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CAUÊ DIAS CARRILHO

Forest conservation and well-being outcomes of a REDD+ initiative: A quasi-experimental assessment among smallholders in the Brazilian Amazon

Resultados de iniciativa de REDD+ na conservação das florestas e no bem-estar humano: uma investigação quase-experimental entre pequenos agricultores na Amazônia brasileira

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Versão corrigida

Tese apresentada ao Programa de Pós-Graduação em Ciência Ambiental (PROCAM) da Universidade de São Paulo para a obtenção do título de Doutor em Ciência Ambiental.

Orientadora: Prof.ª. Dra. Carla Morsello

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FOLHA DE APROVAÇÃO

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Membros da Comissão Julgadora

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RESUMO

CARRILHO, Cauê Dias. Resultados de iniciativa de REDD+ na conservação das florestas e no bem-estar humano: uma investigação quase-experimental entre pequenos agricultores na Amazônia brasileira. 2021. Tese (Doutorado). Programa de Pós-Graduação em Ciência Ambiental (PROCAM), Instituto de Energia e Ambiente. Universidade de São Paulo, São Paulo, 2021.

Avaliações de impacto de REDD+ indicam que o desmatamento é comumente reduzido, embora os efeitos sobre o bem-estar humano sejam nulos. Porém, como essas avaliações ainda são raras, a eficácia das iniciativas de REDD+ permanece em aberto. Mais raros ainda são os estudos que investigaram se os resultados se sustentam após o término das iniciativas. Como a maioria delas foi avaliada somente no início, os efeitos no longo prazo são pouco conhecidos. O objetivo desta tese, portanto, foi avaliar os efeitos de curto e longo prazo de uma iniciativa de REDD+ na Amazônia brasileira sobre o desmatamento e o bem-estar da população local. Também buscou-se identificar os fatores que impulsionaram tais efeitos. Foi analisado o Projeto Assentamentos Sustentáveis na Amazônia, iniciativa de REDD+ implementada pelo Instituto de Pesquisa Ambiental da Amazônia (IPAM) na região da rodovia Transamazônica no estado do Pará (Brasil). Para reduzir o desmatamento de pequenos agricultores, o Projeto forneceu Pagamentos por Serviços Ambientais (PSA) e incentivos para adoção de atividades econômicas de baixo impacto. Delineamentos quase-experimentais foram adotados nos três capítulos. Foram analisados dados em painel coletados por entrevistas estruturadas em três anos. No primeiro capítulo, avaliamos os efeitos da iniciativa de REDD+ no desmatamento e bem-estar percebido, incluindo efeito de transbordamento intracomunitário. Ademais, investigamos o quanto os efeitos persistiram após o término da iniciativa. Os resultados indicam que, em média, 7,80% a 10,32% de cobertura florestal foi salva provavelmente pelo fornecimento de PSA. A iniciativa também aumentou a probabilidade de melhorar o bem-estar dos participantes em 27-44%. Não encontramos evidência de transbordamento. Após o término da iniciativa, o desmatamento foi retomado e o bem-estar percebido reduzido - porém, as áreas de floresta salvas não foram derrubadas. No segundo capítulo, investigamos se a adoção de atividades econômicas alternativas foi um mecanismo causal para autossustentar a redução do desmatamento. Nossa hipótese foi a de que a iniciativa teria promovido resultados heterogêneos no longo prazo, os quais variavam conforme a adoção de atividades econômicas alternativas pelas unidades participantes. De fato, as unidades domésticas que adotaram atividades alternativas tiveram uma média de 14,67% a 16,90% a mais de cobertura florestal do que as do grupo controle, enquanto impactos nulos foram observados nas unidades que não adotaram tais atividades. No terceiro capítulo, avaliamos os efeitos de curto e longo prazo da iniciativa sobre a renda e a produtividade agrícolas. Também investigamos se incrementos na produtividade contribuíram para a conservação da floresta (efeito poupa-terra) ou para sua perda (efeito rebote). Encontramos impactos iniciais nulos. Porém, no longo prazo, foram detectados rendimentos agrícolas totais e por hectare mais elevados. Não foram encontradas evidências suficientes para o efeito rebote nem para o efeito poupa-terra. No geral, nossos resultados indicam que a iniciativa de REDD+ deixou resultados positivos em termos de conservação da floresta e aumento da lucratividade agrícola. As principais implicações para a conservação das florestas desse estudo são: i) pagamentos temporários podem atrasar, embora não erradicar permanentemente o desmatamento; ii) a adoção de atividades econômicas alternativas pode garantir redução autossustentada no desmatamento.

Palavras-chave: REDD+, mitigação das mudanças climáticas, permanência, Pagamentos por Serviços Ambientais, avaliação de impacto.

ABSTRACT

CARRILHO, Cauê Dias. Forest conservation and well-being outcomes of a REDD+ initiative: A quasi-experimental assessment among smallholders in the Brazilian Amazon. 2021. Tese (Doutorado). Programa de Pós-Graduação em Ciência Ambiental (PROCAM), Instituto de Energia e Ambiente. Universidade de São Paulo, São Paulo, 2021.

REDD+ impact evaluations indicate deforestation is commonly reduced, despite null outcomes on well-being. However, as those evaluations are still rare, the effectiveness of REDD+ initiatives remain an open question. Even less studied is if outcomes achieved are sustained after initiatives end. Because most initiatives were evaluated shortly after the application of incentives, there is a knowledge gap about their long-term effects. Therefore, the main goal of this thesis was to assess both short and long-term effects of a Brazilian Amazon REDD+ initiative on deforestation and local people's well-being. We also wanted to identify which were the driving factors behind the observed outcomes. We scrutinized the *Projeto Assentamentos Sustentáveis na Amazônia*, a REDD+ project implemented by a Brazilian NGO – *Instituto de Pesquisa Ambiental da Amazôni*a (IPAM) – in the Transamazon highway region of the Pará state (Brazil). The initiative combined Payments for Environmental Services (PES) with sustainable livelihood alternatives to reduce smallholder deforestation. In the three chapters presented here, quasi-experimental designs were adopted. Data came from face-to-face surveys in a three-datapoint panel design. The purpose of the first chapter was to assess the effects of the REDD+ initiative on deforestation and perceived well-being, including intra-community spillover effects, besides scrutinizing to what extent the observed outcomes persisted after the initiative ended. Results indicate an average of 7.80% to 10.32% of forest cover was saved by the REDD+ initiative probably by providing PES. It also increased the probability of improving enrollees' wellbeing by 27-44%. We found no evidence for significant intra-community spillover. After the initiative ended, forest loss rebounded and perceived wellbeing declined – yet, importantly, past saved forest was not cleared. In the second chapter, we revisited the long-term evaluation of the deforestation outcomes to analyze whether the adoption of alternative livelihood activities was a causal mechanism for self-sustaining the deforestation reduction induced by a REDD+ initiative. We hypothesized the REDD+ initiative promoted heterogeneous outcomes in the long-term, which varied according to whether households adopted alternative livelihood activities. Indeed, treated households that adopted new activities had an average of 14.67% to 16.90% more forest than controls, while null impacts were observed in treated households that did not adopt alternative livelihood activities. In the third chapter, we assessed both short and long-term effects of the initiative on farm income and agricultural productivity. We also investigated if increases in agricultural productivity may have contributed to forest conservation (land sparing) or to forest loss (rebound effect). Results indicate null impacts on farm income and agricultural productivity in the early project stage. Yet, in the long-term, higher farm income and yields per hectare were detected. We found no sufficient evidence neither for the rebound effect nor for land sparing. On aggregate, our findings indicate the REDD+ initiative left win-win outcomes in terms of forest conservation and increasing agricultural profitability. Notably, the main REDD+ implications to conservation of our findings are: i) temporary payments might effectively delay, though not permanently eradicate forest loss; ii) adoption of alternative livelihoods may ensure self-sustained deforestation reduction.

Keywords: REDD+, climate change mitigation, permanence, Payments for Environmental Services, impact assessment.

SUMÁRIO

LISTA DE SIGLAS

AFOLU	Agriculture, Forestry and Other Land Use
ATT	Average Treatment Effect on the Treated
BACI	Before-After-Control-Impact
BRL	Brazilian *reais*
CAR	*Cadastro Ambiental Rural*
CIFOR	Center for International Forestry Research
COP	Conference of the Parties
DID	Difference-in-Differences
REDD+	Reducing Emissions from Deforestation and Forest Degradation and conservation, sustainable management and enhancement of carbon stocks
GCS	Global Comparative Study
GHG	Greenhouse Gas
IBAMA	*Instituto Brasileiro do Meio Ambiente e dos Recursos Renováveis*
ICDP	Integrated Conservation and Development Project
IGP-M	*Índice Geral de Preços – Mercado*
IPAM	*Instituto de Pesquisa Ambiental da Amazôni*a
MapBiomas	*Projeto de Mapeamento Anual do Uso e Cobertura da Terra no Brasil*
MATT	Mechanism Average Treatment Effect on the Treated
MRV	Monitoring, Reporting and Verification
NDC	Nationally Determined Contribution
NGO	Non-Governmental Organization
NNM	Nearest Neighbor Matching
PAS	*Projeto Assentamentos Sustentáveis na Amazônia*
PES	Payments for Environmental Services
PSM	Propensity Score Matching
RCT	Randomized Control Trial
RISEMP	Regional Integrated Silvo-pastoral Ecosystem Management Project
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar

GENERAL INTRODUCTION

Curbing deforestation in developing countries has moved to the center stage in the international climate debate over the last decade (Angelsen and Atmadja, 2008), and there are two main reasons for that. First, because deforestation is the main source of Agriculture, Forestry and Other Land Use (AFOLU) Greenhouse Gas (GHG) emissions, which altogether represent almost a quarter of the global anthropogenic emissions (IPCC, 2019). Second, reducing deforestation would be relatively cheaper than other types of climate change mitigation, such as investing in technologies that reduce fossil fuel emissions (Stern, 2006). Moreover, forests serve as important carbon sinks (Griscom et al., 2017) and provide a wide range of additional ecosystem services (Brockerhoff et al., 2017).

To promote the reduction of deforestation emissions, the REDD+ mechanism was created – short for "Reducing Emissions from Deforestation and Forest Degradation and conservation, sustainable management and enhancement of carbon stocks". An outcome of negotiations between signatory countries of the United Nations Framework Convention on Climate Change (UNFCCC), this mechanism underwent certain changes until reaching its current scope (Pistorius, 2012). At first, the mechanism was restricted to reducing emissions from deforestation, being named RED during the Conference of the Parties (COP) 11, in 2005. Forest degradation, represented by the second "D", was included in 2007 at the COP 13, when the mechanism gained prominence in the global agenda of climate change mitigation. Finally, at COP 15, in 2009, three supplementary elements were added to the scope, represented by the "+" sign: (i) forest conservation, (ii) sustainable forest management and (iii) increases in forest carbon stock (Pistorius, 2012). Safeguards were later assumed, at COP 16 in 2010, to ensure REDD+ implementation would do no harm to local people and the environment (Duchelle and Jagger, 2014). Consequently, REDD+ evolved to be a triple-win policy, combining climate change mitigation with poverty reduction and biodiversity conservation (Angelsen and Mcneill, 2013).

The original idea behind REDD+ was to make standing forests more profitable than cut (Angelsen and Mcneill, 2013), with funding primarily sourced from carbon markets (Angelsen, 2017). Countries committed to reducing GHG emissions under the Kyoto Protocol (i.e., Annex I) would purchase carbon credits, generated by emission reductions from avoided deforestation initiatives in non-committed countries (i.e., non-Annex I) (Angelsen and Wertz-Kanounnikoff, 2008). To reduce forest emissions, initiatives would be implemented mainly by Payments for Environmental Services (PES) to local governments or forest dwellers (Angelsen and Mcneill, 2013). PES represent a voluntary transaction where external beneficiaries of environmental services make conditional payments to landowners or land users for ecosystem conservation or restoration (Wunder, 2007, 2005).

However, at least three aspects of the REDD+ mechanism actual implementation differ from what was originally envisaged. First, a global carbon market under the Paris Agreement has failed to materialize. Thus, despite some transactions have occurred in voluntary carbon markets (Streck, 2012), REDD+ is currently sourced mostly by result-based aid from multilateral and bilateral agreements, with below than expected investments (Angelsen, 2017; Sunderlin et al., 2015). For instance, Norway established between 2008 and 2010 bilateral agreements with Tanzania, Brazil, Guyana and Indonesia for monetary donations (Angelsen, 2017). In Brazil, donations were destinated to the Amazon Fund – the world's largest results-based funding program to REDD+ (Correa et al., 2019).

Second, REDD+ is operating on the ground through different interventions across locations (Duchelle et al., 2017), and PES has been relatively under-utilized (Sunderlin et al., 2015). In fact, most of the current initiatives are based on Integrated Conservation and Development Projects (ICDPs) (Angelsen et al., 2017), which may be implemented through different strategies (Bauch et al., 2014). Yet all ICDP-type programs rely on non-conditional support (e.g., free agricultural inputs, technical assistance) aimed to boost rural communities to adopt alternative livelihood activities, which are expected to reduce their poverty levels while promoting environmental conservation (Sanjayan et al., 1997).

Finally, as enshrined in the Paris Agreement, REDD+ implementation should focus on national-level programs as part of countries' Nationally Determined Contributions (NDCs) for climate change mitigation (Wunder et al., 2020). Indeed, 56 countries included REDD+ as part of their NDCs (Hein et al., 2018), and national programs made some progress (Thuy et al., 2018). For instance, at least 34 countries formulated national strategies for REDD+ and 16 implemented or are planning to implement monitoring, reporting and verification (MRV) systems, as mentioned in their NDCs (Hein et al., 2018). However, most of the action has remained in local-scale initiatives (Wunder et al., 2020), more commonly implemented by non-governmental organizations (NGOs) and private companies (Sills et al., 2014). As of December 2020, 624 local REDD+ initiatives were reported worldwide (Simonet et al., 2021).

Implementing REDD+ has thus proved more challenging than initially expected. At first, REDD+ generated widespread excitement as a fast, cheap and easy way to curb GHG emissions. However, 15 years after its launch, the world's high expectations were not met (Angelsen et al., 2018). In fact, based on allegedly insufficient results, certain actors have already questioned the continuity of the mechanism (Fletcher et al., 2016; Lund et al., 2017), following a common trend in the conservation realm of abandoning and replacing strategies by new alleged “silver bullets”, instead of improving them (Redford et al., 2013).

Whereas is indeed true that forest loss has so far remained high worldwide (Angelsen et al., 2018), we were yet unable to convincingly state whether REDD+ has been successful in reaching desirable outcomes. To do so, we need to focus our attention on rigorous impact evaluations which adopt credible counterfactual scenarios (i.e., what would have happened in the absence of REDD+ interventions) (Sills et al., 2017; White, 2009). These evaluations allow to more confidently attribute observed outcomes to specific interventions. The rationale is to distinguish the impacts of interventions from the effects of other confounding factors, such as contemporary policies and economic changes, based on a counterfactual analysis of an alternative scenario in which the intervention did not occur (Ferraro and Pattanayak, 2006; Sills et al., 2017; White and Raitzer, 2017).

Of the few counterfactual-based evaluations, most of them indicate REDD+ is, in fact, achieving a certain level of forest conservation (e.g., Bos et al., 2017; Jayachandran et al., 2017; Roopsind et al., 2019), typically in a welfare-neutral manner (e.g., Solis et al., 2021; Sunderlin et al., 2017). However, as the number of evaluations is still small (Duchelle et al., 2018), we probably cannot yet confidently make sweeping conclusions about REDD+ effectiveness; thus the question remains open.

Even less studied is whether REDD+ achieved outcomes are persistent over time. Since most previous assessments estimated only short-term impacts (e.g., Bos et al., 2017; Jayachandran et al., 2017; Simonet et al., 2019), evidence on whether REDD+ initiatives are promoting long-term deforestation reduction instead of simply postponing it for a while is almost null (but see: Roopsind et al., 2019; World Bank, 2018). If REDD+ initiatives fail to promote novel land uses able to conserve forests or at least to deforest less while improving economic returns, “business-as-usual” activities (e.g., extensive cattle ranching, swidden agriculture) are expected to return after a while. Consequently, the REDD+ saved forest area will likely be converted after an initiative ends (non-permanence) (Angelsen and Wertz-Kanounnikoff, 2008). The same concern applies to people’s well-being: when REDD+ benefits (e.g., PES, ICDP-type support) are suspended, contributions to well-being, if any, may disappear over time – unless lasting welfare-enhancing assets had been acquired from REDD+ transfers.

In summary, despite the popularity of REDD+ over the last decade, it is not yet clear whether REDD+ initiatives are reaching the desired outcomes for both forests and local inhabitants, and to what extent outcomes persist over time. If outcomes differ across the multiple REDD+ sites worldwide, understanding which factors explain these divergences is essential for guiding the design of effective initiatives.

Therefore, the main goal of this thesis was to assess both short and long-term effects of a Brazilian Amazon REDD+ initiative on deforestation and local people's well-being, as well as to identify which were the driving factors behind the observed outcomes.

Specifically, we scrutinized the *Projeto Assentamentos Sustentáveis na Amazônia* (PAS), a REDD+ project implemented by a Brazilian NGO – *Instituto de Pesquisa Ambiental da Amazôni*a (IPAM) – between 2012 and 2017 in the Transamazon highway region of the Pará state (Brazil). The initiative counted on an ICDP-PES mixed strategy to reduce smallholders' deforestation rates.

This study was associated with the Global Comparative Study on REDD+ from the Center for International Forestry Research (CIFOR), a research initiative aimed at assessing the social and environmental outcomes of 22 local REDD+ initiatives implemented in six countries – Brazil, Peru, Indonesia, Vietnam, Cameroon, and Tanzania (see more in: www.cifor.org/gcs). CIFOR's panel data, collected through face-to-face interviews in three rounds (2010, 2014, 2019), were used for the impact analyzes. 2019 data collection was conducted by the thesis author.

