Curbing deforestation among smallholders in the Amazon rainforest: impact evaluation of a REDD+ pilot project in the Transamazon highway

Gabriela Simonet, Julie Subervie, Driss Ezzine-de Blas, Marina Cromberg, Amy Duchelle

Curbing deforestation among smallholders in the Amazon rainforest : Impact evaluation of a REDD+ pilot project in the Transamazon highway

Gabriela Simonet [*,†], Julie Subervie [‡], Driss Ezzine-de-Blas [§], Eduardo Marinho [¶], Amy Duchelle[‖]

April 30, 2015

Abstract

Using original data collected from 181 small farmers in the State of Para in Brazil in 2010 and 2014, we show that REDD+ pilots using positive economic and agricultural incentives can slow down deforestation rates in areas dominated by smallholder properties, where command-and-control policies arise political and equity concerns. In the present paper we analyze, using an econometric approach based on DID-matching, the forest conservation impacts of a REDD+ pilot program in the Transamazon highway that combines Payments for Environmental Services (PES) with environmental sensitization and agricultural technical assistance. Although the program attracted farmers who do not depend on livestock and often have a higher wage income than non-participants, a potential limitation to maximizing the environmental additionality of the project, we find a significant conservation impact of the project. Yet at its early implementation stage, our results show that program participants devoted on average 66% of their land to forest in 2014 while it would have decreased to an estimated 61% without the project. We find that the forest conservation impact is even higher for the subset of farmers who had previously participated in a similar program, suggesting a process of time-cumulative learning and confidence on external support that acts as a facilitator for reaching positive conservation outcomes. Moreover, our results show that the forest area has been preserved at the expense of pastures, not of croplands. Extending the average estimate to all participants, we conclude that the project avoided the emission of around 830 000 tCO2.

Keywords: REDD+, Payments for Environmental Services, Brazilian Amazon, agricultural settlements, difference in difference matching.
JEL: Q23, Q57, D12

[*] Chaire Economie du Climat Paris-Dauphine
[†] CIRAD
[‡] INRA
[§] CIRAD
[¶] CIFOR
[‖] CIFOR

1 Introduction

Tropical deforestation and degradation is one of the main players in anthropic emissions of carbon dioxide (CO2), with an annual emission rate estimated at 7-14% of global CO2 emissions (Harris et al.,2012; Grace et al., 2014). Since the start of climate change international negotiations in the early 1990s, tropical forests have received an increasing attention from policy makers. As a response to such interest, afforestation and reforestation projects were included in the clean development mechanism of the Kyoto protocol signed in 1997. Afterwards, as an additional effort to protect forest and foster reforestation, the REDD mechanism aimed at Reducing Emissions from Deforestation and forest Degradation was created during the 11th Conference of Parties (COP of Montreal, 2005). The core idea of the REDD mechanism was to pay developing countries for their efforts in terms of avoided deforestation. In 2009, the mechanism was expanded to include the role of conservation, sustainable management of forests and enhancement of forest carbon stocks, and was subsequently renamed REDD+. As of 2014, there are more than 300 REDD+ projects around the world (Simonet et al., 2014).

Among all forested countries in the world, Brazil is one of the main sources of tropical deforestation (Hansen et al., 2013). Yet, its annual deforestation rate fell by 70% between 2005 and 2013 thanks to, on one side, public policy and supply chain intervention and, on the other side, a drop in the market demand of soya and cattle products, one of the main drivers of deforestation (Nepstad et al., 2014; Assunção et al., 2012). As a result, the observed decrease in deforestation applied mainly to large farmers, with small farmers having had a much limited role in the avoided deforestation measured during this period (Godar et al., 2014). This is partially due to the slow implementation of policies aiming at curbing deforestation among smallholders. Indeed, in 2004, Brazil started implementing a federal "Plan for the Protection and Control of Deforestation in the Amazon" based on three pillars: (i) Tenure regularization and territorial management; (ii) Monitoring and control; and (iii) Incentives for sustainable production (Brazilian Ministry of Environment, 2013). The "monitoring and control" pillar has been the first one to be implemented and is, as of early 2015, the most successful in terms of its economic and forest conservation repercussions on the ground (Gebara and Thuault, 2013). This success has been supported by the technical progress in identifying deforestation through remote sensing. Smallholders have not been directly affected by command-and-control actions because monitoring deforestation among smallholders is more complex and costly than for large farmers, and punishing them raises ethical concerns (Godar et al., 2014). Contrary to command-and-control actions, the other two pillars have experienced a slower progress (Maia et al., 2011; Gebara and Thuaulth, 2013). As a result, small farmers have had a lesser relevant participation in the national deforestation policies that started in 2005, in particular with regard to supporting a transition of their productive systems toward sustainable grounds.

During the last decade, policy makers and scientists have debated on what would be the most beneficial strategies in terms of equity and environmental outcomes to curb deforestation among smallholders (Gebara and Thuaulth, 2013; Godar et al., 2014). One of the most promising strategies advocated by scientists has been of combining command-and-control with economic incentives (Ezzine-de-Blas et al., 2011; Börner et al., 2015). The rationale behind the combination of command-and-control - i.e. law enforcement and tenure regularization - and incentives - e.g. conditional payments and support towards innovation in production systems - follows the "carrots and sticks" strategy that aims at balancing equity and environmental efficiency by partially relieving smallholders from conservation costs through economic incentives, while enforcing forest regulation (Börner et al., 2014). In this regard, the implementation of voluntary Payments for Environmental Services (PES) to small and poor farmers provides a policy tool that respects both equity- by allowing farmers to receive an economic support to compensate for avoided deforestation- and forest conservation goals.

Although the Brazilian Forest Code was enacted in 1934, it started being enforced only since the beginning of the 2000s, generating new constraints for land users. After a decade where command-and-control has been the main strategy, the Brazilian government is investing more in forest conservation incentives, notably through REDD+ projects (Börner et al., 2015). As of 2014, Brazil is the country with the highest number of REDD+ projects (Kshatriya 2013; Simonet et al., 2014). Part of them are financed by the Amazon Fund, a national fund created in 2009 and managed by the National Development Bank of Brazil (BNDES) with the aim to reduce deforestation through the promotion of sustainable development in the Amazon (BNDES, 2014). By the end of 2013, the fund had received a total of 775 million USD from Norway, Germany and the Brazilian company Petrobras, and was supporting 50 projects at regional and local levels (BNDES, 2014). Following the ongoing trend, over the period 2009-2013 the Amazon Fund primarily financed "monitoring and control" activities, with a focus on tenure regularization, strengthening of environmental agencies and fighting illegal fire. Projects to support sustainable productive systems constituted the second main source of expenditure (BNDES, 2014). Among one of these projects is the REDD+ pilot project called "Avoided Deforestation on Small Rural Properties in the Transamazon region" or *Projeto Assentamentos Sustentáveis na Amazônia* (PAS).[1]. The project aims at developing and implementing a model for sustainable agricultural production in small rural properties, in line with a previous federal program implemented in the region in 2003 and named *Proambiente*. The *Proambiente* program was designed to provide payments to small producers for environmental services rendered, as well as technical guidance, monitoring and certification (Hall, 2008). *Proambiente* involved around 4000 families, of which 350 households living in the same settlements where the PAS project is being implemented. Participants received payments for a six-month period but, due to poor inter-governmental coordination, limited funding, and limited implementation capacities, the program was abandoned in 2006 (Hall, 2008). In line with *Proambiente*, one of the components of the PAS project [2] falls under the logic of a PES scheme, by providing technical assistance and payments conditional on forest conservation and on the adoption of sustainable agricultural practices.

A PES scheme can be defined as “a voluntary and conditional transaction between an environmental service (ES) buyer and an ES provider, on the provision of a well-defined ES or a land use presumed to deliver that ES” (Wunder, 2007). Alternative definitions include the role of PES into aligning social interests and foster collective action to attain a negotiated social and environmental outcome (Muradian et al., 2010). Although a bill to create a national PES program is being debated, PES in Brazil have so far been implemented mainly by Non-Governmental Organizations (NGOs) and local governments. They are part of three main policy agendas related to: The promotion of agro-ecological practices, REDD+ implementation and water management (Coudel et al. 2014). The PAS

[1] Renamed in 2012 as “Sustainable Settlements in the Amazon: the challenge of the transition from frontier family production to a low carbon economy”

[2] The other component of the PAS project, which consists in working with three settlements to develop a sustainable production model but without PES system (BNDES, 2014), is not included in this study.

project stands at the interface of the first two agendas.

Rigorous impact analyses of REDD+ projects are scarce (Jagger et al., 2009). Except from Jindal et al. (2012), existing assessments of REDD+ projects (Asquith et al., 2002; Brimont et al., 2015; Brown et al., 2011; Lawlor et al., 2013; May et al., 2004) do no use impact evaluation methods (Todd, 2008; Pattanayak, 2009; Sunderlin et al., 2010) although they are common in the evaluation of PES projects (Arriagada et al., 2012; Costedoat et al., 2015; Pfaff et al., 2008), Integrated Conservation and Development projects (Bauch et al., 2014; Weber et al., 2011) or protected areas (Andam et al., 2008; Blackman et al., 2014; Nelson and Chomitz., 2011; Baylis et al., 2015). This can be explained by the slow implementation of REDD+ project activities, the difficulty of conducting baseline surveys and of finding appropriate control groups. In order to fill this gap, the Global Comparative Study (GCS), carried by the Center for International Forestry Research (CIFOR) from 2009 to 2015, aims at providing new evidence on the social and environmental effectiveness of REDD+ projects. To achieve this aim, the GCS has implemented a quasi-experimental before-after-control-intervention (BACI) approach in 23 REDD+ projects in Brazil, Peru, Indonesia, Vietnam, Cameroon and Tanzania. The Brazilian component of the GCS studies the impact of 6 pilot initiatives in the states of Acre, Amazonas, Pará, Amapa and Mato Grosso in order to cover different institutional contexts and land governance actors. The PAS is one of the two case studies of the GCS in the state of Pará. Given the strong forest conservation law enforcement led by Brazilian forest authorities since the mid-2000s, the PAS project is a good case study to understand how conditional economic incentives in the form of PES can be complementary to command-and-control, in order to achieve efficient and equitable forest conservation outcomes.

