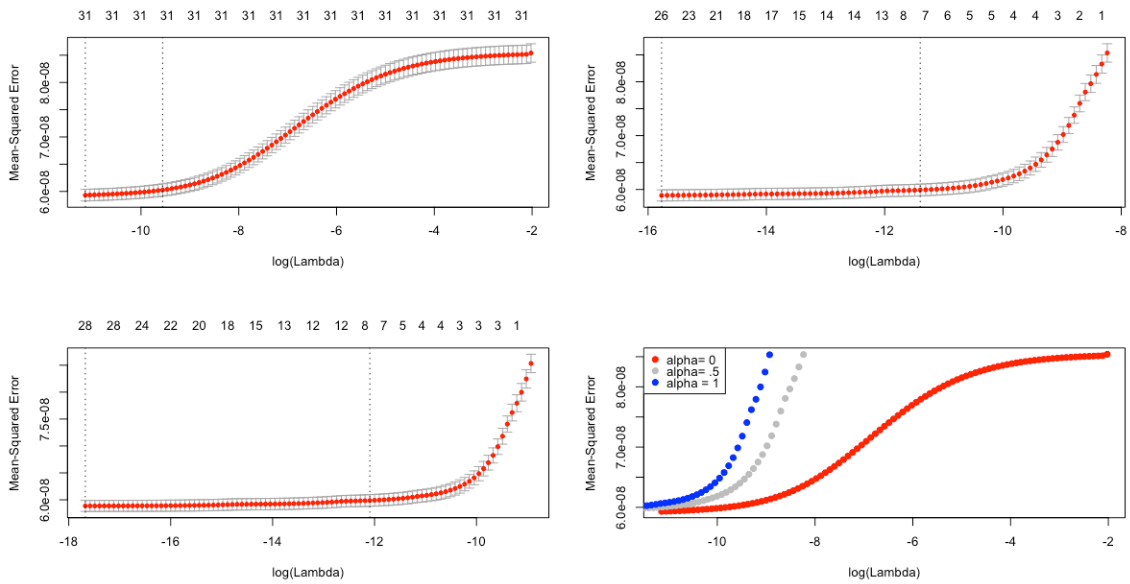
	Gross Deforestation	Percentage Deforestation
λ	0.02020202	0.1010101

Figure 6 BoxCox Transformation

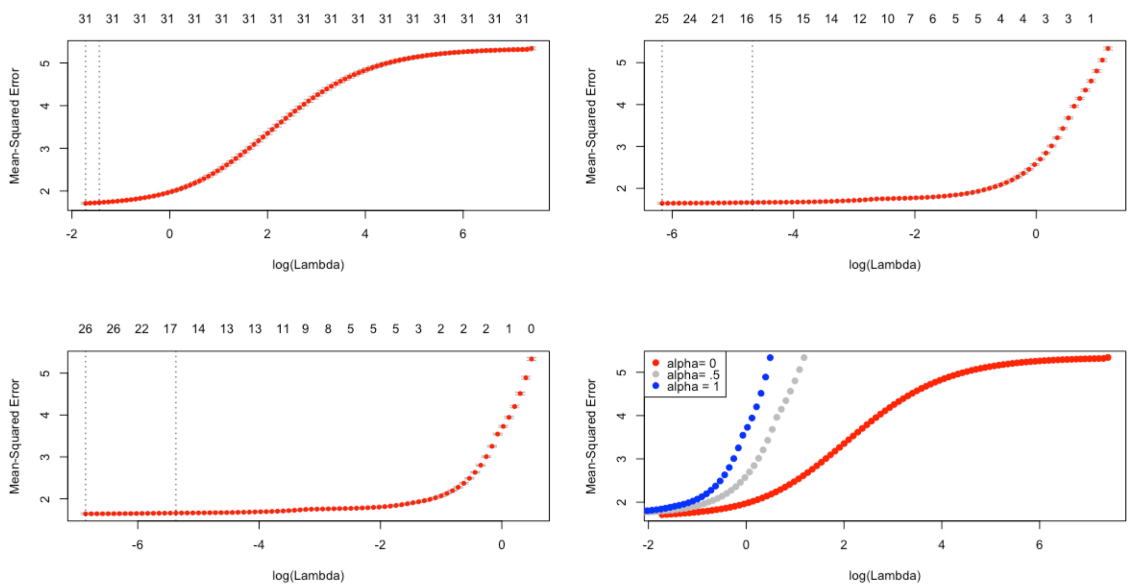


	Prediction Error
Elastic Net ($\alpha = 0.5$)	0.01962525
LASSO ($\alpha = 1$)	0.01432702

