Limits of Brazil's Forest Code as a means to end illegal deforestation

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Edited by Emilio F. Moran, Michigan State University, East Lansing, MI, and approved May 24, 2017 (received for review March 23, 2016)

The 2012 Brazilian Forest Code governs the fate of forests and savannas on Brazil's 394 Mha of privately owned lands. The government claims that a new national land registry (SICAR), introduced under the revised law, could end illegal deforestation by greatly reducing the cost of monitoring, enforcement, and compliance. This study evaluates that potential, using data from state-level land registries (CAR) in Pará and Mato Grosso that were precursors of SICAR. Using geospatial analyses and stakeholder interviews, we quantify the impact of CAR on deforestation and forest restoration, investigating how landowners adjust their behaviors over time. Our results indicate rapid adoption of CAR, with registered properties covering a total of 57 Mha by 2013. This suggests that the financial incentives to join CAR currently exceed the costs. Registered properties initially showed lower deforestation rates than unregistered ones, but these differences varied by property size and diminished over time. Moreover, only 6% of registered producers reported taking steps to restore illegally cleared areas on their properties. Our results suggest that, from the landowner's perspective, full compliance with the Forest Code offers few economic benefits. Achieving zero illegal deforestation in this context would require the private sector to include full compliance as a market criterion, while state and federal governments develop SICAR as a de facto enforcement mechanism. These results are relevant to other tropical countries and underscore the importance of developing a policy mix that creates lasting incentives for sustainable land-use practices.

deforestation | Forest Code | tropical forests | governance | Amazon

Historically, deforestation has accounted for the majority of greenhouse gas (GHG) emissions from developing countries (1, 2). In Brazil, this trend changed dramatically when annual deforestation rates in the Amazon dropped by 76% from 2005 to 2012 (3–5). Avoided deforestation during this period generated emissions reductions on the order of 3.2 Gt CO_2, compared with a historical baseline (5–7). There are several potential explanations for the observed decline in deforestation. These include the establishment of new protected areas (7), restrictions on credit available to illegal deforesters (8, 9), public blacklists of properties and municipalities that deforest illegally (10), moratoria to eliminate deforesters from soy and beef supply chains (5, 11), and command-and-control enforcement actions by state and federal agencies (12–15).

Despite advances, Brazil still faces two key barriers to effective enforcement of deforestation. First, the lack of a comprehensive national database of property boundaries (i.e., a land registry) has made it difficult to link new deforestation to specific land owners. Second, deforestation patches have decreased in size, making them increasingly difficult to detect (16). Both pose substantial challenges for forest monitoring, effective enforcement, and restoration of illegally deforested areas (i.e., forest "deficits") mandated by the Forest Code. This is illustrated by the fact that the majority (~69%) of deforestation from 2002 to 2009 occurred on properties whose boundaries were not publicly registered.

In the face of these difficulties, the Amazon states of Mato Grosso (MT) and Pará (PA) invested in systems to control and monitor deforestation, implementing a land registry known as the Rural Environmental Registry (CAR, Portuguese acronym) in 2008 (MT) and 2009 (PA). To join CAR, landowners must georeference their property boundaries and remaining forests using satellite images (Fig. 1) (17, 18). For the first time, CAR made it possible for government agencies to identify the perpetrators of deforestation and monitor whether individual landowners were complying with the Forest Code. These state land registries served as models for the National Rural Environmental Registry System (SICAR), which today is the main instrument for implementing the new Forest Code. The 2012 Forest Code stipulates that landowners in the Amazon biome should conserve 80% of their property (land area) in native vegetation, whereas those in the Cerrado should conserve 20–35% (19).

SICAR aimed to register roughly 5,000,000 rural properties throughout Brazil by May 2016. This target date was postponed to December 2017 by Law No. 13.295 on June 14, 2016 (20). By August 2016, it had registered 3,700,000 properties spanning 387 Mha (21). The GIS-based environmental registry promises to make landowners accountable for illegal deforestation and restoration requirements, while reducing the cost of monitoring for the government, landowners, and the private sector (22). Commodities buyers currently face high monitoring and transaction costs to ensure deforestation-free supply chains (e.g., the soy moratorium) (23). If the national CAR system were fully implemented—together with complementary public policies—it has the potential to replace these initiatives, reduce deforestation, and lower costs (11, 24).