The thesis is structured in this general Introduction, three self-contained chapters and a final section of general concluding remarks.

In the **first chapter**, we investigated the effects of the REDD+ initiative on deforestation and perceived well-being, including intra-community spillover effects, besides scrutinizing to what extent the observed outcomes persisted after the initiative ended. Results indicate an average of 7.80% to 10.32% of forest cover (6.20 to 8.20 ha *per* farm) was saved by the REDD+ initiative probably by providing PES. It also increased the probability of improving enrollees' wellbeing by 27-44%. We found no evidence for significant intra-community spillover. After the initiative ended, forest loss rebounded and perceived wellbeing declined – yet, importantly, past saved forest was not cleared.

In the **second chapter**, we revisited the long-term evaluation of the deforestation outcomes to analyze whether the adoption of alternative livelihood activities was a causal mechanism for self-sustaining the deforestation reduction induced by a REDD+ initiative. We hypothesized the REDD+ initiative promoted heterogeneous outcomes in the long-term, which varied according to whether households adopted alternative livelihood activities. Indeed, treated households that adopted new activities had an average of 14.67% to 16.90% more forest cover (10.40 to 11.98 ha *per* farm) than controls, while null impacts were observed in treated households that did not adopt alternative livelihood activities.

In the **third** and last **chapter**, we assessed both short and long-term effects of the initiative on farm income and agricultural productivity. Furthermore, we investigated if increases in agricultural productivity may have contributed to forest conservation (land sparing – Borlaug hypothesis) or to forest loss (rebound effect – Jevons' paradox). Results indicate null impacts on farm income and agricultural productivity in the early project stage. Yet, in the long-term, higher farm income and yields per hectare were detected. We found no sufficient evidence neither for the rebound effect nor for land sparing.

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CHAPTER 1

Do REDD+ outcomes persist after initiatives end? A longitudinal impact evaluation in the Brazilian Amazon

Abstract

Rigorous impact evaluations of local REDD+ (reduced emissions from deforestation and forest degradation) initiatives have shown some positive outcomes for forests, while wellbeing impacts have been mixed. However, will REDD+ outcomes persist over time after interventions have ended? Using quasi-experimental methods, we investigated the effects of one REDD+ initiative in the Brazilian Amazon on deforestation and people's well-being, including intra-community spillover effects (leakage). We then evaluated to what extent outcomes persisted after the initiative ended (permanence). This initiative combined Payments for Environmental Services (PES) with sustainable livelihood alternatives to reduce smallholder deforestation. Data came from face-to-face surveys with 113 households (treatment: 52; non-participant from treatment communities: 35; control: 46) in a three-datapoint panel design (2010, 2014 and 2019). Results indicate the REDD+ initiative conserved an average of 7.8% to 10.3% of forest cover per household. It also increased the probability of improving enrollees' wellbeing by 27-44%. We found no evidence for significant intra-community leakage. After the initiative ended, forest loss rebounded and perceived wellbeing declined – yet, importantly, past saved forest was not cleared. Our results therefore confirm what the theory and stylized evidence envisioned for temporal payments on activity-reducing ('set-aside'): forest loss was successfully delayed, but not permanently eradicated.

Keywords: conservation incentives, emission reductions, additionality, climate change mitigation, impact assessment.

1. Introduction

REDD+, short for "Reducing Emissions from Deforestation and Forest Degradation and conservation, sustainable management and enhancement of carbon stocks", is a nature-based solution devised to mitigate greenhouse gas emissions while achieving co-benefits, mainly the improvement of human well-being and biodiversity conservation (Angelsen and McNeill, 2013). Launched 15 years ago, REDD+ initially generated widespread excitement as a fresh approach to forest conservation through promoting performance-based incentives at scale. However, global carbon markets, initially envisioned to finance REDD+, have expanded insufficiently, implementation proved more complex than expected, and so far tropical deforestation has thus continued (Angelsen, 2017; Angelsen et al., 2018). Notably, while REDD+ initially was conceived as a jurisdictional mechanism in the Paris Agreement, by far most of the action has remained in smaller-scale pilot projects (Wunder et al., 2020b).

To convincingly make conclusions about REDD+ performance, we need to focus our attention on rigorous impact evaluations vis-à-vis both REDD+ conservation and development outcomes. These evaluations allow attribution of observed outcomes to an intervention through construction of a credible counterfactual scenario (i.e., what would have happened in the absence of the REDD+ initiatives) (Sills et al., 2017; White, 2009). Despite the importance of REDD+ over the last decade, studies using a counterfactual approach have been scarce (Duchelle et al., 2018).

Of the few REDD+ studies using counterfactual approaches to assess deforestation reduction, most indicate moderately positive results (Simonet et al., 2018). For instance, a quasi-experimental assessment of 23 local REDD+ initiatives, based on different intervention mixes (e.g., restrictions on forest clearing and access, Integrated Conservation and Development Project (ICDP)-type activities, and Payments for Environmental Services (PES)), in Brazil, Peru, Tanzania, Cameron, Indonesia and Vietnam, showed that half reduced deforestation, although with moderate effect sizes (Bos et al., 2017). This study was undertaken as part of CIFOR's Global Comparative Study on REDD+ (GCS)[1]. Likewise, a Randomized Control Trial (RCT) found a significant reduction in net tree losses in villages participating in an Ugandan PES-based carbon forestry initiative (tree cover declined 4.2% in treatment but 9.1% in control villages), which translated into an average of 5.5 ha of forestland saved per village (Jayachandran et al., 2017). Even more substantial were the outcomes of a mixed ICDP-PES initiative in the Brazilian Transamazon where participating households halved their yearly

[1] As part of GCS REDD+, CIFOR and partners have assessed the outcomes of 23 local REDD+ initiatives in Brazil, Peru, Indonesia, Vietnam, Cameroon, and Tanzania. See more in: https://www.cifor.org/gcs/

deforestation (Avg=4 ha/household) (Simonet et al., 2019). Finally, a unique quasi-experiment of Guyana's national REDD+ program based on synthetic controls found for 2010-15 a 35% reduction in tree-cover loss (5,800 ha/year) vis-à-vis a no-REDD+ baseline, with tree-cover loss increasing after the program ended (Roopsind et al., 2019).

Other studies typically found small (significant or insignificant) effects of REDD+ initiatives on deforestation. For example, a quasi-experimental assessment of REDD+ initiatives in Mexico's Yucatan Peninsula found no overall reduction in forest cover loss using difference-in-differences (DID) regression and propensity score matching (alternatively, using synthetic controls, effects were mixed) (Ellis et al., 2020). For Peru, a recent review found over periods of 4-6 years insignificant forest conservation effects from a public and a private REDD+ pilot program, respectively – both implemented in the Peruvian Amazon (Montoya-Zumaeta et al., 2021). Returning to Brazil, one quasi-experiment found insignificant REDD+ deforestation impacts in Mato Grosso State's Alta Floresta municipality. This is a REDD+ like initiative under the Amazon Fund, mixing environmental land registrations with PES-ICDP incentives: land registration increased attributably in project sites, yet deforestation effects were insignificant, presumably because of already very low rates of deforestation in the pre-intervention period (Correa et al., 2020). Quite similar is the situation for the large-scale Bolsa Floresta program in Amazonas State, holding also Brazil's oldest REDD+ program in the Juma Reserve. Bolsa Floresta combines PES with collective benefits (health, education, community organization) and ICDP investments in alternative livelihoods (Börner et al., 2013). An evaluation using matching techniques found insignificant forest conservation effects, given that most enrolled areas proved to be remote and little threatened in the first place (Cisneros, 2019). Finally, scrutinizing twelve REDD+ sites, all Amazon Fund projects spread over the Brazilian Amazon, a quasi-experiment with synthetic controls showed that only in four sites was deforestation reduced, whereas nil or negative impacts were observed in the remaining eight (West et al., 2020).

Regarding well-being and livelihoods impacts, evaluations of REDD+ initiatives most frequently indicate small, mixed (positive or negative) effects. For instance, a quasi-experiment based on publicly-available social and spatial data at 18 REDD+ sites in Indonesia suggested the strengthening of local land rights, but potentially negative effects on other welfare indicators (Jagger and Rana, 2017). The aforementioned carbon-focused project in Uganda found a significant rise in the non-food, but no impact in the food consumption of target-households monetary income (Jayachandran et al., 2017). In turn, Solis et al. (2021) found for two REDD+ projects in the Peruvian Amazon (Madre de Dios and Ucayali) insignificant income effects, using matched DID estimations. Likewise, a comparison evaluating 22 local REDD+ initiatives in CIFOR's GCS on REDD+ did not observe any significant impact whatsoever (neither positive, nor negative) on household and village-level perceptions of wellbeing and income sufficiency (Sunderlin et al., 2017). Finally, another quasi-experiment targeting 17 of these 22 GCS REDD+ initiatives showed that impacts on subjective wellbeing of REDD+ participants depended on the composition of REDD+ interventions: a predominance of disincentives (e.g., law enforcement) negatively affected households' perceived well-being, but this negative effect was alleviated when incentives (e.g., PES, ICDP) were added (Duchelle et al., 2017).

Hence, the accumulated evidence suggests local REDD+ initiatives are struggling to achieve strong win-win outcomes in terms of simultaneously delivering sizeable deforestation reductions and well-being improvements. So far, REDD+ is on average achieving moderate conservation effects, typically in a welfare-neutral manner. However, still few counterfactual evaluations exist and practically only REDD+ projects, rather than jurisdictional programs, have been evaluated (Duchelle et al., 2018). More assessments will be needed to increase our confidence about if, when, and how REDD+ interventions are working.

Even less studied is whether REDD+ achievements persist after initiatives are suspended. Since most of the above reviewed initiatives were evaluated only at early stages (e.g. 2-3 years after start for Bos et al. (2017), Jayachandran et al. (2017), and Simonet et al. (2019)), there is an understandable knowledge gap about their longer-term effects.

Theoretically, we should expect that if forest conversion paid off better than forest conservation *ex ante*, this will likely persist post-payment, so that deforestation should pick up again after payments stopped. Yet, under some scenarios substantial post-payment permanence could still happen. First, REDD+ initiatives might explicitly manage to achieve the lasting adoption of more benign land uses with sustained economic returns (e.g. establishing agroforestry systems). Second, REDD+ benefit transfers could have had a motivational 'crowding-in' effect, boosting landowners' altruistic motives for forest conservation – not the most common, but still a possible scenario (Ezzine-de-Blas et al., 2019). Finally, REDD+ might just have successfully bought time for the external environment to have substantially adapted in its own right (e.g. falling commodity prices, alternative employment options, or political changes), thus exogenously reducing the opportunity costs of conservation.

However, these exceptions apart, as default scenario we should rather expect the original environmental externality problem to persist: once REDD+ initiatives have ended, the incremental conversion to alternative land uses (e.g., extensive cattle ranching, swidden agriculture) will continue. Forests that were temporarily spared by the initiatives would thus likely be converted after REDD+ ends (non-permanence) (Dutschke and Angelsen, 2008). If so, REDD+ initiatives would postpone deforestation, instead of permanently reducing it (Angelsen and Wertz-Kanounnikoff, 2008). On the livelihoods side, when REDD+ on-the-ground incentive flows (e.g., PES) end, welfare impacts may also fade, unless longer-lasting welfare-enhancing assets had been constructed from those accumulated REDD+ transferred benefits.

Indeed, the two published evaluations of REDD+ outcomes' permanence that we are aware of found support for our default scenario. The first is the aforementioned quasi-experiment showing that Guyana's national REDD+ program, funded by Norway through performance-based payments for reducing deforestation, decreased tree cover loss during the implementation period (2010-2015) (Roopsind et al., 2019). Yet, right after Norway's payments ceased, in 2016, the authors detected an increase in tree cover loss, which suggested forest protection was not guaranteed without continued payments. The second is a follow-up evaluation of the forest outcomes from the carbon-focused project in Uganda. Implemented between 2011 to 2013, the program had reduced deforestation substantially (Jayachandran et al. 2017). However, using satellite imagery from 2016, World Bank (2018) showed the previous PES recipients resumed forest clearing at similar rates to control group households after payments had ended; yet, importantly, without 'catching up' with the initial curve, i.e. leaving the temporary, payment-induced conservation gains intact.

The results of these two studies, therefore, would suggest REDD+ initiatives are struggling to induce self-sustained deforestation reductions. However, we cannot make sweeping generalizations from only two cases. Fortunately, drawing also on the broader family of forest carbon-focused PES interventions may help us to get a clearer picture (Wunder et al., 2020a), and they present some more optimistic evidence. One example is a natural experiment in PES permanence that occurred in Cuyabeno, Ecuador, within Socio Bosque – the national PES-like program for forest conservation. The program had attributably reduced annual deforestation on enrolled plots by annually 0.4–0.5% points during 2011-14 (Jones et al., 2017). However, when public funds run dry during 2015–17, Socio Bosque payments were suspended for some recipients. Even without pay, they continued to clear less forest than similar non-participating landowners, unless though they held plots close to roads or oil wells: in these plots with higher deforestation threat and presumably larger conservation opportunity costs, forest loss reverted back to rates similar to what applied to unenrolled properties (Etchart et al., 2020).

In the case of using PES as an adoption subsidy for environmentally more benign practices that pay off for land stewards ('asset-building' PES), the prospects for permanence should be better. At least a few case studies seem to also support this empirically, in particular from the World Bank-supported trinational Regional Integrated Silvo-pastoral Ecosystem Management Project (RISEMP). This carbon- and biodiversity-focused PES program paid landowners between 2003 and 2008 for the introduction of silvopastoral practices. In Quindío (Colombia), four years after payments ended, these systems had been widely retained (Pagiola et al., 2016). Similar permanence results were reconfirmed again in 2016 (Calle, 2020). The sister silvopastoral program implemented simultaneously in Nicaragua was assessed also in 2012, showing also widespread permanence, although the evidence here is based only on a before-after comparison of various interventions, without a no-intervention control group (Pagiola et al., 2020). The third rollout was in Costa Rica (2002-07), and also here there is about a decade after (2016) evidence of a high degree of permanence (Rasch et al., 2021). The corollary of their findings is that inducing the lasting adoption of more benign land uses is feasible. In the REDD+ context, this could, in turn, self-sustain the deforestation reduction reached by the initiatives.

On aggregate, permanence is clearly important for the effectiveness of any conservation intervention. It is true that conservation-focused payment programs will typically strive to make conditional contracts and payment flows renewable, but we cannot guarantee funding streams will last forever. Yet, our knowledge about the degree of, and factors influencing permanence remains quite limited – not only for REDD+, but also for other types of conservation payments. Even in the developed Global North, most empirical assessments of post-intervention permanence or 'persistence' are derived from stated landowner intentions, not de facto behavior (Swann and Richards, 2016). It seems likely that permanence is higher for incentives that are linked to asset-building, rather than activity-restricting conservation action (Dayer et al., 2018), but surely the socio-institutional context will also matter at different scales (Rasch et al., 2021).

In this article, we investigate the effects of a local REDD+ initiative in the Brazilian Amazon on deforestation and people's well-being, including intra-community spillover effects (leakage), scrutinizing in particular to what extent outcomes persisted after the initiative and associated 'treatments' ended, thus helping to fill a knowledge gap on REDD+ permanence. The remainder of the paper is organized as follows. In Section 2, we present the study site plus all applied REDD+ interventions. Section 3 accounts for the methods for our sampling and panel data collection. In Section 4, we present our quasi-experimental approach to estimate both short and long-term impacts of the REDD+ initiative. We then show the longitudinal effects of the REDD+ initiative on both deforestation and people's well-being (Section 5). In Section 6, we explore possible explanations for our estimation results, and in the last section, we present conclusions.

2. The Transamazon REDD+ initiative

As part of CIFOR's GCS REDD+, we scrutinized the *Projeto Assentamentos Sustentáveis na Amazônia* (PAS), a REDD+ initiative implemented by a Brazilian non-governmental organization (*Instituto de Pesquisa Ambiental da Amazôni*a – IPAM). PAS started in 2012 but it was suspended in 2017, after IPAM had its refinancing request denied by the Amazon Fund.

Approximately 2,700 households from the western part of the Pará state (Brazil) participated in PAS (IPAM, 2016). However, our study only focused on the 350 households for which IPAM offered PES (see all interventions' description below). They lived in twelve communities located in the municipalities of Anapu, Pacajá and Senador José Porfírio, near the Transamazon highway. This is a high-deforestation area dominated by smallholders (properties up to 100 ha), mostly colonists from the northeast part of the country (Godar et al., 2012; Stella et al., 2020). The 350 households had participated in a previous PES-ICDP mixed federal program (*Proambiente*) from 2003 and 2006, where actual payments were delivered only for six months though (Bartels et al., 2010; Simonet et al., 2019).

Households' main economic activities were cattle ranching and swidden agriculture. Part of the production was sold (e.g., rice, cassava, cocoa), despite poor transportation infrastructure. Secondarily, households depended on forest resources, collected mainly for auto-consumption, such as firewood for cooking, fruits, fish and bushmeat, in addition to monetary income from other sources, especially from government transfers, such as retirement pensions and the *Bolsa Família* conditional cash transfer program (Cromberg et al., 2014b).