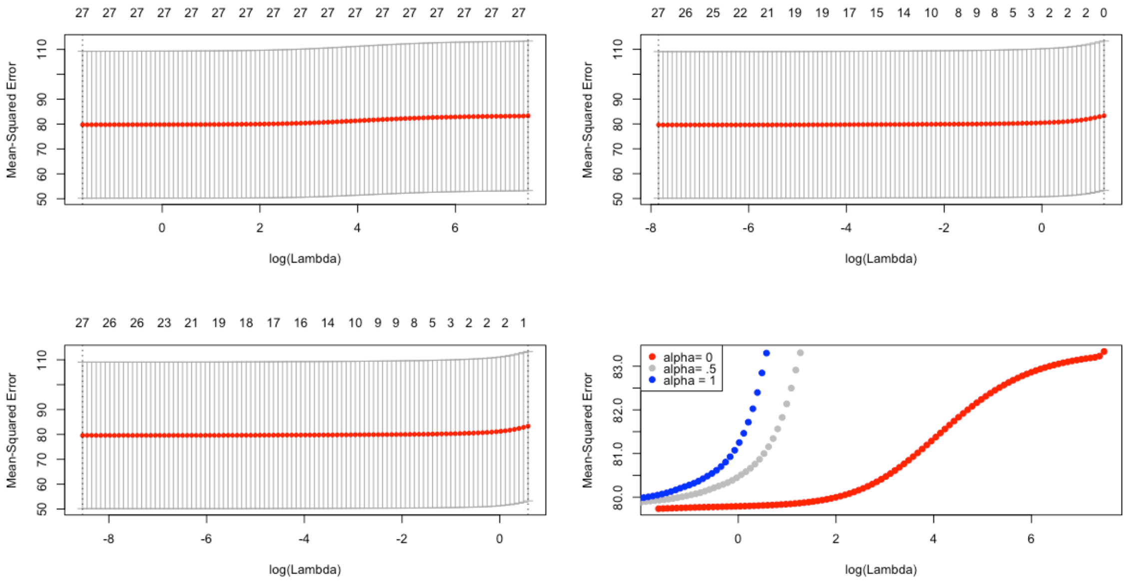
Figure 7 Variable Selection for Model on Zero Deforestation



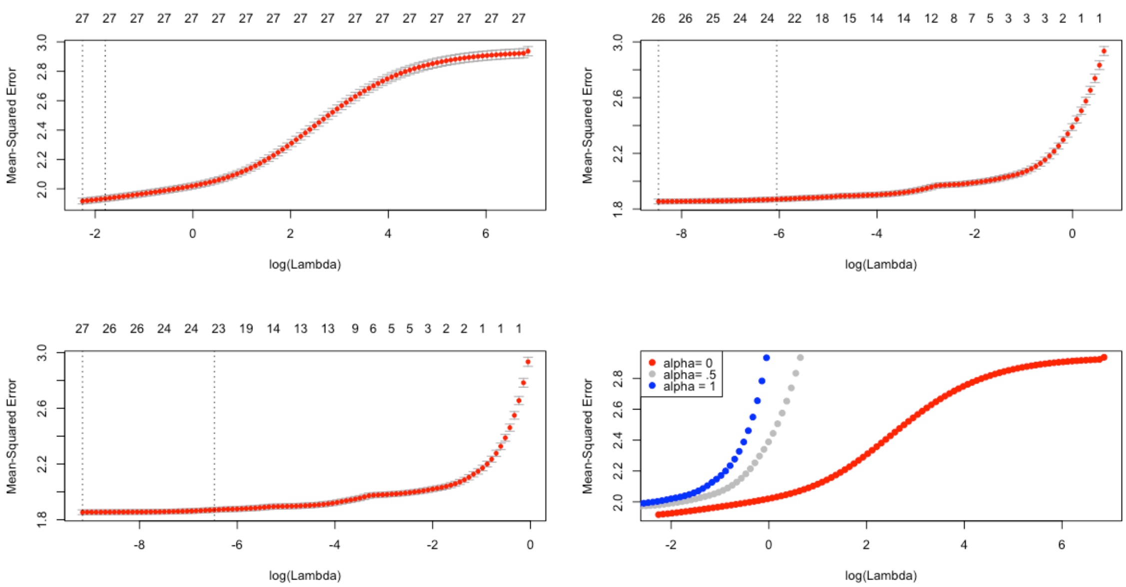
8a Gross Deforestation Gamma Inverse-link



