Partnerships to Prevent Deforestation in the Amazon[1]

Running title: Preventing deforestation in the Amazon

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Abstract: Environmental protection, even with strong environmental laws on the books, often fails in developing countries because of limited government ability to monitor and enforce environmental laws. An alternative route to government monitoring and enforcement involves partnerships with private firms and non-governmental organizations. In this paper, we evaluate the performance of the Responsible Soy Project, a partnership between Cargill and The Nature Conservancy, to curb deforestation following the opening of a new soybean export facility in the Brazilian Amazon. We find that the project significantly decreased deforestation rates in properties enrolled in the project, despite its late arrival two years after the opening of the export facility. Theoretical predictions and empirical results show that the impacts of the project were greater on smaller properties that are more likely to be credit-constrained, and on properties initially not in compliance with Brazil's Forest Code that faced binding constraints on deforestation.

Keywords: Amazon deforestation; impact evaluation; private initiative; environmental regulation, credit

1. Introduction

There often is a tradeoff between economic development and environmental conservation. Agricultural expansion in many developing countries contributes to economic development through increased production of agricultural commodities, but also causes environmental degradation including widespread deforestation. In Brazil from 1988 to 2014, the total value of agricultural production increased 2.6 times, contributing to a 1.4 times increase in per capita real gross domestic product (GDP) (FAO 2018; World Bank 2015). During the same period, 407,511 km^2 (8%) of the Legal Amazon[4] was deforested (INPE 2015), an area comparable to the state of California.

Typically, governments are responsible for monitoring economic activities and enforcing regulations to maintain environmental quality because many valuable ecosystem services[5], such as carbon sequestration and water purification, are under-provided by markets because of externalities and public goods. Deforestation of a property to plant soybeans leads to a loss of habitat and release of carbon. While the landowner benefits from crop production the loss of biodiversity and increase in greenhouse gas emissions can impose costs globally. The government can implement various policies to provide ecosystem services, including direct regulations, permit systems, taxes, or subsidies. Brazil's Forest Code, enacted in 1934 and most recently modified in 2012, requires preservation of 50-80% of each property in the Amazon as primary forest. Despite the law, rapid deforestation continued through 2004, highlighting ineffective government monitoring and enforcement. Brazil cleared an average area of 17,633 km^2 of forest per year from 1990 to 2003. In 2004 alone, 27,772 km^2 of forest were cleared, the second highest annual total since 1988 when annual record keeping began. Deforestation declined significantly in subsequent years reaching a low of 4,571 km^2 in 2012. Deforestation increased slightly following 2012 ranging from 5,012 km^2 in 2014 to 7,893 km^2 in 2016 (PRODES 2018). Part of the success in reducing deforestation since 2004 can be attributed to an

[4] The Legal Amazon encompasses seven states (Acre, Amapá, Amazonas, Pará, Rondônia, Roraima and Tocantins) and parts of Mato Grosso and Maranhão, overlapping with three biomes: Amazon, Cerrado, and Pantanal.

[5] The Millennium Ecosystem Assessment (MA 2003) defines ecosystem services as "the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth."

improved monitoring system and the Brazilian government's increased enforcement of the environmental regulations, including the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAM) in 2004 and targeted policy and institutional changes in 2008[6] (Assunção et al. 2015). However, deforestation continues in the Amazon with consequent loss of ecosystem services. It is possible that the value of carbon and other ecosystem services generated from intact forest might exceed the value of income generated from agricultural production or logging (Kennedy et al. 2016; Ring et al. 2010), but the absence of function markets for ecosystem services prevents those values from being realized by land-owners.

An alternative or complementary route to government monitoring and enforcement is a market-oriented approach that engages multinational companies and non-governmental organizations (NGOs). Consumer demand for sustainable products as well as commitments to corporate social responsibility give corporations an incentive to enforce environmental regulations. The buying power of corporations can provide strong incentives to farmers and other suppliers to comply with environmental laws. Environmental NGOs can provide assurance that environmental standards are upheld as well as technical expertise on environmental monitoring using remote sensing and other tools.

In this paper, we study the performance of the Responsible Soy Project, a collaboration between Cargill, a multinational company, and The Nature Conservancy (TNC), an international conservation NGO. The Responsible Soy Project is an example of a new type of market-oriented

[6] The institutional changes included creating a list of 36 Municípios Prioritários (priority municipalities) that were responsible for 45% of the deforestation in the Amazon Biome. In these municipalities, there was an increase in monitoring and enforcement. In the same year, access to credit was made conditional on compliance with the Forest Code. See Assunção et al. (2015) for detailed discussion.

approach to monitor and enforce environmental regulations. The Responsible Soy Project started in 2005 with a pilot project in the municipalities of Santarém and Belterra located near where the Tapajós River joins the Amazon River (Figure 1). TNC tracked deforestation through a satellite monitoring system and Cargill agreed to buy soybeans only from farmers in compliance with the Forest Code and not engaged in deforestation on their land.

In order to predict the impacts of the Responsible Soy Project and guide the empirical strategy and findings, we first develop a simple economic model of a profit-maximizing farmer to predict farmers' deforestation and production decisions. In 2003, Cargill opened a new port facility in Santarém that allowed for increased export of soybeans from the Santarém and Belterra area. Our economic model suggests that farmers would take advantage of higher soybean demand and prices following the opening of the new port facility in 2003 by immediately engaging in deforestation to increase soybean production. However, once this deforestation was accomplished farmers would have little incentive to continue to engage in deforestation. Therefore, a ban on deforestation imposed *after* the opening of the port would likely be ineffective. However, the ban on deforestation could be effective, even if imposed after the opening of the port, if farmers are unable to immediately deforest the desired amount of land due to market imperfections such as credit constraints, or if there are changes in market conditions.

We use a unique data set from the Responsible Soy Project to test hypotheses from the economic model and to see if the Responsible Soy Project was successful in reducing deforestation rates. We investigate the overall impacts of the Responsible Soy Project on deforestation as well as heterogeneous impacts of the project by property size, where we take property size as being indicative of the likelihood of facing credit constraints, and compliance with the Forest Code, which indicates whether a property was under binding constraints preventing further deforestation. We find that empirical estimates support hypotheses from the economic model. There was an increase in deforestation after the opening of the soybean export facility in 2003, especially for larger properties. Deforestation declined after the Responsible Soy Project began in 2005, especially for smaller properties and with forest cover less than the required minimum amount of 80% in 2000. These results show that imposing strict limits on deforestation even after opening opportunities for economic expansion can have a significant impact in reducing deforestation. The economic model also predicts that the best results would occur if the policy had started before or simultaneously with the opening of the port, but we lack data to test this result.