Although an important first step, registering with CAR does not guarantee that landowners will comply with the law or reduce deforestation. Full compliance involves very high restoration

Significance

Brazil's new Forest Code has the potential to halt illegal deforestation in the country's native forests and savannas through implementation of a federal land registry—along with powerful tools that facilitate enforcement and give landowners a pathway to restoring or compensating their "forest deficits." This study suggests that these tools fall short of their promise. Although landowners in eastern Amazonia have been motivated to join state land registries, many continue to deforest and few have restored their illegally cleared areas. Results indicate that the economic benefits of full compliance with the Forest Code remain scant. To end deforestation, Brazil must realign its financial and policy incentives to encourage this outcome. The fate of the country's forests hangs in the balance.

Author contributions: A.A.A., R.R., M.A.C., M.C.C.S., and A.A. designed research; A.A.A., R.R., M.A.C., and M.C.C.S. performed research; B.S.S.-F. contributed new analytic tools; R.R., A.A., and R.P. collected data in the field; A.A.A., R.R., M.A.C., M.C.C.S., and T.N.P.R. analyzed data; and A.A.A., R.R., M.A.C., M.C.C.S., and M.N.M. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1604768114/-/DCSupplemental.

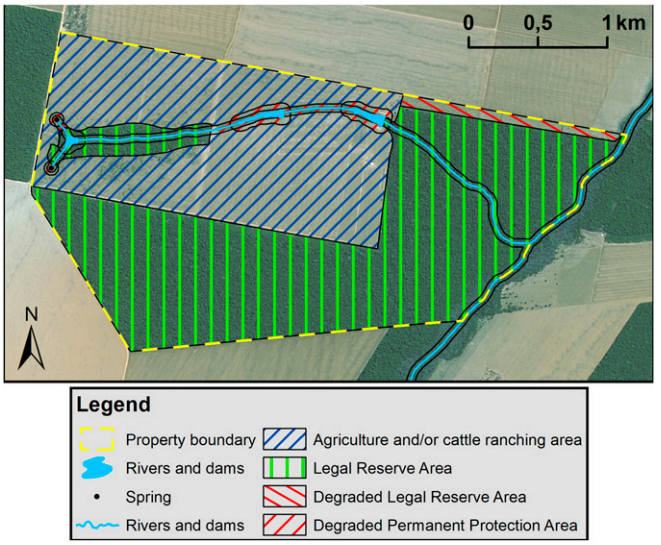


Fig. 1. Example of a CAR (Rural Environmental Registry) property registered according to the national registry standard (SICAR). The property boundary is shown by the dashed yellow line. Legal Reserves are designated by the green hatching, whereas Legal Reserve deficits are marked by red hatching. Buffer zones around rivers and dams (areas of permanent protection) are included in the Legal Reserve area. Blue hatched areas represent agriculture and cattle-ranching areas.

costs, opportunity costs of foregone production, and negligible benefits, given the relatively low risk of receiving fines due to poor enforcement. This also reflects a lack of market demand for legality as a criterion for purchase of commodities (24).

Despite the great potential of public land registries, few studies have quantified their effects on deforestation in the Amazon (but see 17, 25, 26) or their role in ensuring compliance on private properties. Studies of other deforestation-control measures—including payments for environmental services (27, 28) and protected areas (29, 30)— suggest that these programs do not always yield the expected conservation outcomes. The effectiveness of these policies in improving forest governance in the tropics remains an open question, including CAR, which has yet to be fully implemented. To address this gap, we analyzed the recent experiences of Mato Grosso and Pará, with the goal of improving implementation of SICAR in Brazil and similar systems in other countries.

This study addresses three central questions: (*i*) What motivates producers to join CAR? (*ii*) Are registered producers less likely to deforest? (*iii*) Are registered producers more likely to comply with Forest Code restoration requirements? These questions are essential to understanding how individual farmers perceive the incentives at each stage of CAR implementation. To address them, we evaluated costs and benefits of environmental compliance from the producer's point of view. We quantified deforestation in 49,669 rural properties in Mato Grosso and Pará that joined CAR from 2008 to 2013. The control group included properties before CAR registration, whereas the treatment group included properties after registration (31) (*SI Appendix*). To control for exogenous factors (other than CAR) that might influence deforestation, we evaluated a series of models including several potential explanatory variables. Deforestation probability was modeled based on distance to markets, infrastructure, agricultural suitability, and slope (7). Forest patch size represented the supply of forests available for deforestation in a given property. We also assessed the impact of public policies such as the Green Municipalities Program (GMP) in Pará (a federal blacklist restricting credit to municipalities with high rates of illegal deforestation) and the number of fines related to environmental infractions over time.