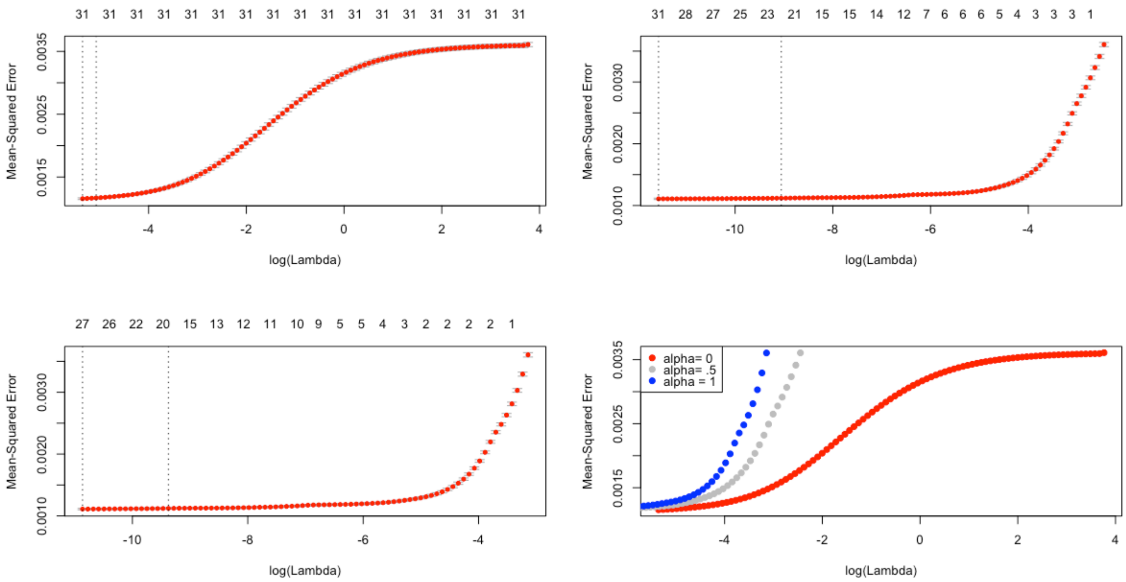
8b Gross Deforestation Gamma Log-link



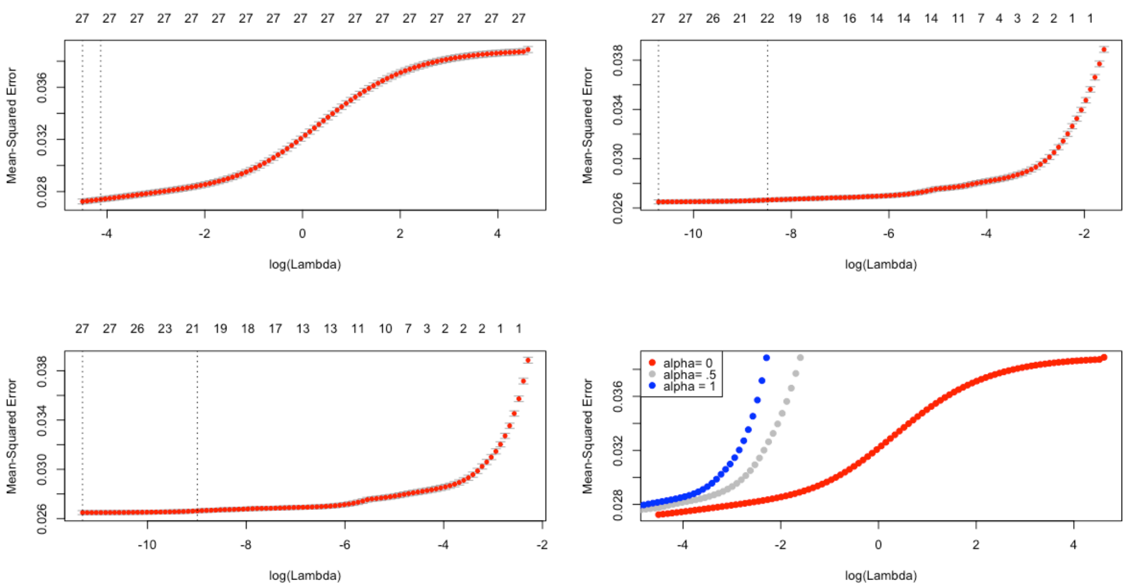
8c Percentage Deforestation Gamma Inverse-link