Some prior research has studied the impact of market-oriented environmental projects undertaken by businesses, governments, and NGOs. Studies in the political science and business literature conduct qualitative analyses of the causes and consequences of collaborations among different stakeholders for environmental conservation, including private companies, NGOs, government, and civil society (Fuchs and Kalfagianni 2010; Mayer and Gereffi 2010). Studies in the conservation and economics literature have quantitatively estimated the impact of market-oriented approaches, such as payment for ecosystem services (PES) and sustainability certification system, on environment and livelihoods (Arriagada et al. 2010; Blackman and Rivera 2011; Landell-Mills and Porras 2002; Miteva et al. 2012; Pattanayak et al. 2010; Wunder et al. 2008). Other studies have investigated the environmental and social impacts of Forest Stewardship Council (FSC) certification, which often involves NGOs bridging the gap between the requirement for the certification and forest concessionaires' performances (e.g., Miteva et al. 2015; Blackman et al. 2015). Our study adds to this literature on the impact of market-oriented environmental programs, by developing a simple economic model predicting when such programs are likely to be successful, and analyzing the impacts of a corporate-NGO partnership on deforestation rates in a region of the Brazilian Amazon using a unique data set from the Responsible Soy Project.

2. Background

2.1. The Opening of a New Port Facility and the Responsible Soy Project

Cargill opened a new grain terminal and export facility at the port of Santarém, located on the confluence of the Amazon and Tapajós Rivers in northern Brazil, in 2003 (see Figure 1). Cargill built the facility because of increased congestion in southern Brazilian ports and the desire to have an Amazonian port closer to European markets. Santarém is a regional center for trade and finance with waterway, road, and air transportation links. The Santarém port exports soybeans with 95% of soybeans coming from the state of Mato Grosso. The opening of the Santarém port also made soybean production in the local area around Santarém more attractive.

In 2004, shortly after the Santarém facility opened, Cargill and TNC began discussions about how to ensure that Cargill's operations did not lead to further deforestation in the area. Though it was illegal to deforest more than 20% of land area in each property under the Forest Code, Cargill did not have a way to distinguish between farmers in compliance with the Forest Code and farmers who were not. Cargill and TNC had substantive discussions about the impact of road construction from the state of Mato Grosso to the Santarém municipality and a possible compliance tracking scheme for soybeans. These initial meetings led to the creation of the

Responsible Soy Project, which officially began in December 2004. Between December 2004 and June 2005, TNC and Cargill had meetings with farmers to explain the deforestation monitoring system and the reasons for such a system. In June 2005, Cargill informed farmers that they would only purchase soybeans from farmers who participated in the monitoring system and complied with a set of project rules.

Cargill and TNC staff agreed on three main compliance criteria for farmers in order to sell soybeans to the Cargill grain terminal in Santarém: i) legal compliance with the Forest Code; ii) compliance with ecological-economic zoning (EEZ); and iii) registration in the Rural Environmental Registration (CAR) system. Legal compliance with the Forest Code criterion includes keeping native vegetation on at least 80% of total property area as well as restoration of Areas of Permanent Preservation (APP)[7]. Conservation on APP was a key element of the Responsible Soy Project because of the ecological importance of these areas for water resources and biodiversity. TNC, working with the Forest Ecology and Restoration Laboratory (LERF) from the University of São Paulo, trained farmers on how to restore APP. The second criterion of the Responsible Soy Project mandates that soy areas be located within areas identified for consolidation or expansion of agricultural areas according to the EEZ. The EEZ established areas where agriculture was permitted and protected areas that prohibited agricultural activities. The third criterion requires farmers to register their properties' spatial boundary information with the CAR system. Beginning in 2008, the Responsible Soy Project adopted a rule that required that no deforestation occurs on the property. This rule followed a rule adopted in the Soy

[7] APP are areas that are environmentally sensitive and critical for conservation such as areas close to rivers, reservoirs, and headwaters, as well as mangroves, wetlands, and hillsides with a slope steeper than 45˚ (Jung et al. 2017).

Moratorium, where all major agricultural companies agreed not to buy soybeans from farmers who had deforested their land after July 2006. NGOs, such as TNC, World Wildlife Fund (WWF), and Greenpeace, were responsible for oversight of the Soy Moratorium.

Cargill was the main buyer of soybeans in Santarém area. The only other soybean buyers in the area were small-scale buyers such as local chicken farms. This fact gave Cargill considerable leverage in enforcing compliance with these criteria. The compliance criteria provided clear and simple standards for soy sourcing. In order to prevent a leakage problem where ineligible farmers would sell their soybeans to Cargill through farmers that were participating in the program, the project compared the amount of soybeans produced and sold to Cargill every year. If the amount of soybeans sold to Cargill significantly increased from the previous year, then the project tracked the source of the increased amount to make sure that the increased amount was from the participating farm.

TNC monitored whether farmers were complying with the Forest Code (2005-2007). Beginning in 2008, TNC also monitored whether there was any deforestation. TNC monitoring used the registered property boundaries in conjunction with satellite imagery and field inspection. Yearly observation allowed TNC to compare the differences in forest cover on the property. The first version of the database was established in June 2005. It covered the municipalities of Santarém and Belterra. These two municipalities have a combined area of 27,285km^2. The database was later extended to the neighboring municipalities outside of Santarém and Belterra (96,256 km^2) in order to cover farmers outside of Santarém and Belterra that supply soybeans to the Santarém terminal (Cleary 2007). The initial assessment was used to create a map showing stands of primary forest in Santarém and Belterra as well as farm locations. Updated maps were completed in May 2007 and December 2008. Since then the map has been updated annually.

2.2. Institutional Contexts

The rules of the Responsible Soy Project are closely linked with the development of rules of the Forest Code and other regulatory tools that support the enforcement of the Forest Code. The two regulatory tools that are relevant to the Responsible Soy Project are the CAR and the Rural Environmental License (LAR), neither of which were fully enforced at the time the Responsible Soy Project started. In the state of Pará, which includes Santarém, the LAR was started in 2004. The LAR certifies that the landholder is complying with environmental regulations and is required for properties with agriculture or forestry activities. In Para, registration in the CAR became a precondition for the LAR in 2006. Later, registration for the CAR became mandatory for all properties in the state of Pará in 2008. Nationally, the CAR was introduced in 2009 on a voluntary basis, and it became mandatory with the revision of the Forest Code in 2012[8].

One way to interpret the requirements of the Responsible Soy Project is that it made mandatory the revised version of the 2012 Forest Code for properties enrolled in the starting in 2005. In 2005, the Responsible Soy Project required farmers to register their property boundaries and closely monitored their land use. The registration rate for the CAR was low before it became mandatory in 2012. In Santarém, less than 20% of the total CAR-eligible area registered before 2011. Only by 2015 did over 50% of the total eligible area register.

[8] The revised version of the 2012 Forest Code provided amnesty for illegal deforestation before 2008 for small-scale properties that range up to 440 ha in the Amazon (Soares-Filho et al. 2014). We expect that this won't significantly affect our analysis given that our study period is between 2001 and 2012.

3. Economic Model

3.1. Basic Model

In this section, we develop a simple three-period profit maximization model to explain farmers' production and deforestation decisions for a case like that in the Santarém area. We first consider a simple case with no credit constraints and no change in prices or costs through time. Then we discuss how changes in these factors change the implications of the simplified version of the model.

