UNIVERSITY OF COPENHAGEN

# Understanding smallholders' intended deforestation behavior in the Brazilian Cerrado following environmental registry

Rasmussen, Laura Vang; Jung, Suhyun; Brites, Alice Dantas; Watkins, Cristy; Agrawal, Arun

*Citation for published version (APA):*
Rasmussen, L. V., Jung, S., Brites, A. D., Watkins, C., & Agrawal, A. (2017). Understanding smallholders' intended deforestation behavior in the Brazilian Cerrado following environmental registry. *Environmental Research Letters*, *12*(9), [094001]. https://doi.org/10.1088/1748-9326/aa7ee5

# Understanding smallholders' intended deforestation behavior in the Brazilian Cerrado following environmental registry

You may also be interested in:

# Environmental Research Letters

**LETTER**

# Understanding smallholders' intended deforestation behavior in the Brazilian Cerrado following environmental registry

**Laura Vang Rasmussen**[1,2,4] , **Suhyun Jung**[1,4], **Alice Dantas Brites**[3], **Cristy Watkins**[1] and **Arun Agrawal**[1]

1   Forests and Livelihoods: Assessment, Research and Engagement (FLARE) Network, School of Natural Resources & Environment, University of Michigan, Ann Arbor, MI 48109, United States of America
2   Department of Geosciences and Natural Resource Management, University of Copenhagen, 1350 Copenhagen K, Denmark
3   Universidade de São Paulo, CEP: 05508-010 São Paulo, SP, Brazil
4   Both authors contributed equally to this work. Authors to whom any correspondence should be addressed.

**E-mail:** lrasmuss@umich.edu **and** sjungx@umich.edu

## Abstract

Brazil's Rural Environmental Registry (CAR) is a potentially promising avenue to slow deforestation on private properties as it facilitates the monitoring of land use. Yet limited empirical evidence exists on how the CAR affects smallholders' behavior and recent scholarly efforts have in fact indicated that it may be doing less to protect forests than previously assumed. Based on 1177 smallholder surveys conducted in the Cerrado, we assess 1) whether the CAR might incentivize smallholders to pursue deforestation and 2) which factors are associated with smallholders' intended deforestation behavior. We find that upon CAR registration, factors significantly associated with smallholders' intention to deforest are: the existing percentage of native vegetation on the property, the use of agricultural loans, property owner's age, and livestock production experience. To curb deforestation that may follow expressed intentions of smallholders, the CAR, and environmental registration programs alike, should account for existing land use by, for example, improving the system already in place for trading areas of native vegetation as this system is not widely adopted by those smallholders with more native vegetation than the legal cut-off. Also, such programs should assess the role of whether conditions related to land cover maintenance may protect against deforestation if credit access is supported especially to younger smallholders and/or livestock producers with a high percentage of native vegetation in their properties.

## 1. Introduction

Brazil's new Forest Code from 2012 (Republic of Brazil, Federal Law 12,615/2012) has been heavily criticized as it relaxed the previous code from 1965 (Kröger 2017). For example, the new law granted amnesty to 'small or family farms'[5]; who deforested more than their legal limit before 2008 and it reduced reforestation requirements by approximately 60%, albeit more than 20 million hectares of 'forest debt' remained unforgiven (Soares-Filho *et al* 2014, Soares-Filho *et al* 2016). Currently, there are many legislative proposals circulating

5   Landholdings up to four fiscal modules. The fiscal module *(módulo fiscal)* is a land unit established by the National Institute of Colonization and Agrarian Reform *(Instituto Nacional de Colonização e Reforma Agrária,* INCRA) mainly for rural real estate taxation according to Federal Decree N° 8.485/1980 and INCRA NI° 20/1980. A smallholder (e.g., family landholder and rural family entrepreneur) is one who carries out activities in rural areas, simultaneously meeting

the following requirements: (i) he or she does not hold, in any capacity, an area of above four fiscal modules; (ii) he or she mostly uses the manual labor of his or her own family in the economic activities of his or her establishment or undertaking; (iii) he or she has a minimum percentage of household income arising from economic activities of his or her establishment or enterprise, i.e. those defined by the Executive Authority (wording of Law No 12.512 of 2011 (Republic of Brazil 2011)); and (iv) he or she directs his or her establishment or undertaking with his or her family (Law 11.326/2006 (Republic of Brazil 2006)).