The central goal of PAS was to reduce deforestation rates, mainly by increasing profitability in pasture and agricultural plots. To do that, IPAM relied on a ICDP-PES mixed approach, with project activities divided into the following four main components (Simonet et al., 2019).

a. Awareness-raising meetings on environmental legislation and tenure regularization

Between 2013 and 2017, IPAM conducted farmer meetings, explaining the processes involved in land tenure regularization (many local properties were not titled) and Brazilian environmental legislation, especially the Forest Code (Law 12.651/2012), which requires for rural properties in the Amazon to retain a fixed proportion of 50-80% of land covered with native vegetation (Legal Reserve). Failing to comply, landowners could be fined by environmental agencies, such as the federal Brazilian Institute for the Environment and Renewable Natural Resources (*Instituto Brasileiro do Meio Ambiente e dos Recursos Renováveis* – IBAMA).

b. Properties environmental registration

The Forest Code also requires rural landowners to register their properties in the Rural Environmental Registry (*Cadastro Ambiental Rural* – CAR), a public document with information on property boundaries and the location of its areas set aside for protection (Legal Reserve and Permanently Protected Area). During 2012-14, IPAM provided administrative support for CAR registration, as a main instrument for forest monitoring in Brazil. It is legally required when rural landowners want to sell cattle or to access rural credit.

c. Payments for Environmental Services

IPAM offered direct cash payments for households whose properties had at least 30% of forest cover (IPAM, 2016). Contracts were signed in 2013, and quarterly payments were provided from 2014 to 2017. Households could receive up to 1,600 BRL/year (725 USD/year, as of 07/01/2014), depending on the level of compliance with the following conditionalities (Cromberg et al., 2014a): (i) 30% of the payment was contingent upon the conservation of at least 50% of the property as forest (Legal Reserve); (ii) another 30% was contingent upon the conservation of 15 meters-wide forest riparian zones (the Permanently Protected Areas); (iii) the 40% left was based on the adoption of fire-free land management (Simonet et al., 2019).

d. Sustainable livelihood alternatives (ICDP component)

IPAM promoted sustainable livelihood alternatives in the project area, such as cattle ranching intensification, agroforestry (e.g., cacao – *Theobroma cacao*, *açaí* – *Euterpe oleracea*, babassu – *Attalea speciosa*), vegetables (e.g., lettuce – *Lactuca sativa*, cabbage – *Brassica oleracea var. capitata*) and black pepper (*Piper nigrum*). Between 2013 and 2016, IPAM developed customized property management plans together with household heads to decide which economic activities to develop. From 2014 to 2017, IPAM offered technical assistance through regular visits, and free inputs (e.g., wire for fences, fertilizers). According to IPAM, each household could choose a list of inputs valued at up to 5,000 Brazilian reais (BRL) (2,267 USD, as of 07/01/2014) for the planned activities.

Figure 1 synthetizes the timeline of PAS activities, including data collection.

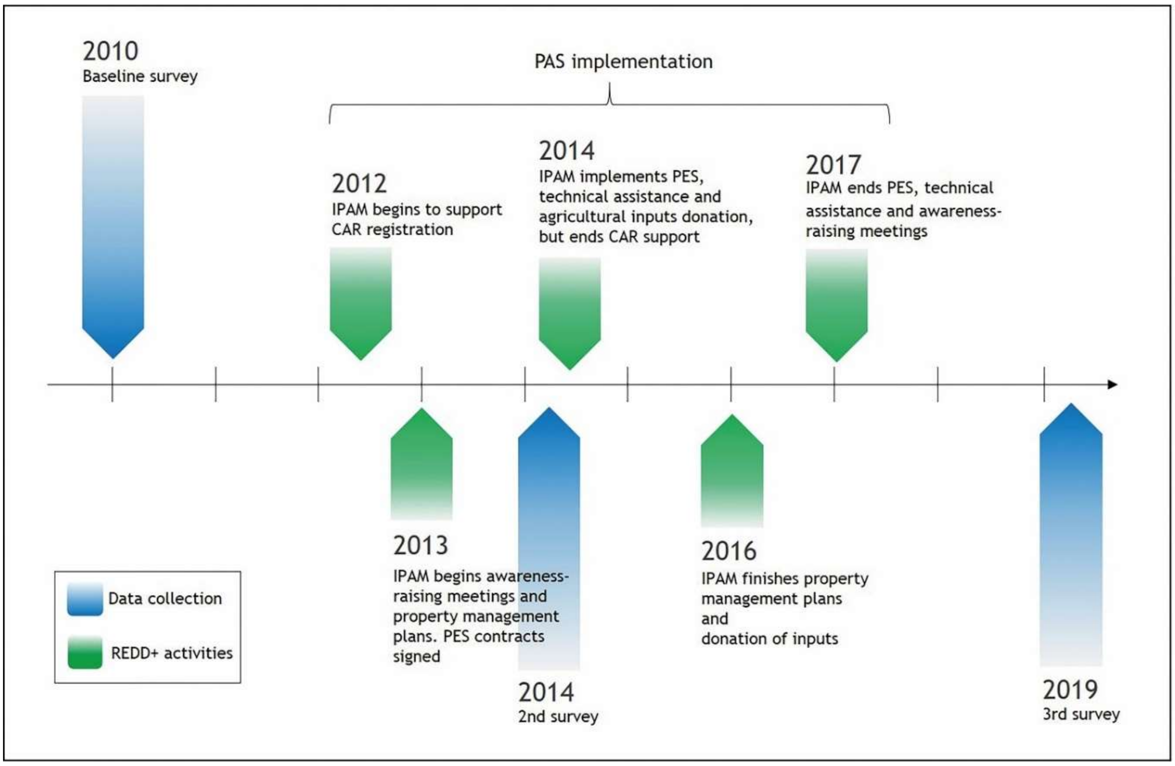

Figure 1 – PAS implementation and CIFOR-GCS data collection timeline. Source: own elaboration, based on Cromberg et al. (2014b) and IPAM (2016).

3. Sampling and data collection

Identical survey instruments were employed through face-to-face interviews in four treatment and four control communities (Figure 2) in three time periods: June-July 2010 (baseline period), February-March 2014 (~2 years after the REDD+ initiative's onset) and March-May 2019 (~7 years after onset and 2 years after the initiative ended).

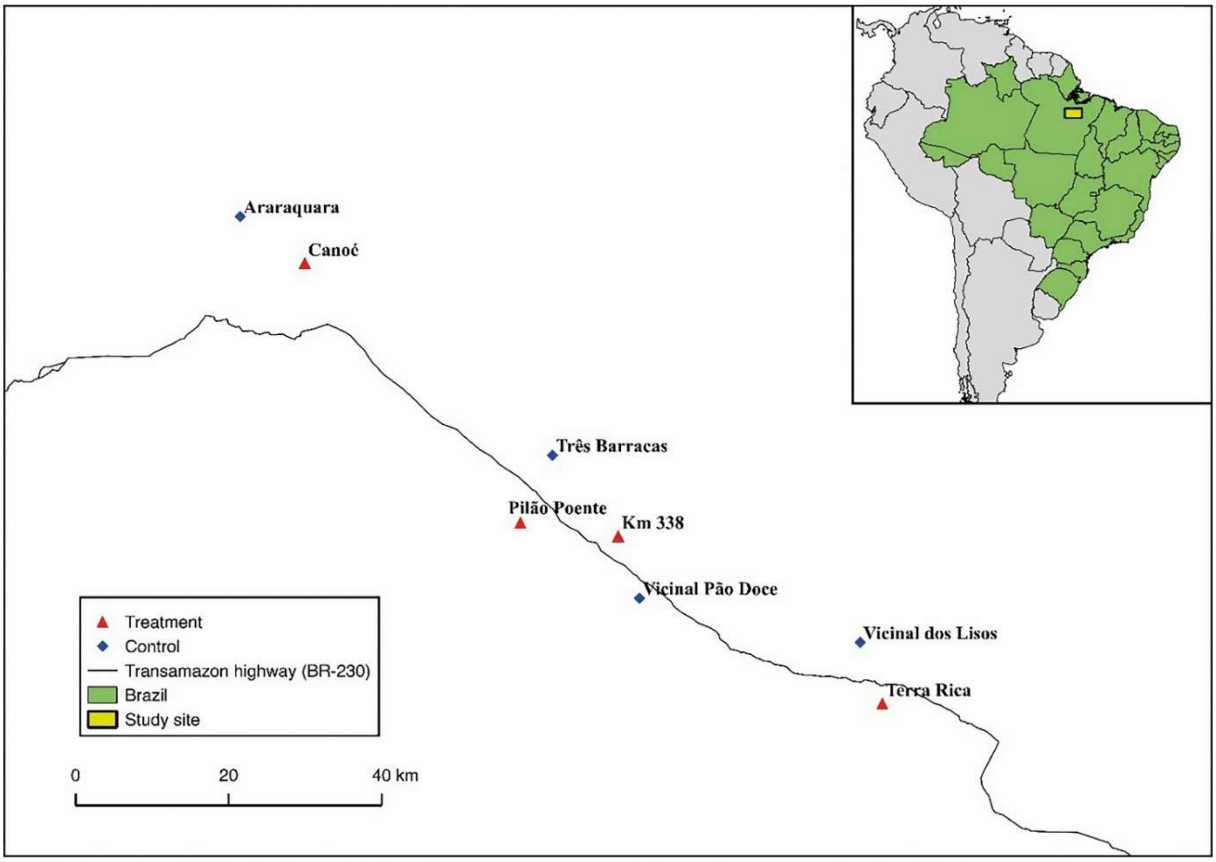

Figure 2 -Location of both treatment and control communities along the Transamazon highway (Brazil).

Treatment communities were randomly selected among the twelve communities in which IPAM intended to implement the initiative. Control communities were selected from a pool of fifteen other Transamazon communities, based on a pre-matching procedure to find communities with similar characteristics likely to influence both initiative placement and land use/well-being outcomes (e.g., forest cover, deforestation pressures, and distance to the main road) (Sunderlin et al., 2016).

For our analysis, the key unit is the household, defined here as the group of people, usually family members, living under the same roof and pooling resources (Sunderlin et al., 2016). We chose this level because households make the deforestation decisions, mainly driven by farming, and received REDD+ incentives (e.g., PES, sustainable livelihood alternatives).

In each of the four treatment and four control communities, 30 households (240 in total) were randomly selected for interviews in the baseline period. The sample in treatment communities was further stratified to include both PAS participants and non-participants, a procedure adopted to investigate intra-community spillover effects. A total of 113 households were interviewed in the three survey points (2010, 2014, 2019), comprising three different groups: 46 control households; 52 treatment households (i.e. participated in REDD+ initiative, receiving all interventions described in Section 2); and 35 non-participant households (i.e. did not participate in REDD+, but inhabited treatment communities).

4. Empirical strategy

4.1.Assessing short-term outcomes

Our first goal was to assess the outcomes of the REDD+ initiative on deforestation and household wellbeing, respectively. To do so, we adopted a DID approach also known as Before-After-Control-Impact (BACI) evaluation. Thus, we assumed that changes in outcome variables from pre- to post-intervention in the control group represented what would have happened to the treatment group without the intervention (counterfactual scenario) (Fredriksson and Oliveira, 2019). For this to be credible, both groups should follow the same trend in pre-treatment outcomes (parallel trend assumption). This assumption implies that, in the absence of the treatment, outcomes for the treatment and control groups would change at the same rate (Ryan et al., 2019). Indeed, the parallel trend assumption was confirmed using a placebo test over a pre-treatment period (2008-2010) in which no effects were detected (Appendix A).

Accordingly, we estimated the impact of the intervention on treatment households by calculating the difference between the changes in outcomes over time (between 2010 – the baseline – and 2014 – two years post the REDD+ indicative's launch) from the control and treatment groups. This is the so-called Average Treatment Effect on the Treated (ATT): ATT = $E\ (y^1 - y^0|D = 1)$, where y^1 denotes the result variable under the treatment, y^0 the same variable in the absence of treatment, and D is a dummy that takes on the value of one when the household has been treated, and zero otherwise. We adopted two outcome variables (Table 1): (i) forest cover (% of primary and secondary forest in the household property), as self-stated by household respondents, and selectively validated through remote-sensing data (cf. discussion below), as our proxy for deforestation; (ii) perceived wellbeing (self-declared by household respondents in interviews, compared to previous years: 1 = improved; 0 = not improved).

Table 1 – Summary statistics for treatment and control groups.

Variables	Treatment group		Control group		ND	
Pre-treatment variables	Mean	Std dev.	Mean	Std dev.	Raw	Matched
Forest cover in 2008 (% of land area)*	0.75	0.16	0.64	0.23	0.55	0.09
Forest cover in 2010 (% of land area)*	0.70	0.16	0.60	0.23	0.52	0.04
Total land area in 2010 (ha)*	79.45	35.19	91.61	54.39	-0.26	-0.01
Total income in 2010 (BRL)*	27,931.35	21,525.78	34,906.54	25,455.53	-0.29	0.06
Household head age in 2010 (years)*	48.48	11.45	53.91	11.42	0.47	0.12
Household members in 2010 (number)*	5.54	2.45	5.33	2.63	0.08	0.07
Perceived well-being in 2010 (1 = improved; 0 = not improved)	0.65	0.48	0.59	0.50	-	-
Post-treatment variables						
Forest cover in 2014 (% of land area)	0.65	0.19	0.50	0.24	-	-
Forest cover in 2019 (% of land area)	0.54	0.23	0.45	0.24	-	-
Perceived well-being in 2014 (1 = improved; 0 = not improved)	0.79	0.41	0.46	0.50	-	-
Perceived well-being in 2019 (1 = improved; 0 = not improved)	0.58	0.50	0.35	0.48	-	-
Total land area in 2014 (ha)	79.45	35.19	91.61	54.39	-	-

Note: *matching covariates. Treatment group: 52 households that participated in the REDD+ initiative. Control group: 46 households living in the control communities. ND: normalized differences between the two groups. Forest cover was estimated for 2008 as a recall period from the 2010 survey.

As the intervention was not randomly attributed, confounders could be unevenly distributed between treatment and control groups (Ferraro and Pattanayak, 2006). Therefore, besides using DID to control for time-invariant unobserved confounders (Deschenes and Meng, 2018), we minimized selection bias combining DID with matching to preprocess the data and control for observable confounders (Ho et al., 2007). This means we applied the DID estimator to those households from treatment and control groups that were statistically similar in pre-treatment observable characteristics (baseline observable covariates – Table 1) (Imbens, 2004). We adopted the nearest-neighbor matching estimator, by matching each treated household to two of the most similar control households (Abadie et al., 2004), as well as two robustness checks. For the first, we again used the nearest-neighbor, but this time matching each treated household to four of the most similar controls. The second was the kernel-based propensity score matching, by which we compared households with the closest probability of being treated given the same set of observable covariates we used before (Rosenbaum and Rubin, 1983).

Baseline values of observable covariates before matching were significantly different between treatment and control groups (Table 1). All normalized differences of the matching covariates, except for household members, were higher than 0.25 standard deviations. After matching, however, normalized differences dropped below 0.25, demonstrating that a plausible counterfactual was created from the matching procedure (Imbens and Wooldridge, 2009).

Finally, following Börner et al. (2020) and Wunder et al. (2020), we calculated normalized effect sizes (Cohen's *d*) as indicators of the magnitude of the initiative's impact on both forest cover and perceived well-being. The effect size is the standardized mean difference of the outcome variables between control and treatment groups (Coe, 2002). The formula is $d = M_1 - M_0$ / SDpooled, where M_1 denotes the mean of the treatment group, M_0 denotes the mean of the control group, and SDpooled = $\sqrt{}SD_1^2 (N_1 - 1) + SD_0^2 (N_0 - 1) / N_0 - N_1 - 2$, where SD_1^2 and SD_0^2 are the square of the respective standard deviations, and N_1 and N_0 are the respective sample sizes (Acock, 2014).

To minimize the risk of bias in our household self-reported forest data, we cross-checked the estimates with remotely sensed data from the Brazilian Annual Land Use and Land Cover Mapping Project (MapBiomas) (www.mapbiomas.org). IPAM shared property boundaries from 43 of the 52 treated households in our sample. Through MapBiomas forest cover and total land area data, we analyzed changes in percent forest cover from 2010 to 2018 for these 43 overlapping households. We found that estimates matched well to those derived from self-reported data. Paired t-test and f-test of annual differences in self-reported and observed forest cover revealed that they are not statistically significantly different in the means, as well as in standard deviations (see Appendix B).

4.2.Evaluating outcomes after the initiative ended

Our second goal was to evaluate to what extent potential outcomes persisted after the initiative ended. To this end, we also used the DID-matching estimators to compare differences in the same outcome variables (Table 1) over 2014 (during the initiative's implementation) and 2019 (two years after its end) between treatment and control groups. If the outcomes were sustained, we would expect similar results in this analysis than those with the comparison between 2010 (baseline) and 2014.

4.3. Intra-community spillover

Finally, to check for intra-community spillover effects, we reused the DID matching estimators to test for outcome variables differences between the control and the non-participant group, for 2010-14 and 2014-19, respectively. We first confirmed the parallel trend assumption for control and non-participant groups running another placebo test (Appendix A). We also compared the normalized differences of the matching covariates before and after matching, concluding once more that a plausible counterfactual had been constructed (Appendix C).

5. Results

5.1.Longitudinal impact assessment

Our results show that the REDD+ initiative achieved positive outcomes in terms of both forest conservation and perceived well-being improvement (Table 2). Aligned with the results of the earlier study on the effectiveness of PAS in reducing deforestation (Simonet et al., 2019), ATT for forest cover was significant for all DID matching estimators in the first period (2010-14). This implies an average of 7.80% to 10.32% of forest cover was saved by the initiative, or the equivalent of 6.20 to 8.20 ha per farm, given that the average land area of the treatment group was 79.45 ha in 2014 (Table 1). Moreover, ATT for perceived wellbeing was also positively significant in this first period: the REDD+ initiative increased the probability of improved enrollee perception of wellbeing by 27% to 44%. Cohens' *d* for forest cover (0.32 – Table 3) and perceived wellbeing (0.37) were numerically similar, both indicating small-to-medium effect sizes according to Sawilowsky (2009) (0.01 = very small; 0.2 = small; 0.5 = medium; 0.8 = large; 1.2 = very large; 2.0 = huge).

Table 2 - Longitudinal forest and wellbeing impacts of the REDD+ initiative on the treatment group.