Let D_i^0 be the initial area of deforestation on the land of farmer i. Let $d_i^t \geq 0$ denote the area of land deforested by farmer *i* in period *t* and let D_i^t represent the cumulative deforestation in period *t*: $D_i^t = D_i^0 + \sum_{s=1}^{t} d_i^s$. We assume there is a constant cost of deforestation per unit area, C_D. Assuming that net marginal revenue from agricultural production on cleared land is positive so that a farmer will produce on all cleared land, farmer *i*'s agricultural production function in period *t*, $f_i(D_i^t)$, is a function of the total land deforested by period *t*. The agricultural production costs of farmer *i* in period *t* is given by $C_i(D_i^t)$. We assume that both the production function and cost function are continuous and twice differentiable with:

Assumption 1. $f_i(.)$ increasing and concave $(f' > 0, f'' < 0)$

Assumption 2. $C_i(.)$ increasing and convex $(\mathrm{C}' > 0, \mathrm{C}'' \geq 0)$

In period 1, farmers can only sell agricultural output to firm 1. Firm 1 may be thought of as a local buyer that pays a low price, P_1 per unit of production, and does not impose environmental standards on farmers. Firm 2 enters the market in period 2 and pays a higher price per unit of production, $P_2 > P_1$. Firm 2 can be thought of as a multinational company that exports agricultural output. In period 3, firm 2 introduces a strict environmental standard and will only buy from farmers who do not engage in deforestation in period 3 (deforestation that occurs before the standard is put in place in period 1 and 2 is not restricted). The transportation cost per unit of agricultural products sold by farmer *i* to firm *j* is C_{ij}. Farmer *i* will sell to firm 1 if $P_1 - C_{i1} \geq P_2 - C_{i2}$, and will sell to firm 2 otherwise, as long as it has met the environmental standard in period 3. Let δ be the discount factor between time periods. Suppose that farmers do not anticipate the future entry of firm 2 or the implementation of strict environmental standards, either because they are myopic or because they do not have access to information about future changes[9]. In period 1 each farmer expects to sell agricultural products in periods 1, 2, and 3 to firm with production and cost functions defined above. A farmer solves the following profit maximization problem to decide how much forest to clear and how much to produce:

$$\max_{D_i^1} E \sum_{t=1}^{3} \delta^{t-1} \left[(P_1 - C_{i1}) f_i(D_i^t) - C_i(D_i^t) - C_D d_i^t\right]$$

With constant marginal costs of deforestation, a farmer will plan on clearing land for production in period 1 and not in periods 2 and 3 since clearing in period 1 allows production in all periods while clearing later foregoes production in earlier periods. Let $D_i^{1^*}$ represent the profit maximizing choice of deforestation for farmer *i*. The farmer will produce on all cleared land with production of $f_i\left(D_i^{1^*}\right)$ and anticipated net revenue in each period of $E\left\{(P_1 - C_{i1}) f_i\left(D_i^{1^*}\right) - C_i\left(D_i^{1^*}\right) - C_D d_i^1\right\}$, with $d_i^1 = D_i^{1^*}, d_i^2 = d_i^3 = 0$.

In period 2, farmers realize they have the option of selling to firm 2. Farmers now solve the following problem:

[9] The case with fully informed farmers generates qualitatively similar results in terms of the pattern of deforestation across periods and will not be discussed here.

$$\max_{D_i^t} \sum_{t=2}^{3} \delta^{t-2} \left[(P_j - C_{ij}) f_i(D_i^t) - C_i(D_i^t) - C_D d_i^t\right]$$

A farmer will find it profitable to sell to firm 2 if $P_2 - C_{i2} > P_1 - C_{i1}$. For those farmers selling to firm 2, it will profitable to clear more land in period 2 as long as expected marginal profit from land clearing, evaluated at $D_i^{1^*}$ is positive:

$$E \sum_{t=2}^{3} \delta^{t-2} [(P_2 - C_{i2}) \frac{\partial f_i(D_i^{1^*})}{\partial D_i^1} - \frac{\partial C_i(D_i^{1^*})}{\partial D_i^1} - C_D] > 0$$

Farmers selling to firm 1 will not engage in deforestation.

In period 3, farmers cannot deforest to sell to firm 2 and there will be no further deforestation. However, even without a ban on deforestation, neither farmers selling to firm 1 nor to firm 2 would find it profitable to engage in further deforestation in period 3. The environmental standard imposed by firm 2 in period 3 to prevent further deforestation has no impact on deforestation behavior of farmers.

3.2. Other Factors that Lead to Deforestation

With market or behavioral imperfections, or changes in market conditions over time, the ban on deforestation in period 3 can affect deforestation and production decisions. Examples of market or behavioral imperfections that might change or delay farmers' deforestation decisions include credit or labor constraints, lack of knowledge of options, inertia, and lags in behaviors. For example, a farmer may not be able to choose the optimal amount of deforestation in a given period if they are credit-constrained and cannot afford incurring the cost of deforestation all at once but must spread the cost over time. Changes in market conditions over time can also affect deforestation and production decisions. For example, suppose that in period 3 some combination of price increase or transportation or production cost decrease makes marginal profitability rise compared to period 2. In this case, farmers may find it profitable to expand the production area through deforestation if they are not constrained by environmental standards.

Another factor that might affect deforestation decisions and the effectiveness of the Responsible Soy Project in preventing deforestation is the initial amount of deforested area. As discussed above in the background section, enrollment in the Responsible Soy Project required compliance with the Forest Code, which mandates 80% of the total property area to be under forest cover. Farmers who participate in the Responsible Soy Project and have less than 80% of total area under forest cover have a binding constraint requiring no deforestation. A farmer with more than 80% forest cover can engage in deforestation and not violate the rule of the program (until 2008 when deforestation was prohibited).

3.3 Summary

Based on the simple model with no market imperfections and unchanging market conditions, we would expect that farmers enrolled in the Responsible Soy Project would engage in deforestation after the port opens (period 2) and *cease* to deforest after the project begins (period 3). Farmers who do not enroll in the project would not be expected to deforest in either period 2 or 3. However, both types of farmers (enrolled and non-enrolled) might want to continue to engage in deforestation in periods 2 and 3 when there are market or behavioral imperfections, or changing market conditions. In this case, the period 3 deforestation ban might reduce deforestation for farmers enrolled in the Responsible Soy Project. In addition, we expect that farmers whose properties are already in violation of the Forest Code as they participate in the project, i.e., have less than 80% of total area under forest cover, are likely to deforest less compared to the non-participants due to the binding constraint imposed by the project.