To estimate the incentives to comply with the Forest Code, we used secondary data and published studies to evaluate the legal status of CAR properties and estimate the economic costs of being compliant (19, 32–34). We also used primary data from questionnaires with farmers and GIS professionals to evaluate costs and benefits at each stage of Forest Code compliance, using a sample of 20 municipalities and 33 in-depth interviews with state officials.

Results and Discussion

Incentives for Joining CAR. By 2013, registered CAR properties covered roughly 32% (23 Mha) of the areas eligible for registration in Mato Grosso and 57% (34 Mha) in Pará. Registered properties were distributed uniformly in both states, suggesting that a broad cross section of producers have joined (Fig. 2). Among the surveyed producers outside CAR, 30% in Pará and 36% in Mato Grosso declared that they would join only if forced to by government or market sanctions.

Both the rapid adoption of CAR and data from our questionnaires suggest that the incentives to join CAR outweighed the costs of remaining outside the system. The most immediate benefit of joining was a lower chance of receiving fines for not complying with state laws in Mato Grosso and Pará, where CAR membership is mandatory for all rural properties. To encourage adherence to the system, state officials reported having ignored legal infractions within CAR properties to avoid "scaring off" new registrants from joining the system.

A second (and likely stronger) incentive to join CAR was access to additional lines of credit for farmers. Resolution No. 3545/2008 of Brazil's Central Bank made it mandatory for producers to present a "license, certificate, or equivalent evidence of environmental compliance" to qualify for public loans (35). Because public loans are Brazil's main instrument for subsidizing the agricultural sector, their interest rates are much lower than those of private banks (28).

The third incentive to join CAR stemmed from the intervention of public prosecutors. To control growing deforestation rates in Pará, in 2009 public prosecutors pressed the state's large slaughterhouses to stop buying cattle from ranches that did not comply with environmental and labor laws. That same year, Greenpeace proposed an agreement urging the Amazon's four biggest slaughterhouses to boycott cattle from ranches with illegal deforestation after July 2009

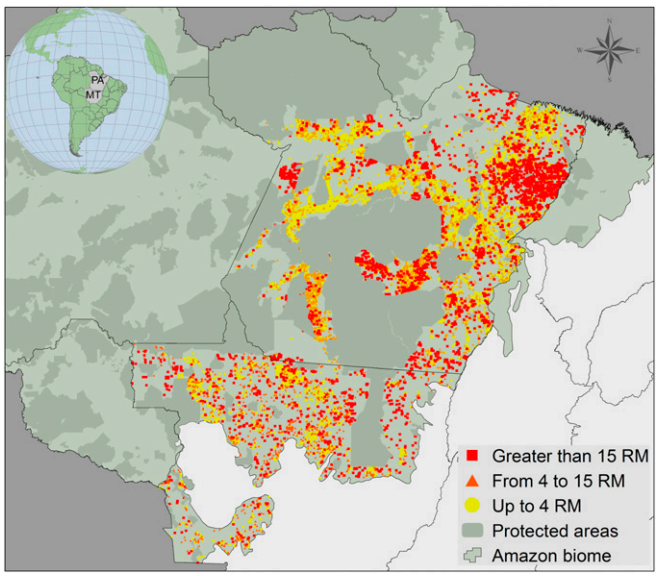


Fig. 2. Spatial distribution of properties enrolled in CAR (Rural Environmental Registry) by 2013, grouped according to their size class. Properties in yellow are small properties of up to four Rural Modules (<4 RM); orange are medium-sized properties (4–15 RM); and red are large properties (> 15 RM).

(36). These initiatives required cattle ranchers in both states to join CAR to sell their product to large slaughterhouses.