This paper presents the first impact assessment led on a Brazilian REDD+ project using difference-in-difference estimators. To assess the impact of the project on the forest cover, we use data from a two-phase survey, applied in both intervention and comparison villages. We apply multivariate regressions and matching, based on quantitative data, and triangulate our results with qualitative data from household surveys and discussions with key informants. We show that the process of self-selection led to the involvement of a particular category of smallholders, less dependent on forest clearing. Although the project was only about to initiate payments and agricultural investments when the second phase of the survey was conducted, we find a significant positive impact on forest conservation. Participants devoted on average 66% of their land to forest in 2014 while it would have decreased to an estimated 61% without the project, saving in average 4ha of forest. Extrapolating to the 350 participants, the project might have avoided the emission of around 833 512 tCO2. The impact is even higher for a sub-category of participants who also participated in the *Proambiente* program in the early 2000s. Based on a preliminary cost-benefit analysis, we find a positive net surplus of the project.

The present paper is organized as follows: Section two describes in detail the case study; Section three explains the sampling and empirical strategy; Section four presents the results regarding what factors explain participation and the project conservation impacts. Section five consists in a preliminary cost-benefit analysis. Section six discusses the observed positive forest conservation outcomes with regard to the institutional context of the project region and the characteristics of participants. Finally, we identify the policy implications of our results if conditional economic incentives experience a geographical scaling up.

2 Case study description

The PAS project is implemented by the Brazilian NGO IPAM (Amazon Environmental Research Institute), in partnership with the Brazilian National Institute of Colonization and Agrarian Reform (INCRA) and a local foundation created to defend the rights of small farmers in land conflicts and represent their interests when negotiating with government institutions, NGOs and private actors (*Fundação Viver Produzir e Preservar* or FVPP). IPAM is a recognized local actor regarding the implementation of REDD+ in the Brazilian Amazon (Gebara et al., 2014). The project is financed by the Amazon Fund since 2012 and will end in 2017. As previously mentioned, the project combines conservation and development actions to support the ecological intensification of agricultural systems in land settlements of the Transamazon highway, a historical and still active deforestation hot spot (Godar et al., 2014; IPAM and FVPP, 2009).

The PAS project is composed of three main axes (Cromberg et al., 2014a): (i) Forest conservation cash payments, conditional on halting deforestation ; (ii) The adoption of sustainable agricultural systems, implemented via individual management plans; (iii) Helping people comply with the environmental legislation by supporting the administrative procedure for tenure regularization and compliance with the Brazilian new Forest Law. The project will support paying 350 families living near the BR-230 Transamazon Highway to compensate their forest conservation efforts.

The 350 households involved in the PAS project live in 13 settlements, located in the municipalities of Anapu, Pacajá and Senador José Porfirio (Figure 1). Agricultural settlers arrived in the area in the early 1970s, as part of the early stages of the National Integration Plan for the colonization of the Brazilian Amazon [3]. Amazonian colonizers received land and in-kind support to settle along the Transamazon Highway, which became the most important arc of deforestation. Indeed, settlers were formally encouraged to deforest more than half of their plots to guarantee possession. The INCRA was created to manage and regularize the creation of these first agricultural settlements (Cromberg et al., 2014b). The land reform program was a fluctuant policy in terms of political and economic support with regard to rural credits, agrarian production subsidies, and expansion of transport infrastructure at Amazonian forest margins (Walker and Homma, 1996). In our area of study, the government prioritized to support large-scale agribusiness and abandoned the settlers in a precarious situation in the mid-1970s that has overall remained unchanged since (Campari, 2002; Davis, 1978). The livelihoods of smallholders in our region of study have traditionally depended on slash-and-burn agriculture (roça) and extensive cattle ranching, which are the main factors of deforestation in the area (Smith et al., 1996; Soares-Filho et al., 2006). Cocoa production has recently raised in the area, due to guaranteed market and high prices, and thanks to the intervention of several NGOs and private firms (Cromberg et al. 2014a). However, its expansion is limited by the need of fertile soils. As a result, two out of the eight communities we interviewed have no cocoa production due to poor soil quality.

The environmental compliance component of the project (component (iii) previously described) is particularly important as the project is implemented in a context of increasing control by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). Indeed, the three municipalities where the interviewed communities are located –Anapu, Pacajá, Senador José Profirio- entered the list of priority municipalities of the Amazon in 2009 and 2012. This list is established by the Brazilian Ministry of Environment in order to identify the municipalities where most deforesta-

[3] Estatuto da Terra, Law 4504, of 30th of November of 1964.

tion is observed and take measures accordingly. Given the geographic isolation of settlements, IPAM has organized in PAS communities, meetings to inform settlers on environmental legislation and tenure regularization. The new Forest Law requires maintaining 80% of land located in the Amazon as forestland (the “Legal Reserve”) and preserving riparian zones, hillsides and mountaintops (the “Permanent protected area”). The PAS project is located on an Environmental-Economic Zoning (ZEE) area where the Legal Reserve has been lowered to 50% in order to enable economic development. Landowners owning less than four tax modules (which represents around 280 ha in our area of study) are not required to restore the forest but should not clear forest anymore if they are below this threshold. Restoration can include up to 50% of exotic species, which can be exploited economically. Moreover, the use of fire is regulated. Although the application of the new Forest Law to smallholders has been so far limited, half of the households interviewed in the second phase of the survey feel affected by the legislation because they are not allowed to clear nor burn forest anymore, a practice at the foundation of their agricultural management systems. Such a perception and fear of being monitored can be explained by the punishment in a form of chainsaw confiscation that happened to one of the smallholders interviewed. In addition, 27 households mentioned that they “decreased clearing and burning because they are scared of being fined” (Quoted from a farmer of the Terra Rica settlement). This fear has been reinforced by the development of the Environmental Rural Register (CAR), which helps the government track land use changes. Another villager stated that they are “afraid of clearing forest because with the CAR they [the government] have the details of land area” (Quoted from a farmer of the Vicinal do Pão Doce). On the other hand, the CAR provides land tenure security and is necessary to sell livestock. In spite of the fear created by the enforcement of the new Forest Law, most households consider that command-and-control is positive[4] to achieve forest preservation but that the government should provide alternatives and technical assistance to help small farmers comply with the law. The PAS project addresses this need by proposing payments conditional on the respect of the Forest Law (30% of the payment based on the goal of having 50% of their land as “Legal Reserve” and 30% based on the goal of conserving 15m of forest on riparian zones - the “Permanent protected area”) and by supporting the adoption of sustainable agricultural production systems (40% of the payment, based on individually defined indicators) (personal communication from IPAM). This project is an example of the synergies that are emerging between the Brazilian REDD+ strategy and the new Forest Law (Gebara and Thuault, 2013). By January 2014, all the families involved in the PAS project had signed contracts to receive PES, although individual management plans were not established yet. In 2014, it was decided that all the participants would receive the maximum payment of 572USD/year (1680 Reais/year, paid quarterly), as an initial incentive and because the management plans were not ready. From 2015, payments will require a further evaluation of the respect of the contract, through analysis of satellite images and field visits (personal communication from IPAM).

[4] 27.7% of households declared a negative or very negative effect on well-being; 26.9% declared no effect; 32% a positive or very positive effect; and 13.4% both a positive and negative effect.

3 Methods

3.1 Sampling and descriptive statistics

The CIFOR ran two surveys in eight villages. The first survey took place in June-July 2010, before the PAS project started. The second survey took place in February-March 2014, a year and a half after the official start of the project[5]. We interviewed a total of 263 households in 2010 and 245 households in 2014. Approximately 30% of the households interviewed in 2010 were not interviewed in 2014 because they had moved out of the village, had died or were temporarily missing at the time of the interview. Therefore our analyses are based on the subset of 181 households who were interviewed twice.

Table 1 describes information collected in the survey on the characteristics of the 181 farmers and their main activities. The total area in 2014 is 93 hectares on average, with 59% of forest, 32% of pasture and 7.5% of land dedicated to agriculture. Their deforestation rate over the 2008-2010 period is around 2% per year, which is close to the statistics provided in Godar et al.(2014), which are representative of smallholders in the Transamazon highway. Agriculture and livestock breeding represent the main sources of income in the study area, albeit alternative sources of income such as off-farm salary and government social programs – in particular Bolsa Familia and retirement pensions – can also be significant.

The surveys were conducted in 4 intervention villages chosen among the 13 villages involved in the project. These 4 villages were selected with the view to evaluate possible effects of previous projects run by the NGO (*Proambiente*) and to reflect the diversity of the villages. In the intervention villages, we performed a stratified randomization in order to have approximately half of the households who previously participated in the *Proambiente* program. The surveys were also conducted in 4 comparison villages. These 4 villages were selected from a list of reachable villages located outside of project boundaries, far enough away from intervention villages in order to avoid leakage effects. In those villages, the interviewed households were randomly selected. From the 181 households that will be used in this study, 106 households were surveyed in the intervention villages and 75 households were surveyed in the comparison villages. Half of the 106 households living in the intervention villages got involved in the REDD+ project after the first survey.

Table 2 displays the summary statistics for several variables referring to the pre- and post-program years in the two main groups of households, namely those living in the intervention villages and those living in the comparison villages. Households in intervention villages do not differ much from households in comparison villages in terms of age (50 years), education (2.5 years), family size (5 members) and total area (90 ha). However, in both pre- and post-program years, intervention villages are characterized by more forestland and cropland, less pasture land and more revenue from off-farm income than comparison villages. The two groups also differ in land use changes over time, with less conversion from forest to pasture among intervention villages. In what follows, we assess to what extent such changes can be attributed to the PAS project.

[5] Project operational activities such as selection of participants and signature of PES contracts started only in 2013 since funding from the Amazon Fund to IPAM was awarded only at the end of 2012 (Cromberg et al. 2014a).