in the Brazilian Congress, which aim to weaken the country's environmental regulations, thereby encouraging rapid development of energy facilities, mines and agriculture (Tollefson 2016). One proposed constitutional amendment would, for example, essentially eliminate government review by replacing standard environmental licensing procedures with a quicker, more flexible system in which different Brazilian states, can decide which licenses agribusiness projects should have. Because of these anti-environmental initiatives, concerns are rising about Brazil's globally significant, carbon-rich, and biodiverse forests (Fearnside 2015, Fearnside 2016, Ferreira *et al* 2014). Yet, a potentially promising mechanism of Brazil's new Forest Code is the *Cadastro Ambiental Rural* (the Rural Environmental Registry—CAR) program (Soares-Filho *et al* 2014, Newton *et al* 2016). The CAR requires geo-referencing of property boundaries as well as Legal Reserves (LR) and Areas of Permanent Preservation (APP) which are mandatory private areas protected by the Brazilian Forest Code and play an important role in environmental conservation. The immediate goal of this type of environmental property registry is to reveal and systematize information about land use within properties for the purposes of monitoring and planning (Vital 2016). It aims ultimately to improve both agricultural and environmental outcomes in Brazil and, through example, elsewhere (Cavaglia-Harris *et al* 2016, Shankland and Goncalves 2016). With the expectations of positive ecological outcomes of the CAR assuming improved monitoring through the use of CAR data (Jung *et al* 2017) and because the CAR is consequential at a global scale due to Brazil's sheer size, international funding, originating from donors such as the International Climate Fund (ICF) and the German Development Bank, has been directed to its implementation. The initial deadline for CAR registration was extended from May 2015 to May 2017 by the Brazilian Ministry of Environment—primarily because of the low registration rates.

Although the success of the CAR is critical to environmental conservation as it leverages the availability of satellite imagery to allow for monitoring and enforcement of the Forest Code as well as other environmental legislations, limited scholarly attention has been devoted to understanding the outcomes of its nationwide implementation, partly because the implementation is still ongoing. A few exceptions do exist. These studies address state-specific implementation of the CAR. One such exception is L'Roe *et al* (2016) who evaluate the initial outcomes of the CAR in the state of Pará in the Amazon and find that there is no effect on registrants' deforestation behavior except for a significant reduction in deforestation on 'smallholder' properties in the size range of 100–300 ha. Another example is Azevedo *et al* (2014) who likewise find a significant reduction in deforestation in Pará and Mato Grosso for smallholder properties of up to four fiscal modules. For properties between four and 15 modules,

a reduction in deforestation was only observed in Pará and for propreties with more than 15 fiscal modules the effects of the CAR on deforestation were unclear (Azevedo *et al* 2014). Therefore, although the CAR is one of the largest environmental management systems in the world and covers millions of hectares of forest across Brazil's six biomes, there is limited evidence of its impact on landholders' behavior and a better, more expansive understanding of how the CAR may affect deforestation behavior is needed. The success of CAR is globally important and lessons learned from its implementation will be of interest to many other countries experiencing similar land use issues.

In this paper, we examine how the CAR might incentivize smallholders to forego deforestation or perversely, to increase it. We note that this study is designed to evaluate how CAR registration might affect *expected* deforestation behavior, which could be different from the *actual* behavior. We do so by using primary survey data of 1177 smallholders across 11 municipalities in the states of Bahia and Piauí in the Cerrado biome. We focus on smallholders and these two states for two reasons. First, they represent past deforestation trends in the Cerrado biome (on the order of 6500 km$^2$ in 2010 (Beuchle *et al* 2015)). Second, ICF has actively engaged with smallholders' CAR registration in the 11 sample municipalities. Our data enables us to advance understandings of smallholders' intended deforestation behavior following CAR registration. This study is an initial attempt to disentangle the factors that are linked to smallholders' deforestation intentions and behaviors in the context of CAR using micro-level data. The Cerrado is a particularly interesting case because large parts of the biome is referred to as Brazil's newest agricultural hotspot—about half of the biome has been converted for agricultural production in recent decades (MMA 2009, Jepson *et al* 2010, Gibbs *et al* 2015a, Strassburg *et al* 2017) causing substantial carbon emissions (Noojipady *et al* 2017). Also, the Cerrado has less protection than Amazon forests in the Forest Code in terms of the amount of native vegetation to be preserved within private landholdings (Federal Law 12,615/2012) despite having some of the world's most biodiverse savannahs (Carranza *et al* 2013, Oliveira 2013).

## 2. A potentially promising mechanism of the new Forest Code: the CAR

The Forest Code sets mandatory caps on the proportion of native vegetation that can be legally cleared on any rural property. In the Legal Amazon, 80% of private holdings must be preserved as LRs, whereas for properties in Cerrado areas within the Legal Amazon, the native vegetation must constitute 35%. Outside of the Legal Amazon, 20% of native vegetation needs to be maintained although some state laws stipulate an increased percentage.

The CAR became a nationwide and mandatory endeavor after the revision of the Forest Code (Soares-Filho *et al* 2014). Initially, CAR registration was a voluntary process with state-specific systems, each with somewhat different procedures but with high expectations within Brazil and among the international environmental community for the potential to slow deforestation (Fearnside 2003). For example, in the state of Pará implementation began in 2008 (L'Roe *et al* 2016) and in Mato Grosso the System for Environmental Licensing (LAU)[6], which is a part of the Land Zone Planning System (Portuguese acronym: SLAPR) was implemented from the early 1990s, albeit not involving CAR until 2009 (Azevedo and Saito 2013).