Governmental and nongovernmental organizations provided a fourth incentive by subsidizing the GIS surveys needed to register with CAR. Surveys of GIS professionals indicate that the cost of joining CAR averages US $549 for small and US $1686 for large properties in Mato Grosso, compared with US $307 for small and US $845 for large properties in Pará. Estimates are based on the 2013 average exchange rate between the Brazilian Real and US Dollar. These upfront costs represent half the monthly income for some small farmers, making them a significant barrier to entering CAR. NGO programs to cover these costs are an important incentive to join and exist in at least 64 municipalities where such work is undertaken by the following organizations: The Nature Conservancy (TNC), Instituto Socioambiental (ISA), Instituto do Homem e Meio Ambiente da Amazônia (IMAZON), Instituto Centro de Vida (ICV), and Instituto de Pesquisa Ambiental da Amazônia (IPAM).

Since its introduction, CAR has shifted from an instrument focused exclusively on environmental sustainability to one that is vital for the economic sustainability of rural producers. Our results suggest that subsidies to decrease the cost of entering CAR, combined with credit and market restrictions that increase the costs of production outside CAR, have made it relatively costly to remain outside the registry.

Deforestation Within CAR. A key assumption of CAR supporters at the federal level is that registering rural properties in the system will substantially decrease illegal deforestation. This is rooted in the idea that the land registry could radically reduce the cost of property-level monitoring and enforcement. To understand how CAR affected deforestation decisions, we compared annual deforestation rates in registered and unregistered properties, stratifying by property size. To control for other factors that might influence deforestation, we considered a series of models and explanatory variables (*Methods* and *SI Appendix*, Table S5). The final model included deforestation probability (7), remaining forest area, and whether the municipality was part of a federal blacklist to combat high deforestation (37).

Our results indicate that registering with CAR did not necessarily reduce illegal deforestation. Despite controlling for other spatial, economic, and policy factors, we observed substantial variation in the effectiveness of CAR over time and across property sizes (Table 1 and *SI Appendix*, Fig. S1). Small properties (<400 ha) in Mato Grosso and Pará had lower deforestation immediately after entering CAR, but this effect decreased over time and, in the case of Pará, disappeared entirely by 2012. Medium and large properties in both states showed no consistent pattern. For instance, in medium properties (400–1,500 ha) in Mato Grosso, deforestation was higher inside CAR for 2009–2010, but lower for 2011. The inverse was true for large properties (>1500 ha) in Mato Grosso, where deforestation was lower inside CAR in 2009, but higher in 2011 (Table 1 and *SI Appendix*, Fig. S1).

Including the effect of the municipalities blacklist improved our model, but other public policies had no clear effect. Including Pará's green municipalities program (38) and the number of fines at the municipal level issued by IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis) (13, 15) did not change the general conclusions described above and, in some cases, reduced the overall predictive power of the models. This suggests that these policies either (*i*) did not reduce deforestation beyond the CAR effect or (*ii*) covaried with CAR at the property level.

Interviews with local farmers in Pará and Mato Grosso confirm the results presented above. Some small farmers reported feeling like they were being watched more closely by the state after joining CAR, supporting the idea that CAR could lower monitoring costs and improve enforcement. However, this initial perception of risk has decreased over time—in some cases to the point where the benefits of increasing deforestation (e.g., increased land value)

Table 1. Average property-level deforestation (ha) within CAR and Control groups

Size Class (RM)	Year	Before CAR (Control)	After CAR	CAR effect (%)	CAR effect (*P* value)
			Mato Grosso		
Up to 4 RM	2009	0.0772	0.0556	−3.25%	0.6513
	2010	0.1293	0.0374	**−7.21%**	**0.0051**
	2011	0.1925	0.0987	−6.12%	0.6445
4–15 RM	2009	0.0949	0.1253	7.41%	0.4346
	2010	0.1204	0.1182	**8.50%**	**0.0737**
	2011	0.2707	0.1323	−4.93%	0.8112
Over 15 RM	2009	0.1780	0.0268	−10.12%	0.2944
	2010	0.2206	0.1609	0.21%	0.9700
	2011	0.1733	0.2294	10.75%	0.6589
			Pará		
Up to 4 RM	2008	0.4430	0.1702	**−27.47%**	**0.0108**
	2009	0.3133	0.0803	**−21.34%**	**0.0000**
	2010	0.3573	0.2653	**−10.89%**	**0.0000**
	2011	0.2596	0.2200	**−5.29%**	**0.0000**
	2012	0.1836	0.1592	−3.19%	0.2785
4–15 RM	2008	0.8486	0.0277	**−34.71%**	**0.0956**
	2009	0.5589	0.4379	**18.54%**	**0.0177**
	2010	0.5400	0.3460	−4.72%	0.1933
	2011	0.3174	0.2612	0.96%	0.7498
	2012	0.3616	0.1728	**−14.61%**	**0.0173**
Over 15 RM	2008	0.9885	0.9923	13.78%	0.5111
	2009	0.5416	0.5416	**21.37%**	**0.0079**
	2010	0.6480	0.4546	**−8.13%**	**0.0416**
	2011	0.4379	0.3288	−2.91%	0.4065
	2012	0.1614	0.2380	14.09%	0.1277