3.2 Determinants of participation in the project

In order to identify the determinants of participation in the PAS project, we use data collected from households living in the intervention villages, but who did not participate in the project, to compare them with the participants. We perform tests on the equality of means between these two groups for a variety of variables measured in 2010. Results are displayed in Table 3. Before the project starts, participants did not differ from non-participants in terms of forestland (around 70% of the land area), agricultural land (almost 10%) nor pasture land (around 20%). However, they had on average smaller plots, they own less livestock and earn more money from wage labor by working outside their own farm (e.g. agricultural labor) and from government social program (the so-called *Bolsa Familia program*). This is actually what can be expected from participants in such a project. Because participation is voluntary and payment is the same for all participants, the potential for adverse selection is high: farmers with the lowest costs of opportunity associated to participation in the project (those who are the least dependent on forest clearing for their subsistence) are the most likely to enter it.

We moreover fit a maximum-likelihood logit regression including all covariates presented in Table 3 [6]. In this empirical model, the dependent variable takes on value one if the farmer is a participant and takes on the value zero if he belongs to the group of non-participants living in intervention villages. Results are displayed in Table 4. They are presented in terms of odds ratios. Only the income derived from wage labor appears to play a significant role in determining participation in the project and its effect remains small in size: holding the other variables constant at a certain value, the odds of being participants are 1% greater for farmers who earn 500 Reais more from wage labor than others on average. These results provide some insights on the determinants of self-selection into the PAS project. They are at the heart of the identification strategy that we provide to recover the impact of the project.

3.3 Identification strategy

Parameters of interest

In this section, we provide an identification strategy to recover various parameters of interest. First, we aim to recover the impact of the project on participants. It is the average forestland saved thanks to the project in the subset of farmers living in intervention villages who self-selected into the project. Second, we investigate a possible cumulative effect of previous conservation projects, which refers in our case to the impact of participating in the PAS project for those who had participated to the *Proambiente* project. Finally, we study the indirect impact of the PAS project, which refers to the impact of living in an intervention village without participating in the PAS project. This is the average forestland saved thanks to the project in the group of farmers who did not participate in the PAS project but were likely to benefit from some spillover effects of the project because they lived in intervention villages and had the opportunity to attend the PAS meetings or to discuss with the participants. In all three cases, the comparison group (the untreated group thereafter) is used to construct valid control groups.

Let us focus on the average forestland saved thanks to the project in the group of participants. This parameter answers the question: what is the land area covered by forests in participating farms

[6] We do not include the dummy variable which captures participation in the previously run project *Proambiente* because no farmer in the comparison group participated in the *Proambiente* project.

in 2014 compared to the forestland that we would have observed in those farms, had they not been involved in the project? This is the so-called average treatment effect on the treated, defined as $ATT = E(y^1 - y^0|D = 1)$, where y^1 denotes the farmer's forestland in the presence of the project, y^0 denotes the forestland in the absence of the project, and D is a dummy which takes on the value of one when the farmer participated in the project and zero elsewhere. We use matching methods to estimate the outcome level in the unobserved state, namely $E(y^0|D = 1)$.

DID-matching approach

The matching approach is widely used when evaluating voluntary programs (Todd, 2008). The main concerns in assessing the impact of such programs are related to the fact that such programs are not offered at random and that participants in intervention villages self-select into them. We indeed found evidence that the NGO which implemented the project has targeted villages that differed from comparison villages in terms of land use and sources of income (see Table 2). We also found statistical evidence that farmers in intervention villages who self-selected into the program systematically differed from non-participants before the project starts (see Table 3 and Table 4). The crucial issue is thus to control for observable factors X that are likely to drive both decision to participate in the PAS project as well as forestland in 2014. It is important that the covariates X are not affected by the project (Imbens, 2004), which is why we use values from the pre-treatment year 2010 (and 2008 when available). We include in the set of observable factors X the total land area in hectares in 2010, the forestland as a share of the total land area in 2010 and in 2008,[7] the agricultural land as a share of the total land area in 2010 (which includes cocoa), pastures as a share of the total land area in 2010, the market value of agricultural production in 2010 (which includes both sales and self-consumption), the market value of their stock of livestock in 2010, the amount of other sources of income such as off-farm wage salary, government social programs, retirement pensions and various businesses (in Reais, in 2010), the age and the education (school years) of the head of the household, and his/her family size.

Matching eliminates selection bias due to observable factors X by comparing treated farmers (i.e. participants) to observationally identical untreated ones (Imbens, 2004). Because, even after conditioning on observable factors X, there may be systematic differences between treated and untreated farmers' outcomes that could lead to a violation of the identification conditions required for matching, we apply the difference-in-difference matching estimator, as defined in (Heckman et al., 1997). This estimator allows for temporally invariant differences in outcomes between participants and their X-matched untreated counterparts. It requires that $E(\Delta y^0|X, D = 1) = E(\Delta y^0|X, D = 0)$, meaning that the average difference in forestland between the two groups must be constant through time in the absence of treatment, in other words, that observationally identical treated and untreated individuals must exhibit the same change in forestland in the absence of treatment (the parallel trend assumption). Applied to our data, this identification strategy consists in comparing the forestland change of participants over 2010-2014 with the forestland change of matched untreated farmers over 2010-2014. We measure the change in forestland as the difference in the proportion of land area covered by forests between 2010 and 2014. Note that controlling for forestland share in 2010 through a matching

[7] Some variables in the baseline survey are constructed from recall-type questions.

procedure means that the ATT we obtain can be expressed in terms of levels as well as in terms of changes.

Another key assumption for the validity of the-DID matching approach is that the treatment received by one farmer does not affect the outcome of another farmer. This assumption is referred to as the Stable-Unit-Treatment-Value-Assumption in the statistics literature (Rubin et al., 1978). In our framework, the validity of this assumption is not likely to be threatened because interactions between villages are very limited due to road and transport conditions. Moreover, we do not expected smallholders to curb deforestation outside cash-based compensation programs.

Estimators

We use the nearest-neighbor matching estimator (Abadie et al., 2004) and the kernel-based matching estimator. The general form of the DID-matching estimator is:

$$E(y^1 - y^0|D = 1) = \frac{1}{n1} \sum_{i \in I_1} \left(y^1_{it} - y^0_{it'} - E(y^0_{it} - y^0_{it'}|D = 1, X_i) \right) \tag{1}$$

with

$$E(y^0_{it} - y^0_{it'}|D = 1, X_i) = \sum_{j \in I_0} \lambda_{ij} (y^0_{jt} - y^0_{jt'}) \tag{2}$$

where I_1 denotes the group of treated farmers, I_0 denotes the group of untreated farmers, n_1 is the number of treated farmers in I_1. Matching estimators differ in how matched untreated farmers are selected through the matching procedure. This difference is driven by the weights λ_{ij} that we assign to potential matches given their characteristics X. The nearest-neighbor matching estimator we use in the analysis matches each participants to the closest untreated farmer or the four closest untreated farmers from the comparison villages, according to the vector X. We also apply the matching procedure to the summary statistic $\Pr(D_i = 1|X_i)$, the so-called propensity score (Rosenbaum and Rubin, 1983). We use the asymptotically-consistent estimator of the variance of the nearest-neighbor matching estimator provided by (Abadie and Imbens, 2006), and we implement a bootstrap procedure (500 repetitions) to obtain an estimator of the variance of the kernel matching estimator. Another, computationally easier, way to generate an estimate of the ATT is to regress D on Δy, controlling for X, by using ordinary least squares.[8] We run linear regressions as a robustness check. The estimators are presented in Table 6.

4 Results of the impact analysis

4.1 Direct effects on participants

We first apply the matching procedure to the group of participants (the treated group) and to the group of farmers living in the comparison villages (the untreated group). Conditional probabilities for participation in the project are computed by estimating a probit model where the dependent variable is D and which includes all covariates X mentioned before as regressors. The graph of the distribution of these propensity scores suggests that densities are high enough for a wide range of propensity

[8] In addition to the assumption of linearity, this requires us to assume that the gain associated with the program is constant across X, meaning that the impact of the program is the same for all informed farmers.

scores (Figure 2). The matching procedure is considered successful when significant differences of covariates X among the treated and matched-untreated are removed. We compare the extent of balancing between the two groups before and after having performed matching. Results are displayed in Table 5. They show that participants differed from untreated farmers before matching in terms of land use and off-farm income: participants devoted more land to forestry (in 2010 as well as in 2008), and less land to pastures; they moreover derived more income from off-farm wage labour. The matching procedure successfully removed several gaps that could be seen as important bias sources, such as land use. Although the gap between groups in terms of off-farm wage labour considerably decreased, it remains statistically significant at the 5% level (about 5000 Reais on average among participants against 3100 Reais on average among controls). Farmers who derive more income from off-farm labour are less dependent on forest clearing. Consequently, they are more likely to participate on the project and also more likely to curb deforestation even in the absence on the project. Without controlling for this potential off-farm labour effect, our estimate would be biased upward and should be seen as the upper bound of the project impact. We provide further discussion on this issue in what follows.

Table 6 gives the estimated ATT expressed in terms of forestland as a share of land area. The estimates are quite close from each other and range between 5% and 8%. This represents the difference in 2014 between the average land area devoted to forests among participants (66%) and the average land area devoted to forests among controls (61%), taking the smallest significant matching estimator. Taking the average total land area among participants (79.3 ha), this means that about 4 ha of forest have been saved on average on each participating farm in 2014, compared to a situation without project. This impact is represented graphically on Figure 3, which also clearly shows that participants and controls were on the same trend before the project starts. Then participants significantly curbed deforestation on their plots, while controls continued the same trend.