4. Empirical Methods and Data

The Responsible Soy Project is a non-randomized experiment because farmers choose whether to register their properties in the project. Farmer and property characteristics that make a farmer more likely to enroll in the project may be correlated with the deforestation rate on the property. Unobservable characteristics correlated with the participation decision and deforestation rate, such as a farmer's attitudes towards the environment, or the profitability of growing soybeans for export, can bias regression results (Imbens and Wooldridge 2009). We use matching-difference-in-difference (DID) methods to deal with endogeneity and control for observables as well as time-invariant unobservables. This method performs better than using only matching or only DID methods especially when the set of covariates is not extensive (Smith and Todd 2005). Matching, DID, and the combination of those two methods have been widely used in recent years to evaluate the impact of environmental policies and projects (e.g., Andam et al. 2008; Honey-Roses et al. 2011; Nelson and Chomitz 2011; Robalino and Pfaff 2013; Jung et al. 2019).

We run matching-DID regressions with different specifications and conduct a series of tests to check the robustness of the results and our identifying assumptions. We run matching-DID regressions including or excluding municipal fixed effects that are interacted with time and treatment status. We also run the model with and without observations in 2003 and 2004, years when the soybean export facility was open but before the start of the Responsible Soy Project.

These years are when the effect of the opening of the port facility might have had different effects on the treatment and control groups, as suggested by the economic model. Therefore, the exclusion of observations in 2003 and 2004 controls for the potential bias from differences in treatment and control groups from the opening of the port facility (Ashenfelter 1978). We test our identifying assumption of no pre-treatment trends between control and treatment groups by estimating DID within each year after preprocessing the data by matching. This set-up allows us also to test the effectiveness of the Responsible Soy Project through time (Ho et al. 2007; Blackman et al. 2015), and if the changes in the rules imposed by the Responsible Soy Project had any impacts.

We further test the robustness of our results by separating out the effects of adherence to the Forest Code on deforestation. We test whether people who adhered to the Forest Code by maintaining forest cover over 80% in the baseline year 2000 had lower deforestation rates after 2005. This enables us to test an alternative hypothesis that observance of the Forest Code, rather than the Responsible Soy Project, explains lower deforestation rates. We explain in detail the data and methods used in what follows.

4.1. Dependent Variable: Deforestation Rates

The deforestation rate in each year is calculated for the properties in the control and treatment groups. Data on deforestation from 2001 to 2012 come from Hansen (2013). We use this dataset instead of the Brazilian national monitoring system (PRODES) because PRODES does not detect deforested patches less than 6.25 ha, which is the minimum area that can be detected through its satellite imagery system (Richards et al. 2017). The deforestation rate on each property is defined as the percentage of the deforested area during time t over the total property area. Data on individual property boundaries come from TNC for the treatment group and from the Environmental Registry System (CAR) of the Pará State Environmental Agency (Secretaria Especial do Meio Ambiente, SEMA) for the control group (SEMA 2012).

4.2. Construction of Treatment and Control Groups

The treatment group consists of properties participating in the Responsible Soy Project. There are 317 properties in the treatment group, after excluding 65 properties with no forest cover (with no forest there is no possible deforestation). We only considered properties that remained in the project in any given year, which excludes 15 properties in 2009-2010 and an additional 8 properties in 2011-2012. The control group consists of properties not participating in the project but within the municipalities of Santarém and Belterra and located east of the Tapajós River and south of the Amazon River, where the farms in the treatment group are located. This geographic range minimizes bias that can occur because of geographic mismatch between control and treatment groups (Heckman et al 1997; 1998). In addition, in the control group we used only farms whose boundaries have been reviewed and confirmed by SEMA. Properties without confirmed boundaries might not be accurate and therefore can introduce bias from measurement errors. We also exclude properties with zero recorded forest cover in any given year. There are 231 properties in the control group.

One potential complication with using properties as the unit of observation arises from a program called the forest reserve quotas (costas de reserve florestal). This program allows property owners to compensate for a reduction in forest coverage on one property with greater forest coverage elsewhere, which could result in not correctly representing legal compliance status. However, use of forest reserve quotas was very limited during our study period (May et al. 2015).

4.3. Control Variables

We use data on nine variables that may affect farmers' decisions to participate in the Responsible Soy Project and to engage in deforestation for both matching and DID estimations. These variables were chosen based on the theoretical model, interviews with farmers, and the availability of data. Given that farmers face the same or similar prices for their products, each farmer's production and deforestation decisions depend on factors affecting yield and cost. Our biophysical variables include percentage of forest cover in 2000, elevation, slope, a land quality index, distance to the soybean delivery facility, distance to the nearest water body, total property area, and percentage of deforested and soybean planted area in 2004.

All biophysical variables are calculated using the ArcMap GIS software. Average elevation and slope within property boundaries are calculated using Shuttle Radar Topography Mission (SRTM) data with 1km resolution. Distances to Cargill's soybean delivery facility, the nearest major road, and closest water body are calculated from the coordinates of Cargill's soybean delivery facility and from road and water body shape files from the Brazilian Agricultural Research Corporation (Embrapa 2013). Distances are measured as the travel distance from a point to the nearest edge of a feature through the road network. The land quality index is calculated for each farm by assigning proportional area weights using data from Embrapa (Embrapa 2013). We use an area-weighted land quality index developed by Ramalho and Pereira (1995), ranging from 0 (no production capability) to 7 (most productive soil), to control for the potential yield of the property. We also calculate the percentage of soybean plantation area within each property using agricultural land use data from Dias et al. (2016). The description of variables used in the model and summary statistics are given in Table 1.

4.4. Nearest Neighbor Covariate Matching Method

In matching methods, each observation in the treatment group is matched with one or more observations in the control group that have similar observable characteristics. We match each observation in the treatment group to observations in the control group based on observable variables. We use Mahalanobis distance matching with a caliper by dropping 25% of the observations that had the highest distance between control and treatment groups to achieve a better balance after matching (Rosenbaum and Rubin 1985).

We first match observations based on seven covariates (land quality index, distance to water body, distance to the soybean delivery facility, elevation, slope, total property area, and initial forest cover in 2000). After this first-stage matching, we additionally match observations in the treatment group to those in the control group using deforestation rates and the percentage of soybean planted area in 2004. Ignoring the impacts of the opening of the port might cause bias in evaluating the impact of the project and violate the “parallel trend” assumption. In 2004, the port facility was open but the Responsible Soy Project had not yet started. The effect of the opening of the port facility arguably has the largest differential effect on the treatment and control groups in 2004 (Ashenfelter 1978). The second stage matching, in essence, matches export farmers (those that sell to Cargill) and local farmers (those that do not sell to Cargill) based on the rate of deforestation from the time the soy export port opened to the time the Responsible Soy Project was enacted. These additional variables match farms whose response to the opening of the soy export facility was similar, controlling for characteristics of farmers that drive their deforestation behaviors with the port opening. After matching, 78 observations in the control group have been used to match 179 observations in the treatment group.[10] Only matched observations that have similar observable characteristics have been used for the following analyses in order to satisfy our identification assumption.[11]

We calculate normalized differences in means and variance ratios of each covariate between treatment and control groups before and after matching. The normalized differences in means are calculated by dividing the difference in means of control and treatment groups by the square root of the sum of the variances of control and treatment groups (Stuart 2010). After matching, we find that matching improves covariate balance between control and treatment groups. Figure 2 shows the plot of the quantiles of the control group against the quantiles of the treatment group for each covariate before and after matching. It shows that matching made both the distribution and means closer between control and treatment groups.