DID-matching estimator	Forest cover (%)		Perceived well-being (1 = improved; 0 = not improved)	
	2010-2014 Coeff[a] (S.E.)[b]	2014-2019 Coeff (S.E.)	2010-2014 Coeff (S.E.)	2014-2019 Coeff (S.E.)
NNM(2X)	7.80* (4.36)	-1.75 (4.67)	0.45** (0.19)	-0.31** (0.15)
NNM(4X)	8.08* (4.57)	-1.73 (5.29)	0.44** (0.18)	-0.28* (0.15)
PSM(kernel)	10.32** (4.00)	-3.65 (4.87)	0.27* (0.16)	-0.17*** (0.15)

Note: Significance level: *=10%; **=5%; ***= 1%. DID-matching estimators: nearest neighbor using four matched observations as controls (NNM(4X)) and using two matched observations (NNM(2X)); kernel-based propensity score matching (PSM(kernel)). [a] Coefficient represents ATT (treated are the treatment group: 52 households that participated in the REDD+ initiative). [b] Standard errors in parentheses.

Table 3 - Normalized effect sizes (Cohen's *d*) of the outcomes.

Variables	Cohens' *d*	Treatment group		Matched control households	
		Mean	Std dev.	Mean	Std dev.
Δ Forest cover between 2010-2014 (% of land area)	0.32	0.05	0.11	-0.10	0.20
Δ Perceived well-being between 2010-2014 (1 = improved; 0 = not improved)	0.37	0.13	0.63	-0.13	0.79

Note: Treated households: 52 that had participated in the REDD+ initiative. Matched control households: 40 that matched to treated households using nearest neighbor estimator with two matched observations as controls, from the total of 46 households living in the control communities.

However, according to our estimates, deforestation resumed after the initiative ended (Table 2). Indeed, for the second period (2014-2019), we found that ATT from all DID matching estimators were non-significant for forest cover. We also detected a significant negative impact on perceived well-being for the same period.

The results for forest cover change from the nearest neighbor estimator, using two matched observations as controls, are provided in Figure 3. We observe that forest cover continued to decrease from 2008 to 2019 in both treatment and control groups. However, there is a break in the forest loss trend between 2010 and 2014 in the treatment group. Despite that, from 2014 and 2019, the treatment group lost forests again in a similar trend to the control group.

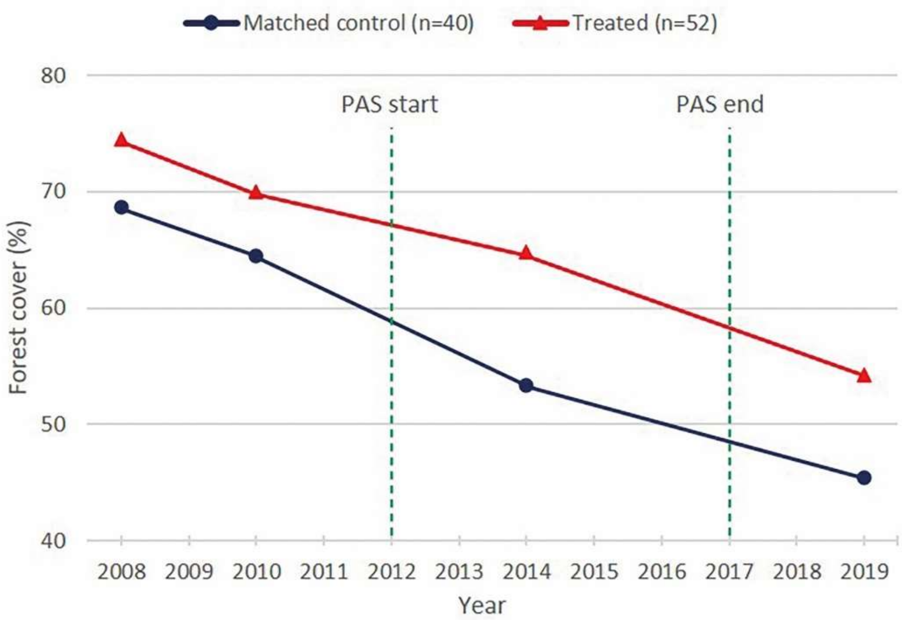

Figure 3 – Forest cover (% of forest of the household property) change among treated and their matched control households.

Note: Treated households: 52 that had participated in the REDD+ initiative. Matched control households: 40 that matched to treated households using nearest neighbor estimator with two matched observations as controls, from the total of 46 households living in the control communities. Forest cover was estimated in 2008 as a recall period from the 2010 survey. The REDD+ initiative started in 2012 and ended in 2017 (see Figure 1).

5.2.Intra-community spillover

We found no evidence for intra-community spillover effects for the REDD+ initiative (Appendix D). ATT from all DID matching estimators were insignificant for forest cover and perceived well-being in both periods (2010-2014; 2014-2019).

6. Discussion

6.1.Short-term effects on forests and well-being

Our results indicate the REDD+ initiative investigated here for the group of ICDP-cum-PES treated households achieved win-win outcomes in terms of reducing deforestation and improving well-being while it was being implemented. These findings therefore add to the emerging evidence that REDD+ initiatives have demonstrated statistically significant success in reducing deforestation (Simonet et al., 2018). Moreover, our findings highlight positive impacts on perceived well-being, which differ from observations in other REDD+ initiatives that evidenced insignificant impacts (Sunderlin et al., 2017).

Notably, we found no evidence that deforestation reduction reached by the REDD+ initiative was offset by intra-community spillover. This means that, according to our estimations, reducing deforestation in REDD+ participant properties did not lead to an increase in deforestation in non-participant properties. This could have occurred, for instance, if participants had shifted their deforestation activities to non-enrolled plots, which would have reduced REDD+ net impacts as a consequence (Pfaff and Robalino, 2017).

As this REDD+ initiative was based on a mix of on-the-ground interventions (see Section 2), we might want to also discuss the likely efficiency across different components. We conjecture the original deforestation reduction likely resulted more from PES than from the ICDP-type sustainable livelihood alternatives or CAR registration, for two reasons. First, in 2014, households were surveyed when the REDD+ initiative was still beginning (Figure 1), therefore before the main livelihood alternatives (technical assistance, free agricultural inputs) were delivered. Although the first conditional payment also occurred soon after the 2014 survey, PES contracts were signed earlier (beginning of 2013). It is therefore reasonable to suppose that households could have reduced deforestation in the dry season of 2013 (when they usually convert forest to pasture/crops) in anticipation of conditional payments that would begin around March 2014. Similarly, perceived wellbeing improvements could have resulted from an expectation of the payments that would start soon. Second, besides IPAM, several other organizations offered administrative support in the Transamazonian region for registering households' properties under CAR. As a result, most of the control households received the same intervention from elsewhere, as already noted by Simonet et al. (2019).

If the initial outcomes did result mostly from PES, as we believe, our findings corroborate the majority of studies employing counterfactual designs, showing the potential effectiveness of PES in forest conservation (e.g., Alix-Garcia et al., 2012; Costedoat et al., 2015; Jayachandran et al., 2017; Montoya-Zumaeta et al., 2019; Robalino and Pfaff, 2013; Scullion et al., 2011), and in delivering small but often significant wellbeing improvements (e.g., income, assets) (e.g., Duan et al., 2015; Hegde and Bull, 2011; Jack and Cardona Santos, 2017; Sims and Alix-Garcia, 2017; Uchida et al., 2007), despite fewer studies finding null impacts (e.g., Arriagada et al., 2018, 2009; Sánchez-Azofeifa et al., 2007; Wiik et al., 2019). The moderately positive outlook on PES for delivering these win-win outcomes is supported by more recent meta-studies and systematic reviews (Snilsveit et al., 2019; Wunder et al., 2020a).

Our findings also align with the emerging evidence showing the effect size of PES on forest conservation outcomes is limited, even if our estimated effect sizes (0.32 – Table 3) were above average. Based on data from 19 studies measuring PES outcomes for forest conservation, Wunder et al. (2020a) showed Cohens' *d* effect size ranged from 0.0 to ~0.5, with an average value around 0.2. According to Sawilowsky's (2009) interpretation of Cohens' *d*, this means PES effect size varies in reviewed studies from very small to medium, being small on average. However, to make a fair evaluation, PES must be compared with other forest conservation interventions (e.g., protected areas, certification, decentralized forest management) and they all exhibit small effect sizes in general (Börner et al., 2020). In fact, PES has larger impacts than these other interventions, though differences are small (Wunder et al., 2020a).

6.2.Long-term effects of the REDD+ initiative

In our study, deforestation reductions and wellbeing improvements were more temporary than permanent – both improving trends reversed post-treatment. However, the REDD+ initiative still left a lasting gain for the environment: the treatment group cleared forests again as quickly as the control group, but without exceeding it to 'catch up' on the earlier mitigations, meaning there was a net forest gain over time (Skutsch and Trines, 2010). Our findings therefore match very well with the aforementioned evaluation of the permanence outcomes from the PES RCT in Uganda (see Section 1) (World Bank, 2018). The study showed deforestation resumed among former PES recipients once payments ended, but without exceeding the reference scenario; thus, leaving the initial conservation gains intact.

Notably, the literature on PES permanence suggested that asset-building PES (‘active establishment’) may have better chances of locking in forest gains than activity-reducing (‘passive conservation’) PES, to the extent the former manage to lastingly boost the adoption of environmentally desirable land uses established (e.g. agroforestry systems) (see Section 1). In fact, this was the main goal of the REDD+ initiative investigated here when providing the ICDP investments in alternative livelihoods (see Section 2). Following this logic, one possible explanation for why deforestation reduction was not sustained after the REDD+ initiative ended could be that the alternative livelihood activities promoted did not take off, leastways at a desirable scale. Notably, during the 3rd data collection phase, 27 treated interviewees (i.e., 52%) declared they did not adopt alternative livelihood activities between 2014 (when the main ICDP-type support started) and 2019. Studies accessing conservation outcomes of ICDP-type programs indeed most indicate failures rather than successes (Hughes and Flintan, 2001; Roe et al., 2015). This may be because programs often rely on upfront subsidies instead of conditional payments to promote alternative livelihood activities, which increases the risk of non-compliance (Pagiola et al., 2020). Therefore, despite that targeted households had received technical assistance and free agricultural inputs, a significant part of them may have not adopted sustainable livelihood alternatives. Otherwise, lasting deforestation reduction outcomes might have been possible.

7. Concluding remarks

We presented one of the first evaluations of the permanence of a local REDD+ initiative’s outcomes. We found that the PAS initiative reduced deforestation in the Transamazon region and improved the perceived well-being of treated households, while being actively implemented. Post-intervention, deforestation resumed at a similar pace as the control group, yet without ‘catching up’ on the temporary forest gains made. Our results, therefore, suggest that temporary performance-based REDD+ benefit flows may effectively delay, though not permanently eradicate deforestation. Still, they can be important in mitigating the climate change challenge the world is facing.

As long as the basic environmental externality persists, i.e. that standing forests privately cannot compete with the yields from alternative land uses, we should not expect the miracle that a temporary payment would permanently change the logic of the productive system. ICDP type of investments try to achieve exactly this type of change, but have typically been little successful, as also seems the case, at first sight, in the PAS initiative we analyzed.

PES used as adoption subsidies for environmentally beneficial land uses seem to have a somewhat better record (see Section 1).

As for perceived wellbeing impacts, we failed to detect permanence of improvements; perceptions clearly improved during REDD+ implementation but were then negatively impacted after the initiative ended. Does that mean the project left no permanent welfare gains behind? We would be cautious to press such an extreme interpretation, given that ex-post stated negative subjective wellbeing can also sometimes be seen as a vote of protest against the sudden withdrawal of benefits that were expected to be steadily provided anew – and still go perfectly hand in hand with lastingly higher incomes (e.g. Montoya-Zumaeta et al., 2019).

We close by highlighting that the external validity of our study must be approached with two cautions. First, our analysis relied on a subsample of households that were targeted for PES payments; thus from this we cannot extrapolate to the entire PAS project (see Section 2). Second, REDD+ as implemented on the ground is a basket of interventions, which includes incentives (direct payments and alternative livelihood activities), disincentives (e.g., law enforcement) and enabling measures (e.g., tenure clarification) (Duchelle et al., 2017). Thus, any generalization to other REDD+ sites must consider, besides the local context, the type of interventions applied.

Appendix A. Impact on treatment and non-participant groups over 2008 and 2010 (placebo test).

DID-matching estimator	Forest cover (%) Treatment group Coeff[a] (S.E.)[b]	Non-participant group Coeff (S.E.)
NNM(4X)	0.00 (0.00)	0.00 (0.00)
NNM(2X)	0.00 (0.00)	0.00 (0.00)
PSM (kernel)	-0.71 (0.01)	-0.45 (0.01)

Note: Treatment group: 52 households that had participated in the REDD+ initiative. Non-participant group: 35 households from treatment communities that had not participated in the REDD+ initiative. No statistically significant effects were detected to both groups in comparison to the control group over the pre-treatment period (2008-2010), which confirms the parallel trend assumption. [a] Coefficient represents ATT. [b] Standard errors in parentheses. Forest cover was estimated in 2008 as a recall period from the 2010 survey.

Appendix B. Paired tests on the equality of forest cover means and standard deviations.

	Forest cover (%)							
	Mapbiomas data		Self-reported data		Paired t-test		Paired f-test	
Year	Mean	Std dev.	Mean	Std dev.	t	p-value	f	p-value
2009/2010	0.67	0.17	0.70	0.15	-1.33	0.19	1.39	0.29
2013/2014	0.65	0.16	0.65	0.17	-0.12	0.91	0.87	0.66
2018/2019	0.59	0.18	0.55	0.21	1.33	0.19	0.76	0.39

Note: Mean forest cover was estimated based on 43 households' properties from our treatment group (N=52). The paired t-test of annual differences and the f-test of equality of variances revealed that self-reported and observed forest cover were not statistically significantly different both in the means and in standard deviations, confirming the validity of our self-reported data. We used MapBiomas data from the preceding years to our interview surveys because the Amazon dry season, when households usually convert forest to pasture/crops, runs between May-September, but interviews were conducted before this period or in its beginning (see Section 2).

Appendix C. Summary statistics for non-participants and control group.

Variable	Non-participant group		Control group		ND	
Pre-treatment variables	Mean	Std dev.	Mean	Std dev.	Raw	Matched
Forest cover in 2008 (% of land area)*	0.72	0.20	0.64	0.23	0.41	-0.04
Forest cover in 2010 (% of land area)*	0.68	0.19	0.60	0.23	0.38	-0.08
Total land area in 2010 (ha)*	117.70	101.30	91.61	54.39	0.32	0.17
Total income in 2010 (BRL)*	43,224.72	74,367.73	34,906.54	25,455.53	0.16	0.20
Household head age in 2010 (years)*	50.91	13.48	53.91	11.42	-0.29	-0.10
Household members in 2010 (number)*	5.06	2.38	5.33	2.63	-0.13	-0.10
Perceived well-being in 2010 (1 = improved; 0 = not improved)	0.59	0.50	0.59	0.50	-	-
Post-treatment variables						
Forest cover in 2014 (% of land area)	0.61	0.21	0.50	0.24	-	-
Forest cover in 2019 (% of land area)	0.55	0.22	0.45	0.24	-	-
Perceived well -being in 2014 (1 = improved; 0 = not improved)	0.62	0.49	0.46	0.50	-	-
Perceived well -being in 2019 (1 = improved; 0 = not improved)	0.53	0.51	0.35	0.48	-	-
Total land area in 2014 (ha)	118.22	102.78	91.61	54.39	-	-

Note: *matching covariates. Non-participant group: 35 households from treatment communities that had not participated in the REDD+ initiative. Control group: 46 households living in the control communities. ND: normalized differences for the two groups. Forest cover was estimated in 2008 as a recall period from the 2010 survey.

Appendix D. Longitudinal impact of the REDD+ initiative on the non-participant group.

DID-matching estimator	Forest cover (%)		Perceived well-being (1=improved; 0=not improved)	
	2010-2014 Coeff[a] (S.E.)[b]	2014-2019 Coeff (S.E.)	2014-2019 Coeff (S.E.)	2014-2019 Coeff (S.E.)
NNM(4X)	3.77 (4.21)	2.21 (5.53)	0.16 (0.21)	0.11 (0.16)
NNM(2X)	5.36 (4.47)	2.03 (5.87)	0.10 (0.20)	0.11 (0.17)
PSM (kernel)	7.93 (4.57)	-3.21 (5.01)	0.13 (0.18)	- 0.00 (0.17)

Note: DID-matching estimators: nearest neighbor using four matched observations as controls (NNM(4X)) and using two matched observations (NNM(2X)); kernel-based propensity score matching (PSM(kernel)). [a] Coefficient represents ATT (treated are the non-participant group: 35 households from treatment communities that had not participated in the REDD+ initiative). [b] Standard errors in parentheses.

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CHAPTER 2

The permanence of deforestation reduction may depend upon the adoption of alternative livelihood activities: Evidence from an Amazon REDD+ site

Abstract

Recent impact evaluations have shown local REDD+ initiatives more frequently have some level of success in reducing deforestation. However, there have been few efforts to evaluate the permanence of these outcomes, as well as the causal mechanism responsible for sustaining outcomes after REDD+ interventions are suspended. In this article, we investigated whether the adoption of alternative livelihood activities was a causal mechanism for self-sustaining the deforestation reduction induced by a REDD+ initiative in the Brazilian Amazon. Implemented between 2012 and 2017, the initiative relied mostly on Payments for Environmental Services (PES) besides non-conditional assistance to boost the adoption of alternative livelihood activities and reduce smallholders' deforestation. Through the use of quasi-experimental methods, we first accessed whether the initiative promoted the adoption of alternative livelihood activities; second, whether this adoption was responsible for long-term forest conservation by searching for heterogeneous effects among households that adopted/did not adopt those activities. Data came from face-to-face interviews with 98 households (control: 46; treatment: 52) in a panel design (2010; 2019). Results indicated the initiative increased the probability of enrollees adopting these activities by ~ 40 %. Yet, not all target-households adopted new activities, which led to heterogeneous outcomes for forest conservation. Treated households that adopted new activities (N=25) had an average of 14.67% to 16.90% more forest cover (~10.40 to ~11.98 ha) than controls. Instead, we observed null impacts in treated households that did otherwise (N=27). The corollary of our findings is that, for reaching self-sustaining outcomes for deforestation reduction, we need to promote the adoption of sustainable livelihood activities.