Given that the total land area varies slightly, it seems relevant to test whether less deforestation among participants has translated into less land conversion toward pastures and crops. We thus apply again the matching procedure to the same sample but looking this time at the proportion of land devoted to crops on the one hand and to pastures on the other hand. We find no evidence of an impact on the agricultural land. The estimated ATT that we obtain range between -0.6% and 2% and the null assumption (ATT= 0) cannot be rejected whatever the estimator considered.[9] On the contrary, we find evidence that the project has an impact on pastures. Results are displayed in Table 7. The estimates are quite close from each other and range between -6% and -11%. This represents the difference in 2014 between the average land area devoted to pastures among participants (22%) and the average land area devoted to pastures among controls (28%), taking the smallest significant matching estimator. Taking the average total land area among participants (79.3 ha), this means that almost 5 ha of pastures have not been created on average for each participating farm in 2014, very likely to the benefit of more forestland, compared to a situation without project.

Finally, because participants did not receive any payment for forest conservation before 2014, we investigate whether the change in land use observed over the period among participants due to the project involved also a change in the search of alternative sources of income. We look at the impact on wage labour. Results are displayed in Table 8. The estimated ATT are quite close from

[9] Results are available from authors upon request.

each other, ranging between 2700 Reais and 5300 Reais, but often suffer from a lack of precision. Taking the smallest significant estimator (ATT= 3600 $Reais$), the estimate suggests that participants earn 3600 Reais more in 2014 than what they would have earned, had they not been involved in the project. Interestingly, this amount is twice the annual maximum payment received as a financial compensation (1680 Reais) in the PAS project.

4.2 Focusing on previously informed participants

Because it seems relevant to examine the effect on farmers who participated in a previous PES program, we also apply our identification strategy to the subset of farmers who participated in the *Proambiente* project. Results of the balancing tests are provided in Table 9. Contrary to what we obtained when focusing on all participants in the PAS project, the matching procedure here appears to perform well for all variables likely to create bias, including the one measuring wage labour. We are thus confident that these estimates do not suffer from any (upward) bias that would be driven by a possible off-farm labour effect.

The results of the estimates are displayed in Table 10. While focusing on those households considerably reduces the sample size, our estimates are still significant and even often larger in size. Taking the smallest significant matching estimator (ATT= 5.6%), we show that the participants to *Proambiente* project devoted 68.6% of their land to forests in 2014, while controls devoted only 63%. Taking the average total land area among participants in *Proambiente* project (81.3 ha), this means that about 4.5 ha of forest have been saved on average on each participating farm in 2014, compared to a situation without project. This suggests that the result that we obtain when looking at participants in the PAS project may well be driven by the subset of those who also had participated in the *Proambiente* project. This might be due to learning and/or confidence effects.

We find no evidence of an impact of cumulating projects on the agricultural land while we do find evidence of a significant impact on pastures. Participants in both the PAS and the *Proambiente* projects devote only 19% of their land to pastures in 2014 while controls devote 27% on average, taking the smallest estimated ATT (see Table 7). This suggests again that the forest area has been preserved at the expense of pastures, not areas under crops. Our estimates of the impact on wage labour do not allow us to conclude with the same precision. OLS estimators suggest that the participants in both projects earn 4700 to 6000 Reais more in 2014 than what they would have earned, had they not been involved in both projects. On the contrary, matching estimators do not reject the null assumption of no impact[10].

4.3 Spillover effects

We then consider the group of farmers who chose not to participate in the PAS project but were likely to benefit from some spillover effects of the project because they lived in intervention villages and had the opportunity to attend the PAS meetings or to discuss with participants. Table 11 gives the estimated ATT in terms of forestland as a share of land area. The estimates are quite close from each other, around 3%, but the null assumption (ATT= 0) cannot be rejected whatever the estimator considered. These results indicate that if there is any spillover effect, it is too small to be shown using this

[10]Results are available from authors upon request.

sample. We however show that this impact, if there is any, is not small enough to cancel the impact of the projet on intervention villages taken as a whole. We estimate the impact of the project on intervention villages, which combines the direct effect on farmers who participate in the project and the indirect effect on their neighbors (non-participants) through information leakage. The results are displayed in Table 12. They show that overall, the average forestland saved thanks to the project in the intervention village is about 4.3 % (taking the smallest estimate). Given that the average total land area in those villages is about 96 ha, this means that about 4 ha of forest have been saved, on average, on each farm in 2014, thanks to the project.
Deforestation leakages could have been feared since the participants increased their revenue from wage salary, and notably agricultural labor, thus participating in the deforestation that occurs outside their own farm. However, having a global impact of the project different form zero tends to exclude the hypothesis of leakage inside intervention communities. Similarly, the linear trends of deforestation among comparison villages between 2008 and 2014 (see Figure 3), allows us to exclude the hypothesis of deforestation leakagesin neighbouring communities. Moreover, the project had no impact on the decision to start working as agricultural labor. The likelihood to work as agricultural labor increases for younger head of family and for lower values of crops harvested on the own land, but not with the participation in the project[11].

5 Cost-effectiveness analysis

Although deforestation among participants did not stop, the PAS project led them to devote on average 66% of their land to forest in 2014 while it would have decreased to an estimated 61% without the project. Considering a mean total area of around 79.3ha, participants thus saved in average 5.15ha since the beginning of the project. Expanding to the 52 interviewed households, a total of 268ha has been saved. Using the reference of 126tC/ha (IPAM and FVPP, 2009, based on IPCC estimates) and converting in tCO2eq (1 tC =3.67 tCO2) the project avoided the emission of around 123 929 tCO2. Expanding to the 350 households involved in the project, the project has avoided the emission of around 833 512 tCO2. Depending on the value given to one ton of CO2, the environmental benefit of the project so far varies. This value ranges from 5USD/tCO2, which corresponds to the mean price sale of carbon credits on the voluntary market in 2013 (Peters-Stanley and Gonzalez, 2014), to 65 USD/tCO2 when considering the social cost of carbon (Greenstone et al., 2013). The environmental benefit of the project is estimated between 4 167 560 USD and 5 4178 410 USD (Table 13). As all the households received the maximum payment of 759USD in 2014, the cost of the PES component of the project is 200 200 USD, leading to a net surplus between 3 967 360 and 53 978 210 USD. The net surplus generated by the project is overestimated because we did not include the costs of the project other than those linked to the payment, notably administrative and transition (information, monitoring, technical assistance, etc.) costs.

[11] Results based on a logistic regression, available from authors upon request.

6 Discussion

Our results show that the PAS project reduced deforestation in participants by slowing down pasture expansion compared to non-participant farmers, who followed the observed regional trend of increasing pastures. This result can be understood as resulting from a combination of participants' and project characteristics. First, since participation in the project is voluntary, we can expect the self-selection process to attract a very determined socio-economic profile of participants. These participant households are those who had the 'least to loose' by joining the PAS conservation project. Their pre-existent development trajectories, characterized by a limited investment in livestock farming and high revenue from wage labor outside their farm, were not in conflict with the objectives of the project. Although matching allowed to compare similar farmers in terms of income coming from livestock, project participants scored significantly higher in terms of wage labor. As a result, our analyses were not able to exclude the potential bias coming from this variable, and its role in explaining the reduction of deforestation in PAS participants. Similarly, the majority (79%) of the project participants had been involved in the *Proambiente* program in the beginning of the 2000's. This probably reflects both a positive pro-environmental motivation created by *Proambiente* and the long term interest of farmers to participate in projects that match their wills of conserving the forest while developing more productive and profitable systems. The higher impact measured on the sub-group of households who participated in both projects tend to validate this assumption.

The meetings organized by IPAM in the intervention communities enhanced the environmental awareness of households, in particular with regard to their knowledge of the environmental legislation and forest conservation requirements. This raised their awareness on the sanctions they can incur if deforesting illegally. Such fear of being punished could have participated in the observed stemming deforestation although we have no variables to control for this effect. Indeed, from the 53 households who participated in at least one meeting, 21 mentioned that it had "repercussions" on their land use, "increased [their] environmental awareness" and "clarified the rules" contained in the new Forest Law.

Moreover, the positive conservation impact measured on project participants can probably be explained by the confidence the project created on the participants, which made them commit with forest protection. Qualitative evidence collected during the implementation of the impact evaluation protocol confirms this hypothesis. Indeed, of the 52 participants, 13 expressed that the forthcoming payments had had an influence on their land use. Data shows that these households started conserving more forest than they used to after entering the program, because payments are proportional to the percentage of forest on their property. They must have minimum 30% of forest to enter the program and can expect to receive the maximum payment only if they have more than 50% of forest and 15m of forest on riparian zones. Between 30% and 50%, the payment is proportional to the percentage of forest (personal communication from IPAM). At the moment of the survey, interviewed farmers were concerned with the fact that payments and technical assistance may not arrive, a fear that might have been exacerbated by the previous abandonment of *Proambiente*, and that put pressure on IPAM technicians to kick-start payments. In fact, technical assistance appeared to be the most expected component of the project, above cash payments. This is in line with the claims from communities made to first survey in 2010 that related with the improvement of local production systems through technical assistance and improved infrastructure (Cromberg et al., 2014b). A claim that traces back to the will made when *Proambiente* started (Coudel et al., 2014). This finding supports the idea that project participants are farmers willing to adopt sustainable practices, and that such has survived the passing of the time. Cash payments were generally considered too small: each household can receive a maximum of 572USD/year (1680 Reais) the first year, which represents around 14% of the mean annual value of crops harvested in 2014 and nearly the mean value of sold crops (1881 Reais). The value of the payment is based on the estimation of the opportunity cost of households and will increase by 9% every year (Personal communication from IPAM).

