Pay for Performance and Deforestation: Evidence from Brazil

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Abstract

Environmental cash transfers can be seen in the light of a typical principal-agent problem in which the agent (beneficiary) provides a service (conservation) to the principal (government) and the principal pays the agent in return. These types of transfers are becoming popular in low-income economies but mechanisms are not well understood. We study Brazil's Bolsa Verde program, which pays extremely poor households for forest conservation evaluated at an aggregate level. Using difference-in-differences, we find between three to five percent reduction in deforestation among grant-receiving areas. These program effects are increasing in the number of beneficiaries, suggesting that both conservation and group monitoring are potential mechanisms for these results. The former is unobservable but we show that the areas with more beneficiaries have more fines resulting from illegal environmental crimes other than deforestation. We interpret this finding as evidence that the program reduces deforestation by enforcing peer monitoring, which leads to indirect positive effects on fines against other illegal environmental offenses. (***JEL*** I38, O13, Q23, Q28, Q56)

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1 Introduction

A fundamental question behind effective policy making involves knowing the kinds of incentives that drive the desired outcome. A popular policy tool is cash transfers, and there is substantial empirical evidence demonstrating the effectiveness of paying poor households in improving development outcomes, notably in health and education (see e.g. Duflo 2003, Baird et al. 2011, 2012; Haushofer and Shapiro 2016). Cash transfers conditional on environmental outcomes, typically in the form of Payments for Ecosystem Services (PES), are also promising but there is a lack of consensus about the mechanisms that determine the effectiveness of these programs (see e.g. Jayachandran (2013); Simonet et al. 2015).[1] When environmental cash transfers have development objectives as well, existing studies show that it is not straightforward to obtain both welfare and environmental gains (Alic-Garcia, Sims, and Yanez-Pagans 2015).[2]

In this paper, we evaluate Brazil's Bolsa Verde (BV) program, which constitutes a quarterly payment to extremely poor households. Translated as the "Green Grant, the BV is implemented in designated rural areas with an environmental conditionality at the aggregate level. Specifically, if the forest cover of an area violates the Forest Code, which require at least 80% of forests as legal reserves, then every beneficiary in the area exits the program, regardless of the form of land tenure or ownership. As such, any conservation or deforestation activity within the area has consequences on all BV participants. Since the main pressures to deforest in these areas originate from outside, we argue that the BV is a performance-pay mechanism for forest monitoring de facto.

Exploiting this unique set up, we aim to contribute to the emerging literature on environ-

[1] In her study of deforestation in Uganda, Jayachandran (2013) suggests that PES program offer a steady flow of payments in exchange for a flow of pro environmental behavior. As such, PES programs may face low take up when opportunity costs of participatns are more front loaded than the time profiles implied by a typical PES program.

[2] Household gains are high in places where deforestation risks are low, while the program achieves the highest levels of forest loss reductions in poor regions.

mental transfers with development objectives by understanding the mechanisms that drive progarm compliance. We first quantify the overall program impact on deforestation. Using panel data from 2009 to 2015, we compare deforestation rates of eligible areas with and without BV beneficiaries using a generalized difference-in-differences framework. We then explore heterogeneity in program impact by pre-program mean and variance in deforestation, as well as by poverty of the region. We also discuss and test two mechanisms for compliance.

We find that BV is associated with 4.72% reduction in deforestation, or 2.2 hectare (ha) in receiving areas. Moreover, we find that this negative effect of BV on deforestation differs by program intensity: the treatment effect increases in the number of BV recipients. The estimated effects translate into 0.7 ha reduction in forest loss per recipient in Sustainable Use Conservation Zones (SUCs) and 0.27 ha reduction in forest loss per recipient in Settlements. We show that the estimated treatment effect is driven largely by priority areas with high levels of deforestation ex-ante, implying that BV targets the appropriate actors of deforestation. This result is consistent with the energy conservation literature, which documents important heterogeneity in the treatment impact. In particular, Ferraro and Price (2013) show that the economically meaningful average treatment effects of Home Energy Reports documented in the US are driven by high usage users to a large extent. We also show that the BV program has a higher impact on reducing deforestation in poor areas than in rich areas, as the former are more likely to have beneficiaries for whom the cash transfer is a more sizable addition to the household budget.

Our study contributes to the literature studying social programs with environmental objectives by rigorously investigating the mechanisms that drive impact. We hypothesize that the program provides social incentives for forest conservation and we distinguish between two channels for compliance. First, the beneficiaries sign a contract (Figure A1) and commit to engaging in sustainable use of natural resources. As such, there might be incentives for recipients to increase both their own and collective efforts in conserving the forests, creating a new social norm. The social norm that encourages conservation at large may generate positive spillovers onto non-beneficiaries living in grant-areas and drive down deforestation rates. Since beneficiaries risk losing payments as a group if the forest cover in the priority area no longer complies with the Forest Code, the BV program could also drive beneficiaries to monitor illegal deforestation activities in their areas of residence. The higher threat of being reported to authorities or the actual fines associated with illegal deforestation may discourage and drive down deforestation in grant-receiving areas. We empirically test and discuss the implications of these channels on deforestation. Although conservation efforts are unobservable in this context, we show evidence that the peer monitoring channel exists and at least partly drive the main results.

Our work also contributes to the limited but emerging literature on environmental outcomes of large-scale avoided deforestation programs. Using retrospective data, few studies have evaluated the effects of Mexico's program, and they are either limited in space (Honey-Roses, Baylis, and Ramirez 2011) or in time (Alix-Garcia, Shapiro, and Sims 2012).[3] To date, the only research with avoided deforestation at the national level over time as an outcome has only been conducted for Costa Rica's program (see e.g. Arriagada et al. 2012; Robalino and Pfaff 2013) and Mexico's program (Alix-Garcia, Sims, and Yanez-Pagans 2015). In Brazil, the only paper that examines the effectiveness of a PES program on deforestation is one that evaluates a REDD+ pilot project implemented in the state of Para on 181 farmers (Simonet et al. 2015). Thus, to our knowledge, this paper is the first rigorous evaluation of a cash transfer program with an environmental conditionality at the group level.

The rest of the paper is organized as follows: Section 2 provides a brief history of deforestation in the Brazilian Amazon and describes the Bolsa Verde program; Section 3 presents the main data sources and summary statistics; Section 4 outlines the empirical strategy and discusses the estimation results; Section 5 discusses the possible mechanisms driving the results and Section 6 concludes.

[3] Honey-Roses, Baylis, and Ramirez (2011) evaluates Mexico's program in the Monarca reserve; Alix-Garcia, Shapiro, and Sims (2012) analyze the effectiveness of the program using only the 2004 cohort.

2 Background

2.1 Deforestation in Brazil: 1960s to 2000s

The Brazilian Amazon hosts 40% of the world's tropical forests. When the local economy relied on extraction of forest resources in 1960s, Brazil implemented policies that encouraged the occupation of the Amazon. In the 2000s, however, government policies have been focused on reducing deforestation. In fact, the deforestation rate in 2014 is approximately 75% lower than the average from 1996 to 2005 (Tollefson 2015). Our study area is the Legal Amazon region, where the trends in deforestation are consistent with the national scale. As Figure 1 shows, total deforestation rate in the Legal Amazon from 2002 peaks in 2003 and has since then fallen annually. While there is a lack of consensus among economists as to what drives this large drop in deforestation in the mid-2000s, one of the popular views attributes this reduction to regulation efforts and conservation policies of the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA).[4]

In addition to the level of deforestation inside priority areas, the upward trend in deforestation from 2012 also raises concern, which, in part, motivates rigorous evaluations of programs like BV. Unlike areas outside priority areas where much of the deforestation is likely driven by economic activities of large landowners, whose contribution to deforestation has fallen by 63% since 2005, much of the deforestation inside are due to farmers with smallholdings, whose contribution to deforestation has increased by 69% (Godar et al. 2014). Against the somewhat rosy backdrop of large reductions in deforestation on the national scale, policies that target the increasing deforestation activities of small-scale farmers and households, such as BV, may become more important in sustaining the overall reductions in deforestation in the years to come.

[4]See, e.g. Gibbs, et al. (2015) and Nepstad, et al. (2014) for their analysis on the roles of interventions in the supply chain of soy and beef in reducing deforestation; Pfaff et al. (2014) and Assunção et al. (2015) for their evaluation of conservation policies as a driver of reduced deforestation; and Burgess et al. (2016), who analyze the power of the Brazilian state in shaping deforestation over time.

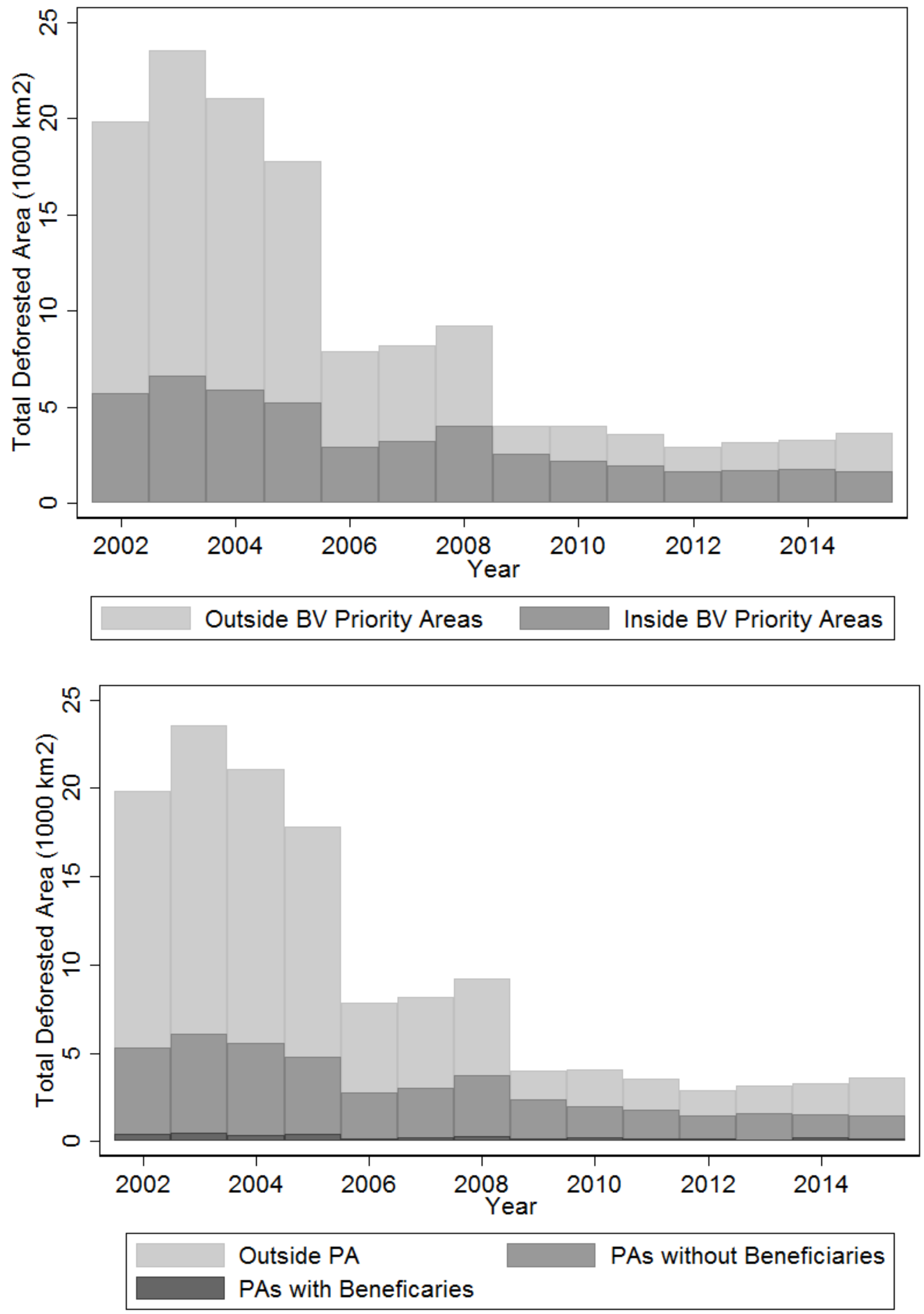

Figure 1. Annual Deforestation from 2002 to 2015 in the Legal Amazon

*N*otes: The top figure plots total deforestation (sqkm) per year inside and outside priority areas eligible for BV in the Legal Amazon. Areas eligible for BV are subcategories within SUC or Settlements (see Table 1). The bottom figure plots total deforestation (sqkm) outside BV-eligible priority areas, inside receiving areas and non-receiving priority areas.