The estimated CAR effect (model 3) is adjusted for forest size, an index of deforestation risk (developed using the Dinamica EGO modeling platform), and presence of the blacklist within the municipality. Bold numbers indicate *P* values that are significant ($P \leq 0.1$).

outweigh the potential costs (e.g., fines). Some farmers confessed to clearing small areas (<10 ha) on their properties, hoping that this small-scale deforestation would escape detection by satellites or be overlooked by state prosecutors. Satellite observations confirmed that a large proportion (63% for PA and 51% for MT) of clearings inside CAR were smaller than 10 ha. Recent studies indicate that this decrease in the size of deforestation patches is widespread (16, 39). Officials from both federal and state agencies confirmed that, in practice, small clearings are systematically ignored due to the logistical difficulty of inspecting deforestation events in situ. Although federal and state environmental agencies have started to use CAR data to issue fines remotely, officials report that this requires substantial labor and that personnel limitations make it impractical to prosecute small deforestation events. This suggests that most landowners deforesting within CAR do so with the expectation of impunity because small deforestation patches are not being detected or prosecuted by the control agencies.

Compliance with Forest Restoration Requirements Within CAR. Attaining zero illegal deforestation within CAR is an important target, but is not enough to guarantee Forest Code compliance. The law requires landowners who have deforested illegally to restore or compensate these clearings to fulfill the minimum Legal Reserve requirement (19). To weigh the costs and benefits of complying, the farmer must consider (*i*) incentives reserved for farmers that are fully compliant, (*ii*) the cost of forest restoration or compensation, (*iii*) the opportunity cost of foregone rents from agricultural production, (*iv*) the potential for future changes in the law, and (*v*) the probability of getting caught and punished for noncompliance. Using our sample and the survey data, we assessed the influence of most of these factors on producer decisions to maintain or restore Legal Reserves and riparian areas on their properties.

Incentives for compliance. At the moment, the economic benefits of full compliance with the Forest Code are scant. Officials from both states report that compliance with these obligations is rarely verified on the ground. Farmers need only present a report stating that they have taken steps to restore their forest debts, but only a fraction of CAR participants provide these reports on a regular basis.

Results from the questionnaires corroborate these findings. Only 6% of landowners with forest debts in Pará and Mato Grosso reported that they were taking the necessary measures to compensate or restore their Legal Reserves, whereas 76% affirmed that they would only compensate or restore if coerced to do so through government fines or market incentives. Even faced with a scenario in which strong restrictions were imposed by private and public actors, 18% said they would never compensate or restore their forest debts. Aside from a lower probability of receiving fines, the only economic incentive currently applicable to forest restoration is a 15% increase in the total amount of subsidized loans available to farmers who can demonstrate a commitment to full compliance with the Forest Code (40). No market initiative targets the forest debts of individual farmers under the Forest Code; they focus instead on eliminating newly deforested areas from commodity supply chains (11, 24). From a market perspective, there is still no difference between a landowner with an 80% Legal Reserve (compliant) and one with only 2% (noncompliant). Nevertheless, compliant and noncompliant landowners will obtain very different economic returns and environmental outcomes from properties of the same size.

Costs of compliance. The economic benefits of fully complying with the Forest Code are very low, whereas the costs are substantial. Illegally deforested areas provide a sizable portion of the income of Amazon farmers. In addition to forgoing this income, farmers are faced with the costs of restoration, which may be high depending on the method used. To estimate the potential costs, we first quantified the environmental deficit in our sampled properties. We found that 2,944 (82.6%) properties in Mato Grosso and 15,170 (76.6%) properties in Pará were not compliant with the Forest Code before joining the CAR system. This represented 841,564 ha and 3,951,664 ha to be restored in Mato Grosso and Pará, respectively (*SI Appendix*, Tables S1 and S2). Considering that restoration costs range from US \$536 to 1,327 ha^{-1}, depending on the property's land-use history and adjacent land uses (19, 32), we estimated a total restoration cost from US \$0.5 to 1.1 billion in Mato Grosso and from US \$2.1 to 5.2 billion in Pará.