Our study raises the question of the trade-off existing between equity, environmental effectiveness and economic efficiency when implementing conservation and development policies. When combining command-and-control with economic incentives, a tradeoff appears between equity and cost-effectiveness (Börner et al., 2015). Moreover, equity issues are often neglected in PES in favor to economic efficiency (Pascual et al., 2014). By supporting poor small farmers, the PAS project favors equity, by redistributing economic and technical support to an economic population that would have been otherwise excluded from agricultural development. However, its environmental effectiveness might not be optimal since households specialized in livestock farming were not attracted by the project, whereas cattle ranching is one of the main sources of deforestation. For the project to attract these farmers, they should be offered either higher payments (proportional to their opportunity cost) or productive packages in line with their interests. An alternative view that also privileges equity concerns, is to consider that strict command-and-control should be only applied to those who can afford it, leading to a segmentation of the conservation strategy between mixed incentive-coercive measures and pure coercive. Although to maximize additionality of PES it is better to target habitats at high risk independently of poverty criteria (Sierra and Russman, 2005), a PES scheme reserved to poor households with low opportunity costs would be both equitable and affordable for the Brazilian government. Since implementing economic incentives is more costly than pure command-and-control measures (Börner et al., 2015), implementing hybrid-PES for land-users who need it most while applying command-and-control to wealthier land-users, would help reconcile the objectives of equity and cost-effectiveness at regional level. In opposition to such approach, one can criticize that paying people to comply with the law entails a risk of moral hazard (Börner et al., 2015) and of motivation crowding out (Rode et al., 2014) i.e. the risk that people might, in the future, refuse to respect the law without being paid. However, we argue that applying temporary economic incentives to offer the poorest the means to respect the law satisfies equity concerns and makes the conservation policy acceptable at a large geographical scale. The PAS project appears thus as a necessary support for smallholders in a situation where they have no option but breaking the law, especially when they rely on slash-and-burn for food production. In this sense, a key informant explained that "people will have to apply the law sooner or later, so any help to reach this goal is welcome" (key informant in Canoé).

This project is a good 'spear-arrow' initiative that tests at local level the social and environmental effectiveness of an implementation model that combines positive hybrid incentives with command-and-control, and which has proved to be more expensive but more equitable than pure command-and-control according to regional models (Börner et al., 2015). The self-selection of 350 households to participate in the PAS project and the preliminary impacts measured are encouraging for reflecting with more solid grounds on the conditions and consequences of scaling-up this kind of program.

Admittedly, different tradeoffs exist when implementing PES at different geographical scales (Coudel et al., 2014; Farley and Constanza, 2010). Local implementation is better adapted to local needs but their scale up capacity is limited, leading to the risk of vanishing impacts. Implementing PES at larger scales allows to take advantage from administrative economies of scale but makes monitoring more complex, and increases costs sharply if to adapt the program to local needs, since local detailed diagnosis are needed to match the level of knowledge IPAM has on farmers' needs. Another barrier to the implementation of large scale PES is the poor delimitation and regulation of land tenure in the Amazon (Börner et al., 2014). Scaling up could thus start on land reform settlements where tenure categories are quite well-defined and a wide number of unpublished grey literature exists to guide project design (Ezzine-de-Blas et al., 2011). As of early 2015, there are 9255 settlements in Brazil, covering a total area of 88 316 523ha and involving 969 691 families [12].

Theoretically, combining different implementation scales should improve the efficiency of PES programs (Nagendra and Ostrom, 2012). However, the *Proambiente* experience, which combined federal and local governances, has shown that this was not so easy. The new context of strong law enforcement might be a good sign for future attempts of scaling up. This change of scale would be also in line with the current evolution of the REDD+ strategy from projects to a geographically larger jurisdictional approach. For example,the State of Acre has been so far particularly innovative, by implementing the first Brazilian state-level REDD+ program with incentives aimed at valuing forests, biodiversity, water, soil, climate and traditional and cultural knowledge.

Finally, the productive focus of the PAS project raises also the question of the permanence of the impact. First, the PAS project will end in 2017 and we can wonder whether such a time lapse will be sufficient for the agricultural transition. Moreover, if we are to ensure the long-term permanence of PAS positive forest conservation outcomes, it is needed to first consolidate the added value of agricultural land, but also to add value to forest land. In this sense, cocoa production is emerging as an interesting option because it is a stable source of revenue in areas where the Legal Reserve needs to be restored. Sablayrolles et al. (2012) present cocoa production as a good option for family farmers of the Alto Xingu (also in the State of Pará) to comply with the Forest Law because this activity can generate at least the same revenue than extensive livestock farming but using an area ten times smaller. However, they highlight the necessity of technical assistance to obtain good cocoa quality and of diversification (agroforestry systems, forest management, small animal husbandry, beekeeping, fish farming, etc.) to limit the risks linked to monoculture. Another limitation is that cocoa production requires fertile soils (see section 2).

Moreover, to maximize the success of PES hybrid measures in the long term, it is needed to maintain enforcement efforts at a high level, particularly at the end of the project (Börner et al., 2014). However, this would first require expanding the PES system to all the smallholders that are in a similar situation of inability to comply with the law, which arises again the issue of the need of scaling-up the program.

7 Conclusion

REDD+ projects are blossoming around the world, particularly in Brazil. Yet, their impact has been under-studied to date. This paper filled this gap by presenting the first impact assessment of a REDD+

[12]http://painel.incra.gov.br/sistemas/index.php.

pilot project in the Brazilian Amazon, which combines Payments for Environmental Services (PES) with environmental sensitization and agricultural technical assistance. Our analysis focused on the impact of the project on forest conservation and showed that REDD+ pilots using positive economic and agricultural incentives can slow down deforestation rates in areas dominated by smallholder properties. We found a significant conservation impact of the project after two years of implementation, with program participants devoting on average 66% of their land to forest in 2014 while it would have decreased to an estimated 61% without the project. We found an even higher impact for the subset of farmers who had previously participated in a similar program called *Proambiente*, suggesting a process of time-cumulative learning and confidence on external support. Extending the average estimate to all participants, we conclude that the project avoided the emission of around 830 000 tCO2. We led a preliminary cost-benefit analysis, which suggested a positive net surplus of the project. Technical assistance to implement alternative options to slash-and-burn and extensive livestock farming, as well as improved market access, will be crucial to consolidate the positive impacts of the project.

While the choice of the instruments to fight deforestation is still a matter of debate in Brazil, we found encouraging results on the possibility of combining incentive and coercive measures for poor households with low opportunity costs, while applying pure coercive measures to whelthier land-users. This segmentation of conservation instruments could address both equity and efficiency concerns, but still raises the issue of scaling up PES programs.

8 References

Abadie, A.; Drukker, D; Herr, J. L. & Imbens, G. W. (2004): "Implementingmatching estimators for average treatment effects in Stata," Stata Journal, 4(3), 290–311.

Abadie, A., and Imbens, G. W. (2006): "Large Sample Properties of Matching Estimators for Average Treatment Effects," Econometrica, 74(1), 235–267.

Andam, K. S.; Ferraro, P. J.; Pfaff, A.; Sanchez-Azofeifa, G. A. & Robalino, J. A. (2008), 'Measuring the effectiveness of protected area networks in reducing deforestation', Proceedings of the National Academy of Sciences 105(42), 16089–16094.

Arriagada, R. A.; Ferraro, P. J.; Sills, E. O.; Pattanayak, S. K. & Cordero-Sancho, S. (2012), 'Do payments for environmental services affect forest cover? A farm-level evaluation from Costa Rica', Land Economics 88(2), 382–399.

Asquith, N. M.; Rios, M. T. V. & Smith, J. (2002), 'Can forest-protection carbon projects improve rural livelihoods? Analysis of the Noel Kempff Mercado Climate Action Project, Bolivia', Mitigation and Adaptation Strategies for Global Change 7(4), 323–337.

Assunção, J.; Gandour, C. C. & Rocha, R. (2012), 'Deforestation slowdown in the Legal Amazon: prices or policies', Climate Policy Initiative Working Paper.

Bauch, S. C.; Sills, E. O. & Pattanayak, S. K. (2014), 'Have We Managed to Integrate Conservation and Development? ICDP Impacts in the Brazilian Amazon', World Development.

Baylis, K.; Honey-Roses, J.; Boerner, J.; Corbera, E.; Ezzine-de-Blas, D.; Ferraro, P.; Lapeyre, R.; Persson, M.; Pfaff, A. & Wunder, S. (2015), 'Mainstreaming impact evaluation in nature conservation'.

Blackman, A. (2014), 'Strict versus Mixed Use Protected Areas: Guatemala's Maya Biosphere Reserve', Resources for the Future Discussion Paper(14-03).

BNDES (2014), 'Amazon Fund activity report 2013', Technical report, BNDES and Minister of the Environment.

Börner, J.; Wunder, S.; Wertz-Kanounnikoff, S.; Hyman, G. & Nascimento, N. (2014), 'Forest law enforcement in the Brazilian Amazon: Costs and income effects', Global Environmental Change 29, 294–305.

Börner, J.; Marinho, E. & Wunder, S. (2015), 'Mixing Carrots and Stickstoff Conserve Forests in the Brazilian Amazon: A Spatial Probabilistic Modeling Approach', PloS one 10(2), e0116846.

Brazilian Ministry of Environment (2013), 'Plano de acao para prevencao e controle do desmatamento na Amazônia legal (PPCDAm)- 3ra fase (2012-2015)', Official report.

Brimont, L.; Ezzine de Blas, D.; Karsenty, A. & Toulon, A. (2015), 'Achieving conservation and equity amidst extreme poverty and climat risk: the Makira REDD+ project in Madagascar', Forest.

Brown, D. R.; Dettmann, P.; Rinaudo, T.; Tefera, H. & Tofu, A. (2011), 'Poverty alleviation and environmental restoration using the clean development mechanism: a case study from Humbo, Ethiopia', Environmental management 48(2), 322–333.

Campari, J. S. (2002), 'Challenging the turnover hypothesis of Amazon deforestation: evidence from colonization projects in Brazil', PhD thesis, University of Texas at Austin.

Costedoat, S.; Corbera, E.; Ezzine-de-Blas, D.; Honey-Rosés, J.; Baylis, K. & Castillo-Santiago, M. A. (2015), 'How effective are biodiversity conservation payments in Mexico?', PloS one 10(3), e0119881.

Coudel, E.; Ferreira, J.; Amazonas, M.; Eloy, L.; Hercowitz, M.; Mattos, L.; May, P.; Muradian, R.; Piketty, M. & Toni, F. (2014), 'A Ascensão do Pagamento por Serviços Ambientais no Brasil: Negociando uma Governança Policêntrica', Boletim da Sociedade Brasileira de Economia Ecologica 32.