The inclusion of deforestation rates and soybean area in 2004 as matching covariates supports the parallel trend assumption and enables us to compare control and treatment groups that are likely to have similar deforestation rates and soybean area in 2004. Figure 3 shows changes in the trends of average deforestation rates in control and treatment groups after matching. Before matching, the average deforestation rates between control and treatment groups

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[10] On average, each observation in the control group has been used 2.3 times, where 90% of the observations have been used 1-5 times and 10% of the observations have been used 6-10 times. As a test to check the sensitivity of our results, we run the same models by excluding treated observations paired with control observations that have been used over 5 times and find that our main results do not change (Table A3 in the Appendix).

[11] We find that there are no significant differences in the average values of covariates between full treatment sample and sample after matching except for the deforestation rate and soybean planted area in 2004. In the matched sample, we dropped properties in the treatment group with high deforestation rates and soybean planted area in 2004 to improve the balance with the control variables. We find that the non-parallel trend appears when matched without a caliper.

do not follow a parallel trend, where the treatment group's average deforestation rates are significantly higher than those of the control group in 2003 and 2004 compared to previous years. After matching, the deforestation rates show similar patterns between control and treatment groups.

4.5. Difference-in-Differences (DID) Method

The DID method is useful for disentangling the impacts of a specific project that affects only those participating in a project from more general trends that affect everyone. The DID estimator controls for unobserved time-invariant farmer characteristics that affect selection into the project by double differencing. The DID estimator takes differences in the pre- and post-project deforestation rates within control and treatment groups and takes differences between control and treatment groups. We also control for municipality specific effects by using municipality dummy variables.

The DID after matching is estimated using the following regression (Imbens and Wooldridge 2009):

$$d_{it} = \alpha + \beta T_t + \gamma G_{it} + \tau_{DID} T_t G_{it} + \delta X_{it} + \varepsilon_{it}$$

where d_{it} is the deforestation rate of property *i* at time period *t*; T_t is a time dummy variable which is 1 if $t \geq 2005$, and 0 otherwise; G_{it} is a participation dummy variable equal to 1 if the property is eventually in the project, and 0 otherwise; X_{it} is a vector of other control variables that affect the deforestation rate in property *i* as well as their participation in the project including the seven variables used for the matching estimation and time and municipality fixed effects; and ε_{it} is an error term that is assumed to be independent of both G_{it} and T_t. The initial time period

$2001 \leq t \leq 2004$ and control group of $G_{it} = 0$ coefficients have implicitly been normalized to zero. This model assumes that the policy effect is the same for all years.

The resulting coefficient, τ_{DID}, estimates the difference in the average outcome of the treatment group before and after the treatment minus the difference in the average outcome of the control group before and after the treatment. This double-differencing method controls for the time trend and differences in d_{it} caused by time-invariant characteristics and thus isolates the effect of project participation on deforestation. We use a robust clustered variance-covariance matrix. Bertrand et al. (2004) show that serial autocorrelation can lead to overestimated t-statistics and significance levels. The robust clustered variance-covariance matrix clusters all observations in different years by property and corrects for serial autocorrelation.

We test the robustness of the results by including or excluding time and municipality fixed effects. We also run the model with and without observations in 2003 and 2004, which are after the opening of the soybean export facility but before the starting of the Responsible Soy Project.

4.6. Pre-trend and yearly variation analyses: event-study specification

We also run the following regression model in order to test whether matched control and treatment groups have similar pre-treatment trends in deforestation rates and to estimate yearly variations in the treatment impacts.

$$d_{it} = \theta_j + \beta T_t + \gamma_1 G_i + \sum_{k=2001}^{2012} \tau_{DIDt} T_t(t = k) G_i + \delta X_{it} + \varepsilon_{it}$$

where θ_j is a municipality dummy variable indicating 1 if a property is located in Santarem and 0 if located in Belterra; T_t is a time indicator dummy variable which is 1 if t corresponds to any given year (k) between 2001 and 2012 (t=2005 omitted), and 0 otherwise for a property i; G_i, X_{it}, and $\varepsilon_{\mathrm{it}}$ are as defined in the previous equation. The time period $t = 2005$ and control group of $G_i = 0$ coefficients have implicitly been normalized to zero.

The resulting coefficient, τ_{DIDt}, estimates the difference in the average outcome of the treatment and control groups within each year compared to those in the baseline year 2005, which is the start year of the Responsible Soy Project.

4.7. Heterogeneous impacts and mechanisms

We test whether the impacts of the project differ by the market imperfection of whether a property is credit constrained or not and legal status of whether a property has over 80% forest cover in the baseline. We divide the properties into two groups by using two proxy indicators that can help identify credit constraints and legal status of properties. We run the same event-study specification regressions using observations in each group.

We first use the total area of properties as a proxy for whether a property is credit-constrained. We assume that small-scale farmers are more likely to be credit-constrained than larger-scale farmers (Deininger and Feder 2001; de Castro and Teixeira 2012). Our expectation is that deforestation by smallholders is more likely to be reduced by enrolling in the project because smallholders are more likely to be credit-constrained. We define properties under 300 ha in Santarém and Belterra, to be owned by small-scale farmers[12] and therefore credit-constrained compared to the properties over 300 ha.

[12] Our use of 300 ha corresponds to the threshold that the government uses in Santarém and Belterra to divide small farms from medium to large farms. The threshold is set with reference to the estimated amount of land required for the economic subsistence in a given municipality.

We further divide the small properties into two groups: properties that were already in violation of the Forest Code in 2000 and those that were in compliance with the Forest Code in 2000. By doing so, we test whether the project had stronger impacts on properties that already had a binding constraint of lower forest cover than the legally required minimum of 80% in Santarém and Belterra, as discussed in the economic model.

4.8. Robustness check to an alternative hypothesis

We test the robustness of our results by testing whether people who adhered to the Forest Code in the baseline year 2000 had lower deforestation rates compared to the others who did not. We do so by first running the same matching-DID regression in testing the effectiveness of the project but including interaction terms among a dummy variable indicating adherence to the Forest Code in 2000, a dummy variable for participation in the project, and a dummy variable indicating years post-2005. We also run a separate matching-DID regression by using the adherence to the Forest Code in 2000 as the treatment and test whether people who adhered to the Forest Code in 2000 had lower deforestation rates after 2005 using the event-study specification outlined in section 4.6.