Keywords: alternative livelihood projects, emission reductions, additionality, climate change mitigation, impact assessment.

1. Introduction

REDD+ – which stands for “Reducing Emissions from Deforestation and Forest Degradation”, sustainable management of forests and enhancement of forest carbon stocks – emerged in 2007 as a nature-based solution to help mitigate the climate crisis (Sunderlin and Sills, 2013). The core idea behind REDD+ was to implement performance-based payments directed from developed to developing countries, conditional on forest emissions’ reductions (Angelsen, 2017). Payments would therefore finance REDD+ initiatives on the ground, which were expected to be mostly implemented by national governments at the national level (UNFCCC, 2021). However, local-scale REDD+ projects most commonly implemented by non-governmental organizations (NGOs) and private companies moved more quickly (Sills et al., 2014).

Thus, after more than a decade, the current REDD+ situation differs from that originally envisioned, and we still know little about the effectiveness of its initiatives in reducing deforestation (additionality). Of the few rigorous impact evaluations available, most indicates initiatives are somehow effective in reducing deforestation/conserving forests (e.g., Bos et al., 2017; Jayachandran et al., 2017; Montoya-Zumaeta et al., 2019; Roopsind et al., 2019; Simonet et al., 2019), albeit fewer evaluations highlight null or mixed (positive or negative) impacts (e.g., Correa et al., 2020; Ellis et al., 2020; West et al., 2020). As the number of evaluations is still small, however, there remains an open question whether REDD+ is succeeding in reducing deforestation.

But even less is known about the persistence of deforestation reduction over time (permanence), despite this is a major concern in the REDD+ debate (Dutschke and Angelsen, 2008). In this discussion, permanence means the capacity of initiatives to ensure a long-term reduction in deforestation, instead of just delaying it (Angelsen and Wertz-Kanounnikoff, 2008). In turn, this outcome depends on the successful promotion of novel land uses, which can conserve more forests than “business-as-usual” practices. When initiatives just impose forest conservation restrictions without enabling structural changes in production systems, once REDD+ interventions end, deforestation is expected to grow again.

Notwithstanding its importance, we are aware of only two published evaluations of REDD+ outcomes’ permanence, and both present worrying evidences. The first is a quasi-experiment showing that Guyana’s national REDD+ program, funded by Norway through performance-based payments for reducing deforestation, decreased tree cover loss by 35% during the implementation period (2010-2015) (Roopsind et al., 2019). After Norway’s payments ceased, however, the authors detected an increase in tree cover loss, which suggested forest protection was not guaranteed without continued payments. The second is a long-term evaluation of the outcomes from a PES-based local initiative in Uganda. Through a Randomized Control Trial (RCT) experiment, this initiative had initially reduced net tree losses in participant villages: tree cover declined 4.2% in treatment villages, whereas 9.1% in control (Jayachandran et al., 2017). Yet, deforestation resumed among former PES recipients once payments ended, but did not catch up on foregone deforestation; thus leaving the conservation gain intact (World Bank, 2018).

In summary, the accumulated evidence suggests REDD+ initiatives often succeed in reducing deforestation at some level, although they struggle to achieve self-sustained deforestation reduction. That being so, deforestation could be expected to rise soon after REDD+ initiatives are suspended, hopefully without overtaking the counterfactual scenario. A net loss would be expected only if the rate of deforestation in REDD+ intervention sites exceeded the counterfactual scenario by more than the gains in the period of deforestation reduction; i.e. a catch-up behavior (Skutsch and Trines, 2010).

However, if the permanence of deforestation reduction depends upon the continuity of REDD+ interventions, we may run into trouble for three main reasons. First, we cannot assure REDD+ funding will last forever. In fact, an analysis of 624 local REDD+ initiatives in a global database indicated that, by December 2020, 206 or 33% of them had been discontinued or were never actually implemented (Simonet et al., 2021). Second, the available funds are lower than originally envisioned, mainly because the compliance market for forest carbon has failed to materialize. Thus, REDD+ is currently sourced mostly from multilateral and bilateral agreements, with below expected investments (Angelsen, 2017; Sunderlin et al., 2015). Third, this "aidification" of REDD+ – i.e., funding associated with traditional development aid (*sensu* Seymour and Angelsen, 2012) – renders financing more vulnerable to political fluctuations (Atmadja et al., 2018). This fear materialized in 2019, when Norway and Germany's donations to the Brazilian Amazon Fund[2] – the world's largest results-based funding program to REDD+ (Correa et al., 2019) – were suspended, due to disagreements with the Brazilian Environment Minister (Gallo et al., 2020).

Because it is unlikely that funding for REDD+ initiatives will be guaranteed permanently, understanding how to boost self-sustained deforestation reduction is warranted.

[2] The Amazon Fund is Results-Based Funding (RBD) for REDD+ that destinates donations for on the ground initiatives (Correa et al., 2019).

Yet, to date, we still know little about why and when these outcomes occur or fail. This is likely due to a knowledge gap on the causal mechanisms that explain specific conservation outcomes, not only deriving from REDD+ initiatives, but also from other environmental programs in general (Ferraro and Hanauer, 2014a). These mechanisms are the intermediate outcomes that lie on the causal pathway between each environmental program and its conservation outcomes (Ferraro and Hanauer, 2014b). That is, they are caused by the environmental program, and they are the cause of conservation outcomes (Sills and Jones, 2018). Identifying these causal mechanisms is critically important because, with such knowledge, implementers can design environmental programs which foster the mechanisms that will most likely reach the targeted outcomes (Ferraro and Hanauer, 2014a).

Whether REDD+ initiatives will be able to promote self-sustained outcomes depends at least on the type of applied intervention, given that alternative types should operate through different mechanisms (Sills and Jones, 2018). In fact, REDD+ initiatives have been implemented through alternative interventions across locations. Although Payments for Environmental Services (PES) were originally envisioned as the first-choice intervention type (Angelsen and Wertz-Kanounnikoff, 2008), sustainable livelihood alternatives, as well as disincentives (e.g., strengthening law enforcement), have more often been implemented (Duchelle et al., 2017).

It is not usually expected that PES-led deforestation reduction should last after payments cease. The underlying logic is people will avoid deforestation only while their opportunity costs are being compensated (Wunder, 2005). PES functions by providing direct conservation incentives that outcompete those to clear forest for "business-as-usual" land-use practices (Phelps et al., 2013). By making standing forests more profitable than cut (Angelsen and Mcneill, 2013), PES should induce beneficiaries to cooperate with forest conservation. Thus, when payments are suspended, the economic motivation to conserve would vanish and, hence, deforestation would rise again (Swart, 2003). Otherwise, if deforestation reduction persists, this could indicate payments were not needed, which means the program unlikely provided additional conservation benefits (Pagiola and Platais, 2006; Wunder et al., 2008).

However, if payments enhanced somehow the intrinsic motivations to conserve (i.e. motivation crowding-in) (Rode et al., 2015), even after payments ceased, the former beneficiaries could continue to conserve forests. Yet, critiques to PES (e.g., Kosoy and Corbera, 2010) advocate the opposite is more likely: former beneficiaries should be more motivated to conserve forests only in response to extrinsic rewards, undermining their intrinsic motivations (motivational crowding-out). If so, a rise in deforestation after PES ceased would be even more expected. As a literature review shows, both motivational crowding in and crowding out exist in parallel and we should not assume neither as the most likely scenario (Wunder et al., 2020). In fact, it seems that contextual factors determine the prevalence of one from the other (e.g., PES design, and whether intrinsic motivations were previously strong) (Wunder et al., 2020).

Therefore, when based on activity-reducing PES, the persistence of outcomes over time are debatable. Instead, when interventions promote novel sustainable livelihood activities – the main goal of Integrated Conservation and Development Project (ICDP)-type investments and even asset-building PES – the permanence of deforestation reduction after a project ends should be more likely. The underlying logic is these new activities may increase the economic returns in comparison to "business-as-usual" practices (Lutz et al., 1994), while promoting forest conservation or at least reduced deforestation. If so, inasmuch as REDD+ initiatives successfully reduce the initial costs of sustainable activities, target-households may be economically motivated not only to adopt, but also to maintain the sustainable livelihood activities, even after REDD+ incentives cease (Pagiola et al., 2020). The corollary would be that, to ensure the permanence of deforestation reduction, we ought to promote the adoption of sustainable activities.

One shortcoming is that at least part of the target-households might be little prone to adopt novel activities for at least two reasons. First, because poor rural families, such as those usually targeted by REDD+ initiatives, tend to be even more risk-averse than other human populations. One reason is they often face uncertainties, such as fluctuations in natural conditions (e.g., climate) or in product prices (Ellis, 1993; Mendola, 2007). Therefore, despite receiving REDD+ incentives, households may fail to adopt new activities or may adopt them only after observing positive results in their neighbors (Shah et al., 2016). Second, a household's opportunity cost to adopt environmentally beneficial land uses may vary across households from the same community (Piñeiro et al., 2020). In this case, households with previously high levels of farming yields may be less likely to engage in alternative livelihood activities. That being so, the permanence of deforestation reduction should vary according to whether target-families adopted or not novel activities.

Indeed, in a previous article (first chapter), we showed that a Brazilian Amazon REDD+ initiative, combining PES with sustainable livelihood alternatives, saved from 7.8% to 10.32% of forest cover per target-household in its first years of implementation. Yet, average forest loss resumed after the initiative ended. Despite that, we suspected that part of the target-households which adopted alternative livelihood activities did reduce deforestation in the long run, albeit this effect was concealed in average effects estimation. In fact, as other authors previously argued, the estimation of average effects may mask important variation in treatment effects (Sills and Jones, 2018).

In this article, we therefore investigated whether the adoption of alternative livelihood activities was a causal mechanism for self-sustaining deforestation reduction in the same REDD+ initiative. We hypothesized the REDD+ initiative promoted heterogeneous outcomes in the long-term, which varied according to whether or not target-families adopted alternative livelihood activities. The households that adopted alternative economic activities were expected to maintain changes in their reduced deforestation behavior even after REDD+ incentives ceased. In contrast, we expected households that did not adopt these activities should have returned to "business-as-usual" land use practices.

2. The REDD+ initiative

The REDD+ initiative under investigation here is the *Projeto Assentamentos Sustentáveis na Amazônia* (PAS), which was implemented between 2012 and 2017 by a Brazilian non-governmental organization (*Instituto de Pesquisa Ambiental da Amazônia* – IPAM). Although IPAM intended to maintain the initiative for longer, the refinancing request was denied by the Brazilian Amazon Fund (Correa et al., 2019).

PAS' central goal was to reduce smallholder's deforestation rates by targeting around 2,700 households living in several agrarian reform settlements in the western region of the Brazilian Pará state (IPAM, 2016). At least until the interventions initiated, the main economic activities of local households were extensive cattle ranching and swidden agriculture (e.g., for beans, cassava), both considered as highly deforestation dependent. They also depended on raising small livestock (e.g., chicken, pigs) and perennial crops (e.g., cocoa, black pepper) (Stella et al., 2020), besides gathering natural resources, such as firewood, fruits, fish and bushmeat. Households' production was both for own consumption and for sale, despite poor transportation infrastructure in the region (Cromberg et al., 2014).

With the project, IPAM intended to promote more sustainable livelihood activities, which could be (i) a novel occupation for the household (e.g., fish-farming, cultivating vegetables, agroforestry systems), or (ii) an improvement of past activities, through less forest-damaging methods (e.g., from extensive to intensive cattle ranching). The household choice followed a previous agreement between the household head and IPAM, inscribed in a property management plan. To boost the adoption of the activities, IPAM offered technical assistance, besides free inputs (e.g., fertilizers, wire to fence properties) valued at up to 5,000 Brazilian reais (BRL) (2,267 USD, as of 07/01/2014). IPAM also offered transportation and market infrastructure to households sell vegetables in cities. Moreover, IPAM provided administrative support for registering households' properties in the Rural Environmental Registry (*Cadastro Ambiental Rural* – CAR); conducted awareness-raising meetings on environmental legislation and tenure regularization, and offered direct payments conditional on deforestation reduction. But payments targeted only 350 households located in the Transamazon highway region, that had participated in a previous PES federal program (*Proambiente*) from 2003 to 2006 (Simonet et al., 2019)[3].

3. Sampling and data collection

Our framework relies on the household as the unit of analysis, defined here as the group of people, usually family members, living under the same roof, and pooling resources (labor and income) (Sunderlin et al., 2016). The rationale of this choice is, first, households are the unit of deforestation decisions, driven mainly by cattle ranching and agricultural, and, second, this was the level for applying REDD+ interventions.

As part of CIFOR's Global Comparative Study on REDD+, panel data were collected on 52 randomly selected treatment (which received REDD+ interventions) and 46 control households (to construct a counterfactual scenario) through face-to-face interviews in two rounds: June-July 2010 (the baseline) and March-May 2019 (7 years after the REDD+ initiative's onset, or 2 years after the initiative ended). Additional information was collected in the 2019 survey to identify which households had adopted new economic activities since 2014, i.e. when the REDD+ implementer began to offer technical assistance and free inputs to boost more sustainable activities.

Treatment households belonged to four randomly selected communities (*Canoé*, *Terra Rica*, *km 338*, and *Pilão Poente*) among the twelve communities from the Transamazon highway region in which IPAM intended to implement all the REDD+ interventions, including PES. Control households, in turn, inhabited four other communities (*Araraquara*, *Vicinal do Pão Doce*, *Vicinal dos Lisos*, and *Três Barracas*) selected from a pool of fifteen communities in the Transamazon. These controls were pre-matched to treatment communities with similar characteristics, choosing those deemed to influence both initiative placement and land use outcomes (e.g., forest cover, deforestation pressures, and distance to the main road).

[3] More detailed information about the REDD+ interventions, including a timeline of their implementation, are presented in the first chapter (section 2).

4. Empirical strategy

4.1.Estimating the impact of the REDD+ initiative on the adoption of alternative activities

To investigate whether the adoption of alternative livelihood activities was a causal mechanism explaining long-term deforestation reduction, we adopted the two-step approach proposed by Ferraro and Hanauer (2014b). According to them, to estimate the effects of causal mechanisms, one needs to begin by calculating the impact of the treatment on the mechanism, and then estimate the impact of the mechanism on the outcome. Following this procedure, we would consider the adoption of new activities as a causal mechanism only if the REDD+ initiative did result in the adoption by target-households of the proposed activities, which, in turn, caused long-term deforestation reduction.

Therefore, we began our empirical analyses by assessing the impact of the treatment (REDD+ interventions) on the adoption of new livelihood activities. With that aim, we asked household representatives, in the 2019 survey, whether any member of the household adopted new activities since 2014. We explained that, by new activities, we meant the production of any new agricultural product (e.g., fruits, vegetables, horticultural specialties, cattle, milk, chickens) or the novel implementation of alternative techniques (e.g., mechanized agriculture, intensified cattle ranching). Based on their responses, we created a binary variable (1 = adopted any new livelihood activity between 2014-2019; 0 = did not adopt – Table 1).

Table 1 - Summary statistics for treatment and control groups

Variables	**Treatment group** (N=52)		**Stratified treatment households** Adopted new activities (N=25)		Did not adopt new activities (N=27)		**Control group** (N=46)	
Pre-treatment variables	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Forest cover in 2008 (% of land area)[b]	0.75	0.16	0.77	0.15	0.72	0.16	0.64	0.23
Forest cover in 2010 (% of land area)[a,b,c]	0.7	0.16	0.73	0.16	0.68	0.15	0.6	0.23
Total land area in 2010 (ha)[a,b,c]	79.45	35.19	71.23	31.17	87.05	37.51	91.61	54.39
Agricultural area in 2010 (ha)[a]	24.65	17.46	20.33	16.38	28.65	17.77	36.91	33.42
Total income in 2010 (BRL)[b,c]	2,7931.35	2,1525.78	2,3394.03	15,886.18	32,132.58	25,254.99	34,906.54	25,455.53
Livestock total income in 2010 (BRL)[a]	11,415.04	14,220.90	7,082	7,610.50	15,427.11	17,562.94	21,233.39	18,882.84
Government transfers in 2010 (BRL)[a]	2,869.19	3,814.48	2,436.84	3,156.13	3,269.52	4,358.90	4,099.50	4,993.02
Household head age in 2010 (years)[a,b,c]	48.48	11.45	46.04	11.07	50.74	11.52	53.91	11.42
Household members in 2010 (number)[a,b,c]	5.54	2.45	5.60	2.89	5.48	2.03	5.33	2.63
Post-treatment variables								
Forest cover in 2019 (% of land area)	0.54	0.23	0.64	0.21	0.46	0.21	0.45	0.24
Adoption of new activities between 2014-2019 (1 = adopted; 0 = did not adopt)	0.48	0.50	1.00	0.00	0.00	0.00	0.07	0.25
Total land area in 2019 (ha)	78.80	39.82	70.91	33.21	86.10	44.46	95.03	59.52

Note: Forest cover was estimated in 2008 as a recall period from the 2010 survey. Matching covariates used in the estimation of Average Treatment Effects on: [a] the adoption of new economic activities; [b] forest cover. [c] Covariates used in linear regressions.

If the REDD+ initiative did successfully promote the adoption of new livelihood activities among target-households, we expected that a higher proportion of treated households should have adopted these activities when compared to control households. Indeed, summary statistics data reveal that 48% of the treated group (i.e., 25 treated households) adopted new livelihood activities, whereas only 7% of the control households did the same (3 households; see Table 1).