There are also substantial opportunity costs associated with (*i*) forgoing production on a given land parcel to begin restoration and (*ii*) maintaining surplus Legal Reserves—i.e., forest assets that could legally be converted for production. Stickler et al. (32) estimated that the first incurred a cost of US \$673 ha^{-1}, and the latter incurred a cost of US \$500 ha^{-1}. Combining these figures with our sample, we estimate that the total opportunity cost of forgoing production for restoration in 2008 was about US \$0.5 billion in Mato Grosso and US \$2.6 billion in Pará. The costs of maintaining surplus forests were excluded from our estimate of total compliance costs because they reflected both direct and indirect costs of restoration, as described below.

The combined direct cost of restoration and opportunity cost of forgone production ranges from US \$1.0 to 1.6 billion in Mato Grosso (2008) and from US \$4.7 to 7.9 billion in Pará (2007), considering a sample area of 57.2% in PA and 31.7% in MT. Considering the total productive area (In our sample, 1.3 Mha in Mato Grosso and 4.3 Mha in Pará are productive lands), we estimate that the average cost of Forest Code compliance ranges from US \$768 to 1,270 ha^{-1} in Mato Grosso and from US \$1,099 to 1,818 ha^{-1} in Pará. Although the cost of compliance can be reduced significantly through compensation mechanisms such as the Environmental Reserve Quota (CRA), in most cases this remains prohibitively expensive (41). For this reason, the level of Forest Code implementation in Brazil is low (34), and the forest debt in states like Mato Grosso is massive (19, 24).

Changes in the Forest Code. Revisions to the Forest Code have created a substantial disincentive for compliance. The latest of these occurred in 2012, with approval of a new Forest Code that lowered standards for environmental compliance. The 2012 Forest Code not only forgave fines for areas deforested illegally before 2008, but also reduced restoration requirements. The revised law decreased the total area requiring restoration by 41% and 68% in Mato Grosso and Pará, respectively (19). Considering only properties inside CAR, the land area to be restored dropped by 21% in Mato Grosso and 15% in Pará. These reductions affected 55% of the properties in Mato Grosso and 70% in Pará—primarily due to changes in the rules for smallholders. The only prerequisite for this benefit was to join CAR and commit to an official management plan (Portuguese acronym, PRA) to achieve environmental compliance. The new Forest Code thus provided substantial economic payoffs to producers who deforested illegally before 2008, while punishing those that refrained from clearing or invested in forest restoration to comply with the law. The amnesty provided by the new Forest Code increased the perceived risk of compliance by setting a precedent that future changes in the law might benefit farmers who deforest illegally.

Cost–Benefit Analysis of CAR Compliance. The empirical data presented here suggest four stages of compliance (Fig. 3): (*i*) outside CAR (BAU, business as usual), (*ii*) joining CAR (GOV1, governance 1), (*iii*) inside CAR and reducing deforestation (GOV2), and (*iv*) inside CAR and fully compliant with the Forest Code (GOV3). From the farmer's point of view, each stage carries potential costs and benefits that may or may not provide incentives to follow the rules. Our results suggest that there is a clear incentive for landowners to join CAR. This move from business as usual (BAU) to the first stage of governance (GOV1) has a relatively low transaction cost; a minimal increase in the risk of being fined; and substantial financial benefits, such as access to subsidized loans (Fig. 3).

The incentives are less clear when we consider the transition from joining CAR (GOV1) to stopping illegal deforestation (GOV2) and restoring illegally cleared areas (GOV3). Producers

who do not deforest earn less by not expanding agriculture, but may benefit from fewer fines and access to green markets (11, 23). Our finding that some CAR properties had lower deforestation than the control group suggests that the perceived financial risks outweighed the benefits of deforesting. On the other hand, the fact that many producers maintained or increased deforestation after joining CAR suggests that the incentives to avoid deforestation vary in space and time (Fig. 3 and Table 1). Finally, our results indicate that landowners in all size classes are unlikely to invest in forest restoration (GOV3) under current conditions. Because most of the benefits can be accrued by joining CAR, achieving full compliance would require additional government or market interventions to realign the incentives for Forest Code compliance.