The CAR is expected to ease monitoring of farmers' deforestation behavior because it links landowners to land use on a particular property (Gibbs *et al* 2015a). As such, the CAR is intended to be a transparent mechanism for evaluating compliance with the Forest Code and thereby achieving improved environmental outcomes (Gibbs *et al* 2015b). While farmers with less native vegetation than the legal requirements must reforest to achieve compliance with the Forest Code, there is also a risk that those farmers with more native vegetation than the legal cut-off see the Forest Code as permission to deforest up to the legal limit, or they may attempt to subvert the system by registering a lower percentage of native vegetation than what they actually have, enabling them to subsequently clear (Rajão *et al* 2012, Azevedo and Saito 2013). Yet, the Environmental Reserve Quota (Portuguese acronym: CRA) aims to prevent such situations by creating an incentive to register the full percentage. That is, the CRA system allows property owners with more native vegetation than the legal requirements to be paid for maintaining the excess area by other property owners with less native vegetation than the legal cut-off (Soares-Filho *et al* 2016). Other problems related to CAR registration include extensive overlaps in terms of the registered property area (Barros *et al* 2016, Moreira 2016, Pires 2013) and lack of validation of self-declared registrations (Pires 2013).

## 3. Methods

### 3.1. Study sites and smallholder survey
Data collection was carried out from April to July 2016 across two states, Bahia and Piauí. We focused on 11 municipalities in which the ICF provided support for CAR implementation. Two firms (Ambientagro in Bahia and Projetos in Piauí) helped smallholders geo-reference properties and prepare the required documents for registration. As state governments are

---

[6] To obtain LAU, one had to prove compliance with the Forest Code, which is different from the CAR that does not require compliance a priori registration.

compelled by law to assist smallholders with CAR registration, third-party donor agencies have been facilitating this process in most states. We randomly selected our survey respondents from the list of smallholders who had registered for the CAR with the help of technicians from the ProCerrado program supported by the ICF.

We define smallholders based on a standard definition in Brazilian land policy[5] (Republic of Brazil, Federal Law 8629/1993) which is also used in other studies (e.g. L'Roe *et al* 2016): properties up to four fiscal modules. Fiscal module sizes vary across municipalities in Brazil as a fiscal module is a size unit defined for each municipality according to the amount of land required for the primary economic activities of that region (Republic of Brazil, Federal Decree 84,685/1980). The fiscal module in Cerrado municipalities is on average 46 ha. For the five sampled municipalities in Bahia, a fiscal model equals 65 ha, while it equals 70 ha for three of the six sampled municipalities in Piauí (Santa Filomena, Currais, and Palmeira) and 75 ha for the remaining (Uruçui, Baixa Grande do Ribeiro, and Ribeiro Gonçalves). Thus, for the studied municipalities, small properties are less than 260 ha in Bahia and 280–300 ha in Piauí. Moreover, in the state of Piauí, state regulations stipulate that the amount of native vegetation that needs to be preserved constitute 30% of property areas rather than 20% as mandated by the Forest Code (Federal Law 12,615/2012).

In-person surveys were conducted with 1177 smallholders ($n = 851$ across five municipalities in Bahia and $n = 326$ across six municipalities in Piauí). Less than 1% of respondents refused to participate in our survey and therefore the bias from non-response would not significantly change our results. The primarily quantitative survey included questions on household characteristics, income and expenditures, agricultural production, problems and opportunities associated with CAR registration, and intended behavioral changes immediately following CAR registration. Specific questions addressed what those smallholders with more native vegetation than the legal cut-off intended to do with the excess area. Semi-structured interviews were also conducted with a subset of randomly selected smallholders (20 in Bahia and 22 in Piauí) that also participated in the quantitative survey. The aim of the interviews was to provide additional information on behavioral changes in the months following CAR registration.

We first present descriptive statistics from our survey data to illustrate (a) how many smallholders have, according to self-declarations, more or less than the legally required LR area and (b) how smallholders intend to use the excessive LR area. Then we construct a binary response model to identify characteristics of those smallholders who plan to clear excessive vegetation areas for cultivation. This model is explained in detail in the following section. As smallholders are the unit of analysis, changes in expected deforestation

behavior on properties with different sizes (≤ four fiscal modules) count equally. As such, this approach informs us about the type of farmers who are more likely to deforest following CAR registration rather than *how much* deforestation the program may initiate.

### 3.2. Modeling smallholder characteristics associated with deforestation behavior

We investigate the factors associated with smallholders' expected deforestation behavior following CAR registration using the probit regression model. The model is based on our survey and interview data and existing literature on smallholder decision-making (e.g. Angelsen 1999), which assumes that a smallholder maximizes utility from consumption and leisure, and is constrained by labor quantity. That is, each smallholder's decision to clear native vegetation is a function of factors affecting both consumption and production. We include biophysical and socioeconomic variables (for a full list, see table S1 available at stacks.iop.org/ERL/12/094001/mmedia) and run the model to investigate which factors are highly associated with smallholders' likelihood of clearing the native vegetation area on their property:

$$\Pr(Clear_i = 1) = \theta(\alpha + \beta NV_i + \gamma_1 Prod_i + \delta X_i)$$

where $Clear_i$ is a dummy variable indicating whether a smallholder $i$ plans to clear his/her native vegetation cover ($Clear_i = 1$) or not ($Clear_i = 0$); $\theta$ is the cumulative normal distribution; $NV_i$ is the percentage of native vegetation cover in smallholder $i$'s property; $Prod_i$ is a vector of variables that affect production decisions; $X_i$ is a vector of other demographic and socioeconomic control variables. We use a robust clustered variance-covariance matrix to account for correlations within 18 districts in the 11 municipalities. We run the model (a) with all observations and (b) with those observations for which the amount of native vegetation in properties is above the legal cut-off.