However, participation in the REDD+ initiative was not randomly assigned; hence, household characteristics that were likely to drive both participation on the REDD+ initiative and new activities' adoption (confounders) could be unevenly distributed between treatment and control groups. Consequently, a simple comparison between the two groups could generate biased estimates of the treatment effects.

Therefore, to reduce selection bias, we estimated Average Treatment Effect on the Treated (ATT) based on matching estimators. This means we only compared treatment and control groups that were statistically similar in a set of seven potential confounders (baseline covariates – Table 1; see balancing tests in Appendix A) (Imbens, 2004). We adopted the nearest-neighbor matching estimator, by matching each treated household to two of the most similar control households (Abadie et al., 2004), as well as two robustness checks. First, using again the nearest-neighbor, but this time matching each treated household to four of the most similar controls. Second, matching treated and controls based on the kernel-based propensity score, which means we compared households with the closest probability of being treated given the same set of observable covariates we used before (Rosenbaum and Rubin, 1983).

4.2.Estimating the impact of alternative activities' adoption on forest cover

Following the two-step approach from Ferraro and Hanauer (2014b), we proceeded by estimating the impact of the potential mechanism (adoption of new economic activities) on our outcome variable (forest cover: % of both primary and secondary forest in the household property – Table 1). To do that, Ferraro and Hanauer (2014a) propose the estimation of the Mechanism Average Treatment Effect on the Treated (MATT), which is the proportion of the total impact of the treatment (the ATT) that comes from the mechanism. The authors advise that MATT should be estimated by: (i) calculating the difference between the total impact of the treatment on the outcome variable, and (ii) the effect of the treatment when the mechanism is absent. In our framework, this would mean the difference between a) the total impact of the REDD+ initiative on forest cover, and b) the impact of the initiative when new livelihood activities were not adopted.

However, we were expecting to find non-significant total outcomes, based on to the long-term results from our first chapter. Indeed, only a part (48%) of treated households adopted alternative livelihood activities, as we expected (Table 1). Since we hypothesized that the adoption of novel activities should explain deforestation reduction in the long run, the estimation of the total impact of the treatment in average terms was expected to mask important variations in treatment effects between the households that adopted new activities and those that did not.

For this reason, we relied on an alternative approach to Ferraro and Hanauer (2014a) by searching for heterogeneous long-term outcomes between target-households that adopted and did not adopt new activities. To do so, we estimated the initiative's long-term impacts not only on all treated households, as we previously did (Chapter 1), but also separated on (i) treated households that adopted new economic activities, and (ii) treated households that did not. To do that, we relied on a Difference-in-Differences (DID) approach combined with matching to reduce selection bias (Fredriksson and Oliveira, 2019; Schleicher et al., 2019). Therefore, we estimated the impacts of the initiative by calculating the difference between the changes over time (2010-2019) in forest cover from treatment and control households that were statistically similar in a set of six baseline observable covariates (Table 1; see balancing tests in Appendix B) (Imbens, 2004). To do that while checking for robustness, we adopted the same matching estimators we used before (nearest-neighbor matching and kernel-based propensity score).

We run three DID matching analyzes, always keeping the same control group, but adopting alternative treatment groups: i) all treated households (N=52); ii) treated households that adopted new livelihood activities from 2014 to 2019 (N=25), and iii) treated households that did not adopt new activities, despite receiving incentives to do so (N=27) (Table 1). We confirmed DID parallel trend assumption, which requires that, in the absence of the treatment, the difference between treatment and control groups is constant over time (Ryan et al., 2019), by running a placebo test over a pre-treatment period (2008-2010). No effects were detected in the three treatment groups (Appendix C).

We expected to find non-significant effects when comparing the control group to (i) all treated households and (ii) to treated households that did not adopt new activities. In contrast, we predicted to observe significant effects when comparing the same control group, but this time to treated households that adopted new activities. If so, considering that all target-households received the same REDD+ interventions, we should infer that the effect in households that adopted new economic activities was indeed due to the actual adoption. This would mean that, despite we found non-significant total effects in the long-term, in fact the REDD+ initiative reached positive forest outcomes where the adoption of new livelihood activities succeeded.

As a robustness check to validate that the REDD+ initiative helped to conserve forests in the long run only by promoting the adoption of alternative livelihood, we run two linear regressions. In the first, we estimated forest outcomes as a function of the treatment (participation on the REDD+ initiative) while controlling for five baseline covariates to adjust for selection bias (Table 1). The dependent variable was Δ forest cover (forest cover in 2019 – forest in 2010). In this case, we expected not to find that having received the treatment correlated with conserving more forest. The reason is that, among treated households, there were both households that adopted and did not adopt novel livelihood activities, which was expected to mask the effects of adoption on forest cover. That is why in the second regression we again estimated forest outcomes but as a function of an interaction term between the treatment and the adoption of new activities, while controlling for the same baseline covariates. This interaction term was a binary variable that allowed us to estimate the combined effect on forest cover of: (i) the treatment and (ii) the adoption of alternative livelihood activities. The variable assumed the value of 1 when referring to treated households that adopted new activities, and 0 when otherwise (both treated households in which new activities were not adopted plus control households). Both regressions did not exhibit problems of multicollinearity (Variance Inflation Factors ranged between 1.0 and 2.0).

5. Results

5.1.Impact of the of the REDD+ initiative on the adoption of alternative activities

Our results show the REDD+ initiative promoted the adoption of new livelihood activities. The initiative increased the probability of adoption between 41 to 42%, depending on the matching estimator (Table 2). This means, compared to controls, treated households were more likely to enroll in new activities, as expected.

Table 2 - Impact of the REDD+ initiative on the adoption of new activities.

Matching estimator	Adoption of new activities between 2014-2019 (1 = adopted; 0 = did not adopt)
	Coeff.[a] (S.E.)[b]
NNM (2X)	0.42*** (0.08)
NNM (4X)	0.41*** (0.09)
PSM (kernel)	0.41*** (0.08)

Note: Significance level: *=10%; **=5%; ***= 1%. DID-matching estimators: nearest neighbor using four matched observations as controls (NNM(4X)) and using two matched observations (NNM(2X)); kernel-based propensity score matching (PSM(kernel)). [a] Coefficient represents ATT. [b] Standard errors in parentheses.

5.2.Impact of the adoption of alternative activities on forest cover

As predicted, we failed to detect significant average effects of the REDD+ initiative on forest cover in the long run (Table 3). That is, there were no significant average differences in forest cover between all treated households and the control group, which could suggest the participation in the REDD+ initiative had null impacts on forest cover in the analyzed period.

Table 3 – Heterogeneous long-term impacts of the REDD+ initiative.

	Forest cover (%) – 2010-2019		
		Stratified treatment group	
DID-matching estimator	Treatment group	Households that adopted new activities	Households that did not adopted new activities
	Coeff.[a] (S.E.)[b]	Coeff. (S.E.)	Coeff. (S.E.)
NNM (2X)	6.05 (4.36)	15.47*** (5.91)	-0.57 (5.26)
NNM (4X)	6.35 (4.29)	14.67*** (5.43)	-2.22 (5.37)
PSM (kernel)	6.67 (5.31)	16.90** (6.42)	-3.47 (5.84)

Note: Significance level: *=10%; **=5%; ***= 1%. DID-matching estimators: nearest neighbor using four matched observations as controls (NNM(4X)) and using two matched observations (NNM(2X)); kernel-based propensity score matching (PSM(kernel)). [a] Coefficient represents ATT. [b] Standard errors in parentheses. This table show the results of three different DID matching analysis considering separately: (i) the full treatment group (N=52), (ii) treated households that adopted new economic activities (N=25) and (iii) treated households that did otherwise (N=27).

However, when evaluating the effects of the initiative separately on (i) households that adopted new livelihood activities and (ii) households that did not, as expected, we found contrasting results (Table 3). Again, non-significant effects were detected when the treatment group was composed only of households that did not adopt new livelihood activities. In contrast, we found significant effects from all DID matching when considering the treatment group as composed of households that adopted new activities. This implies that, in those households, the REDD+ initiative saved an average of 14.67% to 16.90% of forest cover, or the equivalent of 10.40 to 11.98 ha between 2010 and 2019, as the average land area of this group was 70.91 ha in 2019 (Table 1).

When analyzing the association between Δ forest cover and the treatment variable, while controlling for baseline covariates, we found non-significant results (Table 4). This means a household participation on the REDD+ initiative was not associated with forest cover changes in the analyzed period. Instead, when we regressed the interaction term (i.e. between treatment and new activities' adoption) on forest cover, new activities' adoption by treated households was associated with an increase of 15.80% on forest cover (11.20 ha), on average (Table 5). This finding matches well with the results from the previous analysis, with both indicating that the REDD+ initiative reached long-term forest outcomes where the adoption of new livelihood activities succeeded.

Table 4 – Results from regressions of the association between forest cover and the treatment (participation in the REDD+ initiative).

Variables	Δ Forest cover (%) (2010-2019) Coeff[a] (S.E.)[b]
Explanatory	
Treatment (treated = 1; control = 0)	5.08 (4.26)
Controls	
Forest cover in 2010 (% of land area)	-51.93*** (11.27)
Total land area in 2010 (ha)	0.05 (0.04)
Total income in 2010 (BRL)	0.00 (0.00)
Household head age in 2010 (years)	0.29 (0.19)
Household members in 2010 (number)	-0.44 (0.76)
N	98
Prob. > F	0.00
R-squared	0.20

Note: Significance level: *=10%; **=5%; ***= 1. [a] Coefficients were estimated by linear regressions. [b] Standard errors in parentheses. The dependent variable is Δ forest cover (forest cover in 2019 – forest in 2010).

Table 5 - Results from regressions of the association between forest cover and the interaction term between the treatment (participation in the REDD+ initiative) and adoption of new livelihood activities.

Variables	Δ Forest cover (%) (2010-2019) Coeff[a] (S.E.)[b]
Explanatory	
Interaction term (1 = treated and adopted new activities between 2014-2019; 0 = treated that did not adopt plus control)	15.80*** (4.31)
Controls	
Forest cover in 2010 (% of land area)	-54.90*** (11.00)
Total land area in 2010 (ha)	0.06 (0.04)
Total income in 2010 (BRL)	0.00 (0.00)
Household head age in 2010 (years)	0.36* (0.19)
Household members in 2010 (number)	-0.58 (0.75)
N	98
Prob. > F	0.00
R-squared	0.27

Note: Significance level: *=10%; **=5%; ***= 1. [a] Coefficients were estimated by linear regressions. [b] Standard errors in parentheses. The dependent variable is Δ forest cover (forest cover in 2019 – forest in 2010).

6. Discussion

Our results indicate the adoption of alternative livelihood activities was the causal mechanism of the investigated REDD+ initiative (PAS), which explained deforestation reduction in the long-term. First, we showed the REDD+ initiative promoted, as expected, enrollment in alternative livelihoods, as treated households were more likely to adopt new activities compared to matched control households. Second, this adoption promoted long-standing forest conservation; households that adopted alternative activities had higher average forest cover than controls between 2010 (baseline) and 2019 (7 years after the REDD+ initiative's onset, or 2 years after the initiative ended).

The likely explanation for the observed forest conservation is the REDD+ initiative, as planned, succeeded in offering more sustainable land-use alternatives to at least part of target-households: new practices were, perhaps, preferred over former activities whilst less deforestation dependent. Technical assistance and free inputs offered by the REDD+ implementer (IPAM) could have lowered the initial costs of adopting new activities, making them more economically attractive. Moreover, it is reasonable to suppose that PES contributed to the land-use transition by providing additional income until the new activities began to be lucrative, as originally planned by IPAM (Pinto et al., 2020). Therefore, in the end, when substituting partly or completely the more deforestation-dependent activities for lower impact alternatives, target-households kept conserving more forest cover even after the REDD+ incentives were suspended, when compared to the counterfactual scenario.

There are two anecdotal examples of new livelihood activities pursued by interviewees which are less deforestation-dependent than "business-as-usual" ones (e.g., extensive cattle ranching and swidden agriculture). During the 3rd data collection phase, four interviewees stated that IPAM gave them support to cultivate vegetables (e.g., lettuce, cabbage) and then to sell them in local markets. Support consisted of not only technical assistance and free inputs (e.g., fertilizer), but also transportation and market infrastructure. The second example is a mini-industry to extract and trade fruit pulp (e.g., *açaí – Euterpe oleracea*, pineapple – *Ananas comosus*) which IPAM helped finance to at least two of the sampled target-households.

Notably, ten interviewees (i.e., 19.23%) declared IPAM helped them to implement mechanized agriculture and to improve crop management. Indeed, one of IPAM's goals was to increase farm productivity in deforested areas (Pinto et al., 2020), which could be achieved by those practices. The rationale was that increased productivity could lead households to fulfil their demand for agricultural goods using less cultivated area. This was expected to reduce their need to clear forests, a phenomenon known as land sparing or the Borlaug hypothesis (Meyfroidt et al., 2018). Land sparing could help explain the observed forest conservation outcomes, albeit increasing farm yields might also stimulate forest conversion to agriculture – a rebound effect or Jevons' paradox (Lambin and Meyfroidt, 2011).

In summary, the REDD+ initiative probably had some success in offering more sustainable land-use alternatives. Still, a significant part of the target-households (i.e., 52% –

27 households) failed to adopt them between 2014 and 2019 (see Table 1). Being part of the treated sample had null average impacts on forest cover in this period, for those households that did not adopt novel livelihood activities. This means non-adopting households may have reduced deforestation, while the REDD+ initiative was undergoing, to receive conditional payments, as earlier shown (Chapter 1). Yet, results indicate they returned to "business-as-usual" forest clearing after payments ceased. This is no surprise, since the theory for activity-reducing PES presupposes they can reduce forest loss, but only temporarily (see Section 1), a trend already empirically observed (World Bank, 2018). This finding may imply activity-reducing PES should be combined with the successful promotion of sustainable land uses to ensure long-standing deforestation reduction, without requiring perpetual payments.

There is a plethora of potential reasons why a substantial percentage of the target-households failed to adopt new activities, despite receiving incentives to do so. Rural households in the region, as elsewhere, are not homogenous (Wright et al., 2016) and, hence, they should differ in several characteristics likely to influence their engagement in novel livelihood practices (Pattanayak et al., 2003), such as: i) personal preferences (e.g., job satisfaction, intrinsic motivation to conserve) (Bottazzi et al., 2018; Pollnac and Poggie, 2008), ii) human capital (e.g., number of adults, number of years of formal education) (Ntshangase et al., 2018); iii) their properties' biophysical characteristics (e.g., plot size, soil quality) (Bago et al., 2018); iv) land tenure security (Temegbe et al., 2015); v) trust in proponent institutions (Hunecke et al., 2017); vi) level of risk-aversion (Melisse, 2018), and vi) the opportunity costs of adopting pro-environmental land uses (Piñeiro et al., 2020). Using the last factor as example, if economic incentives do not cover the opportunity cost of changing production techniques (i.e., income losses from abandoning old practices plus additional costs to adopt new activities), farmers would be less likely to adopt the desired land-uses practices (Piñeiro et al., 2020). Hence, since the economic incentives offered to target-households were the same (see Section 2), the adoption of novel livelihood activities perhaps occurred more frequently among households whose opportunity costs for adopting pro-environmental land uses were low. Instead, households which already had high farm yields may have been less prone to adopt them. Indeed, summary statistics showed that non-adopting treated households had, in the baseline (2010), 117% more total income from livestock (i.e., the monetary value of livestock sales, own consumption plus stock) in average than adopting households (15,427.11 against 7,082.00 BRL – see Table 1). This could suggest households with higher yields from extensive cattle ranching were less prone to engage in sustainable livelihood alternatives. As yet this is only speculative, since the association between baseline farm yields and the adoption of alternative livelihoods must still be further investigated.

Another possible explanation for non-engagement is the relatively short timeframe of the initiative, perhaps insufficient to engage more households in alternative livelihood activities. Recall that the refunding request of the REDD+ initiative was denied by the Amazon Fund (see Section 2). Due to that, the main incentives to boost the adoption of new activities (technical assistance and free inputs) were provided for only three years (2014-2017). Instead, environmental outcomes of alternative livelihood projects should be expected only after long-term investments (Sandker et al., 2009). One likely reason for late results is that rural families tend to be even more risk-averse than other populations (Ellis, 1993; Mendola, 2007). Consequently, part of them may decide to adopt new activities only after observing positive results in their neighbors (Shah et al., 2016). Yet, even then, they would probably need the economic incentives to offset the adoption costs.

If more households had adopted new livelihood activities, we should be able to detect positive outcomes for forest conservation even when considering the full treated sample (N=52). Instead, when estimating average effects on the full treated sample, we observed null impacts. The interpretation of this result alone could have hidden important variation in treatment effects, which were revealed when we searched for heterogeneous forest outcomes among adopting and non-adopting households. Therefore, our findings stress the importance of investigating potential REDD+ heterogeneous outcomes to better understand what works and in what circumstances.

7. Conclusions

This article presents the first empirical investigation of a causal mechanism explaining REDD+ conservation outcomes that we are aware off. We showed a clear link between REDD+ interventions, adoption of alternative livelihood activities and long-term outcomes for forest conservation under the PAS – *Projeto Assentamentos Sustentáveis na Amazônia*.

The main implication of our findings is that, for reaching self-sustaining outcomes for deforestation reduction, the adoption of sustainable land uses should be promoted. This means REDD+ initiatives based on temporary activity-reducing PES must include interventions able to boost environmentally beneficial changes in the production systems. Otherwise, deforestation should be expected to rise soon after REDD+ interventions are suspended.

Our results also indicate the need to investigate potential heterogeneous outcomes in REDD+ impact assessments to better understand what drives the desirable conservation results and guide the design of future initiatives. We showed variation in the adoption of alternative livelihood activities led to heterogeneous outcomes for forest conservation among target-households, a knowledge that would be hidden if we had only considered average treatment effects.