Cromberg, M.; Duchelle, A. E.; Simonet, G. & de Freitas, A. C. (2014a), Sustainable Settlements in the Amazon, Brazil'REDD+ on the ground: A case book of subnational initiatives across the globe', Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Cromberg, M.; Duchelle, A. E. & Rocha, I. d. O. (2014b), 'Local Participation in REDD+: Lessons from the Eastern Brazilian Amazon', Forests 5(4), 579–598.

Davis, S. (1978), 'Vitimas do milagre: O desenvolvimento e os indios no Brasil', Zahar Editores.

Ezzine-de-Blas, D.; Börner, J.; Violato-Espada, A.; Nascimento, N. & Piketty, M. (2011), 'Forest loss and management in land reform settlements: Implications for REDD governance in the Brazilian Amazon', Environmental science & policy 14(2), 188–200.

Farley, J. & Costanza, R. (2010), 'Payments for ecosystem services: from local to global', Ecological Economics 69(11), 2060–2068.

Gebara, M. F. & Thuault, A. (2013), 'GHG mitigation in Brazil's land use sector: an introduction to the current national policy landscape', World Resource Institute Working paper.

Gebara, M. F.; Fatorelli, L.; May, P. & Zhang, S. (2014), 'REDD+ policy networks in Brazil: constraints and opportunities for successful policy making', Ecology and Society 19(3).

Godar, J.; Gardner, T. A.; Tizado, E. J. & Pacheco, P. (2014), 'Actor-specific contributions to the deforestation slowdown in the Brazilian Amazon', Proceedings of the National Academy of Sciences, 201322825.

Grace, J.; Mitchard, E. & Gloor, E. (2014), 'Perturbations in the carbon budget of the tropics', Global Change Biology.

Greenstone, M.; Kopits, E. & Wolverton, A. (2013), 'Developing a social cost of carbon for US regulatory analysis: A methodology and interpretation', Review of Environmental Economics and Policy 7(1), 23–46.

Hall, A. (2008), 'Better RED than dead: paying the people for environmental services in Amazonia', Philosophical Transactions of the Royal Society B: Biological Sciences 363(1498), 1925–1932.

Hansen, M. C.; Potapov, P. V.; Moore, R.; Hancher, M.; Turubanova, S.; Tyukavina, A.; Thau, D.; Stehman, S.; Goetz, S.; Loveland, T. & others (2013), 'High-resolution global maps of 21st-century forest cover change', Science 342(6160), 850–853.

Harris, N. L.; Brown, S.; Hagen, S. C.; Saatchi, S. S.; Petrova, S.; Salas, W.; Hansen, M. C.; Potapov, P. V. & Lotsch, A. (2012), 'Baseline map of carbon emissions from deforestation in tropical regions', Science 336(6088), 1573–1576.

Heckman, J. J., Ichimura, H. and Todd, P. E. (1997): "Matching as an Econometric Evaluation Estimator: Evidence from Evaluating a Job Training Programme," Review of Economic Studies, 64(4), 605–54.

Imbens, G. W. (2004): "Nonparametric Estimation of Average Treatment Effects Under Exogeneity: A Review," The Review of Economics and Statistics, 86(1), 4–29.

IPAM & FVPP (2009). Desmatamento evitado em pequenas propriedades rurais na região da Rodovia Transamazônica. Altamira, Brazil: Instituto de Pesquisa Ambiental da Amazônia and Fundação Viver, Produzir, e Preservar.

Jagger, P.; Atmadja, S.; Pattanayak, S.; Sills, E. & Sunderlin, W. (2009), 'Learning while doing: evaluating impacts of REDD+ projects'.

Jindal, R.; Kerr, J. M. & Carter, S. (2012), 'Reducing Poverty Through Carbon Forestry? Impacts of the N'hambita Community Carbon Project in Mozambique', World Development 40(10), 2123–2135.

Kshatriya, M.; Sills, E. & Lin, L. (2013), 'Global database of REDD+ and other forest carbon projects', Interactive map.

Lawlor, K.; Madeira, E. M.; Blockhus, J. & Ganz, D. J. (2013), 'Community Participation and Benefits in REDD+: A Review of Initial Outcomes and Lessons', Forests 4(2), 296–318.

Maia, H.; Hargrave, H. & Gómez, J. and Röper, M. (2011), 'Avaliação de Plano de ação para a prevenção e controle do desmatamento na Amazônia legal: Versão preliminar', Technical report, CEPAL/GIZ/IPEA.

May, P. H.; Boyd, E.; Veiga, F. & Chang, M. (2004), 'Local sustainable development effects of forest carbon projects in Brazil and Bolivia: a view from the field"The International Conference on Rural Livelihoods, Forests and Biodiversity', International Institute for Environment and Development London.

Muradian, R.; Corbera, E.; Pascual, U.; Kosoy, N. & May, P. H. (2010), 'Reconciling theory and practice: an alternative conceptual framework for understanding payments for environmental services', Ecological economics 69(6), 1202–1208.

Nagendra, H. & Ostrom, E. (2012), 'Polycentric governance of multifunctional forested landscapes', International Journal of the Commons 6(2), 104–133.

Nelson, A. & Chomitz, K. M. (2011), 'Effectiveness of strict vs. multiple use protected areas in reducing tropical forest fires: a global analysis using matching methods', PLoS One 6(8), e22722.

Nepstad, D.; McGrath, D.; Stickler, C.; Alencar, A.; Azevedo, A.; Swette, B.; Bezerra, T.; DiGiano, M.; Shimada, J.; Seroa da Motta, R.; Armijo, E.; Castello, L.; Brando, P.; Hansen, M. C.; McGrath-Horn, M.; Carvalho, O. & Hess, L. (2014), 'Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains', Science 344.

Pascual, U.; Phelps, J.; Garmendia, E.; Brown, K.; Corbera, E.; Martin, A.; Gomez-Baggethun, E. & Muradian, R. (2014), 'Social equity matters in payments for ecosystem services', BioScience, biu146.

Pattanayak, S. (2009), 'Rough guide to impact evaluation of environmental and development programs', .

Peters-Stanley, M. & Gonzalez, G. (2014), 'Sharing the Stage State of the Voluntary Carbon Markets 2014', A Report by Forest Trends' Ecosystem Marketplace: Executive Summary, Washington DC .

Pfaff, A.; Robalino, J. A. & Sanchez-Azofeifa, G. A. (2008), 'Payments for environmental services: empirical analysis for Costa Rica', Terry Sanford Institute of Public Policy, Duke University, Durham, NC, USA.

Rode, J.; Gómez-Baggethun, E. & Krause, T. (2014), 'Motivation crowding by economic incentives in conservation policy: A review of the empirical evidence', Ecological Economics.

Rosenbaum, P. R., & Rubin D. B. (1983): "The Central Role of the Propensity Score in Observational Studies for Causal Effects," Biometrika, 70(1), 41–55.

Rubin, D. B. (1978): "Bayesian Inference for Causal Effects: The Role of Randomization," The Annals of Statistics, 6(1), 34–58.

Sablayrolles, P.; Oliveria, C. & Pinto, C. (2012), 'Adequação ambiental e politicas públicas para a agricultura familiar do Alto Xingu', Associação para o Desenvolvimento da Agricultura Familiar do , Technical report, GRET.

Sierra, R. & Russman, E. (2006), 'On the efficiency of environmental service payments: a forest conservation assessment in the Osa Peninsula, Costa Rica', Ecological Economics 59(1), 131–141.

Simonet, G.; Karsenty, A.; de Perthuis, C.; Newton, P. & Schaap, B. (2014), 'REDD+ projects in 2014: an overview based on a new database and typology', Cahiers de la Chaire Economie du Climat - Information and Debates Series 32. Working Paper.

Smith, N. J.; Falesi, I. C.; Alvim, P. d. T. & Serrao, E. A. S. (1996), 'Agroforestry trajectories among smallholders in the Brazilian Amazon: innovation and resiliency in pioneer and older settled areas', Ecological Economics 18(1), 15–27.

Soares-Filho, B. S.; Nepstad, D. C.; Curran, L. M.; Cerqueira, G. C.; Garcia, R. A.; Ramos, C. A.; Voll, E.; McDonald, A.; Lefebvre, P. & Schlesinger, P. (2006), 'Modelling conservation in the Amazon basin', Nature 440(7083), 520–523.

Sunderlin, W. D.; Larson, A. M.; Duchelle, A.; Sills, E. O.; Luttrell, C.; Jagger, P.; Pattanayak, S.; Cronkleton, P. & Ekaputri, A. (2010), Technical guidelines for research on REDD+ project sites with survey instruments and code book, CIFOR.

Todd, P. E. (2008): "Evaluating Social Programs with Endogenous Program Placement and Selection of the Treated," vol. 4, chap. 60, pp. 3847–3894. Elsevier, 1 edn.

Walker, R. & Homma, A. K. O. (1996), 'Land use and land cover dynamics in the Brazilian Amazon: an overview', Ecological Economics 18(1), 67–80.

Weber, J. G.; Sills, E. O.; Bauch, S. & Pattanayak, S. K. (2011), 'Do ICDPs work? An empirical evaluation of forest-based microenterprises in the Brazilian Amazon', Land Economics 87(4), 661–681.

Wunder, S. (2007), 'The efficiency of payments for environmental services in tropical conservation', Conservation biology 21(1), 48–58.