Ideally, we would have a control group of smallholders who are not registering for the CAR and which we could compare with our survey respondents' deforestation behavior in order to find a causal relationship between CAR registration and deforestation behaviors. However, given that the CAR registration is a nationwide policy and most of the properties are being registered with little variation in timing it was not feasible to construct such a control group. Because of the absence of adequate control groups, our survey questions asked specifically about respondents' changes in land use as a result of CAR registration to investigate smallholders' changes in their deforestation behaviors. Specifically, we asked all respondents: 'Do you anticipate making any changes in the way you use your land after you have registered for the CAR? If so, what are they?' Also, we asked those respondents who had more native vegetation than the legal requirements: 'Since

more than the legally-required area of your land is native vegetation (Legal Reserves), what do you plan to do with the excess area?'[7]. With this study design, the findings from the above model can be interpreted as smallholder characteristics that are highly associated with expected deforestation behavior change as a result of CAR registration.
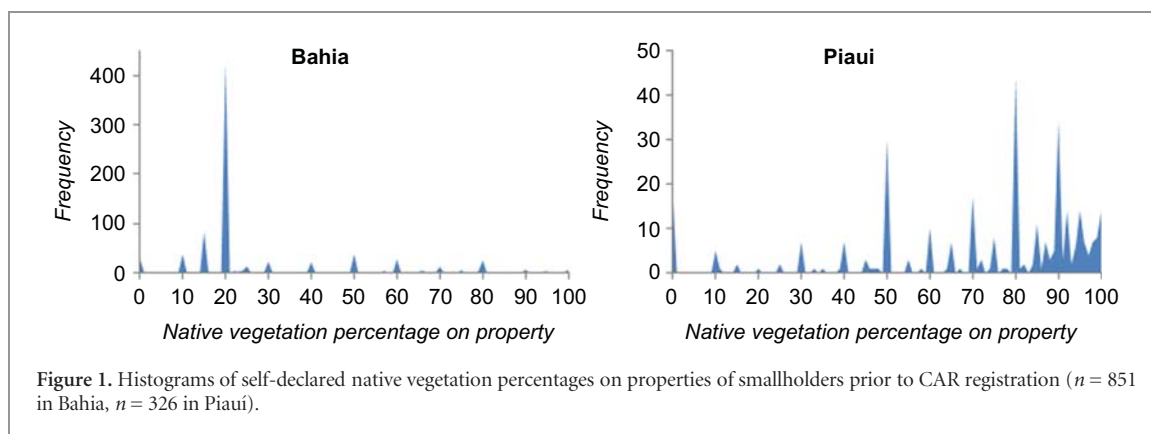
## 4. Results

### 4.1. Deforestation trends among smallholders

To illuminate smallholders'[8] intended deforestation behavior following CAR registration, we first assessed whether the proportion of native vegetation smallholders had on their properties prior to CAR registration was below or above the legal cut-off. We found that 31% ($n = 260$) of the surveyed smallholders in Bahia reported a native vegetation proportion higher than the legal cut-off of 20%. In Piauí, 89% reported values higher than the legal cut-off of 30%. Of those respondents who had more native vegetation than the legal requirements, 36% in Bahia and 41% in Piauí reported that they intended to clear the excess area and begin cultivating the land. Only one respondent intended to make use of the CRA system for trading excess areas of native vegetation. The main reasons for the lack of participation in the CRA system were a lack of knowledge about the system and how to utilize it. Most respondents with an excess area of native vegetation, however, did not intend to alter their deforestation behavior following (or preceding) CAR registration (63% in Bahia and 58% in Piauí). Our semi-structured interviews indicated that lack of resources (e.g. money, labor) as well as a sufficient cultivation area were the main reasons for not clearing more land. Yet, if smallholders were to gain additional financial resources, they would likely clear more native vegetation.

A histogram of the self-declared native vegetation proportion (figure 1) reveals a high frequency of the self-reported native vegetation proportion in Bahia at the legal cut-off of 20%. Because many smallholders actually did not know their proportion of native vegetation prior to CAR registration, they adhered to the proportion recorded when they registered for the CAR which, according to all interviewees, would not fall above the legal cut-off. This indicates that a 'rounded' estimate of 20% might be an under-estimate and that the number of smallholders who plan to clear native vegetation may be even higher. In Piauí, respondents seemed more aware of the proportion of native vegetation on their properties prior to CAR registration and a dense distribution was observed around values

---

[7] We acknowledge that clearing of excess area is legally permitted as long as the required percentage of LR and APP is maintained. Our intention is to investigate smallholders' intended deforestation behaviors regardless of whether it is legal or not.