8d Percentage Deforestation Gamma Log-link



8e Gross Deforestation Truncated Normal

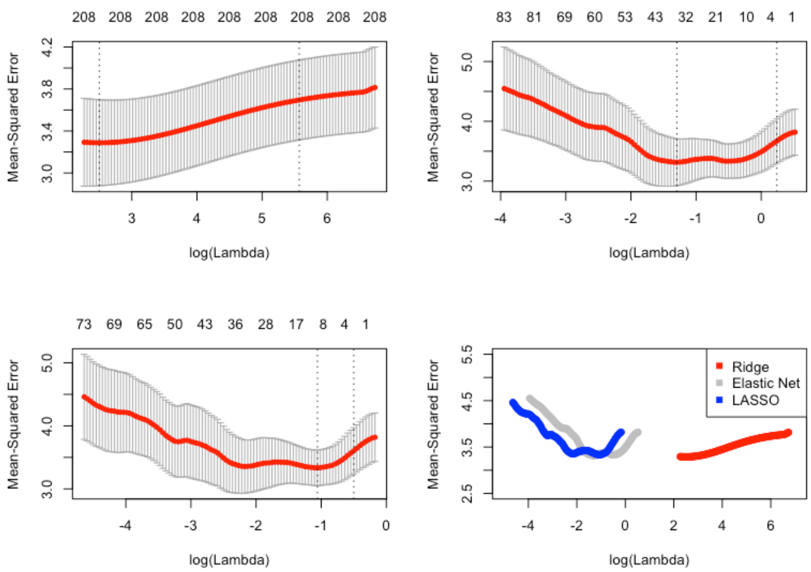


8f Percentage Deforestation Truncated Normal

Models	AIC	BIC
Gross Deforestation Gamma-Inverse	448365.1	448614.6
Gross Deforestation Gamma-log	474878.1	475129.3
Percentage Deforestation Gamma-Inverse	131856.9	132076.7
Percentage Deforestation Gamma-log	108638.2	108858.1
Gross Deforestation Truncated Normal	-83539.2	-83286.3
Percentage Deforestation Truncated Normal	-16515.0	-16293.5

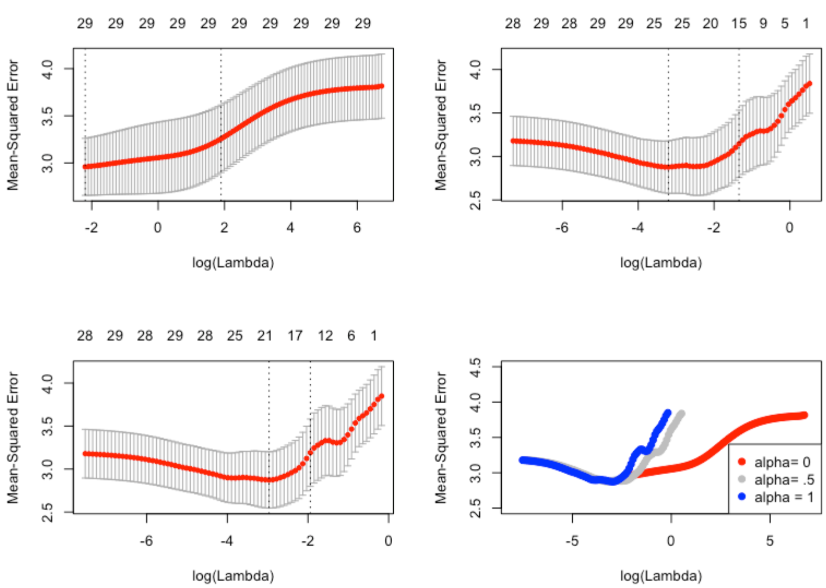
Figure 8 Variable Selection for Models on Gross and Percentage Deforestation

9a Gross Deforestation Model with Interactions (1-kilometer)