2.2 Bolsa Verde: 2011 to Present

The BV program was first implemented in 2011, exclusively in priority areas within the Legal Amazon, covering an area that is approximately 61% of Brazil. The program has been expanded to priority areas in the rest of Brazil in 2012, with 64% of the program areas in the north, 26% in the northeast; 6% in the southeast; and 4% in the central-west (Bindo 2012). Priority areas eligible for the program are Sustainable Use Conservation Zones (SUCs) or Environmentally Distinctive Agrarian Reform Settlements.[5] With respect to Figure 1, BV is relevant for the period 2011 to 2015, and for areas designated as priority areas, where the program is exclusively implemented. While the level of deforestation inside priority areas has always been low relative to the national average, deforestation activities that remain from 2011 are nonetheless non-trivial. In fact, the remaining annual forest loss inside priority areas from 2011 to 2015 averages approximately 850 km^2, which is the size of New York City.

The motivation for launching BV is the recognition that 7.5 million people who live in extreme poverty, or almost half of the country's extremely poor, live in rural areas (Bindo 2012).[6] A household is eligible for the program if it (i) lives in extreme poverty - defined as having per capita monthly income of under 77 Brazilian Real (approximately 30USD); and (ii) resides in an eligible priority rural area, which has vegetation level that is in accordance with the Forest Code: at least 80% of the land is forested. Figure 2, left panel, shows the spatial distribution of BV-eligible zones by category in the Legal Amazon, our study area. The right panel demonstrates the population of these areas in 2010 based on the 2010 Census. On average, Settlements are more populated than conservation zones.

In terms of entry into the program, the administrative process through which an eligible household becomes a beneficiary has minimal selection. A list of households who are eligible

[5]SUC are protected areas created after the 1988 Federal Constitution. Settlements are areas of independent agricultural units that belong to smallholder farmers relocated to the Amazonia under the government-induced migration since the 1970s.

[6]The federal government defines the extreme poverty line to be 77 reais (approximately 30USD) of per capita income per month.

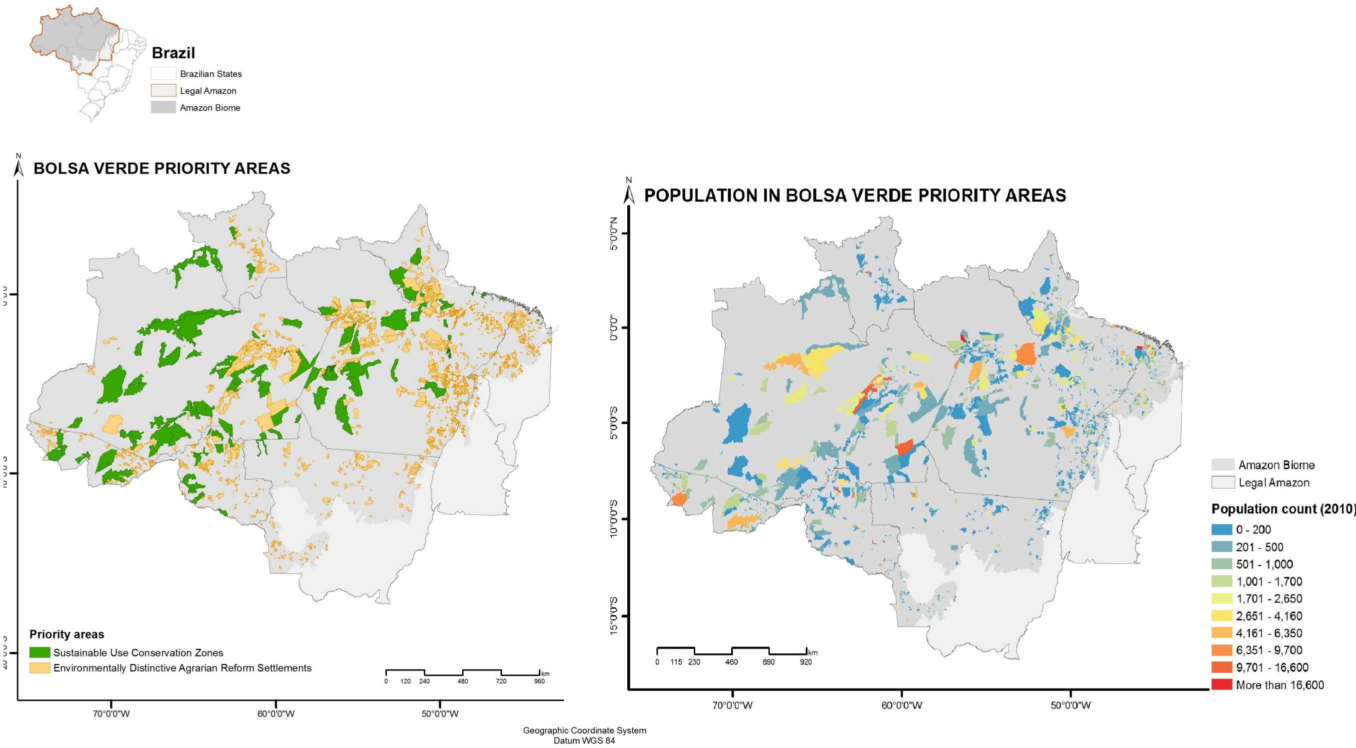

Figure 2. Bolsa Verde Priority Areas by Category and Population

for BV is sent to the Ministry of the Environment (MMA) for evaluation and fact checks. The majority of eligible households become beneficiaries because there are no selection criteria beyond the conditions that determine eligibility. Moreover, the reasons for eligible households to be denied the grant, such as deaths of the responsible family member, missing signature, and incomplete forms, are likely uncorrelated with income level of the household or underlying propensities to deforest. Since there is no selection in the assignment of beneficiary status based on observed or unobserved household characteristics, we rule out concerns about endogeneity in the number of beneficiaries in each priority area.

For our research design and estimation procedures, two elements of the BV program are crucial. First, BV is a cash transfer program with an environmental conditionality, as opposed to a PES program, in which payment is conditional on the flow of environmental services but unconditional on recipient income. PES households who become more well-off over time continue to receive payments for the ecosystem services they provide. A beneficiary household under BV, however, exits the program when the per capita household income no longer falls below the extreme poverty threshold. Therefore, the BV is a social program as much as it is an environmental program in that its objective is to have fewer beneficiaries in subsequent years as their livelihoods gradually improve to the point where their income rises above the extreme poverty line.

Second, the only observable cost for an eligible household to become a beneficiary is the commitment to engaging in conservation and using natural resources in sustainable ways in the resident area. This commitment is made in the form of a contract, or the "Terms of Adhesion," which sets out details of the program, as well as the responsibilities of the families in terms of maintaining the zone's vegetation level and using natural resources in sustainable manners (Figure A1 in the Appendix). Upon signing this contract, BV beneficiaries receive quarterly payments in the sum of 300 BRL (or USD154 in 2012 U.S. Dollars) for a period of up to two years, with the possibility of renewal.[7] For a two-person household with average per-head income of 77 BRL, the BV grant is approximately 60% of household income.

3 Overview of Analysis and Data

To quantify the total program impact on deforestation, identification relies on variation in forest loss over time and across priority areas, as well as variation in BV participation across space and over time, conditional on being an eligible priority area. We begin the analysis with comparing the full sample of priority areas with BV beneficiaries against those without, regardless of the type of priority area, using difference-in-differences. To address concerns that priority areas under different administrative categories may have systematically different drivers for deforestation, we run the estimations on two sub-samples: eligible areas that are

[7]Based on discussions with MMA officials, we find that renewal is a function of the availability of BV funds as well as meeting the income and vegetation requirements of BV. In other words, the continuous enrollment in BV after the initial two-year term has no implications on the zone nor the household beyond those from being eligible in BV the first time around.

(1) SUC and those that are (2) Agrarian Reform Settlements.

3.1 Spatial Data on Deforestation

We use data on annual loss of primary forests and remaining forest cover in the Legal Amazon from the PRODES project at INPE, the Brazilian National Institute of Space Research.[8] The Legal Amazon is an area of 5,032 million km^2 that covers the northern and western parts of Brazil. Approximately 81% of the area is forested, 17% is cerrado (wooded grassland), and 1.8% is water (Skole and Tucker 1993). Using images from the Landsat LT-5, LT-7, and LT-8 satellites, PRODES calculates annual deforestation using the seasonal year, which starts from August in year t to July in year $t+1$.[9] We use data on deforestation in the period 2009 to 2015, which constitute three years before BV and the first four years of the program. The satellite data used in PRODES have spatial resolutions of approximately 30 meters. We resample both the deforestation and remaining forest information from PRODES into 1 km^2 grid cells. Using their centroids, we assign to each grid cell geo-specific information, such as distances to the nearest city and paved road.

Figure 3 shows the levels of annual deforestation in BV-eligible areas from 2009 to 2015. We see that the colored areas are mostly green, that is the overall annual deforestation rate is consistently below 2.78 km^2 from 2009 to 2015. However, since the start of the BV program from 2012, we observe priority areas with increasing deforestation as they turn from green or light yellow to orange or red. This change of color represents a change in deforestation from approximately 4.84 km^2 per year to over 73.86 km^2, a 15-fold increase. We also observe areas with decreasing deforestation, as shown by a change of color from yellow or orange to green.

[8] The PRODES project (http://www.obt.inpe.br/prodes/index.php) generates spatial data on deforestation in the Amazon that are used as the official governmental information to guide policy and local actions.

[9] Satellite images are selected as near to this date as possible for the calculation, generally from July, August, and September. PRODES only identifies forest clearings of 6.25 hectares or larger. Therefore, forest degradation or smaller clearings from fire or selective logging are not detected. For robustness, we will validate the analysis using Hansen et al. (2013)'s forest cover data.