5. Results

5.1. Deforestation Trends for Control and Treatment Groups

The opening of the port in 2003 appeared to push deforestation rates higher in the Santarém and Belterra region, especially for the treatment group (Figure 4) as compared to rates for the whole of Pará state, where Santarém and Belterra are located, and the entire Legal Amazon. While the pattern of deforestation in Pará and the Legal Amazon is similar to that in the treatment group, especially the increase from 2003 to 2004, the magnitude of the spike of deforestation rate from 2003 to 2004 is much higher in the treatment group as compared to Pará and the Legal Amazon. Deforestation rates increased almost threefold in 2004 in the treatment group, the period after the port opened but before the project began. The deforestation rate in the treatment group dropped in 2005 with the beginning of the Responsible Soy Project. It has remained relatively low since. The average deforestation rate dropped from 12% in 2004 to 2.8% in 2005. However, deforestation rates also dropped in the control group starting in 2005, though the decline was not as dramatic as in the treatment group (from 3.8% in 2004 to 1.8% in 2005). Since 2006, the average deforestation rate has been relatively steady. The average deforestation rate was slightly higher in the treatment group than in the control group after 2005 except for the years 2009 and 2010.

From Figure 4, it is not clear whether the large decrease in deforestation rates after 2005 in the treatment group reflect the impact of the Responsible Soy Project in reducing deforestation or whether it is simply a reversion to a more typical deforestation rates following elevated deforestation rates as a result of the opening of the port facility. It is possible that without the project there would have been continued high rates of deforestation after 2005 because of profitable opportunities to produce soybeans given the existence of the port facility. Yet this evidence is also consistent with the view that the deforestation that was going to occur with the opening of the port largely occurred in 2003 and 2004 and would have dropped in any event soon thereafter. The decline in deforestation after 2005 may also have been the result of changes in government policies, such as increased enforcement of the Forest Code, or changes in international agricultural markets, such as the drop in the price of soybeans in 2005. The real price of soybeans dropped by 13%, and that of maize dropped by 14%, from 2004 to 2005 (World Bank 2015). In what follows, we utilize the matching-DID method to test for alternative explanations of the data patterns and to uncover the likely causes explaining deforestation rates.

5.2. Project impact estimation

In this section, we present results from the DID method using only matched observations, which compares control and treatment groups that have similar biophysical characteristics in terms of the seven matching variables as well as deforestation rates and soybean area in 2004.

The overall impacts using binary treatment impacts with and without the municipal fixed effects interacted with time and treatment status consistently show that the deforestation rates in the treatment group were significantly lower compared to those in the control group after the start of the Responsible Soy Project (Table 2 and Table A1, A2 in the appendix). The main estimates in Table 2 show that the treatment group had lower deforestation rates post-2005 compared to those of the control group by between 1.7 and 1.8% between cases using all observations and using observations without 2003 and 2004. This appears to be similar to estimates that range from 1.3 to 1.8% using different fixed-effect specifications in Table A1 and A2 in the appendix.

The matching-DID results in Table 3 that use event-study specification show consistent patterns of differences in deforestation rates between control and treatment groups with no significant differences prior to 2005, and significant difference emerging only after the Responsible Soy Project started. The results of the pre-trends by year suggest that none of the interaction variables between treatment and year is significant at the 5% level of significance. This suggests that there was no significant difference in the deforestation rate trend between control and treatment groups before the start of the project. This result supports the assumption that matched control group would have had similar deforestation rates as the treatment group had there not been the Responsible Soy Project after controlling for covariates.

The coefficients of the interaction between treatment and year 2006-2012 show the yearly variation in the impacts of the Responsible Soy Project. It measures the variations in differences in the deforestation rates between control and treatment groups in the respective year compared to the baseline year 2005. The results in all columns are consistent with the claims from the previous two tables showing that the project had negative and significant impacts on deforestation rates post-2005, specifically in 2009, 2010, and 2012 with no significant impacts in other years. The presence of significant impacts in later years and the lack of significant impacts in earlier years might reflect the fact that the monitoring database of all properties was completed during 2007-2008. Starting in 2008, the project also imposed the additional rule allowing no deforestation, to be consistent with rules under the Soy Moratorium.

5.3. Heterogeneous impacts and mechanisms

Considering the economic model, overall significant impacts of the project on decreasing deforestation indicate that the project's impacts on properties that were credit-constrained and not in compliance with the Forest Code in 2000 are stronger than for other properties. Our estimation of heterogeneous impacts by dividing properties by credit-constraints and forest cover, proxied by the property size and amount of forest cover in 2000, respectively, provides evidence for it.

Table 4 shows that the project had negative and significant impacts on deforestation rates in 2009, 2010, 2012 for properties less than 300 ha (column (1)). The post-project impacts for the larger properties show insignificant impacts in all years except for 2007 where the treatment group had higher deforestation rates than the control group. However, we also find that the treatment group with larger properties had higher deforestation rates compared to the control group in 2002 and 2003 before the project started, which might be why we are observing the higher deforestation rates post-2005. The higher deforestation rates of those larger properties in 2002 and 2003 might reflect the larger properties deforesting their properties when the port facility is being built and opened, i.e., period 2 in our economic model. Alternatively, it could be that the model is not as well specified for larger facilities, for example, because there are too few controls or controls that are poor matches.

The results also show that significant and negative impacts of the project on deforestation are mainly coming from the properties that had less than 80% of forest cover in 2000 (column (3) in Table 4). The treatment group had significantly lower deforestation rates immediately following the start of the project in 2006 as well as in 2009 and 2010. This evidence supports the notion that properties with less than 80% forest cover in 2000 had binding constraints that kept them from deforesting when enrolled in the project. Properties that had more than 80% forest cover and were in compliance with the Forest Code did not seem to have lower deforestation rates by participating in the project.

These results suggest that the Responsible Soy Project significantly decreased deforestation rates despite the fact that it began two years after the opening of the port, potentially due to credit constraints experienced by farmers or other constraints or behavioral responses, and the initial forest cover status of properties. The Responsible Soy Project's effects were only statistically significant in changing behaviors of farmers whose properties are less than

300 ha and had less than 80% of the total area covered by forest. This supports the effectiveness of the Responsible Soy Project in decreasing deforestation in areas where they already have high deforestation rates and any positive deforestation is illegal according to the Forest Code. Also, larger properties with the size over 300 ha seem to have deforested in earlier years, which makes the introduction of the responsible soy project ineffective, as suggested by the economic model and estimation results.

On the other hand, the project did not seem to cause further decreases in deforestation for small-scale properties that have more than 80% of forest cover (column (4) in Table 4). It is interesting to note that the signs of the coefficients for those whose properties had a higher forest cover are positive (column (4) in Table 4) between 2006 and 2008, although statistically not significant at 5%. The positive sign implies that the Responsible Soy Project might have provided a perverse incentive to deforest. As indicated as a higher price from Firm 2 in the economic model, the participation in the project provided an incentive to produce more by providing an export outlet for soybeans produced within properties that are participating in the project.

5.4. Robustness check to an alternative hypothesis

Our test of the alternative hypothesis shows that the significant impact of the Responsible Soy Project is not coming from the adherence to the Forest Code. The inclusion of the interaction terms in Table 5 does not appear to change the negative and significant impacts of the project on deforestation. Rather, the magnitude of the coefficients of Treat × Post-2005 increased by more than 10% compared to those in Table 2. This is also supported by the results from the separate matching-DID regressions in Table 6 that use the adherence to the Forest Code in 2001 as the treatment. The deforestation rates of properties that were in compliance with the Forest Code in 2001 were not significantly different from those that were not in compliance with the Forest Code in 2001 at 5% level of significance. This indicates that the significant impact of the project is not driven by people adhered to the Forest Code. The coefficients seem to indicate that people who adhered to the Forest Code in 2001 might have deforested more, particularly in 2008, where the coefficients are positive and significant at 10% level of significance.