9 Figures

Figure 1: Location of the PAS project and of the villages interviewed

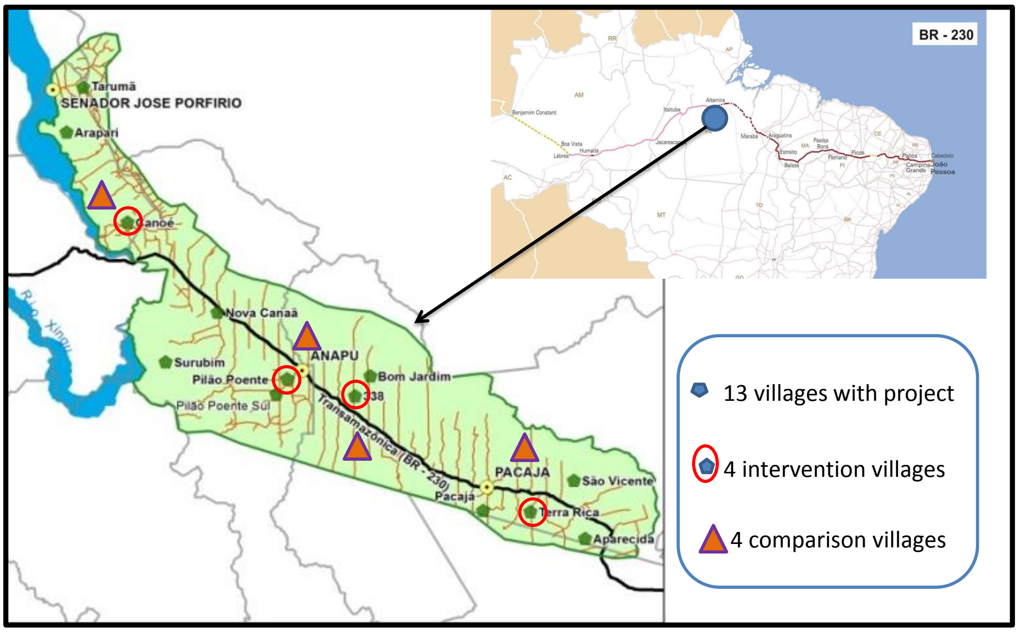


Figure 2: Propensity score distribution in the participant and comparison group

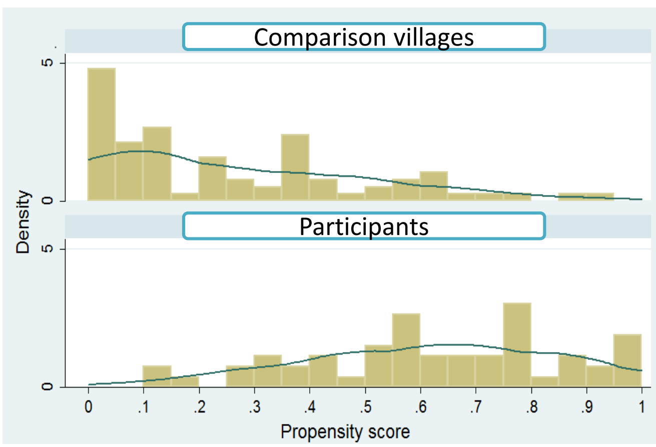
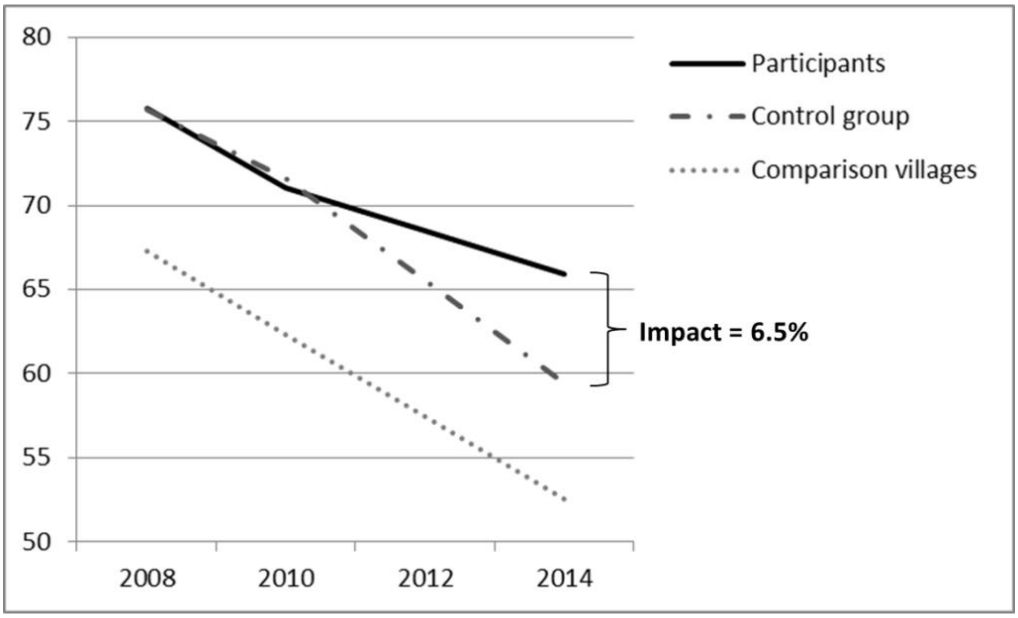


Figure 3: Evolution of the forest cover between 2008 and 2014



10 Tables

Table 1: Main characteristics of the sample for the year 2014

Variable	Unit	Obs.	Mean	Median	Std dev.
Total area used in 2014	hectares	181	92.86	87.30	63.17
Percentage of land dedicated to forest in 2014	%	181	58.77	58	21.01
Percentage of land dedicated to agriculture in 2014	%	181	7.48	4.80	8.30
Percentage of land dedicated to pasture in 2014	%	181	32.28	29.41	21.66
Estimated value of all crops harvested over one year	Reais/year	181	11990	5908	19484
Estimated value of all livestock owned in 2014	Reais	181	26790	12570	50649
Income from Bolsa Familia government program	Reais/year	181	1856	1400	2322
Income from retirement pension	Reais/year	181	3952	0	5964
Income from wage labour	Reais/year	181	4696	720	9631
Income from own business	Reais/year	181	1734	0	6827
Age of the head of the household in 2014	Years	181	52.91	55	12.69
Number of years of education of the head of the household	Years	181	2.62	2	3.13
Number of members in the household	Members	181	4.73	4	2.62

Note: n=181.

Table 2: Descriptive statistics and t-tests for difference between intervention and comparison villages

Variable	**Mean comparison villages**	**Mean intervention villages**	**pvalue**	**Significance**
Total area used, in hectares	88.34	96.37	0.390	
Percentage of land dedicated to forest in 2010	62.31	69.47	0.012	**
Percentage of land dedicated to forest in 2014	52.56	63.16	0.001	***
Variation of forest land between 2010 and 2014	*-9.75*	*-6.30*	*0.182*	
Percentage of land dedicated to agriculture in 2010	6.35	8.40	0.095	*
Percentage of land dedicated to agriculture in 2014	6.46	8.20	0.165	
Variation of agricultural land between 2010 and 2014	*0.11*	*-0.21*	*0.806*	
Percentage of land dedicated to pasture in 2010	30.36	21.22	0.001	***
Percentage of land dedicated to pasture in 2014	39.85	26.93	0.000	***
Variation of pasture land between 2010 and 2014	*9.49*	*5.71*	*0.117*	.
Percentage of land dedicated to forest in 2008	67.27	74.30	0.015	**
Estimated value of all crops harvested over one year, in Reais/year	5522.94	7660.33	0.154	
Estimated value of all livestock owned in 2010, in Reais	14399.39	13161.32	0.680	
Income from Bolsa Familia government program, in Reais/year	776.99	1146.70	0.085	*
Income from retirement pension, in Reais/year	2689.61	1544.03	0.072	*
Income from wage labour, in Reais/year	1270.27	3202.51	0.005	***
Income from own business, in Reais/year	225.33	441.17	0.421	
Age of the head of the household in 2010	50.92	49.94	0.602	
Number of years of education of the head of the household	2.28	2.82	0.146	.
Number of members in the household	4.83	5.15	0.376	

Note: n=181, Comparison villages = 75 households, Intervention villages = 106 households.
Significance: ***: pavlue<1%, **: pvalue<5%, *: pvalue<10%, “ .”:<15%.
The total of land categories is not 100% because we excluded categories such as infrastructure and sylvopasture due to their limited importance in terms of area and/or number of households concerned.

Table 3: Student tests to compare participants and non-participants within intervention villages

Variable	Mean non participants	Mean participants	pvalue	Significance
Participation in the Proambiente program	0.26	0.79	0.000	***
Percentage of land dedicated to forest in 2010	67.96	71.03	0.360	
Total area used, in hectares	114.48	77.56	0.011	**
Percentage of land dedicated to agriculture in 2010	0.08	0.09	0.621	
Percentage of land dedicated to pasture in 2010	0.23	0.19	0.228	
Percentage of land dedicated to forest in 2008	72.92	75.74	0.420	
Estimated value of all crops harvested over one year, in Reais/year	9127.80	6136.42	0.205	
Estimated value of all livestock owned in 2010, in Reais	18432.17	7687.75	0.028	**
Income from Bolsa Familia government program, in Reais/year	845.39	1459.60	0.116	.
Income from retirement pension, in Reais/year	1732.59	1348.21	0.564	
Income from wage labour, in Reais/year	1492.99	4977.78	0.006	***
Income from own business, in Reais/year	791.22	77.65	0.146	.
Age of the head of the household in 2010	51.65	48.17	0.144	.
Number of years of education of the head of the household	2.65	3.00	0.518	
Number of members in the household	4.83	5.48	0.173	

Note: n=106, Non participants=54 households, Participants=52 households
Significance: ***: pavlue<1%, **: pvalue<5%, *: pvalue<10%, “ .”:<15%.

Table 4: Determinants of participation in the PAS project (logistic regression)

Covariate X	Odds ratio	Std. Error	z	pvalue	significance
Total area used, in hectares	0.99	0.01	-0.85	0.393	
Percentage of land dedicated to forest in 2010	1.12	0.09	1.41	0.158	
Percentage of land dedicated to agriculture in 2010	1.11	0.08	1.32	0.187	
Percentage of land dedicated to pasture in 2010	1.07	0.07	0.98	0.329	
Percentage of land dedicated to forest in 2008	0.96	0.04	-1.24	0.217	
Estimated value of all crops harvested over one year, in Reais/year	1.00	0.00	0.25	0.803	
Estimated value of all livestock owned in 2010, in Reais	1.00	0.00	-1.08	0.280	
Income from Bolsa Familia government program, in Reais/year	1.00	0.00	1.49	0.137	
Income from retirement pension, in Reais/year	1.00	0.00	0.59	0.554	
Income from wage labour, in Reais/year	1.00	0.00	2.79	0.005	**
Income from own business, in Reais/year	1.00	0.00	-0.48	0.634	
Age of the head of the household in 2010	0.97	0.03	-1.15	0.252	
Number of years of education of the head of the household	0.95	0.10	-0.51	0.608	
Number of members in the household	0.96	0.11	-0.36	0.720	

Note: n=106 households, including 52 participants and 54 non-participants.
One asterisk (*) denotes rejection of the null hypothesis (equality of means) at the 5% significance level; two asterisks (**) denote rejection of the null hypothesis (equality of means) at the 1% significance level".