	Prediction Error
Elastic Net	3.31
LASSO	3.33

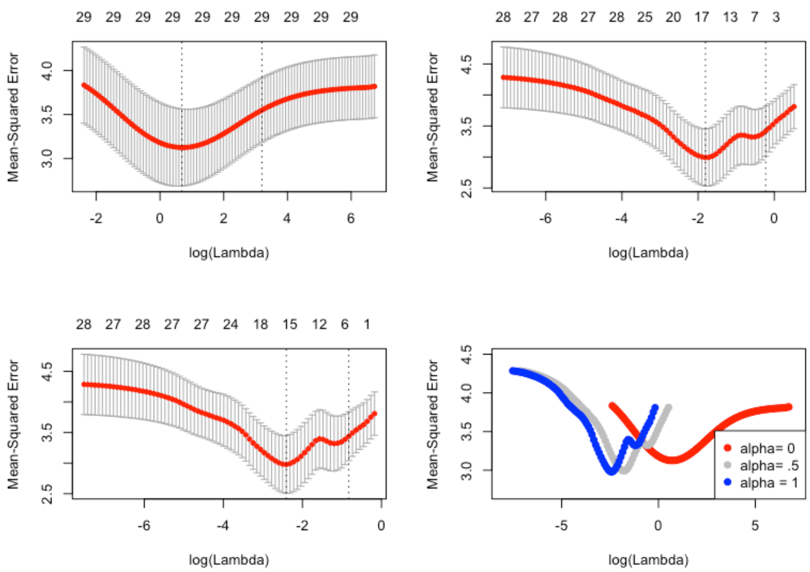
9b Gross Deforestation Model without Interactions (1-kilometer)



	Prediction Error
Elastic Net	2.88
LASSO	2.87

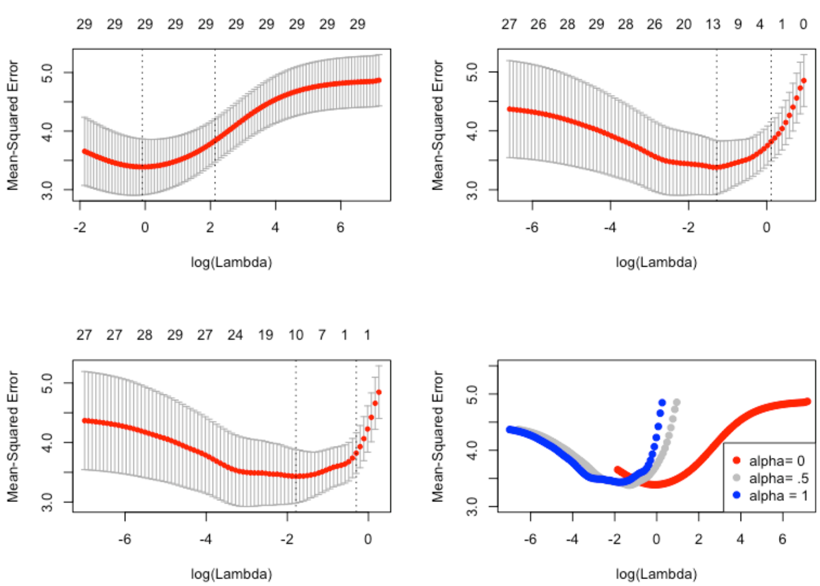
Figure 9 Variable Selection for Models on Gross Deforestation with and without Interaction Terms at 1-kilometer Radius

10a Gross Deforestation Model with Interactions (2-kilometer)



	Prediction Error
Elastic Net	2.99
LASSO	2.98

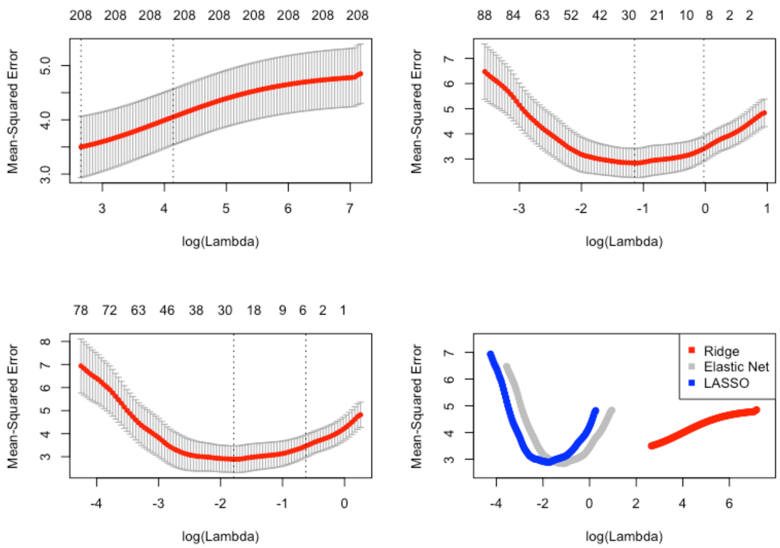
10b Gross Deforestation Model without Interactions (2-kilometer)