6. Conclusion

Despite having strong environmental laws on the books, Brazil experienced high rates of deforestation for many years, in part because of lax monitoring and enforcement of the Forest Code. An alternative route to monitoring and enforcement is to engage the private sector and NGOs. The Responsible Soy Project, a partnership between Cargill, a multinational corporation, and The Nature Conservancy, an international conservation NGO, was initiated with the aim of reducing deforestation rates in the Amazon after the opening of the new soybean export facility in Santarém in northern Brazil.

As our results show, the Responsible Soy Project had a statistically significant impact in reducing deforestation rates. We found that deforestation rates declined in the treatment group enrolled in the project as compared to those in the control group not enrolled following the start of the program in 2005. We found that the impacts of the project on deforestation rates appear to be greatest after 2008, which corresponds to the time when the complete monitoring system was functioning and when stronger rules requiring no deforestation were in place. These results are robust to various econometric model specifications. We also found that the project had a significant effect on reducing deforestation when we controlled for adherence to the Forest Code prior to the start of the project. Consistent with our economic model, we find evidence that the Responsible Soy Project was effective in reducing deforestation for smaller properties that are more likely to be credit-constrained, and on properties that had less than 80% forest area in 2000 and thus faced a binding constraint on no further deforestation.

The data also suggest that efforts to prevent deforestation could have been more effective had they been in place prior to the opening of the export facility in Santarém. Deforestation rates showed a marked increase in 2003 and 2004 in the neighboring districts of Santarém and Belterra. Deforestation rates rose much more in Santarém and Belterra compared to Pará state in which Santarém and Belterra are located, and the Amazon region as a whole. The decline in deforestation rates with the start of the Responsible Soy Project, however, indicates that the program was effective in reducing deforestation by restricting the opportunity to profit from soybean expansion in forested areas.

As the results in this paper show, it is possible for partnerships between corporations and NGOs to assist with monitoring and enforcing of environmental laws when there is a lack of government capacity to do so. Such partnerships can result in improved environmental performance, such as reducing the deforestation rate in a portion of the Amazon in Brazil. Our study, however, was for a specific case study involving a specific partnership in a specific area. More research is needed to understand whether such partnerships work more generally, and if there are important institutional and market contexts that make success more or less likely. This work could provide useful information for understanding conditions when partnerships can be effective in complementing governmental regulations and improving environmental outcomes.

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Table 1. Variable descriptions, means, and standard deviations (S.D.)

Variable	Description	Mean (S.D.)		
		Total (N=548)	Control (N=231)	Treatment (N=317)
Deforestation rate (%)	The percentage of deforested area over total area in each year	2.49 (6.69)	1.67 (4.86)	3.10 (7.71)
Fcover2000 (%)	The percentage of forest cover in 2000 over total area	76.12 (21.26)	75.26 (24.15)	76.75 (18.90)
Elevation (m)	Average elevation within properties	123.06 (37.23)	112.12 (35.38)	131.03 (36.57)
Slope (degree)	Average slope within properties	1.74 (0.93)	2.10 (0.95)	1.47 (0.82)
Dist_facility (km)	Travel distance through a road network from a property to Cargill's soybean delivery facility	68.28 (32.95)	77.20 (35.18)	47.01 (26.02)
Dist_water (km)	Travel distance through a road network from a property to the closest water body	14.09 (9.56)	10.80 (8.8)	16.50 (9.36)
Land_quality	Area-weighted land quality based on the classification of Ramalho and Pereira (1995). Scores range	5.23 (1.88)	4.60 (2.09)	5.70 (1.58)

	from 0 (no production capability) to 7 (most productive soil)			
Area (ha)	Total area of a property	381.99	374.36	387.55
		(678.92)	(450.31)	(806.35)
Def2004 (%)	The percentage of deforested area in 2004 over total area	8.52	3.80	11.96
		(13.80)	(6.93)	(16.32)
Soy2004 (%)	The percentage of soybean area in 2004 over total area	0.67	0.48	0.81
		(0.81)	(0.71)	(0.86)

Table 2. Estimation of overall treatment impacts using difference-in-differences (DID) regression method after matching by dividing years into pre- and post- periods with year-fixed effects, where their impacts vary by municipality and year

	Dependent variable: Deforestation rate (%)			
	Using all observations	Without 2003 and 2004	Using all observations	Without 2003 and 2004
Treat	1.25**	1.06	1.24**	1.05
	(0.57)	(0.71)	(0.56)	(0.71)
Post-2005	0.61	1.73**	-0.56	0.65
	(0.58)	(0.68)	(1.02)	(1.29)
Treat × Post-2005	-1.81***	-1.65**	-1.81***	-1.65**
	(0.52)	(0.70)	(0.52)	(0.70)
Santarém	Yes	Yes	Yes	Yes
Santarém × Treat	Yes	Yes	Yes	Yes
Santarém × Post-2005	Yes	Yes		
Santarém × Each Year			Yes	Yes
Observations	3034	2520	3034	2520
R^2	0.04	0.03	0.08	0.07

Notes: Control variables include forest cover in 2000 (%), elevation, slope, dist. Facility (km), dist. Water (km), soil quality, total area, and price of soybeans. ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively.

Table 3. Pre-trend and yearly variation analyses results using event-study specification regression results after matching for the effect of the Responsible Soy Project on deforestation

	Dependent variable: Deforestation rate (%)			
Pre-trends				
Treat × year=2001	-0.93	-0.93	-0.71	-0.71
	(0.67)	(0.67)	(0.74)	(0.74)
Treat × year=2002	1.34	1.34	1.95*	1.95*
	(1.07)	(1.07)	(1.14)	(1.14)
Treat × year=2003	1.11	1.11	1.18	1.18
	(0.70)	(0.70)	(0.71)	(0.71)
Treat × year=2004	0.41	0.41	0.71	0.71
	(0.97)	(0.97)	(0.95)	(0.95)
Impacts by year				
Treat × year=2006	-0.51	-0.51	-0.34	-0.34
	(0.62)	(0.62)	(0.71)	(0.71)
Treat × year=2007	0.63	0.63	1.08	1.08

	(0.71)	(0.71)	(0.81)	(0.81)
Treat × year=2008	-0.48	-0.48	-0.64	-0.64
	(0.79)	(0.79)	(0.86)	(0.86)
Treat × year=2009	-2.89**	-2.89**	-2.69**	-2.69**
	(1.14)	(1.14)	(1.16)	(1.16)
Treat × year=2010	-1.69***	-1.70***	-1.66***	-1.66***
	(0.46)	(0.46)	(0.47)	(0.48)
Treat × year=2011	-0.77	-0.77	-0.88	-0.89
	(0.60)	(0.60)	(0.58)	(0.58)
Treat × year=2012	-3.01*	-3.02*	-3.27**	-3.27**
	(1.57)	(1.57)	(1.53)	(1.53)
Santarém	No	Yes	Yes	Yes
Santarém × Year	No	No	Yes	Yes
Santarém × Treat	No	No	No	Yes
Observations	3034	3034	3034	3034
R^2	0.08	0.08	0.09	0.09

Notes: Control variables include forest cover in 2000 (%), elevation, slope, dist. facility (km), dist. water (km), soil quality, total area, and year fixed effects. ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively.