We close with two caveats. First, we did not investigate which were the specific determinants of household's adoption of new activities, and how they operated in the PAS site. Understanding these factors is essential to design interventions able to boost the adoption of sustainable activities. For instance, if households with high opportunity costs were truly less likely to engage in sustainable alternatives, the corollary would be that incentives must be adjusted to the individual opportunity costs of households. Yet, even if potentially more effective, this option could be debatable or raise concerns because it likely goes against pro-poor targets. Second, we are aware that framing adoption of livelihood activities as a binary variable (adopted vs. did not adopt) may be considered too simplistic. The reason is poor rural households often prefer livelihood strategies that minimize risk, such as engaging in a diversified set of practices (Ellis, 2000). If so, they might combine novel activities with former practices (Barrett et al., 2001). More research is needed to identify the degree of household engagement in sustainable alternatives versus the abandonment of environmentally damaging activities. More importantly, to understand how the variance in such aspects correlates with household's deforestation practices.

Appendix A. Normalized differences between treatment and control group (balancing tests).

Matching variables	Normalized differences	
	Raw	Matched
Total land area in 2010 (ha)	-0.27	0.05
Agricultural area in 2010 (ha)	-0.46	0.11
Forest cover in 2010 (% of land area)	0.52	-0.02
Household head age in 2010 (years)	-0.48	-0.09
Household members in 2010 (number)	0.08	0.03
Livestock total income in 2010 (BRL)	-0.59	-0.03
Government transfers in 2010 (BRL)	-0.28	0.08

Note: This table shows normalized differences from matching covariates after and before matching households from treatment and control groups. This set of matching covariates were used in the analysis that estimated average treatment effects on the adoption of new economic activities. All normalized differences of the matching covariates dropped below 0.25 after matching, demonstrating that a plausible counterfactual was created.

Appendix B. Normalized differences between treatment and control group (balancing tests).

Matching variables	Normalized differences between treatment and control group					
			Stratified treatment group			
	Treatment group		Households that adopted new activities		Households that did not adopted new activities	
	Raw	Matched	Raw	Matched	Raw	Matched
Forest cover in 2008 (% of land area)	0.55	0.09	0.70	0.22	0.42	0.09
Forest cover in 2010 (% of land area)	0.52	0.04	0.65	0.16	0.40	0.04
Total land area in 2010 (ha)	-0.26	-0.01	-0.46	-0.11	-0.10	0.07
Total income in 2010 (BRL)	-0.29	0.06	-0.54	0.03	-0.11	0.04
Household head age in 2010 (years)	0.47	0.12	-0.70	-0.21	-0.28	-0.08
Household members in 2010 (number)	0.08	0.07	0.10	0.04	0.07	0.12

Note: This table shows normalized differences from matching covariates after and before matching households from treatment and control groups. This set of matching covariates were used in the analysis that estimated average treatment effects on forest cover. We made three different matching procedures considering separately (i) all treated households (N=52), (ii) treated households that adopted new economic activities (N=25) and (iii) treated households that did otherwise (N=27). All normalized differences of the matching covariates dropped below 0.25 after matching, demonstrating that a plausible counterfactual was created.

Appendix C. Impact on treatment group over 2008 and 2010 (placebo test).

DID-matching estimator	Forest cover (%)		
		Stratified treatment group	
	Treatment group (N=52)	Households that adopted new activities (N=25)	Households that did not adopted new activities (N=27)
	Coeff[a] (S.E.)[b]	Coeff[a] (S.E.)[b]	Coeff[a] (S.E.)[b]
NNM(4X)	0.00 (0.00)	0.00 (0.37)	0.00 (0.25)
NNM(2X)	0.00 (0.00)	0.00 (0.35)	0.00 (0.17)
PSM (kernel)	-0.71 (0.01)	-0.49 (1.69)	-0.41 (1.39)

Note: No statistically significant effects were detected to both groups in comparison to the control group over the pre-treatment period (2008-2010), which confirms DID parallel trend assumption. [a] Coefficient represents ATT. [b] Standard errors in parentheses. Forest cover was estimated in 2008 as a recall period from the 2010 survey.

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CHAPTER 3

May agricultural intensification help reach REDD+ goals? Evidence from a Brazilian Amazon site

Abstract

Transitioning extensive farming to more intensive production is often addressed as a REDD+ strategy to reduce deforestation and to achieve human co-benefits such as improvement of food security and poverty alleviation. However, intensification may lead to a rebound effect by generating more financial incentives to expand cultivated areas, therefore jeopardizing deforestation reduction. By quasi-experimental methods, we investigated: (i) whether a REDD+ initiative in the Brazilian Amazon promoted agricultural intensification, while reducing deforestation and increasing farm income; and (ii) if intensification was associated with land sparing or a rebound effect. The initiative combined Payments for Environmental Services (PES), technical assistance, and free agricultural inputs to reduce smallholders' deforestation and to increase agricultural productivity. Data came from face-to-face interviews to 98 households (treatment: 46; control: 52) in a panel design (2010, 2014 and 2019). Results indicate the REDD+ initiative reduced deforestation in the early stage, but neither increases in farm income, nor in agricultural productivity were achieved. However, in the long-term, after all REDD+ incentives were suspended, PES included, higher farm income and yields per hectare were detected, as well as forest loss rebounded. Although these results could have suggested that a rebound effect had occurred, we instead found a correlation between higher yields per hectare and more forest cover, though only marginally. On aggregate, we found no sufficient evidence neither for the rebound effect nor for land sparing.

Keywords: agricultural intensification, forest conservation, emissions reduction, climate change mitigation.

1. Introduction

Reducing deforestation is a key part of climate change mitigation, as recognized in the Paris Agreement, and therefore the primary goal of the REDD+ mechanism, short for Reducing Emissions from Deforestation and Forest Degradation. In fact, deforestation is the main source of Agriculture, Forestry and Other Land Use (AFOLU) Greenhouse Gas (GHG) emissions, which altogether represent almost a quarter of global anthropogenic emissions (IPCC, 2019). Given the importance of deforestation reduction, 56 countries included REDD+ in their Intended Nationally Determined Contributions (INDCs) (Hein et al., 2018), and 624 local REDD+ initiatives have been implemented worldwide as of December 2020 (Simonet et al., 2021).

Besides reducing emissions from deforestation and forest degradation, REDD+ initiatives are expected to achieve human co-benefits, such as food security improvements and poverty alleviation, or at least do no harm to local inhabitants (Duchelle and Jagger, 2014). To reach these multiple goals, initiatives rely on a variety of interventions, including Payments for Environmental Services (PES), forest monitoring, law enforcement, and nonconditional benefits (e.g., technical assistance, free agricultural inputs) to encourage sustainable livelihoods (Duchelle et al., 2017).

Transitioning extensive farming to more intensive production is often addressed as a REDD+ strategy able to achieve such goals (Phelps et al., 2013). The rationale is simple: by fulfilling a certain demand for agricultural goods using less cultivated area, agricultural intensification (i.e., increase in land productivity) spares land which could then be used for forest conservation (Borlaug hypothesis) (Meyfroidt et al., 2018). Additionally, agricultural intensification would prevent REDD+ land-use restrictions to negatively impact food security and rural economic development (Garrett et al., 2018).

Indeed, decoupling agricultural production growth and forest loss is acknowledged as essential in meeting the global demand for both food production and deforestation reduction (Solymosi et al., 2013). Since global food demand is expected to continue growing (Valin et al., 2014), the world will need highly efficient food production systems, which would be able to prevent the expansion of cultivated areas into forestlands. Instead, in tropical forested regions, forestlands are commonly converted to low-efficient production systems. For instance, in the Brazilian Amazon, 65% of the deforested area is covered in pastures, with an average stocking rate of less than one cattle head/ha (IPAM, 2017). This situation may imply there is no need to clear more forests to increase agricultural production, as previously argued (IPAM, 2017). Given that there is plenty of deforested lands occupied by low-productivity systems, agricultural intensification seems to be the first choice to increase agricultural yields while reducing forest conversion into agriculture.

However, agricultural intensification may also lead to a rebound effect (Jevons' paradox) (Lambin and Meyfroidt, 2011). By generating financial incentives to expand cultivated areas, intensification might drive more deforestation (Angelsen, 2010). If so, REDD+ initiatives promoting agricultural intensification are likely to induce deforestation instead of reducing it. In reality, when higher yields per hectare are achieved, both land sparing and the rebound effect may coexist in parallel, with contextual factors explaining the prevalence of one outcome above the other (Paul et al., 2019). For instance, land sparing is more likely to occur when the product demand is inelastic to price – i.e., when the demand for the product does not change as much as its change in price (Meyfroidt et al., 2018). This is usually expected for essential goods, such as staple food. In these cases, albeit intensification may lower product price by increasing production efficiency, product demand will probably not increase and, therefore, more cultivated land will not be needed (Hertel et al., 2014; Meyfroidt et al., 2018). Instead, if intensification occurs by focusing production on highly profitable products with high income elasticity of demand – i.e., products for which demand rises sharply as income rises (e.g., meat in developing countries) – a rebound effect is more likely (Meyfroidt et al., 2018).

Therefore, agricultural intensification is not a stand-alone panacea (Solymosi et al., 2013) and it should be combined with forest protection policies that limit the rebound effect (Byerlee et al., 2014). Restrictions on accessing forests (e.g., by law enforcement, protect areas), as well as PES, may potentially curb the expansion of cultivated areas into forests even when farmers are economically motived to do so (Ceddia et al., 2015; Lambin and Meyfroidt, 2011; Meyfroidt et al., 2018; Paul et al., 2019; Phelps et al., 2013). When using PES, the idea is to promote direct conservation incentives to outcompete escalating incentives to clear forest for agriculture (Phelps et al., 2013). In other words, the strategy is to make standing forests more profitable than cut, which was actually the original rationale envisioned for the REDD+ mechanism fight against deforestation (Angelsen and Mcneill, 2013).

In summary, by mixing interventions for agricultural intensification and forest protection, it is possible that REDD+ initiatives will achieve the desired win-win outcomes: intensification could improve economic gains, whereas strengthening forest protection would limit the rebound effect, if any.

However, it is unknown whether REDD+ initiatives are fostering agricultural intensification while reducing deforestation and improving farmers' economic gains. So far, we know from the few REDD+ impact evaluations that initiatives are more often achieving a certain level of deforestation reduction (Simonet et al., 2019), though with mixed effects on economic well-being indicators (e.g., cash income, perceived income sufficiency) (Duchelle et al., 2018). Yet we still know little about the potential driving factors behind the observed effects (causal mechanisms), such as agricultural intensification. This is problematic, since understanding why REDD+ initiatives are succeeding or failing in achieving target outcomes is critical for guiding better design of initiatives. Given that agricultural intensification is often addressed as a REDD+ strategy, we need to understand whether raised agricultural productivity contributes to farmers' gains while reducing deforestation. In addition, whether REDD+ initiatives are avoiding the rebound effect.

In this article, we investigated whether a REDD+ initiative in the Brazilian Amazon promoted agricultural intensification while reducing deforestation and increasing farm income. Furthermore, we assessed if intensification contributed to forest conservation or, instead, lead to a rebound effect. Implemented between 2012 and 2017, the initiative combined PES, technical assistance, and free agricultural inputs to reduce smallholders' deforestation and to increase agricultural productivity.

In a previous article (first Chapter), we showed this initiative saved, on average, 7.8% to 10.32% of forest cover per target-household between 2010 (baseline period) and 2014 (~2 years after the REDD+ initiative's onset), but average forest loss resumed between 2014 and 2019 (~7 years after onset and 2 years after the initiative ended). Here, we evaluated whether the REDD+ initiative promoted agricultural intensification and increased farm income at the early stage (between 2010-2014) or at the longer term (between 2010-2019). We expected to observe these two outcomes only at the longer term, since technical assistance and free agricultural inputs, offered by the REDD+ implementer to target-households in order to intensify their production systems, were still commencing in 2014. In addition, we hypothesized the promotion of agricultural intensification contributed to more deforestation (rebound effect).

2. The REDD+ initiative

We estimated agricultural productivity, farm income and forest cover outcomes of the *Projeto Assentamentos Sustentáveis na Amazônia* (PAS), implemented between 2012 and 2017 by a non-governmental organization (*Instituto de Pesquisa Ambiental da Amazôni*a – IPAM) in the Brazilian Amazon. More specifically, our study targeted a PAS site with 350 participant households living in twelve communities of the Pará state municipalities of Anapu, Pacajá and Senador José Porfírio, all located in the Transamazon highway, albeit IPAM targeted also other western Pará regions.

Households relied on several economic activities, mainly cattle ranching, swidden agriculture (e.g., for rice, cassava and beans), agroforestry (mostly for cacao production), poultry and pig farming. Farm production was directed towards own consumption and trade in local markets. Households also gathered forest resources, including firewood for cooking, fruits, fish and bushmeat, as well as counted on monetary income from other sources, especially government transfers, such as retirement pensions and the *Bolsa Família* conditional cash transfer program (Cromberg et al., 2014).

PAS aimed to reduce households' deforestation rates while increasing profitability in pasture and agricultural plots. For this, the initiative relied on five intervention types: especially PES, technical assistance and free agricultural inputs, but also administrative support for registering household properties under the Rural Environmental Registry (*Cadastro Ambiental Rural* – CAR) and awareness-raising meetings about environmental legislation and tenure regularization (Simonet et al., 2019)[4]. Technical assistance and free agricultural inputs were offered to promote more profitable and less deforestation-dependent land uses, which could be both a (i) novel household occupation (e.g., cultivating vegetables, agroforestry systems), or (ii) an improvement of past activities, through the implementation of more intensified practices (e.g., mechanized agriculture, intensive cattle ranching).

3. Sampling and data collection

Panel data were collected through an interview survey along three years (2010 – the baseline period, 2014 and 2019) in four treatment and four control communities, within the Global Comparative Study on REDD+ of the Center for International Forestry Research (CIFOR). Treatment communities were randomly selected among the twelve in which the REDD+ proponent (IPAM) intended to implement the initiative. Control communities were selected based on a pre-matching procedure to identify communities with similar characteristics likely to influence both initiative placement and land use/income outcomes (e.g., forest cover, deforestation pressures, and distance to the main road) (Sunderlin et al., 2016).

A total of 98 adult representatives of randomly selected households were interviewed in the three years: 52 treated; 46 controls. Our unit of analysis is the household, here defined as the group of people, usually family members, living under the same roof, and pooling resources together (labor and income) (Sunderlin et al., 2016), because: (i) households are the units of land-use decisions, such as the conversion of forests into pasture/crop area, and (ii) REDD+

[4] More detailed information about the REDD+ interventions, including a timeline of their implementation, are presented in the first chapter (Section 2).

incentives (e.g., PES, technical assistance and free agricultural inputs) were implemented at this level.

4. Empirical strategy

4.1. Assessing the initiative's outcomes on forest cover, agricultural productivity, and farm income

To assess the outcomes of the REDD+ initiative on agricultural productivity and farm income, we adopted a Difference-in-Differences (DID) approach, which is effective to evaluate outcomes when treatment cannot be randomly attributed (Conner et al., 2015). We therefore estimated the intervention's impact – participation in the REDD+ initiative – by calculating the difference between the changes in outcomes in pre- (2010) to post-intervention periods (2014; 2019) in both control and treatment groups (Fredriksson and Oliveira, 2019). We adopted two outcome variables: (i) total farm income (BRL), and (ii) farm productivity (total farm income/farm area) (Table 1). Total farm income was estimated as the sum of the household agricultural yields, from crop and livestock production (both own consumption and trade), obtained in the twelve months prior to the interview survey.

Table 6 - Summary statistics for treatment and control groups.

Variables	Treatment group		Control group	
Pre-treatment variables	Mean	Std dev.	Mean	Std dev.
Forest cover in 2010 (% of land area)[a,b]	0.70	0.16	0.60	0.23
Total land area in 2010 (ha)[a,b]	79.45	35.19	91.61	54.39
Total income in 2010 (BRL)[a,b]	27,931.35	21,525.78	34,906.54	25,455.53
Household head age in 2010 (years)[a,b]	48.48	11.45	53.91	11.42
Household members in 2010 (number)[a,b]	5.54	2.45	5.33	2.63
Farm income (crop + livestock) in 2010 (BRL)[a]	18,208.93	15,556.20	27,731.69	23,359.59
Farm productivity in 2010 (total farm income/farm area) (BRL/ha)[b]	1,002.92	1,215.72	1,105.98	1,588.42
Post-treatment variables				
Total farm income in 2014 (BRL)	34,582.86	28,067.04	48,059.77	40,997.99
Total farm income in 2019 (BRL)	86,776.88	94,648.71	72,937.3	80,336.67
Farm productivity in 2014 (total farm income/farm area) (BRL/ha)	2,681.33	8,387.46	1,444.46	1,809.16
Farm productivity in 2019 (total farm income/farm area) (BRL/ha)	4,572.69	11,089.29	1,702.78	1,590.41
Total land area in 2014 (ha)	79.45	35.19	91.61	54.39

Note: Treatment group: 52 households that participated in the REDD+ initiative. Control group: 46 households living in the control communities. Matching covariates used in the estimation of Average Treatment Effects on: [a] total farm income; [b] farm productivity. 2010- and 2014-income numbers were adjusted to 2019 through General Index of Market-Prices (IGP-M).

We combined DID with matching to further reduce selection bias (Ho et al., 2007), which means the DID estimator was applied only to those households from treatment and control groups statistically similar in six pre-treatment observable characteristics (baseline observable covariates – Table 1; see balancing tests in Appendix A and B) (Imbens, 2004). To do that while checking for robustness, we adopted two DID-matching estimators: (i) nearest-neighbor, which matches each treated household to two or four of the most similar control households (Abadie et al., 2004), and (ii) kernel-based propensity score matching, which compares households with the closest probability of being treated, given the same set of observable covariates (Rosenbaum and Rubin, 1983).