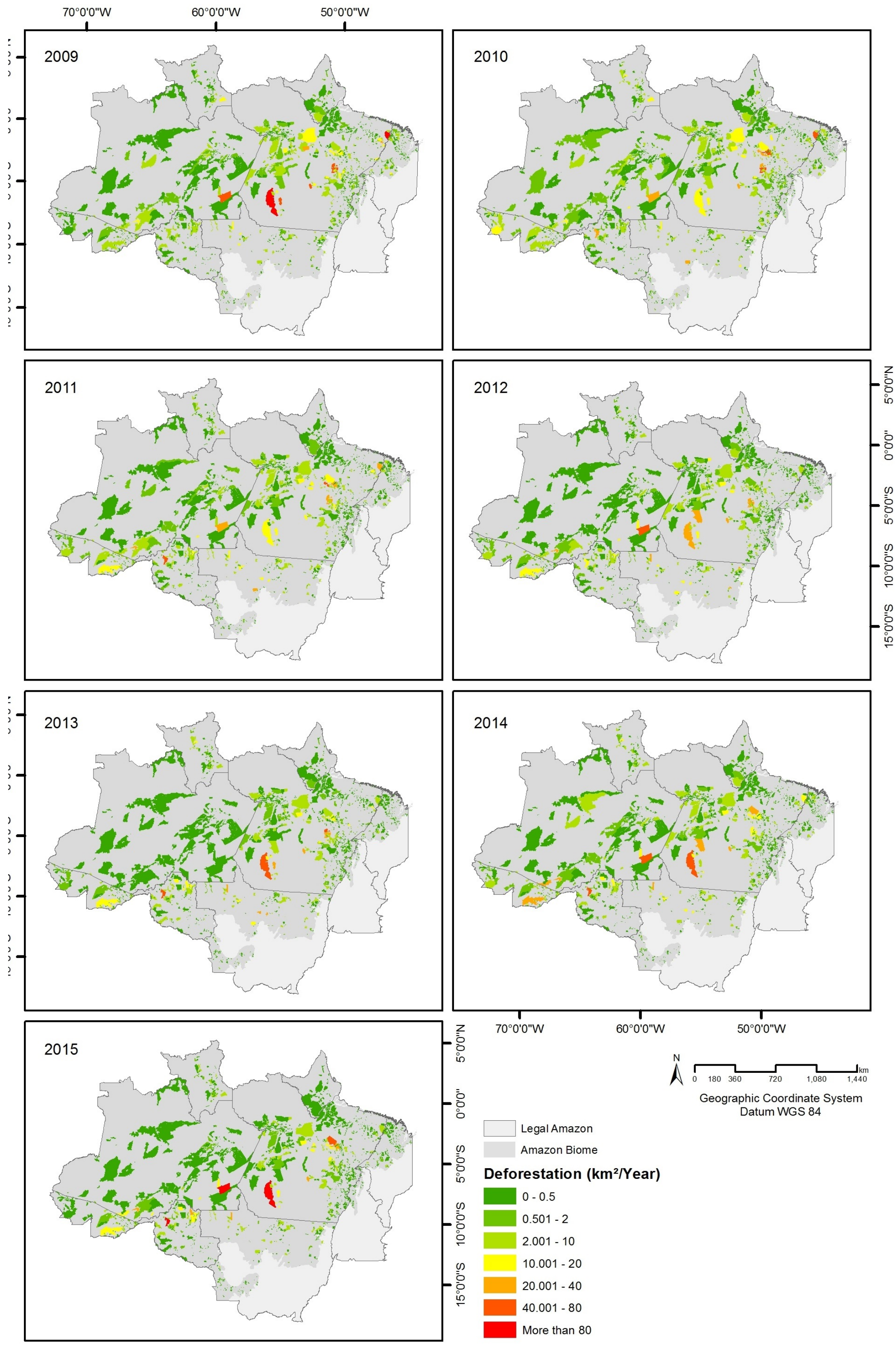

Figure 3. Annual Deforestation Rates in Areas Eligible for Bolsa Verde (2009 to 2015)

3.2 Administrative Data on Bolsa Verde Beneficiaries

To measure the presence and intensity of BV, we use information on beneficiaries from an exhaustive list of eligible households in all BV-eligible areas that we obtain from the MMA. The list includes all households who are eligible for BV from 2012 to 2015, containing information on the names of the representative household member, the priority area of residence, and the date of first BV cash receipt or the reason for rejection.[10] To evaluate the success of BV with respect to its environmental objective, we aggregate these data on eligible households up to the priority area level to match with the deforestation data.

Our analysis considers all eligible SUC and Settlements in the Legal Amazon region with non-zero remaining forests at baseline. Table 1 presents the summary statistics of priority areas eligible for BV by receiving status. By August 2015, 266 areas (17% of the total) have received BV payments. Participation in the program was rolled out gradually over time, with 166 areas (62% of the sample) began receiving the grant by August 2012. Subsequently, 42 additional areas (16% of the sample) entered the program by August 2013, 53 new areas (20% of the sample) started receiving payments by August 2014, and 5 more areas (2% of the sample) entered the program by August 2015. In the regression analysis, we exclude PAs due to low levels of program participation (only 1.9% of all PAs receive BV).

[10]The list includes households who start receiving BV from November, 2011, when the program first launched. Since we combine the BV data with deforestation data, we assign deforestation years to each BV recipient. Since deforestation is calculated using the seasonal year starting in August, households who first received BV payments between September 2011 and August 2012 are matched with deforestation rates in the year 2011.

Table 1. Summary Statistics: Receiving and Non-Receiving Priority Areas

Administrative categories		Mean # of BV beneficiaries	Number of areas		Mean % of remaining forests in 2009		Mean Area (sqkm)	
		Receiving	Receiving	Non - receiving	Receiving	Non - receiving	Receiving	Non - receiving
	FLONA	96.462	13	17	0.979	0.989	4,482.077	4,238.882
		(162.455)	[0.433]	[0.567]	(0.0311)	(0.0097)	(3,123.049)	(3,750.935)
SUC	RESEX	218.69	29	11	0.936	0.886	3,048.759	1,672.8
		(367.860)	[0.725]	0.275	(0.0587)	(0.239)	(2,559.428)	(939.800)
	RDS	202	1	16	0.977	0.949	576	5,845.188
		-	[0.059]	0.9412	-	(0.065)	-	(7,235.365)
	PA	42.269	26	1351	0.417	0.301	548.769	73.770
		(63.086)	[0.019]	0.9811	(0.377)	(0.281)	(1,377.257)	(145.047)
	PAE	119.689	186	59	0.894	0.861	291.762	378.597
		(208.374)	[0.759]	0.2408	(0.111)	(0.187)	(1,029.157)	(1,058.21)
Settlements	PAF	31.333	3	4	0.954	0.975	431.667	337
		(13.650)	[0.429]	0.5714	(0.030)	(0.028)	(538.602)	(100.787)
	PDS	76.625	8	81	0.855	0.784	319.875	265.469
		(59.678)	[0.090]	0.9101	(0.144)	(0.237)	(382.485)	(593.176)

Note: The table presents summary statistics of all BV-eligible priority areas inside the PRODES mapping area in the Legal Amazon region. We exclude areas with zero remaining forests at baseline (2009). Only the following categories within SUC and Settlements are eligible for BV: Extractive Federal Reserves (RESEX), Sustainable Development Federal Reserves (RDS), National Forest Settlement Projects (PA), Agro Extractivist Settlement Project (PAE), Forest Settlement Project (PAF), and Sustainable Development Project (PDS). Percentage of areas by receiving status are in brackets.

4 Estimation and Results

4.1 Program Participation and Deforestation

To capture the roll out of the BV across space and time, we use the following generalized difference-in-differences framework to quantify the total program impact on deforestation:

$$Deforestation_{zt} = \alpha_0 + \beta BoslaVerde_{zt} + \alpha_1 RF_{zt-1} + \alpha_2 X_{zt} + \nu_z + \mu_t + \epsilon_{zt} \tag{1}$$

where $Deforestation_{zt}$ is the rate of deforestation in priority area z, expressed as the percentage of remaining primary forests in period $t-1$ that has been deforested in period t. We calculate the sum of forest loss across all the 1 km^2 grid cells whose centroids lie within a priority area.[11] $BolsaVerde$ is a dummy variable that equals one if the area z has residing households receiving BV payments in year t. Our coefficient of interest is β, which is the difference-in-differences estimate of the average treatment effect of BV on deforestation in the treated priority areas. Our specification includes RF, which denotes the stock of remaining forests in an area in the previous year, as well as a vector of factors at the priority area and year levels that could impact deforestation, X_{zt}, including the proportion of clouds; as well as the interaction of lagged remaining forest with distances to the nearest paved road and city. ν_z are priority area fixed effects that control for differences in time-invariant unobservables across areas, and μ_t are year fixed effects to control for any year-specific unobservables affecting deforestation in all priority areas. We cluster standard errors at the priority area level to control for arbitrary spatial and serial correlation. Table 2 reports the estimated treatment effects.

Column 1 shows that in our preferred specification, the BV areas have 0.139 percentage point lower deforestation than non-receiving areas. This treatment effect translates into

[11] Results using the sum of forest loss are consistent with those that use the mean of deforestation across all grid cells in a priority area.

Table 2. Impact of BV Participation on Deforestation

Dependent variable	Deforetation rate (%)			Log of deforestation rate		
	(1)	(2)	(3)	(4)	(5)	(6)
Sample	All	SUC	Settlements	All	SUC	Settlements
Baseline specification	-0.159**	-0.103*	-0.175**	-0.0564**	-0.0536*	-0.0573**
	(0.0642)	(0.0595)	(0.0795)	(0.0229)	(0.0278)	(0.0281)
Preferred specification	-0.139**	-0.0542*	-0.172**	-0.0472**	-0.0348*	-0.0537**
	(0.0626)	(0.0307)	(0.0747)	(0.0223)	(0.0177)	(0.0271)
Pre-BV deforestation in receving areas (sqkm)	0.158	0.489	0.088	0.158	0.489	0.088
Observations	2,961	602	2,359	2,961	602	2,359
R^2	0.007 [0.022]	0.012 [0.162]	0.008 [0.034]	0.009 [0.024]	0.019 [0.243]	0.010 [0.031]

Note: Dependent variable is deforestation rate, defined as the total area deforested as a percentage of last year's remaining forests. Treatment is a dummy variable that equals one if an area has BV-receiving households and zero otherwise. All specifications include priority area fixed effects and year fixed effects. Baseline model is a fixed effects specification without controls. Covariate controls include clouds, lagged remaining forests, and interaction terms between lagged remaining forests and distances to the nearest paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis. R^2 of baseline specification in brackets. *** p<0.01, ** p<0.05, * p<0.10.

2.2 hectare (ha), or 4.72% reduction in the deforestation rate.[12]. Given the differences in management structures of conservation zones and settlements, we explore the effects of the BV separately for each type of priority area.[13] Columns 2 and 3 show that we find larger effects in SUCs, where the receiving areas have 0.054 percentage point lower deforestation (or 2.64 ha less forest loss per year) than non-receiving areas. In Settlements, receiving areas have 0.172 percentage point lower deforestation or 1.51 ha less forest loss. Since Settlements have lower stocks of remaining forests compared to conservation zones, on average, the reduction in forest loss in absolute terms is smaller than that in SUCs but the estimated reduction in the deforestation rate is 5.37%, about 1.5 times higher than the estimated 3.48% reduction in SUCs. These results are significant at the 5% to 10% levels. These findings confirm our prior that program effectiveness depends on local institutions and organization structures. For robustness, we test whether distance from IBAMA offices as a proxy for strength of enforcement is a meaningful dimension of heterogeneity. Table A2 shows that our main

[12]Before the BV program, average deforestation in treated areas is 0.158 km^2, or 15.8 ha. Therefore, a 0.139 percentage point decrease in the deforestation rate translates into 0.139 x 15.8 or 2.2 ha

[13]Settlements house the rural poor, who are relocated to these areas by the government without much technical support and guidance on sustainable agricultural and forest management practices (Schneider and Peres 2015).

results are robust to controlling for these distances.

Identification in the difference-in-differences analysis so far draws from the variation in deforestation rates over time within receiving-areas versus within non-receiving areas. Thus, the validity of the estimates relies on the assumption that these two types of areas do not have systematically different trends in deforestation in absence of BV, controlling for remaining forest, year and priority area fixed characteristics. Table 3 shows results of the tests for the presence of differential pre-trends by interacting future BV status with the linear time trend using data from 2009 to 2011. Across the full sample as well as the SUC and Settlement sub-samples, we do not find statistically significant differences in the deforestation trends between areas that eventually will receive BV and those that will not.

Table 3. Parallel Trend Test

	All	SUC	Settlements
Future benefiary status x Year	-0.187	-0.00975	-0.233
	(0.114)	(0.00720)	(0.174)
Lagged remaining forest	-0.0740	0.0411**	0.0957
	(0.0538)	(0.0165)	(0.171)
Priority Area FE	Yes	Yes	Yes
Municipality x Year FE	Yes	Yes	Yes
Observations	1,269	258	1,011
R^2	0.423	0.999	0.437

Note: Dependent variable is deforestation rate, defined as the total area deforested as a percentage of last year's remaining forests. All specifications control for cloud cover (sqkm). Regressions use data from 2009 to 2011, prior to the start of BV in 2012. Robust standard errors clustered at priority area level in parenthesis. *** p<0.01, ** p<0.05, * p<0.10

An alternative approach to ruling out the presence of pre-trends is the Granger Causality test, implemented by repeating the main specification in Table 2 with leads and lags of the treatment. A joint significance test for the leads to be zero and insignificant would confirm that there are no substantial differential pre-trends. Table A1 in the Appendix shows that across all specifications, we do not find systematically different pre-trends in deforestation between grant-receiving and non-receiving areas. The estimated effects at each point in time leading up to and after the first year of program implementation is depicted in Figure 4. We find suggestive evidence that the reduction in deforestation rates are persistent and remain at similar magnitude beyond the third year since program implementation.