[8] Main crops produced by respondents were maize, bean, and cassava, and 23% of respondents owned cattle.

**Figure 1.** Histograms of self-declared native vegetation percentages on properties of smallholders prior to CAR registration ($n = 851$ in Bahia, $n = 326$ in Piauí).

of 80%–100% native vegetation with more than half of the surveyed smallholders falling within this range. This conforms to the view that preservation of native vegetation has generally been more pronounced in Piauí as compared to Bahia (Sano *et al* 2010).

### 4.2. Smallholder characteristics associated with deforestation behavior

We turn next to an explicit examination of the factors associated with smallholders' intended change in land use behavior following CAR registration (table S1). First, we found that a high percentage of existing native vegetation cover on smallholders' properties was positively associated with smallholders' intended deforestation behavior after CAR registration, controlling for all other observed biophysical, socioeconomic, and demographic variables. The calculated average marginal effect of one percentage increase in the native vegetation cover on the likelihood of deforestation was 0.52% across all observations. Analogously, the simulation results, using the same model showed that one standard deviation (29.5%) increase in the percentage of native vegetation cover in smallholders' property area from the average percentage of native vegetation cover (40.2%) increased the probability of deforestation by 23% across all observations (figure 2(*a*)). Similar patterns and magnitude hold when using only those observations for which the amount of native vegetation in properties was above the legal cut-off. The greater percentage of native vegetation cover a smallholder had on the property, the higher the likelihood of clearing. This indicates that clearing would more likely occur in those areas with relatively high percentage of native vegetation cover.

We also found that smallholders who had used loans for agricultural purposes in the previous year were more likely to deforest after CAR registration (figure 2(*b*)), which is consistent with Pfaff (1999) and Hargrave and Kis-Katos (2012) who found a positive correlation between credit use and deforestation in the Brazilian Amazon. That CAR registration will be one of the requirements to access rural credit lines in Brazil was reflected in our survey data: 15% of respondents mentioned credit access as one of major reasons for CAR

registration, second highest to the compliance with legal requirements. Because our semi-structured interviews revealed that many smallholders considered the lack of funds as a constraint in clearing land for cultivation and expected to use funds from increased credit access for land clearings, it raises concerns that smallholders without credit access may be granted access through CAR registration as this may fuel further deforestation.

Livestock production experience and smallholder age were also factors highly associated with intended deforestation behavior at the 5% level of significance. The more livestock production experience smallholders have and the younger they are (figure 2(*c*)), the more likely they are to clear native vegetation. The positive association with livestock experience may arise from the importance of pastures for livestock and the vast expansion of pastures into forested areas seen across Brazil during the past decades (Cederberg *et al* 2011). With regards to the importance of age, our semi-structured interviews indicated that younger smallholders are better able and more willing to clear native vegetation due to better health and higher prospects for returns. Yet, the use of rural credit for agricultural purposes appeared more important than the age of smallholders (figure 2(*d*)). That is, only smallholders in the youngest age group, who *had not* used rural credit lines, have a greater likelihood of clearing than those smallholders in the oldest age group who *had* used rural credit lines.