To access the initiative's forest cover outcomes, we also adopted DID matching, as shown in the first and second chapters. The outcome variable was the percentage of primary and secondary forest in the household property.

4.2.Investigating if agricultural intensification led to land sparing or to a rebound effect

To investigate if raised farm productivity correlated with either an increase (land sparing) or a decrease (rebound effect) in forest cover, we run a fixed-effects panel regression, but this time considering only treated households. In the regression, we estimated forest cover outcomes as a function of farm productivity (Table 2).

The fixed-effects model allowed us to adjust for time-invariant confounders (Imai and Kim, 2019). In addition, we controlled for the following time-varying covariates that were likely associated both with our explanatory and outcome variables: household head age, household members, total area, and off-farm income (i.e., household income obtained off the farm, including nonfarm wages and salaries, and government transfers) (Table 2).

To run the regression, we used our data in the long format, therefore ordering chronologically each household observations, according to our interview survey years (2010, 2014, 2019). Ten outlier observations were removed (i.e., farm productivity > 10,000.00 BRL/ha).

Table 7 - Summary statistics of household variables included in the fixed-effects panel regression.

Variables	2010		2014		2019	
Outcome	Mean	Std dev.	Mean	Std dev.	Mean	Std dev.
Forest cover (% of land area)	0.69	0.15	0.64	0.18	0.53	0.20
Explanatory						
Farm productivity (total farm income/farm area) (BRL/ha)	1,514.56	1,267.89	2,003.59	1,528.88	2,502.56	1,958.23
Controls						
Household head age (years)	48.74	11.56	51.86	11.40	56.08	10.96
Household members (number)	5.54	2.50	5.06	2.38	3.94	1.95
Total land area (ha)	80.89	35.12	83.86	41.55	80.36	38.98
Off-farm income (BRL)	8,504.57	8,585.82	16,944.14	26,243.61	21,360.98	20,251.52

Note: 2010- and 2014-income numbers were adjusted to 2019 through General Index of Market-Prices (IGP-M).

5. Results

5.1.Impact assessment

Our results show the REDD+ initiative reduced deforestation in the early project stage, but did not increase farm income, nor agricultural productivity (Table 3). As shown in the first Chapter, ATT for forest cover was significant for all DID matching estimators in the first period (2010-2014). This indicates an average of 7.8% to 10.32% of forest cover was saved by the initiative, or the equivalent of 6.20 to 8.20 ha, considering the average land area of treated households as 79.45 ha in 2014 (Table 1). However, for the same period, we found that ATT from all DID matching estimators were non-significant for both farm income and agricultural productivity.

Table 8 – Short term effects on farm income, agricultural productivity, and forest cover.

DID-matching estimator	2010-2014		
	Forest cover (%)	Farm income (BRL)	Farm productivity (BRL/ha)
	Coeff[a] (S.E.)[b]	Coeff (S.E.)	Coeff (S.E.)
NNM(4X)	8.08* (4.57)	1,145.82 (6143.37)	1,490.37 (1582.70)
NNM(2X)	7.80* (4.36)	-1,695.39 (6095.59)	1,661.36 (1537.27)
PSM(kernel)	10.32** (4.00)	537.27 (7557.73)	1,729.94 (1689.87)

Note: Significance level: *=10%; **=5%; ***= 1%. DID-matching estimators: nearest neighbor using four matched observations as controls (NNM(4X)) and two matched observations (NNM(2X)); kernel-based propensity score matching (PSM(kernel)). [a] Coefficient represents ATT. [b] Standard errors in parentheses. Outcomes for forest cover were estimated in the first chapter.

In the longer term, on the contrary, an increase in farm income and farm yield per hectare were detected, besides null impacts on forest cover (Table 4). Between 2010-2019, ATT for farm income and agricultural productivity was significant for all DID matching estimators. This means, in this period, the REDD+ initiative increased an average of 28,900.90 to 37,016.37

BRL (7,325.40 to 9,382.40 USD[5]) of annual farm income, or an equivalent of between 3,158.33 and 3,186.02 BRL (800.53 to 807.55 USD) per cultivated hectare. However, in this period, we failed to detect statistically significant increases in forest cover, as showed in the second Chapter. Despite the positive effects detected between 2010 and 2014, average deforestation probably resumed among target-households and reached the counterfactual scenario in the long run, as we explained in the first Chapter.

Table 9 - Long term effects on farm income, agricultural productivity, and forest cover.

DID-matching estimator	2010-2019		
	Forest cover (%)	Farm income (BRL)	Farm productivity (BRL/ha)
	Coeff[a] (S.E.)[b]	Coeff (S.E.)	Coeff (S.E.)
NNM(4X)	6.35 (4.29)	32,789.90** (12779.92)	3,158.33** (1557.45)
NNM(2X)	6.05 (4.36)	28,900.90** (12550.26)	3,173.98** (1569.17)
PSM(kernel)	6.67 (5.31)	37,016.37** (17246.40)	3,186.02* (1677.46)

Note: Significance level: *=10%; **=5%; ***= 1%. DID-matching estimators: nearest neighbor using four matched observations as controls (NNM(4X)) and using two matched observations (NNM(2X)); kernel-based propensity score matching (PSM(kernel)). [a] Coefficient represents ATT. [b] Standard errors in parentheses. Outcomes for forest cover were estimated in the second chapter.

5.2.Agricultural intensification associated with forest conservation

As average forest loss probably resumed in the long term, we suspected that agricultural intensification could have induced a rebound effect. However, when analyzing the association between forest cover and farm productivity, controlling for covariates, we found no evidence of such effect (Table 5). Instead, an increase in one unit of farm productivity (i.e., 1 BRL/ha) was associated with 0.00166% more of forest cover. Considering the initiative increased farm productivity in approximately 3000 BRL/ha (Table 4), this would mean a correlation with an increase in 4.98% of forest cover – therefore, indicating agricultural intensification was associated with land sparing. However, farm productivity and forest cover were only marginally correlated (only at 10%). This means we found no sufficient evidence for land sparing either.

[5] Conversion rate from 04/30/2019: 1 BRL = 0.2534661 USD (www.bcb.gov.br/conversao).

Table 10 - Results from the regression of farm productivity and forest cover.

Variables	Forest cover (%) Coeff[a] (S.E.)[b]
Explanatory	
Farm productivity (total farm income/farm area) (BRL/ha)	0.00* (0.00)
Controls	
Household head age (years)	-0.55* (0.32)
Household members (number)	0.44 (0.59)
Total land area (ha)	0.13 (0.08)
Off-farm income (BRL)	-0.00 (0.00)
Phase 2 (1=2014)	-4.74* (2.42)
Phase 3 (1=2019)	-11.80*** (3.46)
N	148
Prob. > F	0.00
R-squared:	
Within	0.42
Between	0.01
overall	0.03
Sigma u	0.18
Sigma e	0.10
Rho	0.77

Note: Significance level: *=10%; **=5%; ***= 1. [a] Coefficients were estimated by a fixed-effects model. [b] Standard errors in parentheses.

6. Discussion

Our results indicate that, in the early stage (i.e., between the baseline and 2014 – ~ 2 years after launch), the REDD+ initiative investigated did not increase farm income, neither agricultural productivity. Yet, deforestation was reduced. Our findings therefore suggest that agriculture intensification was unlikely a driving factor for reducing deforestation in this period. This supports the explanation argued in the first Chapter that PES was probably responsible for reducing deforestation at the initiative's early stage. As PES contracts were signed in the first months of 2013, households could have reduced deforestation in 2013 to receive conditional payments that would start one year later.

However, in the longer term (i.e., between the baseline and 2019 – ~ 7 years after REDD+ onset or 2 years after its end), we observed an opposite trend: both farm income and agricultural productivity increased, but we failed to detect significant forest conservation outcomes. The explanation could be that, by providing technical assistance and free agricultural inputs between 2014 and 2017, the REDD+ implementer succeed in intensifying the production systems of target households. We did show in the second chapter that 52% of the households (i.e., 27) declared they did not adopt alternative livelihood activities between 2014 and 2019.

Yet, they still may have benefited from free agricultural inputs (e.g., fertilizers) to improve the efficiency of former production systems. Notably, as PES was suspended in 2017, farmers had lost the direct conservation incentives, which are expected to outcompete incentives to clear forest for agriculture (Phelps et al., 2013). Therefore, at least part of former beneficiaries should had returned to “business-as-usual” forest clearing practices, as argued in the previous chapters. This added to the rise in agricultural productivity probably explains the observed increase in farm income. If forest conservation restrictions imposed by PES conditionalities had persisted, we could have observed rises in agricultural productivity without increasing on farm income.

Since deforestation practices probably resumed in the long run *vis-à-vis* increases in agricultural productivity, for at least part of target households, we suspected that agricultural intensification led to a rebound effect. In this case, intensification could have generated more financial incentives to expand cultivated areas, driving more deforestation (Angelsen, 2010), instead of reducing it as envisaged by the REDD+ implementer (Pinto et al., 2020).

However, when investigating the association between forest cover and farm productivity, we found no evidence supporting the rebound effect. Instead, our results indicate a correlation, though only marginal, between higher yields per cultivated hectare and more forest cover.

At least three factors could explain this result. First, family farming is often associated with labor shortages, particularly in contexts whereby labor markets are scarce. Therefore, even when there is willingness to convert more forests into cultivated lands, the workforce may be insufficient (Perz and Walker., 2002). Second, swidden agriculture in the region is intended to produce stapple food (e.g., rice, cassava, beans), whose demand is unlikely to significantly rise even if production has become more efficient (see Section 1). Third, at least part of the households supposedly adopted agroecological forms of intensification (i.e., more profitable but less deforestation-dependent practices), following REDD+ technical assistance.

In fact, we previously showed that target households which adopted alternative livelihood activities (i.e., 25 – 57%) kept reducing deforestation in the long run (second Chapter). In such cases, increases in farm productivity may have accompanied long-standing deforestation reduction, as originally envisioned by IPAM. If so, it seems reasonable to suppose that if more households had adopted sustainable livelihoods, following IPAM’s guidance, we could have detected more significant correlation between higher farm productivity and more forest cover.

7. Concluding remarks

On aggregate, we found no sufficient evidence neither for the rebound effect nor for land sparing. In fact, we observed that increases in agricultural productivity were followed by null average impacts on forest conservation in our study context. When we did detect forest conservation outcomes, they likely resulted from the PES component of the REDD+ initiative instead of from rises in agricultural productivity.

The association between higher farm productivity and more forest cover we have observed was only marginal. But does that mean we can state with high confidence that land sparing did not occur in the study site? We would be cautious to press such interpretation, given our relatively small sample size. With a larger sample, we would be more confident with this result. Yet, if land sparing had occurred, we would expectably find risen farm productivity followed by significant forest conservation outcomes.

Nevertheless, our findings indicate agricultural intensification could at least help achieve poverty alleviation goals in REDD+, as higher agricultural productivity was accompanied by more farm income. Notably, if either PES had been maintained, or more households had adopted sustainable livelihoods, long-standing deforestation reduction and farm income increases might have followed.

Appendix A. Normalized differences between treatment and control group (balancing tests).

Matching variables	Normalized differences	
	Raw	Matched
Total land area in 2010 (ha)	-0.27	0.07
Total income in 2010 (BRL)	-0.30	0.19
Forest cover in 2010 (% of land area)	0.52	0.11
Household head age in 2010 (years)	-0.48	-0.11
Household members in 2010 (number)	0.08	0.12
Total farm income in 2010 (BRL)	-0.48	0.04

Note: This table shows normalized differences from matching covariates after and before matching households from treatment and control groups. This set of matching covariates were used in the analysis that estimated average treatment effects on farm income. All normalized differences of the matching covariates stayed below 0.25 after matching, demonstrating that a plausible counterfactual was created.

Appendix B. Normalized differences between treatment and control group (balancing tests).

Matching variables	Normalized differences	
	Raw	Matched
Total land area in 2010 (ha)	-0.25	-0.03
Total income in 2010 (BRL)	-0.28	0.07
Forest cover in 2010 (% of land area)	0.49	0.11
Household head age in 2010 (years)	-0.46	-0.11
Household members in 2010 (number)	0.09	0.10
Farm productivity in 2010 (total farm income/farm area) (BRL/ha)	-0.07	0.05

Note: This table shows normalized differences from matching covariates after and before matching households from treatment and control groups. This set of matching covariates were used in the analysis that estimated average treatment effects on farm productivity. All normalized differences of the matching covariates stayed below 0.25 after matching, demonstrating that a plausible counterfactual was created.

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GENERAL CONCLUDING REMARKS

We departed in this thesis with the goal of assessing short and long-term effects of a REDD+ initiative in the Brazilian Amazon on deforestation and local people's well-being to help filling a knowledge gap on REDD+ outcomes. We also intended to identify which were the driving factors of this initiative's outcomes.

For deforestation effects, we have shown the investigated REDD+ initiative reduced deforestation, probably by providing Payments for Environmental Services (PES). Yet, post-intervention, deforestation resumed, albeit without 'catching up' on the temporary forest gains – thus leaving conservation gains intact (see Chapter 1). This finding implies that the permanence of REDD+ conservation outcomes need to be addressed in two complementary aspects: i) permanence of induced deforestation reduction, and ii) permanence of forest conservation gains achieved during the initiative's implementation. Our findings therefore corroborate what was argued by Skutsch and Trines (2010) and was empirically showed by the World Bank (2018): even when forest loss resumes at post-intervention, a net environmental gain will still exist as long as the once beneficiaries do not start to deforest more than the reference scenario. However, as long-term evaluations are rare, we still need more assessments to increase our confidence about how much these findings on net environmental gain after REDD+ suspension can be generalized to other REDD+ sites.

Obviously, the ideal post-intervention scenario would be to find self-sustained deforestation reduction. However, we cannot expect a miracle: that temporary payments will permanently change the logic of the productive systems. When "business-as-usual" land uses (e.g., extensive cattle ranching, swidden agriculture) paid off better than forest conservation alternatives, incremental forest conversion is expected to continue. In fact, the original idea behind REDD+ was to act against this environmental-economic problem by making standing forests more profitable than cut (Angelsen and Mcneill, 2013).

Following this logic, two alternatives for promoting long-standing deforestation reduction are presumably more likely to work: i) perpetual payments, and ii) the lasting adoption of more environmentally benign land uses with sustained economic returns.

But what about the feasibility of them? The first alternative might be impractical in face of the shortage of available funds for conservation. Therefore, the second would be preferred, despite the inherent difficulties in implementing that. We showed that, after receiving REDD+ non-conditional support (mainly technical assistance and free inputs), only 48% of the target households adopted sustainable livelihood alternatives (see Chapter 2). Whereas adopting households continued to conserve more forests than control households, this was insufficient to observe significant average deforestation reduction when considering the full treated sample (i.e., adopting and non-adopting households). These results thus indicate the need to understand how to improve interventions to increase the adoption of sustainable land-uses among target households.

One possible strategy to increase the adoption of sustainable land uses is to rely on conditional payments, such as asset-building PES, rather than upfront subsidies, as this seems to explain the successful retention of sustainable practices achieved by the Regional Integrated Silvo-pastoral Ecosystem Management Project in Colombia, Nicaragua, and Costa Rica (Calle, 2020; Pagiola et al., 2020, 2016; Rasch et al., 2021 – see Chapter 1, Section 1). In fact, conditional payments are probably the main innovation of the REDD+ approach, and perhaps we should give them more chance to operate on the ground, instead of relying mostly on non-conditional support as most of the REDD+ initiatives (Angelsen et al., 2017; Sunderlin et al., 2015). Combining activity-reducing with asset-building PES may be promising, as the first could quickly suspend deforestation practices, whereas the second could boost the adoption of sustainable land uses – hopefully ensuring long-standing deforestation reduction.

Nevertheless, our findings align with the emerging evidence suggesting REDD+ initiatives have had some success in reducing deforestation (Simonet et al., 2018). Therefore, calls for abandoning REDD+ based on disappointment with its conservation achievements are probably exaggerated (e.g. showed in Fletcher et al., 2016). Yet, we are aware that implementing REDD+ has still a long way to go. Notably, more action needs to be orientated towards national-level programs implemented by national governments, since they have more potential to promote forest conservation at scale than local projects. For instance, reforming national policies and laws that operate against conservation is needed, as this was expected to have a central role in REDD+ implementation (Angelsen et al., 2018). Still, our findings indicate that even local REDD+ interventions may be effective in delaying deforestation.

One thing for sure is there is no silver bullet that solve the deforestation challenge. Thus, we have to stop abandoning conservation strategies due to supposedly insufficient outcomes and start improving them, as argued by Redford et al. (2013). In this sense, robust impact evaluations of conservation interventions and analyses of their causal chains should play an important role in guiding evidence-based policies to advance forest conservation.

In summary, the main REDD+ implications to conservation of our findings are: i) temporary payments might effectively delay, though not permanently eradicate forest loss; ii) adoption of alternative livelihoods may ensure self-sustained deforestation reduction, but progress in successfully promoting the adoption at a higher scale must be made. Notably, we found no sufficient evidence of land sparing (see Chapter 3).

As regards REDD+ outcomes on people's well-being, results were mixed depending on the indicator adopted. Well-being perceptions improved among participant households at the beginning of the REDD+ implementation, probably in expectation of the soon starting payments. However, perceptions were subsequently impacted negatively after the initiative ended (see Chapter 1) – the same period in which we detected an increase in farm income, probably led by agricultural intensification (see Chapter 3). This coincidence between lower subjective well-being and increased income repeats a finding in another PES program in Peru (Montoya-Zumaeta et al., 2019). The likely explanation is former beneficiaries became frustrated by the suspension of REDD+ benefits, despite the observed increase on farm income.

On aggregate, our findings therefore indicate the REDD+ initiative left win-win outcomes in terms of (i) forest conservation (post-suspension, past saved forest was not cleared) and (ii) increasing agricultural profitability.

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