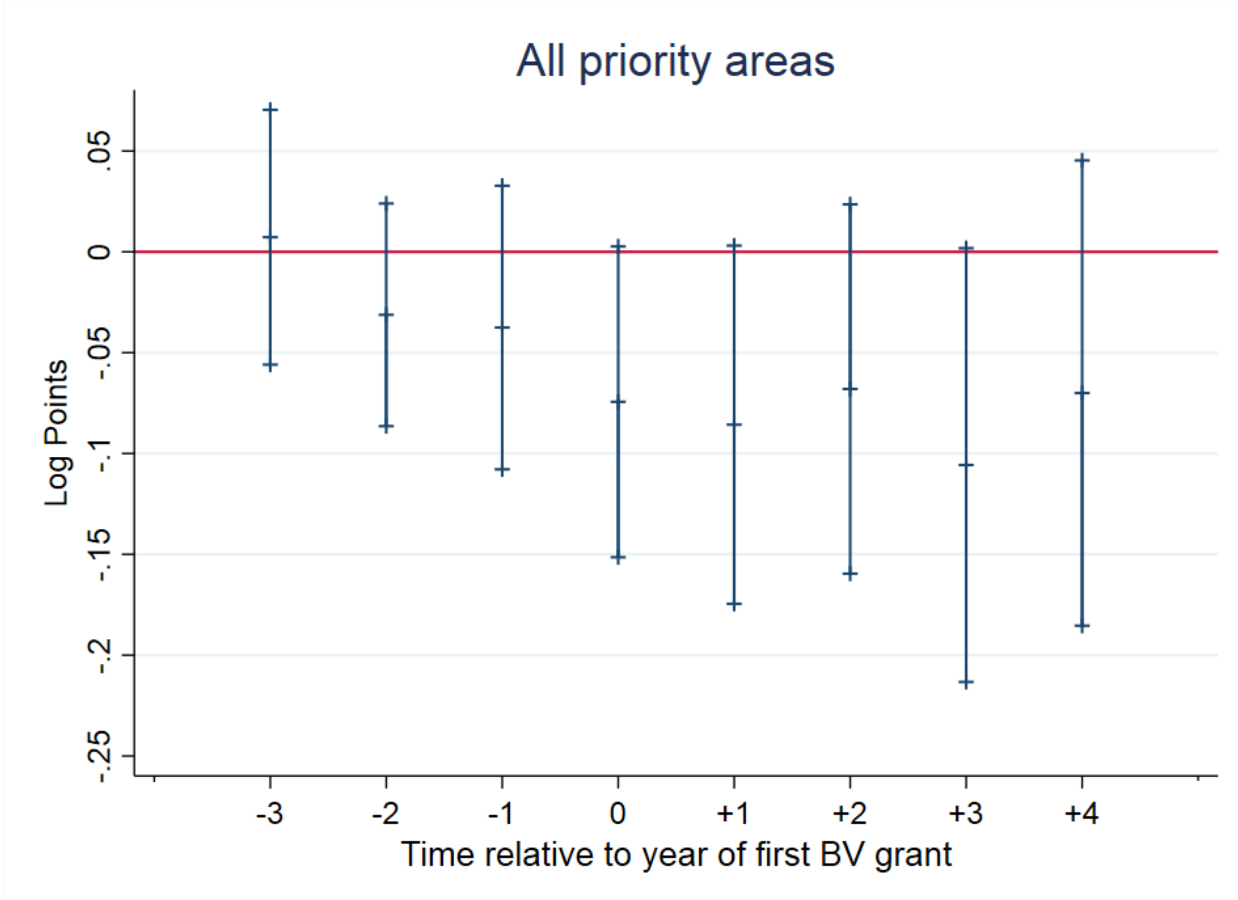

Figure 4. Estimated impact of the BV for years before, during, and after the first payment.

One potential source of bias for our evaluation of the BV so far is the fact that all BV recipients are by definition also part of the Bolsa Familia (BF), a general cash transfer program in Brazil. To estimate the impact of the BV on deforestation without confounding with the effects of the BF, we exploit the variation in the number of households who only receive the BF but not the BF in a given priority area. This variation is credibly exogenous because eligibility for the BF depends not only on income but also the number and ages of children residing in each eligible household. By assuming that households do not self select into the BF by changing their fertility decisions, we exploit the transfers structure in BF in conjunction with the discontinuity of BV's eligibility rule to distinguish between households who only receive BF and those who receive BF and BV, conditional on residence in BV-eligible zones. We test whether the effect of the BV on deforestation differs between areas with more or fewer BF households. We find suggestive evidence that the BV has an independent effect on reducing deforestation from BF.

4.2 Spillover Effects

Although participation in the BV program reduces deforestation in treated areas, the possibility that deforestation at a more disaggregated level is being pushed just outside the borders remain. If this was true, then our treatment effect overstates the program impact. To check for the presence of negative spillover effects, we use grid cell-level data from 2009 to 2015 to explore the causal effects of program participation on deforestation using a sharp regression discontinuity design (RDD).

The outcome is annual total area deforestated at the grid cell level. For each grid cell, we calculate the distance to the nearest border of a receiving BV priority area. We only compare cells inside a receiving BV priority area with outside cells that lie inside a non-receiving but eligible priority area.[14] We also limit the analysis to 10 kilometers outside and inside the relevant borders. We define a cell to be treated if it lies inside a priority area that eventually receives BV. The running variable is the distance of the cell's centroid to the border of BV-receiving priority areas. The cutoff value is zero.

Figure 5 plots the the local averages of deforestation across cells inside and outside all BV-receiving SUCs. Before the sustainable use conservation zones receive the BV, we observe an almost-continuous level of deforestation at the border. Therefore, we interpret the sharp increase in deforestation levels outside the border and low levels of deforestation inside the border after the realization of the BV payments to be suggestive evidence that the program

[14] If a cell is just outside a BV receiving priority area but lies in a urban area, for example, which is ineligible for BV, then this cell is excluded from the regression discontinuity analysis.

has led to spillovers in deforestation outside the receiving areas. This finding is consistent with the difference-in-differences estimates reported in Table 2. Among Settlements, however, we do not observe continuity in average deforestation across the border prior to the program (Figure A2). Therefore, we cannot use RDD to attribute any observed reduction in deforestation inside Settlements after they have started receiving BV payments to be causal effects of the program. In fact, the ex-ante discontinuity in deforestation inside and outside the borders suggest the presence of positive selection - areas with low initial levels of deforestation are more likely to eventually receive the BV, leading to an overstatement of the estimated program impact.

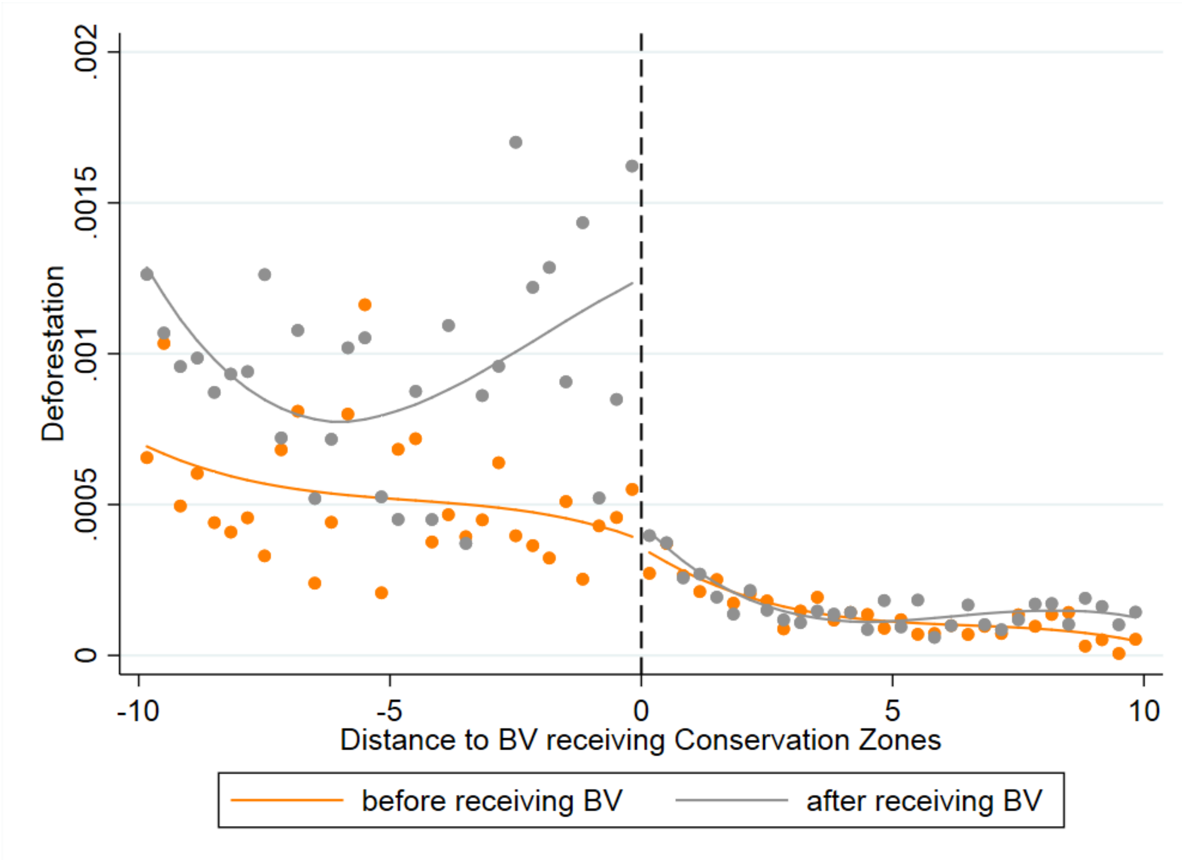

Figure 5. Deforestation Inside and Outside BV-Receiving Sustainable Use Conservation Zones

Notes: The figure plots local averages of deforestation in a given grid cell using data from 2009 to 2015. The x-axis shows the distance (in km) of grid cells to the borders of sustainable use conservation zones that eventually receive BV. The orange line is a third degree polynomial fit for averages over periods before the conservation zones receive the BV grant; the grey line is the equivalent over periods after the conservation zones have started receiving BV payments. The necessary assumption for RD to be valid is that the running variable (in this case, distance) is continuous around the threshold in the pre-BV periods.

4.3 Program Beneficiaries and Deforestation

Next, we explore whether the treatment effect varies by the number of beneficiaries. Our prior is that the effect of the BV on deforestation is larger in areas with more households receiving the grant. This conjecture is based on the design of the BV contract, which penalizes all beneficiaries by stopping their payments if remaining forests in their resident priority areas no longer comply with the Forest Code. This program design differs from typical PES schemes, such as Mexico's Payments for Hydrological Services Program (PSAH), where landowners commit to conserving only the pieces of land they own.[15] Under the BV program, beneficiaries are not necessarily landowners, but participation in the program for each beneficiary is vulnerable to any deforestation in the priority area of residence, regardless of whether the source of deforestation comes from beneficiaries themselves, non-receiving residents, or from outside the area. We therefore hypothesize that the program may reduce deforestation by encouracing beneficiaries to collectively conserve and/or to monitor the area for deforestation activities. We assume that the more beneficiaries there are in a priority area, the larger is the conservation and/or monitoring effort, which may translate into reductions in deforestation.