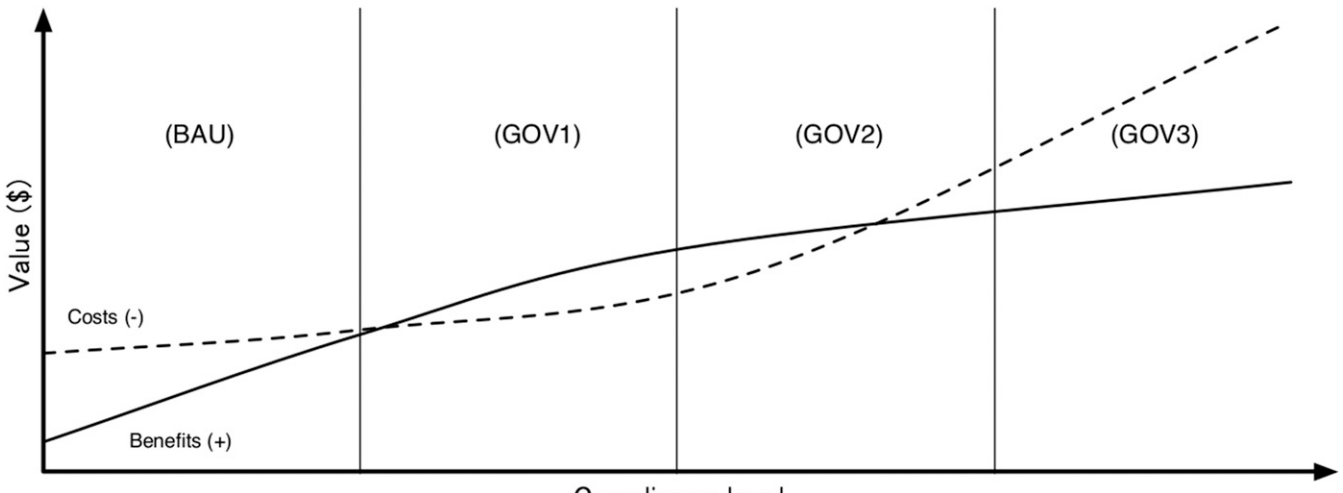
Conclusion and Policy Considerations

The CAR system will play an increasingly central role in the implementation of the Forest Code and climate policy in Brazil (19). This study shows that credit and market restrictions provide strong incentives for producers to join CAR. However, results suggest that its implementation has not contributed significantly to the observed reductions in deforestation from 2008 to 2012. Furthermore, the cost of restoring Legal Reserves and riparian areas remains prohibitively high relative to the benefits of joining CAR.

This study demonstrates that CAR membership does not yet provide the full suite of financial incentives (or command-and-control disincentives) needed to prevent deforestation and ensure full compliance with Forest Code restoration requirements. The existence of incentives like the soy and beef moratoria has helped to inhibit deforestation, but no comparable incentives exist to encourage restoration. Inconsistent monitoring and enforcement and the reluctance of state and municipal managers to punish landowners within CAR act as a safeguard for registered producers who continue deforesting. The resulting perception of impunity severely weakens environmental policies to control deforestation.

CAR's biggest potential stems from the fact that it drastically reduces the cost of monitoring and enforcement, but these savings have yet to materialize in Mato Grosso and Pará. To remedy this, public and private actors will need to shift the costs and benefits related to each of the four stages of compliance outlined above. At a minimum, the government must increase the likelihood of prosecution of illegal deforesters. To accomplish this, the Ministry of Environment could use SICAR to develop mechanisms to automatically detect illegal deforestation, identify the responsible parties, and levy fines. Restoration agreements signed by producers registered with CAR should also be monitored and evaluated using a combination of remote-sensing technologies and field sampling to increase compliance.