## 5. Discussion

Whereas Brazil can celebrate reductions in the large-scale clearing of forest in the Amazon, our findings from the Cerrado biome indicate that clearings are likely to happen at the property level, threatening some of the world's most biodiverse savannahs. As we show how the process of CAR registration might incentivize clearing for cultivation among those smallholders with more native vegetation than the legal cut-off, our results indicate that current conservation initiatives in the Cerrado might not be sufficient to impede significant deforestation in the future (Richards *et al* 2017), without putting into question the efficiency of conservation initiatives in other biomes of Brazil. Because the
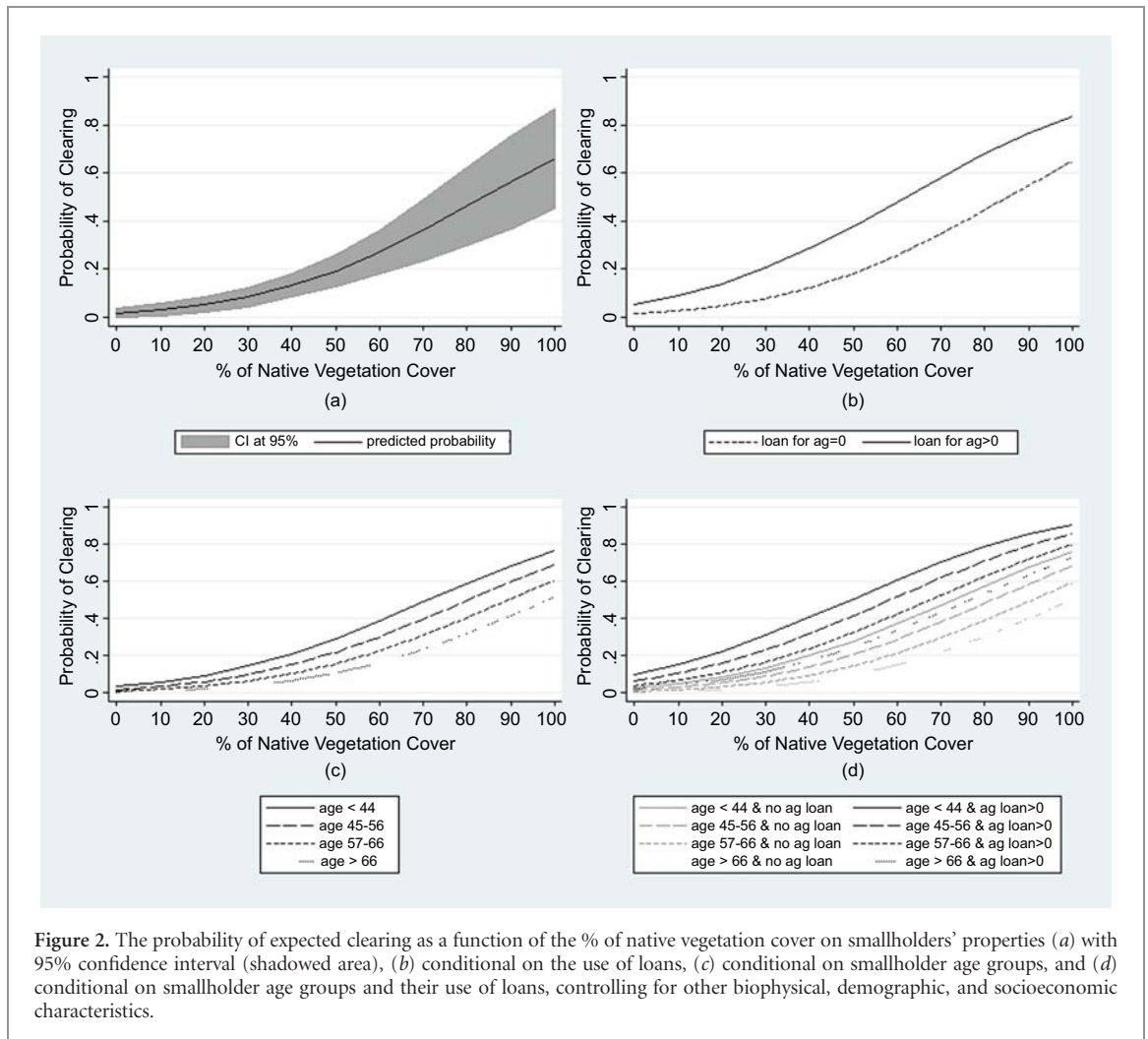
**Figure 2.** The probability of expected clearing as a function of the % of native vegetation cover on smallholders' properties (*a*) with 95% confidence interval (shadowed area), (*b*) conditional on the use of loans, (*c*) conditional on smallholder age groups, and (*d*) conditional on smallholder age groups and their use of loans, controlling for other biophysical, demographic, and socioeconomic characteristics.

Cerrado remains overshadowed by the Amazon forest and is largely privately owned, the deforestation taking place there is especially difficult to halt; thus it proceeds without significant pushback both domestically and internationally (Lahsen *et al* 2016).

We have shown that the existing percentage of native vegetation which smallholders have on their properties is positively and significantly associated with their intention to deforest. On the one hand, this points to a higher likelihood of clearing in highly forested areas that might be critical areas for biodiversity and carbon storage and where the impacts of habitat fragmentation caused by agricultural expansion may be severe (Chaplin-Kramer *et al* 2015). On the other hand, our results also show that upon CAR registration those smallholders with less native vegetation than the legal cut-off appear less inclined to clear areas for cultivation, possibly as a result of their increased awareness of the Forest Code. Because many smallholders have more native vegetation than the legal cut-off and they intend to clear the excess area, our results indicate that the mandated proportion of 20% native vegetation on rural properties in the Cerrado outside of the Legal Amazon is too low. Specific state regulations, such as the state of Piauí's stipulation that an increased proportion of native vegetation (30%) is to be preserved, are

important steps in the right direction, yet in the case of Piauí it is still too low considering the high average percentage of native vegetation cover in our sample (70%). Our results also show that smallholders with loans for agricultural production are more likely to clear land. Given that credit access tends to be also positively associated with poverty reduction (Burgess and Pande 2005, Conning and Udry 2007) and the poverty rates in the Cerrado area are high, restricting access to rural credit is not a viable option.

We argue that there is a need for additional mechanisms built into nation-wide environmental registration schemes, like the CAR, as the CRA system for trading excess areas of native vegetation is currently functioning poorly, partly because of smallholders' unfamiliarity with the system. Such mechanisms should (1) account for the existing land use by, for example, providing additional (monetary) incentives to those smallholders with more native vegetation than the legal requirements to maintain that vegetation, and (2) establish conditioning measures for granting credit access to younger smallholders, in particular, and/or livestock producers with a high percentage of native vegetation in their properties. Such conditioning measures could, for example, be participation in mutual monitoring groups or/and a declaration presented by

the borrower stating any planned land use change. Moreover, because the CAR rests on self-declared registration of native vegetation cover, more stringent verification of the registry data might be necessary to assure that the CAR can actually facilitate enforcement (L'Roe *et al* 2016).