To test the hypothesis, we repeat the estimation of Equation 1 by using the log of the number of BV beneficiaries in a given priority area at time t as the treatment variable. Table 4 reports the estimated treatment effects. A 10% increase in the number of beneficiaries in SUC is associated with 12.2% reduction in the deforestation rate or 0.26 percentage points. This translates into 0.7 ha reduction in forest loss per recipient (statistically significant at the 1% level).[16] The effects are much smaller in magnitude among Settlements, where a 10% increase in the number of BV recipients is associated with 0.36 percentage point reduction in deforestation, or 0.27 ha of forest loss per recipient (statistically significant at the 5% level).[17] These results confirm our conjecture that among BV-receiving priority areas, those with more beneficiaries experience larger impacts of program participation on deforestation.

4.4 Heterogeneity by Baseline Deforestation

To shed light on whether the BV program has identical impacts on deforestation among priority areas with high and low pre-program deforestation, we construct sub-samples of receiving

[15]In Mexico's PSAH, landowners enroll parcels of land they own and agree to conserve the forest cover on the enrolled parcels. See Alix-Garcia et al. (2015) for details of the program.

[16]The average number of beneficiaries in SUCs is 181.35. The estimated impact of adding 10% more or 18.135 beneficiaries is a 12.7 ha reduction in forest loss, or12.7/18.135 = 0.7 ha of forest.

[17]In Settlements, the average number of beneficiaries is 117.026, thus the estimated impact of adding 10% more or 11.703 beneficiaries is a 3.17 ha reduction in forest loss. This reduction translates into 3.17/11.703 = 0.27 ha of forest loss per recipient.

Table 4. Impact of BV Beneficiaries on Deforestation

Dependent variable	Deforetation rate (%)			Log of deforestation rate		
	(1)	(2)	(3)	(4)	(5)	(6)
Sample	All	SUC	Settlements	All	SUC	Settlements
Baseline specification	-0.0350***	-0.0286*	-0.0373**	-0.0135***	-0.0132**	-0.0137**
	(0.0125)	(0.0155)	(0.0156)	(0.00458)	(0.00602)	(0.00565)
Preferred specification	-0.0306**	-0.0257**	-0.0360**	-0.0117***	-0.0122**	-0.0129**
	(0.0121)	(0.0119)	(0.0146)	(0.00440)	(0.00475)	(0.00540)
Pre-BV deforestation in receving areas (sqkm)	0.158	0.489	0.088	0.158	0.489	0.088
Observations	2,961	602	2,359	2,961	602	2,359
R^2	0.007 [0.022]	0.016 [0.168]	0.008 [0.034]	0.010 [0.025]	0.025 [0.252]	0.011 [0.032]

Note: The dependent variable is deforestation rate, defined as the total area deforested as a percentage of last year's remaining forest. The treatment is the inverse hyperbolic sine transformation of the total number of BV recipients in a given area. All specifications include priority area and year fixed effects. Baseline model is a fixed effects specification without controls. Covariate controls include clouds, lagged remaining forests and interaction terms between lagged remaining forests and distances to the nearest paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis. R^2 of baseline specification in brackets.
*** p<0.01, ** p<0.05, * p<0.10.

and non-receiving priority areas based on pre-program deforestation levels. We assign households to either the high or low deforestation group based on two measures. The first measure is the average level of deforestation in the pre-program period, and the second measure is the variance of deforestation over the same period. The high deforestation group consists of households with above-median average deforestation (or variance of deforestation), and the low deforestation group consists of households with below-median averages (or variance). Table 5 reports the estimated treatment effect of program participation on deforestation by the pre-program average deforestation. We find that the established treatment effects of the BV in reducing deforestation in all type of priority areas are driven by those with high pre-program average deforestation. Compared to the full sample estimated effect of a 0.138 percentage point reduction in deforestation, the areas with high ex-ante average levels of deforestation have 1.53 percentage points less forest loss.

We obtain similar results when we construct sub-samples by the variance of pre-program deforestation. Columns 1 and 2 of Table 6 show that the treatment effects of BV are driven by those with above-median variance of deforestation ex-ante. Together, the heterogeneous impact of program participation by pre-program behavior implies that the total program

Table 5. Heterogeneous Impacts by Pre-Program Average Deforestation

	All		SUC		Settlements	
Average Pre-BV Deforestation	High	Low	High	Low	High	Low
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment effect (Bolsa Verde participation)	-1.527***	-0.00237	-2.354*	-0.0205	-1.258*	0.000952
	(0.551)	(0.00552)	(1.282)	(0.0224)	(0.666)	(0.00486)
Treatment effect of full sample	-0.139**		-0.0542*		-0.172**	
	(0.0626)		(0.0307)		(0.0747)	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,475	1,460	448	147	1,027	1,313
R^2	0.041	0.007	0.04	0.066	0.058	0.005

Note: The dependent variable is deforestation rate, defined as the total area deforested as a percentage of last year's remaining forest. All specifications include priority area fixed effects and year fixed effects. Covariate controls cloud cover (sqkm), lagged remaining forests, and interaction terms between lagged remainnig forests and nearest distances to paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis. We adapt the approach described in List et al. (2017) to assign priority areas to the binary category "High" if their average pre-BV (2009-2011) deforestation is above the median and "Low" if it is below. *** p<0.01, ** p<0.05, * p<0.10.

impact on reduction in deforestation comes from priority areas with initially high means and variance in deforestation. This heterogeneity result by pre-program behavior is consistent with the finding in the energy conservation literature showing that the economically meaningful average treatment effects of Home Energy Reports documented in the US are driven by high usage users to a large extent (Ferraro and Price 2013). Our results highlight the importance of the BV in protecting areas with high risks of deforestation.

5 Mechanisms

5.1 Social Incentives

We also explore two plausible social channels through which the BV incentivizes compliance and reduces deforestation. First, the beneficiaries sign onto the two-year contract to commit to using natural resources in sustainable ways. Consequently, a social norm with high levels of conservation may be established in the area, and this new social norm may reduce de-

Table 6. Heterogeneous Impacts by the Variance of Pre-Program Deforestation

	All		SUC		Settlements	
Variance of Pre-BV Deforestation	High	Low	High	Low	High	Low
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment effect (Bolsa Verde participation	-1.525***	-0.00722	-2.345*	-0.0211	-1.269*	-0.00426
	(0.557)	(0.00499)	(1.275)	(0.0228)	(0.692)	(0.00386)
Treatment effect of full sample	-0.139**		-0.0542*		-0.172**	
	(0.0626)		(0.0307)		(0.0747)	
Controls						
Observations	1,468	1,467	448	147	1,020	1,320
R^2	0.041	0.007	0.040	0.067	0.058	0.005

Note: The dependent variable is deforestation rate, defined as the total area deforested as a percentage of last year's remaining forest. All specifications include priority area fixed effects and year fixed effects. Covariate controls cloud cover (sqkm), lagged remaining forests, and interaction terms between lagged remainnig forests and nearest distances to paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis. We adapt the approach described in List et al. (2017) to assign priority areas to the binary category "High" if the variance of pre-BV (2009-2011) deforestation is above the median and "Low" if it is below. *** p<0.01, ** p<0.05, * p<0.10.

forestation (encourage conservation) among non-recipients as well. This argument resembles the empirical evidence on the effectiveness of social norms, typically represented by Home Energy Reports in the US, on subsequent energy use relative to a control group (see. e.g. Allcott 2011, Ayres et al. 2013, Allcott and Kessler 2015). Second, the BV design is such that all recipients will lose their payments if the forest cover in the priority area no longer complies with the Forest Code. As such, the BV recipients may monitor illegal deforestation in the area and possibly report illegal activities to the authorities (IBAMA or ICMBio). Higher levels of peer monitoring and the threat of being reported are expected to reduce deforestation.

Our ability to directly validate these two channels is limited by the lack of data: we do not observe the level of conservation activities in priority areas in our study period. Neither do we observe monitoring effort by recipients. Using a time-series dataset on infractions, which are federal fines issued against illegal environmental activities across the Legal Amazon region, we present suggestive evidence for peer monitoring. A subset of these infractions are due to illegal deforestation, while the remaining infractions are related to all types of illegal environmental activities, such as pollution, infringements of conservation rules, infringements against the administration of conservation zones, illegal acts against wildlife, including hunting and illegal fishing, as well as trafficking of exotic animals.[18] Figure 5 shows the spatial distribution of deforestation-related infractions and DETER alarms in 2015. DETER or the Real Time System for Detection of Deforestation, is a monitoring system developed by the Brazilian government to identify deforestation hot spots in near real time using satellite images. While there is much spatial overlap between DETER alarms and infractions, we observe infractions that are far away from alarms, suggesting that enforcement officials possibly detect illegal deforestation activities from other sources, such as reports from locals.

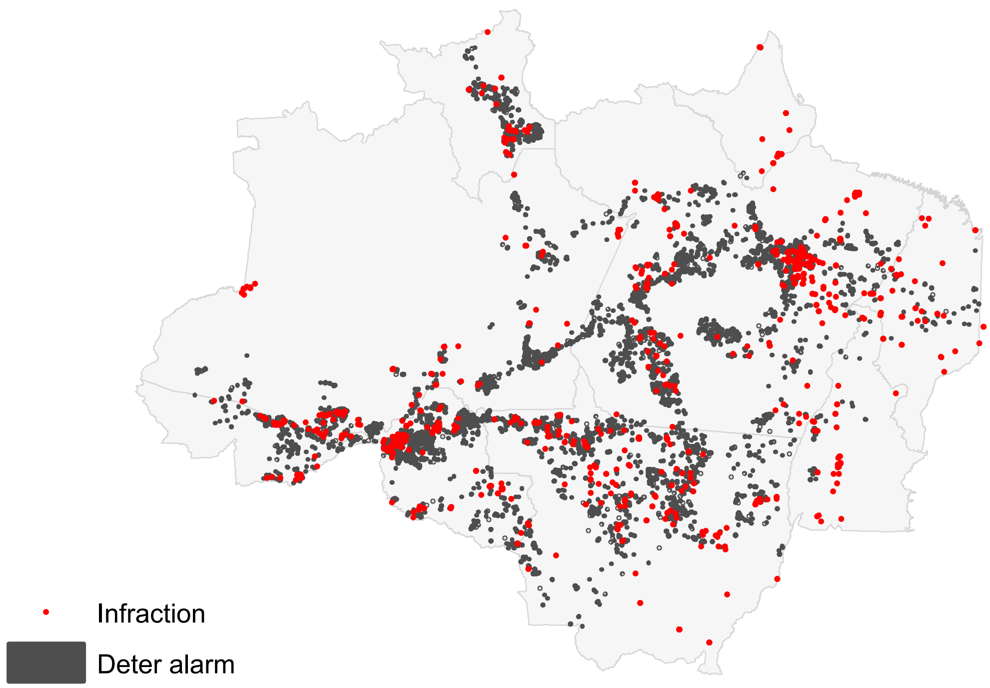

Figure 5. Distribution of Infractions and DETER Alarms in 2015

*S*ource: IBAMA and ICMBio

To separately identify the monitoring channel from the conservation channel, we use the infractions data from 2009 to 2015 to calculate the total number of infractions that lie inside the administrative boundaries of each BV-eligible priority area in a given year. We distinguish between infractions that relate to deforestation, I^{df}, and those that relate to other

[18] For more details on environmental infractions and the source of the data, see http://www.ibama.gov.br/fiscalizacao-ambiental/autuacoes-ambientais.