On the market side, public and private actors must increase the benefits of complying with the Forest Code beyond reducing the risk of fines. The 2012 Forest Code presents an opportunity to do this by creating new market mechanisms that allow landowners with forest surpluses to trade with farmers that need to compensate their forest debts (41, 42). This offset mechanism can be used to avoid legal deforestation and provide incentives to restore forests in highly degraded areas, particularly if integrated into the Brazilian REDD+ strategy and the Amazon Fund (43). New sustainable supply-chain initiatives (e.g., for beef and soy) should strive to adopt more stringent environmental compliance standards for purchase from industry retailers. Aside from requiring CAR, companies could build a network of suppliers who use Forest Code compliance as a criterion for purchasing products and providing financial incentives (18, 24). This would ultimately increase



		BAU	GOV1	GOV2	GOV3
Costs	Market access restrictions	Yes	No	No	No
	Transaction cost for joining CAR	None	Low	Low	Low
	Opportunity costs	None	None	None or Low	High
	Forest restoration costs	None	None	None	High
Benefits	Subsidized bank loans	No	Yes	Yes	Yes
	Protection from fines for deforestation	Low	Low	None or High	High
	Access to green markets	No	No	Yes	Yes
	Protection from fines for lack of compliance	Low	Low	Low	High

Fig. 3. Theoretical cost–benefit curve of CAR. In the BAU scenario, the costs are higher than the benefits of being outside CAR. The inverse is true in scenarios GOV1 and GOV2. The curves overlap again in GOV3, where the costs are higher than the benefits because of legal reserve restoration costs and possible reductions in productive area.

awareness and trust by buyers throughout the supply chains, reduce the risk of contamination with noncompliant products, and lower the reputational risk for large national and international buyers.

In theory, CAR can increase the government's ability to monitor environmental performance, prosecute illegal deforestation, and distribute the economic benefits of compliance. In practice, this potential has not yet been realized due to incomplete implementation of CAR and supporting public policies. Nevertheless, many commodity companies in the world have pledged zero deforestation (and illegality) within their supply chains by 2020. The experiences of CAR in Pará and Mato Grosso provide valuable lessons that could help federal and state governments make SICAR a more effective instrument for ending illegal deforestation and promoting forest restoration. The lessons learned from this study are relevant to the rest of Brazil and other tropical regions trying to balance food production and forest conservation.

Methods

We used a BACI (Before-After-Control-Impact) design to evaluate whether incentives to obey the law and reduce deforestation outweighed incentives to deforest within CAR. We compared areas that had not yet joined CAR (control) with those that had (treatment) to quantify the influence of the policy intervention (31). We used ordinary least squares regression models to evaluate the differences in deforestation rates between the "CAR" and "control" groups. The dependent variable was the logarithm of the deforestation rate plus one (to account for records with zero deforestation) (*SI Appendix, S1. Methods*).

We used different sets of covariates to test the importance of exogenous factors that might influence deforestation and confound our interpretation of CAR's performance, including (*i*) the logarithm of the remaining forest area, because the likelihood of deforestation decreases as forest becomes scarce; (*ii*) a dummy variable to indicate whether the property was enrolled in CAR; (*iii*) an index of deforestation risk (*SI Appendix*) (7); (*iv*) a variable indicating whether the property was in a blacklisted municipality (37); (*v*) the change in the number of fines in a municipality (an indicator of enforcement); and (*vi*) a dummy variable indicating whether the municipality participated in Pará's Green Municipality Program (GMP). We developed a series of models, containing combinations of these covariates, and compared their effectiveness in predicting deforestation at the property level (*SI Appendix, S1. Methods* and Tables S5–S14).

To estimate the incentives for full Forest Code compliance, we evaluated the legal status of CAR properties (*SI Appendix*, Fig. S2 and Tables S1 and S2) and estimated the economic costs of compliance using secondary data and published studies (19, 32–34). We used qualitative methods to estimate the incentives for the BAU and GOV institutional frameworks, administering questionnaires to 92 farmers and GIS professionals in 20 randomly selected municipalities in Mato Grosso and Pará. We conducted 33 semistructured interviews to comprehend the historical and political context of forest governance in the region. The authors were responsible for discussing and approving the methods for the interviews, as well as for obtaining consent for publishing interview results. Details on the conceptual approach to this analysis are provided in *SI Appendix*.

ACKNOWLEDGMENTS. We thank Paulo Moutinho, Vivian Ribeiro, and two anonymous reviewers for helpful comments on earlier drafts of this paper. We are also grateful to the interview participants for sharing their experiences and key insights that made this work possible. Funding for this work came from the Climate and Land use Alliance, Gordon and Betty Moore Foundation, Norwegian Agency for Development Cooperation (NORAD), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG). Various institutions generously shared data, including Secretaria Estadual de Meio Ambiente (SEMA) in Mato Grosso and Pará.

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