We acknowledge that the actual land use decisions remain to be seen since our results are based on smallholders' statement of intended deforestation behavior after CAR registration rather than actual behavior. Nevertheless, understanding the realities of deforestation at the property level is a necessary component of large-scale environmental initiatives aimed at reducing smallholders' deforestation behavior. Because our micro-level data has enabled us to disentangle the factors linked to smallholders' deforestation behavior following registration for one of the largest environmental programs in the world, a program which is serving as an example for potential programs alike in other countries, our findings should be of broad interest for future designs of environmental registration initiatives.

## Acknowledgments

## ORCID iDS

Laura Vang Rasmussen ⬤ https://orcid.org/0000-0001-7786-6783

## References

Angelsen A 1999 Agricultural expansion and deforestation: modeling the impact of population market forces and property rights *J. Dev. Econ.* **58** 185–218

Azevedo A A and Saito C H 2013 O perfil dos desmatamentos em Mato Grosso, apósimplementac, ão do licenciamento ambiental em propriedades rurais *CerneLavras* **19** 111–22

Azevedo A A, Rajâo R L, Costa M, Stabile M C C, Alencar A and Moutinho P 2014 Cadastro Ambiental Rural e sua influência na dinâmica do desmatamento na Amazônia Legal. Boletim Amazônia em Pauta, IPAM. (http://ipam.org.br/wp-content/uploads/2016/04/amaz%C3%B4nia_em_pauta_3_cadastro_ambiental_r.pdf)

Barros C, Barcelos I and Gallo J 2016 As falhas e inconsistências do Cadastro Ambiental Rural. Publica: Agência de reportagem e jornalismo investigativo (http://apublica.org/2016/08/as-falhas-e-inconsistencias-do-cadastro-ambiental-rural/)

Beuchle R, Grecchi R C, Shimabukuro Y E, Seliger R, Eva H D, Sano E and Achard F 2015 Land cover changes in the Brazilian Cerrado and Caatinga biomes from 1990 to 2010 based on a systematic remote sensing sampling approach *Appl. Geogr.* **58** 116–27

Burgess R and Pande R 2005 Do rural banks matter? Evidence from the Indian social banking experiment *Am. Econ. Rev.* **95** 780–95

Carranza T, Balmford A, Kapos V and Manica A 2013 Protected area effectiveness in reducing conversion in a rapidly vanishing ecosystem: the Brazilian Cerrado *Conserv. Lett.* **7** 216–23

Caviglia-Harris J, Sills E, Bell A, Harris D, Mullan K and Roberts D 2016 Busting the boom–bust pattern of development in the Brazilian Amazon *World Dev.* **79** 82–96

Cederberg C, Persson U M, Neovius K, Molander S and Clift R 2011 Including carbon emissions from deforestation in the carbon footprint of Brazilian beef *Environ. Sci. Tec.* **45** 1773–79

Chaplin-Kramer R *et al* 2015 Spatial patterns of agricultural expansion determine impacts on biodiversity and carbon storage *Proc. Natl Acad. Sci.* **112** 7402–7

Conning J and Udry C 2007 Rural financial markets in developing countries *Handbook of Agricultural Economics* vol **3** ed R Evenson, P Pingali and T P Schultz ch 15 (Amsterdam: Elsevier)

Fearnside P M 2003 Deforestation control in Mato Grosso: a new model for slowing the loss of Brazil's Amazon forest *AMBIO: J. Hum. Environ.* **32** 343–5

Fearnside P M 2015 Environment: deforestation soars in the Amazon *Nature* **521** 423

Fearnside P M 2016 Brazilian politics threaten environmental policies *Science* **353** 746–8

Ferreira J *et al* 2014 Brazil's environmental leadership at risk *Science* **346** 706–7

Gibbs H K, Rausch L, Munger J, Schelly I, Morton D C, Noojipady P, Soares-Filho B, Barreto P, Micol L and Walker N F 2015a Brazil's soy moratorium *Science* **347** 377–8

Gibbs H K, Munger J, L'Roe J, Barreto P, Pereira R, Christie M, Amaral T and Walker N F 2015b Did ranchers and slaughterhouses respond to zero-deforestation agreements in the Brazilian Amazon? *Conserv. Lett.* **9** 32–42

Hargrave J and Kis-Katos K 2012 Economic causes of deforestation in the Brazilian Amazon: a panel data analysis for 2000s *Environ. Res. Econ.* **54** 471–94

Jepson W, Brannstrom C and Filippi A 2010 Access regimes and regional land change in the Brazilian Cerrado, 1972–2002 *Ann. Assoc. Am. Geogr.* **100** 1–25

Jung S, Rasmussen L V, Watkins C, Newton P and Agrawal A 2017 Brazil's national environmental registry of rural properties: implications for livelihoods *Ecol. Econ.* **136** 53–61