illegal environmental acts, I^o. We consider the number of infractions issued, I_{zt}, in a given area z and year t, to be a function of the occurrence of an illegal environmental offense, ω_{izt}, for a given offense i; and a probability that this offense is detected, P_{izt}. In absence of the BV, the detection probability of illegal deforestation can be thought of as a positive function of enforcement effort by the infraction-issuing agency, E_{zt}.[19] In grant-receiving areas, if the BV increases peer-moniotring by recicpients, then the detection probability of illegal deforestation is a function of not only E_{zt} but also monitoring from beneficiaries, m_{zt}. We assume that some peer monitoring will result in reports to the authorities and only a subset of local reports will translate into infractions. We remain agnostic about the explicit relationship between local reports and infractions except that we assume infractions to be increasing functions of local reports. Formally, we have:

$$I_{zt}^{df} = f(\omega_{izt}, P_{izt}) \tag{2}$$

where $P_{izt} = g(E_{zt})$ in non-receiving areas. Since the inception of the BV, we rewrite $P_{izt} = g(E_{zt}, m_{zt})$ in grant-receiving areas, where $\frac{\partial P_{izt}}{\partial r_{zt}} > 0$. For non-deforestation related infractions, we could apply the same framework, as long as we assume that peer monitoring by BV recipients have indirect effects on the detection probabilities of other environmental offeneses as well. Following this simple conceptual framework, we test the hypothesis that the BV reduces deforestation by encouraging peer-monitoring via the following reduced form specification:

$$I_{zt}^{df} = \alpha_0 + \gamma BolsaVerde_{zt} + \alpha_1 Deforestation_{zt} + \alpha_2 X_{zt} + \nu_z + \mu_t + \epsilon_{zt} \tag{3}$$

where I_{zt}^{df} denotes the total number of deforestation-related infractions in area z at year t; and the other variables are defined in the same way as in equation (1). We control for deforestation in the specification because we will otherwise be estimating the total effect of the BV on infractions inclusive of the conservation channel. The coefficient of interest is γ,

[19] In the Legal Amazon, two agencies have the authority to issue infractions against illegal environmental acts, IBAMA and ICMBio.

which we expect to be positive if the BV induces beneficiaries to monitor illegal deforestation in their areas of residence and report offenses to the federal agencies. It is important to note that the coefficient captures the upper bound effecs of the BV through monitoring and reporting. We could estimate a null effect of the BV if there is no reporting, or if there are no reports that translate into an infraction. In neither sceario, the null effect does not nullify the peer monitoring channel. The BV may reduce deforestation without an increase in deforestation-related infractions if would-be deforesters internalize the threat of being reported by the peer monitoring agents. If this was the case, we would not see an increase in deforestation-related infractions, but we might see the indirect effects of peer monitoring on non-deforestation related infractions.

To test this possibility, we repeat the reduced-form estimation by using non-deforestation related infractions as the outcome variable. Table 8 reports coefficients where the treatment is participation in the BV program. Columns 1, 3 and 5 include areas with zero infraction while Columns 2, 4, and 6 report the effect of BV on infractions, conditional on having at least one infraction in a given year. Panel A shows that BV-receiving areas do not have statistically higher numbers of deforestation-related infractions. However, we find weak evidence that these areas do have more infractions due to other illegal environmental offenses (Panel B). Conditional on having some infractions, we find that the BV-receiving areas have 48.5% more infractions. These estimates are conditional on contemporaenous deforestation, which may decrease due to higher conservation efforts by recipients. The finding that there is an increase in infractions against other illegal envionmental offenses but not infractions related to illegal deforestation confirm our conjecture that the BV is a pay for performance scheme that encourages peer-monitoring, with indirect effects on non-deforesetation related infractions. Table A5 shows that if we do not distinguish between infractions due to illegal deforestsation or other environmental offenses, we would find a positive effect of the BV on the number of infractions, masking the meaingingful heterogeneity that allows us to separate the conservation channel from peer monitoring.

Table 8. Impact of BV Participation on Infractions

	All		SUC		Settlements	
	(1)	(2)	(3)	(4)	(5)	(6)
	y	log(y)	y	log(y)	y	log(y)
Panel A: $y = I^{df}$						
Treatment effect	0.128	0.136	-0.106	0.198	0.211	-0.0319
	(0.132)	(0.197)	(0.406)	(0.274)	(0.130)	(0.264)
Deforestation (sqkm)	0.176*	0.0434	-1.258***	-0.0169	0.248***	0.0421
	(0.104)	(0.0277)	(0.329)	(0.0673)	(0.0769)	(0.0345)
Pre-BV mean y	0.299 [1.251]		1.181 [2.413]		0.119 [0.715]	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961	368	602	184	2,359	184
R^2	0.320	0.148	0.414	0.122	0.234	0.359
Panel B: $y = I^{o}$						
Treatment effect	0.129	0.485**	0.678	0.517**	0.00649	0.305
	(0.0843)	(0.214)	(0.411)	(0.220)	(0.0231)	(0.209)
Deforestation (sqkm)	-0.0187	-0.0812	-0.154	-0.0344	0.00332	0.124*
	(0.0176)	(0.0504)	(0.230)	(0.0398)	(0.00467)	(0.0648)
Pre-BV mean y	0.256 [1.367]		1.343 [3.057]		0.033 [0.252]	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961	278	602	224	2,359	54
R^2	0.075	0.163	0.099	0.190	0.087	0.734

Note: The dependent variable is total number of infractions or log of infractions (conditional on some infractions). The treatment is a dummy variable that equals one if an area has BV-receiving households, and zero otherwise. All specifications include priority area fixed effects and year fixed effects. Covariate controls include cloud cover, lagged remaining forests, and interaction terms between lagged remaining forests and distances to the nearest paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis Standard deviation of the number of infractions are in brackets.*** p<0.01, ** p<0.05, * p<0.10.

To further confirm this conjecture, we investigate whether the increase in infractions due to BV vary by the number of beneficiaries. Results are reported in Table 9. Overall, a 10% increase in the number of recipients (about 13 households) is associated with a 0.31 unit increase in infractions, or 0.87% in areas with at least one infraction. This effect is statistically zero in Settlements. These results indicate that the peer monitoring channel generates indirect effects to other illegal envionrmental offenses only in SUCs .

5.2 Costs of Monitoring

Another way we could test the conjecture that the BV induces beneficiaries to exert monitoring effort is to explore whether the effects of the BV on deforestation is stronger in areas where the costs of monitoring are low. We proxy for the cost of monitoring by calculating

Table 9. Impact of the Number of BV Beneficiaries on Infractions

	All		SUC		Settlements	
	(1)	(2)	(3)	(4)	(5)	(6)
	y	log(y)	y	log(y)	y	log(y)
Panel A: y = I^{df}						
Treatment effect	0.0210	0.0274	-0.0360	0.0362	0.0342	-0.00790
	(0.0261)	(0.0371)	(0.0985)	(0.0510)	(0.0241)	(0.0490)
Deforestation (sqkm)	0.175*	0.0438	-1.266***	-0.0146	0.247***	0.0420
	(0.104)	(0.0278)	(0.340)	(0.0701)	(0.0768)	(0.0346)
Pre-BV mean y	0.299 [1.251]		1.181 [2.413]		0.119 [0.715]	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961	368	602	184	2,359	184
R^2	0.320	0.148	0.414	0.122	0.233	0.359
Panel B: y = I^{o}						
Treatment effect	0.0314*	0.0877**	0.156**	0.0978***	0.00252	0.0756
	(0.0160)	(0.0352)	(0.0736)	(0.0358)	(0.00483)	(0.0479)
Deforestation (sqkm)	-0.0180	-0.0749	-0.125	-0.0210	0.00343	0.125*
	(0.0175)	(0.0494)	(0.222)	(0.0405)	(0.00468)	(0.0643)
Pre-BV mean y	0.256 [1.367]		1.343 [3.057]		0.033 [0.252]	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961	278	602	224	2,359	54
R^2	0.076	0.159	0.101	0.188	0.087	0.736

Note: In Panel A, the dependent variable is total number (or log) of deforestation-related infractions (conditional on some infractions). In Panel B, the dependent variable is total number (or log) of non-deforestation-related infractions (conditional on some infractions). The treatment is log of number of beneficiaries. All specifications include priority area fixed effects and year fixed effects. Covariate controls include cloud cover, lagged remaining forests, and interaction terms between lagged remaining forests and distances to the nearest paved roads and cities.
Robust standard errors clustered at the priority area level in parenthesis. Standard deviation of the number of infractions are in brackets.
*** p<0.01, ** p<0.05, * p<0.10.

the per recipient share of remaining forests in a given year and a given priority area. Table 10 shows the results. We find opposite effects: in SUCs, the higher the cost of monitoring or the larger the share of the remaining forest per recipient, the smaller the effect of the BV in reducing deforestation (Column 2). in Settlements, however, the larger the share of remaining forests per recipient, the larger the effect of the BV in reducing deforestation (Column 3). There are two caveats to these results. First, the magnitude of the coefficients are small relative to the average treatment effect. Second, the spatial concentration of forests relative to where people live is arguably important for measuring the cost of monitoring but is unobserved in our study and hence unaccounted for in the analysis. How far recipients are from remaining forests may explain the heterogeneity we document here and is an important arena for future future.

Table 10. Estimated Treatment Effects by Monitoring Costs

Dependent variable	Deforetation rate (%)			Log of deforestation rate		
	(1)	(2)	(3)	(4)	(5)	(6)
Sample	All	SUC	Settlements	All	SUC	Settlements
Treatment	-0.140**	-0.0642*	-0.171**	-0.0475**	-0.0396**	-0.0534*
	(0.0629)	(0.0332)	(0.0749)	(0.0224)	(0.0189)	(0.0272)
Treatment X Cost	0.00000322	0.0000295**	-0.0000211***	0.00000204	0.0000140**	-0.00000416
	(5.38e-06)	(1.22e-05)	(6.47e-06)	(2.34e-06)	(5.52e-06)	(3.13e-06)
Pre-BV deforestation in receving areas (sqkm)	0.158	0.489	0.088	0.158	0.489	0.088
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961	602	2,359	2,961	602	2,359
R^2	0.022	0.163	0.034	0.024	0.244	0.031

Note: Dependent variable is deforestation rate, defined as the total area deforested as a percentage of last year's remaining forests. Treatment is a dummy variable that equals one if an area has BV-receiving households and zero otherwise. All specifications include priority area fixed effects and year fixed effects. Cost of monitoring is proxied by share of remaining forests per BV recipient in a given priority area. Covariate controls include clouds, lagged remaining forests, and interaction terms between lagged remaining forests and distances to the nearest paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis. R2 of baseline specification in brackets. *** p<0.01, ** p<0.05, * p<0.10.

6 Conclusions

Exploiting the unique conditionality of a cash transfer program in Brazil, the Bolsa Verde, which is set at the aggregate level, we explore the broader question of whether contracts providing both financial and social incentives by the principal are effective in promoting effort from agents and in achieving the desired payoff, in this case, forest conservation. Since program beneficiaries lose their quarterly cash grant payments if the forests in the area they reside do not comply with the Forest Code, deforestation in any part of the priority area creates negative externality on all beneficiaries. Our main finding is that at the priority area level, BV reduces deforestation by three to five percent. We observe larger effects in Sustainable Use Conservation Zones and the main results are driven by areas with initially high averages and variances in deforestation. The number of beneficiaries also matter, with estimated effects ranging from 0.27 ha to 0.7 ha reduction in forest loss per beneficiary.

To compare the program's costs with benefits, we conduct a back-of-the-envelope calculation to evaluate the treatment effect on forest loss in terms of averted CO_2 emissions. In the full sample, we estimate that a 10% increase in the number of BV beneficiaries is associated with 0.31 percentage point decrease in deforestation. This translates into a 4.9 ha reduction in forest loss or 0.37 ha per recipient.[20] BV beneficiary is associated with 0.7 ha reduction in annual forest loss. To convert these effects into reduction in CO_2 emissions, we first obtain the average carbon stock per hectare of forest in the Amazon by averaging the existing estimates of 150 metric tons (MT) per ha (Andersen et al. 2002) and 100 MT/ha (Margulis 2004). Taking the average of 125 MT/ha, we translate our results into (0.37 ha x 125 MT) = 46.25 MT of carbon sequestered per beneficiary per year. This amount of carbon sequestered translates into (46.25 MT x 3.67) = 169.74 MT of averted CO_2 emissions. Taking the U.S. Environmental Protection Agency's estimated SCC at USD39 per ton of averted CO_2 (in 2012 U.S. dollars), program benefits are at 169.74 x 39 = USD 6,620 per household.[21] These benefits are almost ten times the program's costs, which are 300 reais (USD154) per recipient household per quarter, or USD616 per year.[22] The costs calculated in this way only take into accouunt the quarterly cash payment to each beneficiary household and is likely a lower bound estimate. Given the large estimated benefits, however, we are confident that the BV program is cost effective.