Table 5: Balancing tests before and after matching

Variable		Mean comparison villages	Mean participants	t	pvalue	Significance
Percentage of land dedicated to forest in 2010	Unmatched	62.31	71.03	1.67	0.011	*
	Matched	71.63	71.03	0.39	0.698	
Total area used, in hectares	Unmatched	88.34	77.56	1.93	0.155	
	Matched	75.37	77.56	-0.47	0.642	
Percentage of land dedicated to agriculture in 2010	Unmatched	6.35	8.85	0.55	0.122	
	Matched	6.82	8.85	-1.75	0.086	
Percentage of land dedicated to pasture in 2010	Unmatched	30.36	19.18	1.911	0.000	**
	Matched	20.77	19.18	0.97	0.339	
Percentage of land dedicated to forest in 2008	Unmatched	67.27	75.74	1.73	0.009	**
	Matched	75.71	75.74	-0.02	0.988	
Estimated value of all crops harvested over one year, in Reais/year	Unmatched	5522.94	6136.42	1.48	0.641	
	Matched	4643.21	6136.42	-1.78	0.081	
Estimated value of all livestock owned in 2010, in Reais	Unmatched	14399.39	7687.75	1.92	0.003	**
	Matched	8879.74	7687.75	0.91	0.367	
Income from Bolsa Familia government program, in Reais/year	Unmatched	776.99	1459.60	0.12	0.039	*
	Matched	977.99	1459.60	-1.65	0.105	
Income from retirement pension, in Reais/year	Unmatched	2689.61	1348.21	1.98	0.061	
	Matched	1686.86	1348.21	0.84	0.403	
Income from wage labour, in Reais/year	Unmatched	1270.27	4977.78	0.08	0.003	**
	Matched	3145.91	4977.78	-2.14	0.037	*
Income from own business, in Reais/year	Unmatched	225.33	77.65	3.30	0.226	
	Matched	93.75	77.65	0.27	0.790	
Age of the head of the household in 2010	Unmatched	50.92	48.17	1.16	0.215	
	Matched	51.38	48.17	2.17	0.035	*
Number of years of education of the head of the household	Unmatched	2.28	3.00	0.55	0.140	
	Matched	2.20	3.00	-2.29	0.026	*
Number of members in the household	Unmatched	4.83	5.48	0.93	0.140	
	Matched	5.63	5.48	0.44	0.663	

Note: n=127, Controls=75 households, Participants=52 households.
One asterisk (*) denotes rejection of the null hypothesis (equality of means) at the 5% significance level; two asterisks (**) denote rejection of the null hypothesis (equality of means) at the 1% significance level".

Table 6: ATT measured by OLS regression and six matching methods

Estimator	att	se	stat	
ols_x	6.46	3.41	1.89	*
ols_ps	6.06	3.81	1.59	°
nnm_2_x	4.57	3.15	1.45	°
nnm_4_x	7.02	2.91	2.42	**
nnm_2_ps	1.14	3.73	0.31	
nnm_4_ps	2.94	3.38	0.87	
psm_kernel	7.96	4.48	1.78	*

Significance: *** : pvalue<1%, ** : pvalue<5%, * : pvalue<10%, ° : pvalue<15%.

Table 7: Impact of the project on pasture land

Estimator	Participants		Intervention villages		Participants ex Proambiente	
ols_x	-7.84	**	-4.73	*	-9.43	***
	(3.20)		(2.45)		(3.53)	
ols_ps	-7.15	**	-4.47	*	-8.52	**
	(3.64)		(2.62)		(4.06)	
nnm_2_x	-7.20	**	-4.89	*	-7.98	**
	(3.22)		(2.84)		(3.40)	
nnm_4_x	-8.11	***	-5.57	**	-9.13	***
	(2.93)		(2.65)		(3.14)	
nnm_2_ps	-5.78	°	-7.10	**	-7.38	*
	(3.74)		(3.01)		(4.12)	
nnm_4_ps	-6.03	*	-5.92	**	-7.58	**
	(3.48)		(2.65)		(3.55)	
psm_kernel	-11.32	***	-6.31	**	-12.37	***
	(3.12)		(2.47)		(3.52)	

Significance: *** : pvalue<1%, ** : pvalue<5%, * : pvalue<10%, ° : pvalue<15%.

Table 8: Impact of the project on wage salary

Estimator	att	se	stat	
ols_x	5332	2205	2.42	**
ols_ps	3620	2431	1.49	°
nnm_2_x	3447	3064	1.12	
nnm_4_x	2960	2865	1.03	
nnm_2_ps	3308	2934	1.13	
nnm_4_ps	2741	2840	0.96	
psm_kernel	4034	2683	1.50	°
psm_llr	5785	2951	1.96	**

Significance: ***: pvalue<1

Table 9: Balancing tests before and after matching when focusing on ex Proambiente participants

Variable		**Mean comparison villages**	**Mean participants**	**t**	**pvalue**	**Significance**
Percentage of land dedicated to forest in 2010	Unmatched	64.71	72.62	1.53	0.018	*
	Matched	73.00	72.62	0.20	0.844	
Total area used, in hectares	Unmatched	97.02	79.44	3.76	0.039	*
	Matched	76.81	79.44	-0.47	0.642	
Percentage of land dedicated to agriculture in 2010	Unmatched	7.26	8.54	0.56	0.471	
	Matched	6.48	8.54	-1.49	0.145	
Percentage of land dedicated to pasture in 2010	Unmatched	0.27	0.18	1.72	0.001	**
	Matched	0.20	0.18	0.86	0.394	
Percentage of land dedicated to forest in 2008	Unmatched	69.67	77.24	1.75	0.011	*
	Matched	76.75	77.24	-0.27	0.792	
Estimated value of all crops harvested over one year, in Reais/year	Unmatched	6874.28	6434.54	2.72	0.764	
	Matched	4761.77	6434.54	-1.62	0.114	
Estimated value of all livestock owned in 2010, in Reais	Unmatched	15621.69	7024.80	5.73	0.001	**
	Matched	8828.17	7024.81	1.29	0.204	
Income from Bolsa Familia government program, in Reais/year	Unmatched	812.79	1610.59	0.25	0.050	
	Matched	989.68	1610.59	-1.72	0.094	
Income from retirement pension, in Reais/year	Unmatched	2198.29	1405.54	1.68	0.266	
	Matched	1620.13	1405.54	0.48	0.631	
Income from wage labour, in Reais/year	Unmatched	1602.15	5132.55	0.12	0.017	*
	Matched	3170.24	5132.55	-1.87	0.068	
Income from own business, in Reais/year	Unmatched	430.19	83.85	18.11	0.102	
	Matched	90.24	83.85	0.09	0.929	
Age of the head of the household in 2010	Unmatched	50.77	48.90	1.35	0.395	
	Matched	51.08	48.90	1.54	0.132	
Number of years of education of the head of the household	Unmatched	2.55	2.76	0.71	0.652	
	Matched	2.16	2.76	-1.57	0.125	
Number of members in the household	Unmatched	4.85	5.59	0.84	0.087	
	Matched	5.61	5.59	0.06	0.953	

Note: n=116, Controls=75 households, Participants also involved in Proambiente=41 households.
One asterisk (*) denotes rejection of the null hypothesis (equality of means) at the 5% significance level; two asterisks (**) denote rejection of the null hypothesis (equality of means) at the 1% significance level".

Table 10: ATT measured by OLS regression and six matching methods, focusing on ex Proambiente participants

Estimator	**att**	**se**	**stat**	
ols_x	8.44	3.72	2.27	**
ols_ps	8.21	4.27	1.92	*
nnm_2_x	5.57	3.32	1.67	*
nnm_4_x	7.94	3.03	2.62	***
nnm_2_ps	3.68	4.28	0.86	
nnm_4_ps	4.45	3.63	1.22	
psm_kernel	9.74	4.87	2.00	**

Significance: *** : pvalue<1%, ** : pvalue<5%, * : pvalue<10%, ° : pvalue<15%.

Table 11: Indirect effect of the project on non-participants living in intervention villages

Estimator	**att**	**se**	**stat**
ols_x	3.17	3.2	0.99
ols_ps	3.13	3.29	0.95
nnm_2_x	3	3.67	0.82
nnm_4_x	4.57	3.24	1.41
nnm_2_ps	3.46	3.84	0.9
nnm_4_ps	3.85	3.66	1.05
psm_kernel	4.12	3.25	1.27

Significance: *** : pvalue<1%, ** : pvalue<5%, * : pvalue<10%, ° : pvalue<15%.

Table 12: Impact of the project on intervention villages, including both participants and non-participants

Estimator	**att**	**se**	**stat**	
ols_x	4.56	2.52	1.81	*
ols_ps	4.26	2.63	1.62	°
nnm_2_x	4.42	2.76	1.60	°
nnm_4_x	5.41	2.54	2.14	**
nnm_2_ps	4.80	2.96	1.62	°
nnm_4_ps	4.89	2.79	1.76	*
psm_kernel	5.01	2.80	1.86	*

Significance: *** : pvalue<1%, ** : pvalue<5

Table 13: Estimation of the net surplus generated by the PAS project

Avoided emission reductions (in tCO2)	**Benefit (USD/tCO2)**	**Benefit (USD)**	**Cost (USD)**	**Net surplus (USD)**
833512	5	4167560	200200	3967360
833512	20	16670260	200200	16470060
833512	65	54178410	200200	53978210