Kröger M 2017 Inter-sectoral determinants of forest policy: the power of deforesting actors in post 2012 Brazil *Forest Policy Econ.* **77** 24–32

Lahsen M, Bustamante M M C and Dalla-Nora E L 2016 Undervaluing and overexploiting the Brazilian Cerrado at our peril *Environ. Sci. Policy Sustain. Dev.* **58** 4–15

L'Roe J, Rausch L, Munger J and Gibbs H K 2016 Mapping properties to monitor forests: landholder response to a large environmental registration program in the Brazilian Amazon *Land Use Policy* **57** 193–203

McFadden D 1974 Conditional logit analysis of qualitative choice behavior *Frontiers in Econometrics* ed P Zarembka (New York: Academic)

MMA (Ministry of the Environment) 2009 *Monitoramento do Desmatamento no Bioma Cerrado 2002–2008: dados revisados* ['*Monitoring of Deforestation in the Cerrado Ecosystem 2002–2008: Revised Data*'] (Brasilia: MMA/IBAMA)

Moreira E 2016 O cadastro ambiental rural: a nova face da grilagem na Amazônia? ABRAMPA: (www.abrampa.org.br/site/?ct=noticia&id=230)

Newton P *et al* 2016 Overcoming barriers to low carbon agriculture and forest restoration in Brazil: the Rural Sustentável project *World Dev. Perspectives* **4** 5–7

Noojipady P, Morton C D, Macedo N M, Victoria C D, Huang C, Gibbs K H and Bolfe L E 2017 Forest carbon emissions from cropland expansion in the Brazilian Cerrado biome *Environ. Res. Lett.* **12** 025004

Oliveira G  2013 Land regularization in Brazil and the global land grab *Dev. Change* **44** 261–83

Pfaff A S  1999 What drives deforestation in the Brazilian Amazon? evidence from satellite and socioeconomic datal *J. Environ. Econ. Manage.* **37** 26–43

Pires M O  2013  O Cadastro Ambiental Rural. Das origens às perspectivas para a política ambiental. Inovacar, Conservação Internacional, Brasil (http://inovacar.org.br/uploads/documents/O%20Cadastro%20Ambiental%20Rural%20-%20Origens%20e%20Perspectivas.pdf)

Rajão R, Azevedo A and Stabile M C  2012 Institutional subversion and deforestation: learning lessons from the system for the environmental licensing of rural properties in Mato Grosso *Public Admin. Dev.* **32** 229–44

Republic of Brazil 1980  Decree 84,685 (http://legis.senado.gov.br/legislacao/ListaNormas.action?numero=84685&tiponorma=DEC&data=1980) (Accessed: 19 June 2016)

Republic of Brazil 1993  Law 8, 629 (www2.camara.leg.br/legin/fed/lei/1993/lei-8629-25-fevereiro-1993-363222-normaatualizada-pl.html) (Accessed: 24 June 2016)

Republic of Brazil 2006  Law 11.326 (www.planalto.gov.br/ccivil_03/_ato2011-2014/2011/lei/l12512.htm) (Accessed: 14 June 2017)

Republic of Brazil 2011  Law 12.512 (www.planalto.gov.br/ccivil_03/_ato2011-2014/2011/lei/l12512.htm) (Accessed: 14 June 2017)

Republic of Brazil 2012  Law 12, 651 (www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm) (Accessed: 24 June 2016)

Richards P, Arima E, Vanwey L, Cohn A and Bhattarai N  2017 Are Brazil's deforesters avoiding setection? *Conserv. Lett.* accepted (https://doi.org/10.1111/conl.12310)

Sano E E, Rosa R, Brito J L and Ferreira L G  2010 Land cover mapping of the tropical savanna region in Brazil *Environ. Monit. Assess.* **166** 113–24

Shankland A and Gonçalves E  2016 Imagining agricultural development in south–south cooperation: the contestation and transformation of ProSAVANA *World Dev.* **81** 35–46

Soares-Filho B, Rajao R, Macedo M, Carneiro A, Costa W, Coe M, Rodrigues H and Alencar A  2014 Cracking Brazil's forest code *Science* **344** 363–4

Soares-Filho B, Rajao R, Merry F, Rodrigues H, Davis J, Lima L, Macedo M, Coe M, Carneiro A and Santiago L  2016 Brazil's market for trading forest certificates *PloS ONE* **11** e0152311

Strassburg B B *et al* 2017 Moment of truth for the Cerrado hotspot *Nat. Ecol. Evol.* **1** 0099

Tollefson J  2016 Political upheaval threatens Brazil's environmental protections *Nature* **539** 147–8

Vital A  2016  Ambientalistas: apesar de atrasos, Cadastro Rural é avanço do Código Florestal. Câmara Notícias: (www2.camara.leg.br/camaranoticias/noticias/MEIO-AMBIENTE/511616-AMBIENTALISTAS-APESAR-DE-ATRASOS,-CADASTRO-RURAL-E-AVANCO-DO-CODIGO-FLORESTAL.html)