Our study highlights the importance of social incentives in situations where the principal agent problem is characterized by a principal who is concerned only about the payoff and not effort by individual agents. More understanding on how beneficiaries interact with non-recipients and the extent to which the effectiveness of peer monitoring depends on this interaction remains open for future research.

[20] The average number of beneficiaries is 133, thus the estimated impact of adding 10% more or 13.3 beneficiaries is a 3.17 ha reduction in forest loss. This reduction translates into 4.9/13.3 = 0.37 ha of forest loss per recipient.

[21] In 2010, the EPA estimates the SCC to be USD33 in 2007 U.S. dollars. In 2015, the value is updated to be USD38 in 2007 U.S. dollars. In our calculations of program benefits of BV, we follow Jayachandran et al. (2017) to use the SCC value of USD39 for 2012 in 2012 U.S. dollars.

[22] This cost measure abstracts away from administrative cost of the program that are unobserved by us. Therefore, the actual costs associated with implementing the program is likely higher than only the payment to each beneficiary.

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Appendix

Table A1. Estimated Impact of BV on Deforestation with Leads and Lags

Dependent variable	Deforestation rate (%)			Log of deforestation rate		
	(1)	(2)	(3)	(4)	(5)	(6)
Sample	All	SUC	Settlements	All	SUC	Settlements
$BV_{\_t+3}$	0.0870	0.369	0.00231	0.00725	0.119	-0.0209
	(0.0870)	(0.290)	(0.0716)	(0.0321)	(0.0787)	(0.0355)
$BV_{\_t+2}$	-0.0250	-0.0203	-0.0454	-0.0312	0.0109	-0.0419
	(0.0854)	(0.0435)	(0.0986)	(0.0281)	(0.0201)	(0.0329)
$BV_{\_t+1}$	-0.00535	0.0225	-0.0372	-0.0375	0.00483	-0.0498
	(0.109)	(0.0436)	(0.129)	(0.0358)	(0.0299)	(0.0429)
$BV_{\_t0}$	-0.112	0.0855	-0.189	-0.0744*	0.00688	-0.0947**
	(0.106)	(0.0969)	(0.125)	(0.0392)	(0.0328)	(0.0474)
$BV_{\_t-1}$	-0.169	-0.148	-0.209	-0.0857*	-0.0497	-0.104*
	(0.120)	(0.137)	(0.142)	(0.0452)	(0.0446)	(0.0550)
$BV_{\_t-2}$	-0.163	-0.0553	-0.221	-0.0680	-0.0171	-0.0802
	(0.121)	(0.0556)	(0.146)	(0.0466)	(0.0368)	(0.0569)
$BV_{\_t-3}$	-0.188	0.0417	-0.298*	-0.106*	-0.00778	-0.147**
	(0.143)	(0.100)	(0.173)	(0.0547)	(0.0439)	(0.0680)
$BV_{\_t-4}$	-0.162	-0.127*	-0.224	-0.0700	-0.0577	-0.0821
	(0.159)	(0.0735)	(0.188)	(0.0587)	(0.0477)	(0.0715)
F Test: all leads jointly 0	0.57(0.635)	1.16(0.328)	0.13(0.943)	0.84(0.470)	0.82(0.488)	0.56(0.641)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961	602	2,359	2,961	602	2,359
R^2	0.023	0.193	0.034	0.026	0.266	0.033

Note: Dependent variable is (log) deforestation rate, defined as the total area deforested as a percentage of last year's remaining forests. Treatment is a dummy variable that equals one if an area has BV-receiving households and zero otherwise. All specifications include priority area fixed effects and year fixed effects. Baseline model is a fixed effects specification without controls. Covariate controls include clouds, lagged remaining forests, and interaction terms between lagged remaining forests and distances to the nearest paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis. R^2 of baseline specification in brackets.
*** p<0.01, ** p<0.05, * p<0.10.

Table A2. Estimated Impact of BV on Deforestation by Distance to IBAMA Offices

Dependent variable	Deforetation rate (%)					
	All		SUC		Settlements	
Sample	(1)	(2)	(3)	(4)	(5)	(6)
Treatment	-0.129*	-0.146*	-0.0843	-0.387	-0.168**	-0.162*
	(0.0699)	(0.0818)	(0.0730)	(0.264)	(0.0813)	(0.0897)
Treatment X Distance to IBAMA	-0.0000723		0.000135		-0.0000362	
	(0.000149)		(0.000273)		(0.000143)	
Treatment X Distance (76 km < X < 122 km)		0.0265		0.395		-0.00408
		(0.0533)		(0.276)		(0.0492)
Treatment X Distance (123 km < X < 193 km)		0.0114		0.371		-0.0211
		(0.0534)		(0.277)		(0.0497)
Treatment X Distance (X > 194 km)		-0.0204		0.351		-0.0244
		(0.0589)		(0.274)		(0.0519)
Pre-BV deforestation in receving areas (sqkm)	0.158		0.489		0.088	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961	2,961	602	602	2,359	2,359
R^2	0.022	0.022	0.163	0.170	0.034	0.034

Note: Dependent variable is deforestation rate, defined as the total area deforested as a percentage of last year's remaining forests. Treatment is a dummy variable that equals one if an area has BV-receiving households and zero otherwise. All specifications include priority area fixed effects and year fixed effects. Cost of monitoring is proxied by share of remaining forests per BV recipient in a given priority area. Covariate controls include clouds, lagged remaining forests, and interaction terms between lagged remaining forests and distances to the nearest paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis. R2 of baseline specification in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table A3. Estimated Impact of BV on Log of Deforestation by Distance to IBAMA Offices

Dependent variable	Log of deforestation rate					
	All		SUC		Settlements	
Sample	(1)	(2)	(3)	(4)	(5)	(6)
Treatment	-0.0430	-0.0431	-0.0408	-0.123	-0.0545*	-0.0471
	(0.0262)	(0.0330)	(0.0271)	(0.0844)	(0.0316)	(0.0367)
Treatment X Distance to IBAMA	-0.0000294		0.0000266		0.00000572	
	-0.0000684		(0.0000930)		(0.0000821)	
Treatment X Distance (76 km < X < 122 km)		0.00612		0.112		-0.00153
		(0.0289)		(0.0838)		(0.0296)
Treatment X Distance (123 km < X < 193 km)		-0.0168		0.0863		-0.0242
		(0.0277)		(0.0873)		(0.0287)
Treatment X Distance (X > 194 km)		-0.00841		0.0973		-0.00159
		(0.0295)		(0.0854)		(0.0306)
Pre-BV deforestation in receving areas (sqkm)	0.158		0.489		0.088	
Observations	2,961	2,961	602	602	2,359	2,359
R^2	0.024	0.024	0.243	0.249	0.031	0.031

Note: Dependent variable is log of deforestation rate, defined as the total area deforested as a percentage of last year's remaining forests. Treatment is a dummy variable that equals one if an area has BV-receiving households and zero otherwise. All specifications include priority area fixed effects and year fixed effects. Cost of monitoring is proxied by share of remaining forests per BV recipient in a given priority area. Covariate controls include clouds, lagged remaining forests, and interaction terms between lagged remaining forests and distances to the nearest paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis. R2 of baseline specification in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table A4. Infractions and Bolsa Verde Participation

	All		SUC		Settlements	
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable: All Infraction	y	log(y)	y	log(y)	y	log(y)
Treatment effect	0.257	0.332**	0.572	0.419**	0.217*	0.151
	(0.161)	(0.155)	(0.557)	(0.195)	(0.127)	(0.244)
Deforestation (sqkm)	0.157	0.0385	-1.412***	0.0326	0.252***	0.0435
	(0.110)	(0.0259)	(0.473)	(0.0773)	(0.0792)	(0.0302)
Pre-BV mean y	0.555 [2.059]		2.524 [4.151]		0.152 [0.808]	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961	496	602	289	2,359	207
R^2	0.300	0.131	0.350	0.131	0.242	0.310

Note: The dependent variable is total number of infractions or log of infractions (conditional on some infractions). The treatment is a dummy variable that equals one if an area has BV-receiving households, and zero otherwise. All specifications include priority area fixed effects and year fixed effects. Covariate controls include cloud cover, lagged remaining forests, and interaction terms between lagged remaining forests and distances to the nearest paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis. Standard deviation of the number of infractions are in brackets.
*** p<0.01, ** p<0.05, * p<0.10.

Table A5. Infractions and Bolsa Verde Intensity

	All		SUC		Settlements	
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable: All Infraction	y	log(y)	y	log(y)	y	log(y)
Treatment effect	0.0523*	0.0501*	0.120	0.0655*	0.0367	0.0202
	(0.0307)	(0.0297)	(0.125)	(0.0386)	(0.0237)	(0.0481)
Deforestation (sqkm)	0.157	0.0366	-1.391***	0.0374	0.251***	0.0423
	(0.109)	(0.0262)	(0.475)	(0.0813)	(0.0791)	(0.0304)
Pre-BV mean y	0.555 [2.059]		2.524 [4.151]		0.152 [0.808]	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,961	496	602	289	2,359	207
R^2	0.300	0.127	0.350	0.126	0.242	0.309

Note: The dependent variable is total number of infractions or log of infractions (conditional on some infractions). The treatment is log of number BV benficiaries. All specifications include priority area fixed effects and year fixed effects. Covariate controls include cloud cover, lagged remaining forests, and interaction terms between lagged remaining forests and distances to the nearest paved roads and cities. Robust standard errors clustered at the priority area level in parenthesis. Standard deviation of the number of infractions are in brackets. *** p<0.01, ** p<0.05, * p<0.10.

BOLSA VERDE

TERMO DE ADESÃO - PROGRAMA BOLSA VERDE
Dados do(a) Beneficiário(a)

Nome:____

CPF:________________________ Nº NIS:____________________________

Unidade de Conservação/Assentamento:______________________________

Compromissos com a Conservação Ambiental e Uso Sustentável dos Recursos Naturais

a - As atividades de conservação a serem desenvolvidas deverão atender ao previsto nos instrumentos de gestão das Unidades de Conservação (Plano de Utilização ou Uso e/ou Planos de Manejo) ou dos Projetos de Assentamentos (Planos de Utilização ou Planos de Desenvolvimento dos Assentamentos), conforme o caso;

b - Na inexistência dos instrumentos acima referidos, as atividades de conservação a serem desenvolvidas serão regidas pelos Contrato de Concessão de Direito Real de Uso – CCDRU ou Contrato de Concessão de Uso – CCU.

c - Além dos instrumentos acima referidos a família deve, sempre que cabível, se integrar a outros planos ou acordos, que façam referência à conservação e uso sustentável dos recursos naturais, quando estabelecidos na unidade a qual a família se vincula, a exemplo dos acordos de pesca, caça ou de queima controlada.

Informações Gerais

Dos objetivos do Bolsa Verde:

a - Incentivar a conservação dos ecossistemas, entendida como sua manutenção e uso sustentável; e

b - Promover a cidadania, a melhoria das condições de vida e a elevação da renda da população em situação de extrema pobreza que exerça atividades de conservação dos recursos naturais no meio rural;

c - Incentivar a participação de seus beneficiários em ações de capacitação ambiental, social, educacional, técnica e profissional.