	Prediction Error
Elastic Net	2.89
LASSO	2.84

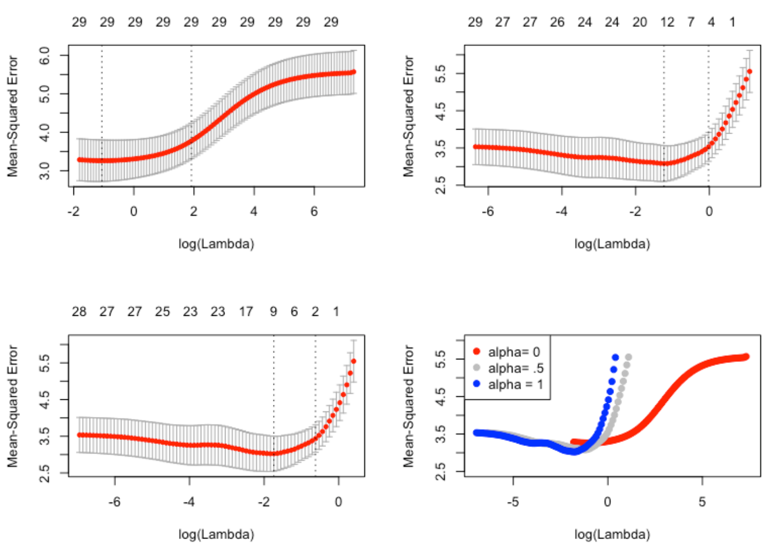
Figure 10 Variable Selection for Models on Gross Deforestation with and without Interaction Terms at 2-kilometer Radius

11a Gross Deforestation Model with Interactions (5-kilometer)



	Prediction Error
Elastic Net	2.84
LASSO	2.89

11b Gross Deforestation Model without Interactions (5-kilometer)



	Prediction Error
Elastic Net	3.08
LASSO	3.02

Figure 11 Variable Selection for Models on Gross Deforestation with and without Interaction Terms at 5-kilometer Radius

Table 13 Linear Estimate of Gross Deforestation (log) without Interaction Terms

	1-km			2-km			5-km		
	Estimate	Pr(>|t|)		Estimate	Pr(>|t|)		Estimate	Pr(>|t|)	
(Intercept)	10.59	0.00	***	11.87	0.00	***	12.98	0.00	***
Forest coverage	1.00	0.00	***	1.19	0.00	***	1.47	0.00	***
Altitude	-0.14	0.55					-0.36	0.62	
Precipitation									
Temperature							0.14	0.86	
Soil productivity	0.25	0.24					-0.16	0.50	
Topsoil texture fine	0.78	0.47					0.71	0.45	
Topsoil texture medium	-0.15	0.84					-0.13	0.83	
Subsoil texture fine	0.32	0.73		-0.47	0.32		-1.40	0.14	
Subsoil texture medium	-0.89	0.24		-1.64	0.00	***	-2.10	0.01	**
Topsoil Organic Carbon (log)				-0.02	0.90		0.01	0.96	
Subsoil Organic Carbon (log)	-0.82	0.01	**						
Topsoil pH				-0.67	0.00	***	-0.32	0.60	
Subsoil pH							-0.14	0.85	
Topsoil base saturation	-1.01	0.00	***				-0.79	0.31	
Subsoil base saturation	0.59	0.01	***	0.37	0.04	*	0.54	0.47	
Right to withdrawal	-0.44	0.28							
Forest ownership community				0.38	0.75		0.44	0.75	
Forest ownership government				0.06	0.96		0.72	0.60	
Forest ownership private				-0.07	0.96		0.67	0.65	
Right to sell	-0.05	0.90		0.35	0.31		0.16	0.70	
Rule Congruence							-0.04	0.90	
Number of rules	-0.28	0.18					-0.26	0.23	
Monitoring	-0.03	0.94							
Graduated Sanction	0.18	0.61		0.33	0.32		0.27	0.50	
Population (log)									
Inaccessibility (log)	-0.43	0.03	*	-0.43	0.02	*	-0.46	0.02	*
Forests Commercial Value Above Normal							0.37	0.50	
Forests Commercial Value Normal							0.95	0.02	*
Forest management unit	-0.11	0.77							

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

	1-km	2-km	5-km
Multiple R-squared/Adjusted R-squared	0.567/0.453	0.636/0.579	0.665/0.561

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