Do funcionamento do Bolsa Verde:

a - A transferência de recursos financeiros do Programa de Apoio à Conservação Ambiental será realizada a famílias em situação de extrema pobreza, inscritas no Cadastro Único para Programas Sociais do Governo Federal e que exerçam atividades de conservação;

b - Serão realizados repasses trimestrais no valor de R$ 300,00 (trezentos reais);

c - A Caixa Econômica Federal exercerá a função de Agente Operador do Programa de Apoio à Conservação Ambiental, realizando os repasses trimestrais;

d - O recebimento destes recursos tem caráter temporário e não gera direito adquirido, sendo que a transferência destes recursos será realizada por um prazo de até dois anos, podendo ser prorrogada;

e - A transferência de recursos de que trata este Termo de Adesão cessará se a família beneficiária: 1. Não cumprir as condições estabelecidas neste Termo de Adesão; 2. Estiver ou for habilitada em outros programas ou ações federais de incentivo à conservação ambiental.condições estabelecidas neste Termo de Adesão; 2. Estiver ou for habilitada em outro programa federal de incentivo à conservação ambiental.

É compromisso e responsabilidade desta família zelar pelo cumprimento de todas as regras estabelecidas por este Termo de Adesão, bem como na Lei nº 12.521, de 14 de outubro de 2011 e em seu regulamento.

Declaro que li e concordo com as condições do Termo de Adesão.

________________, ___/__________ de ______ ________________________

Local | Data | Assinatura do(a) Beneficiário(a)

Ministério do Planejamento, Orçamento e Gestão | Ministério do Desenvolvimento Agrário | Ministério do Desenvolvimento Social e Combate à Fome | Ministério do Meio Ambiente | GOVERNO FEDERAL BRASIL PAÍS RICO É PAÍS SEM POBREZA

Figure A1. Terms of Adhesion Signed by Bolsa Verde Beneficiaries

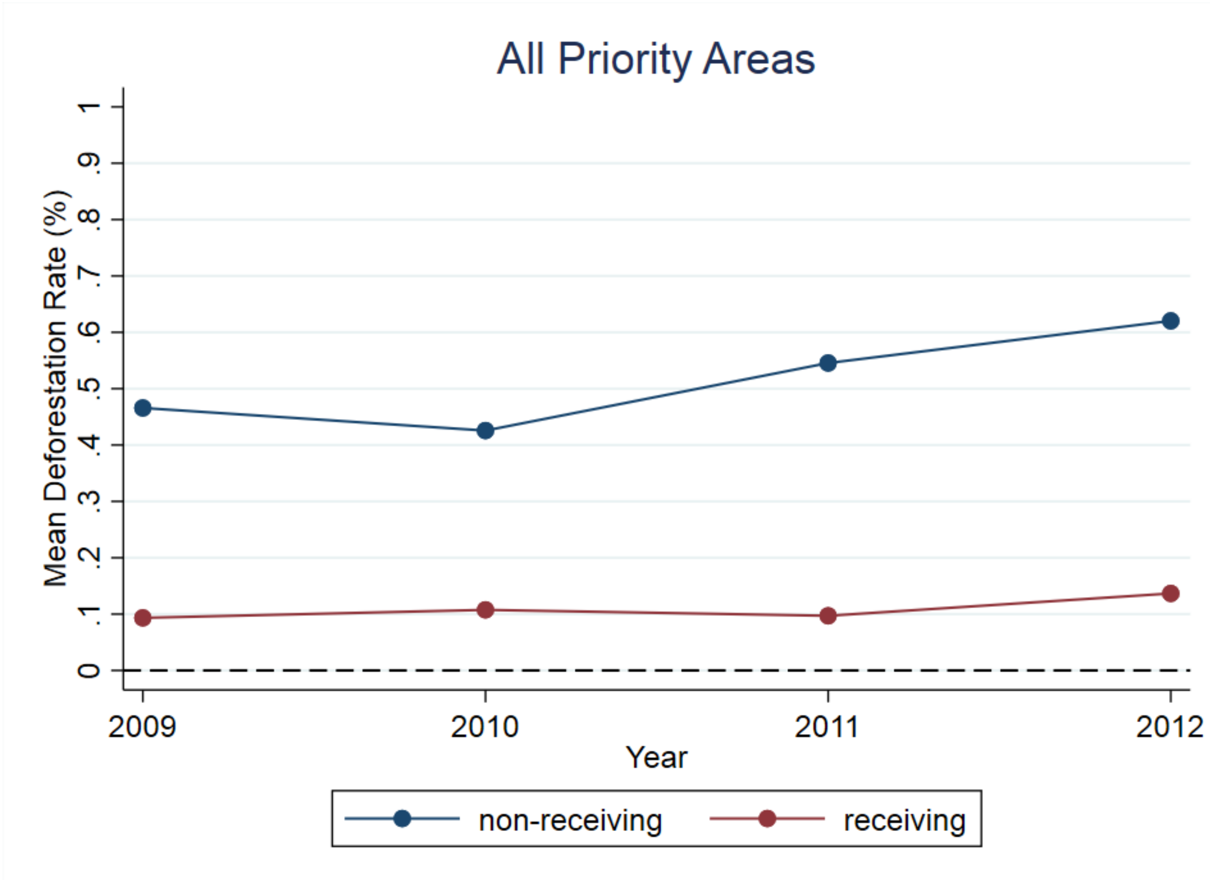

Figure A2. Mean Deforestation Rates by BV Status, 2009 - 2011

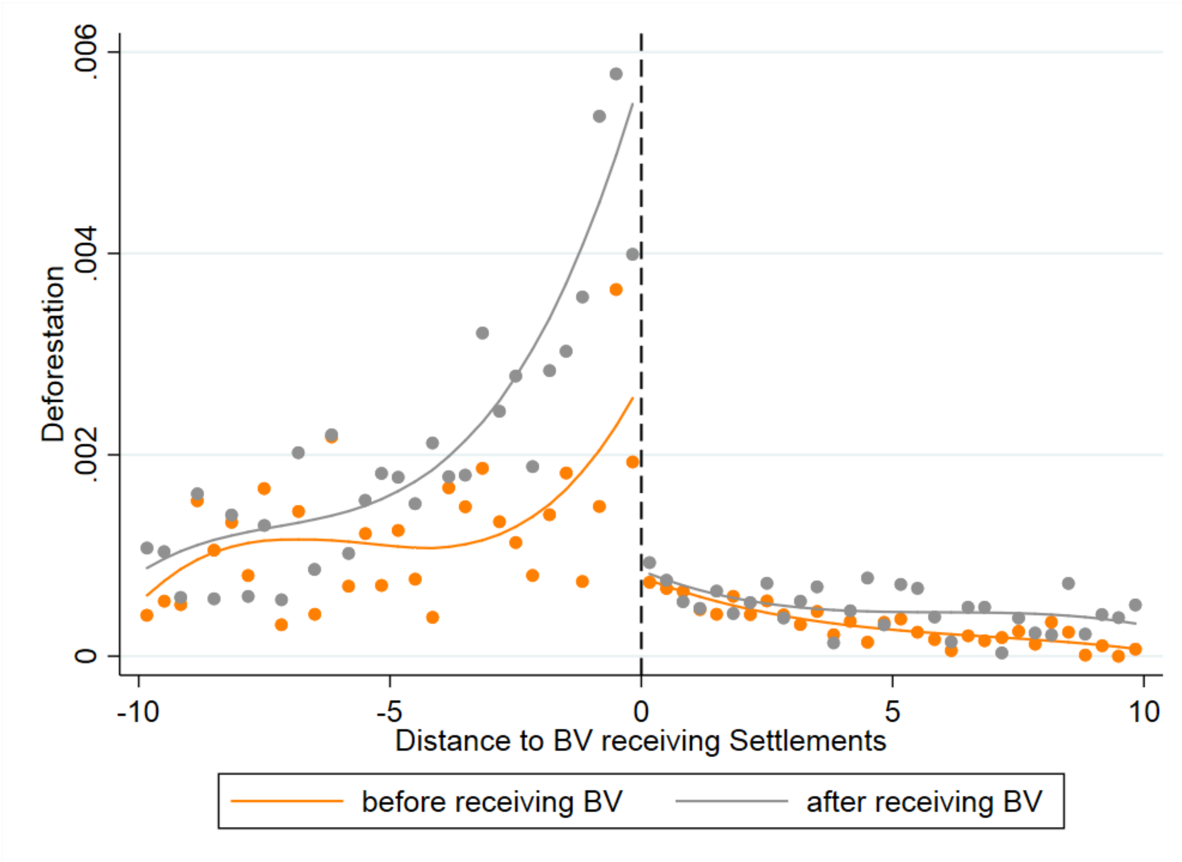

Figure A3. Deforestation Inside and Outside BV-Receiving Settlements

*N*otes: The figure plots local averages of deforestation in a given grid cell using data from 2009 to 2015. The x-axis shows the distance (in km) of grid cells to the borders of settlements that eventually receive BV. The orange line is a second degree polynomial fit for averages over periods before the settlements receive BV; the grey line is the equivalent over periods after the settlements have started receiving BV payments. The necessary assumption for RD to be valid, the continuity assumption across the running variable (in this case, distance), is clearly violated. Before the settlements receive BV, we observe a sharp reduction in the level of deforestation at the border. Therefore, we cannot attribute the similar reduction at the border after the realization of BV payments to the program.

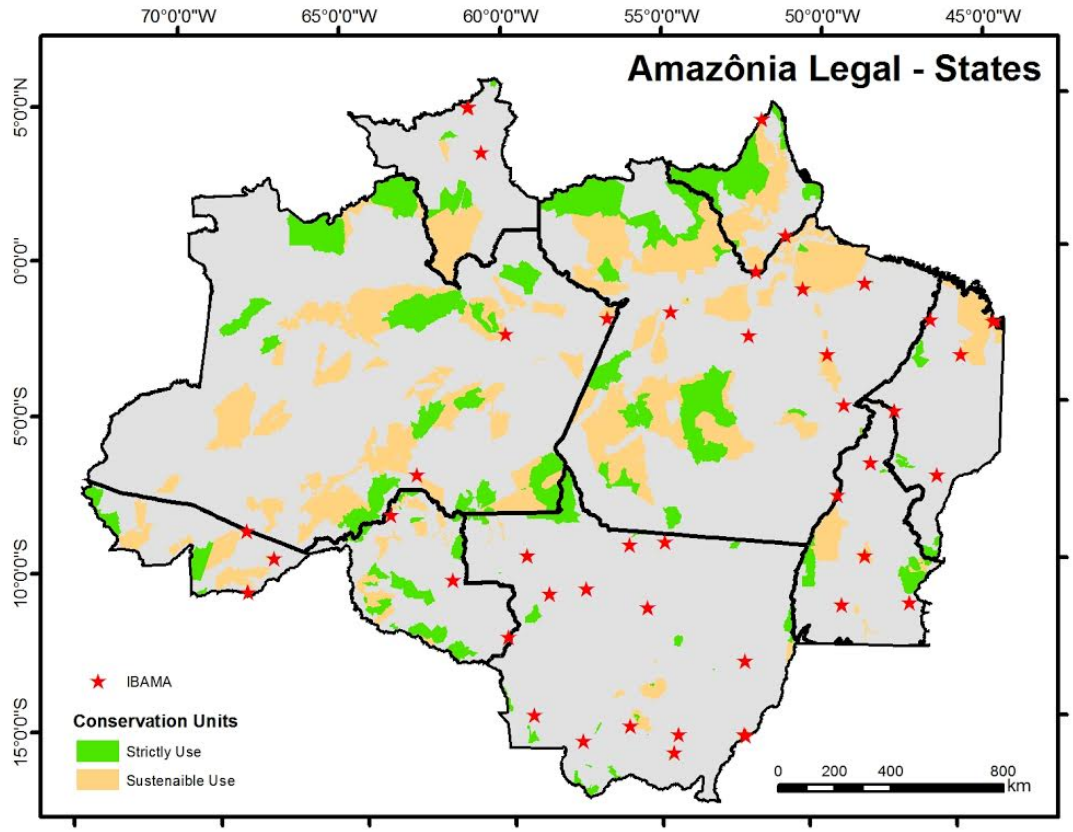

Figure A4. Location of IBAMA offices in the Legal Amazon

*N*otes: The figure plots the local of IBAMA offices in the Legal Amazon.