Table 4. Heterogeneous impacts by the compliance status in 2000 with the Forest Code and by the size of properties

	Dependent variable: Deforestation rate (%)			
	All properties		Small-scale properties (total area < 300 ha)	
	(1) Small-scale properties (total area < 300 ha)	(2) Larger properties (total area > 300 ha)	(3) Not in compliance in 2000	(4) In compliance in 2000
Pre-trends				
Treat × year=2001	-1.27	0.59	-2.11	-0.28
	(0.99)	(0.71)	(1.57)	(1.13)
Treat × year=2002	1.42	3.03**	4.38**	-2.00
	(1.54)	(1.33)	(1.82)	(2.56)
Treat × year=2003	0.30	3.58**	0.39	0.20
	(0.79)	(1.47)	(0.88)	(1.40)
Treat × year=2004	0.28	1.77	-0.84	1.57
	(1.23)	(1.41)	(1.27)	(2.25)
Impacts by year				
Treat × year=2006	-0.34	-0.42	-1.80**	1.34

	(0.94)	(0.48)	(0.80)	(1.83)
Treat × year=2007	0.80	1.54**	-0.78	2.61
	(1.07)	(0.66)	(1.07)	(1.97)
Treat × year=2008	-0.96	0.073	-1.83	0.029
	(1.19)	(0.59)	(1.18)	(2.21)
Treat × year=2009	-3.75**	-0.53	-3.78**	-3.74
	(1.62)	(1.08)	(1.50)	(3.04)
Treat × year=2010	-1.99***	-0.78	-2.26***	-1.68
	(0.63)	(0.52)	(0.75)	(1.06)
Treat × year=2011	-0.96	-0.60	-0.35	-1.65
	(0.79)	(0.49)	(1.14)	(1.17)
Treat × year=2012	-5.11**	0.39	-3.65	-7.21*
	(2.27)	(0.69)	(2.84)	(3.80)
Observations	2184	850	1108	1076
R^2	0.09	0.18	0.12	0.12

Notes: Compliance status was determined by whether forest cover in 2000 was over 80% of total area (in compliance) or not (not in compliance). Control variables include forest cover in 2000 (%), elevation, slope, dist. facility (km), dist. water (km), soil quality, total area, year fixed effects, and Santarém fixed effects that vary by year and treatment status are included in all specifications.. ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively.

Table 5. Robustness check of the overall treatment impacts by investigating the impacts of adherence to the Forest Code (FC) using difference-in-differences (DID) regression method after matching by dividing properties by compliance to the FC in 2000

	Dependent variable: Deforestation rate (%)			
	Using all observations	Without 2003 and 2004	Using all observations	Without 2003 and 2004
Treat	1.45**	1.71*	1.44**	1.70*
	(0.67)	(0.87)	(0.67)	(0.87)
Post-2005	0.050	0.65	-1.12	-0.43
	(0.66)	(0.75)	(1.10)	(1.35)
Treat × Post-2005	-2.07***	-2.37***	-2.07***	-2.36***
	(0.63)	(0.88)	(0.63)	(0.88)
FC compliance in	-0.59	-1.10	-0.59	-1.10
2000 (FC 2000)	(0.62)	(0.81)	(0.63)	(0.82)
Treat × FC 2000	-0.44	-1.40	-0.44	-1.40
	(0.78)	(1.09)	(0.78)	(1.09)
Post-2005 × FC 2000	0.56	0.96	0.56	0.95
	(0.74)	(0.89)	(0.74)	(0.89)

Treat × Post-2005 ×	0.59	1.59	0.58	1.59
FC 2000	(1.01)	(1.26)	(1.01)	(1.27)
Santarém	Yes	Yes	Yes	Yes
Santarém × Treat	Yes	Yes	Yes	Yes
Santarém × Post-2005	Yes	Yes		
Santarém × Each Year			Yes	Yes
Observations	3034	2520	3034	2520
R^2	0.05	0.04	0.08	0.07

Notes: Control variables include forest cover in 2000 (%), elevation, slope, dist. Facility (km), dist. Water (km), soil quality, total area, and price of soybeans. ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively.

Table 6. Robustness check: yearly impacts of adherence to the Forest Code (FC) on deforestation using event-study specification regression results after matching

	Dependent variable: Deforestation rate (%)			
Pre-trends				
FC compliance in 2000	-1.13	-1.13	-0.93	-0.93
(FC 2000) × year=2001	(1.50)	(1.50)	(1.48)	(1.48)
FC 2000 × year=2002	-1.78	-1.78	-1.49	-1.49
	(1.49)	(1.49)	(1.45)	(1.45)
FC 2000 × year=2003	1.60	1.60	1.65	1.65
	(1.05)	(1.05)	(1.03)	(1.03)
FC 2000 × year=2004	-1.09	-1.09	-0.95	-0.95
	(1.32)	(1.32)	(1.33)	(1.33)
Impacts by year				
FC 2000 × year=2006	1.36	1.36	1.60	1.60
	(0.98)	(0.98)	(1.00)	(1.00)
FC 2000 × year=2007	1.81	1.81	2.07^{*}	2.07^{*}

	(1.15)	(1.15)	(1.14)	(1.14)
FC 2000 × year=2008	1.78*	1.78*	1.72*	1.72*
	(0.94)	(0.94)	(0.92)	(0.92)
FC 2000 × year=2009	0.96	0.96	1.23	1.24
	(1.30)	(1.30)	(1.29)	(1.29)
FC 2000 × year=2010	0.94	0.95	1.09	1.10
	(0.85)	(0.85)	(0.84)	(0.84)
FC 2000 × year=2011	0.52	0.52	0.60	0.61
	(0.96)	(0.96)	(0.95)	(0.95)
FC 2000 × year=2012	-1.45	-1.45	-1.47	-1.46
	(2.09)	(2.09)	(2.07)	(2.07)
Santarém	No	Yes	Yes	Yes
Santarém × Year	No	No	Yes	Yes
Santarém × Treat	No	No	No	Yes
Observations	2416	2416	2416	2416
R^2	0.07	0.07	0.08	0.08

Notes: Control variables include forest cover in 2000 (%), elevation, slope, dist. facility (km), dist. water (km), soil quality, total area, and year fixed effects. ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively. The quantile-quantile plot visualizing covariate balance is drawn in the Appendix.

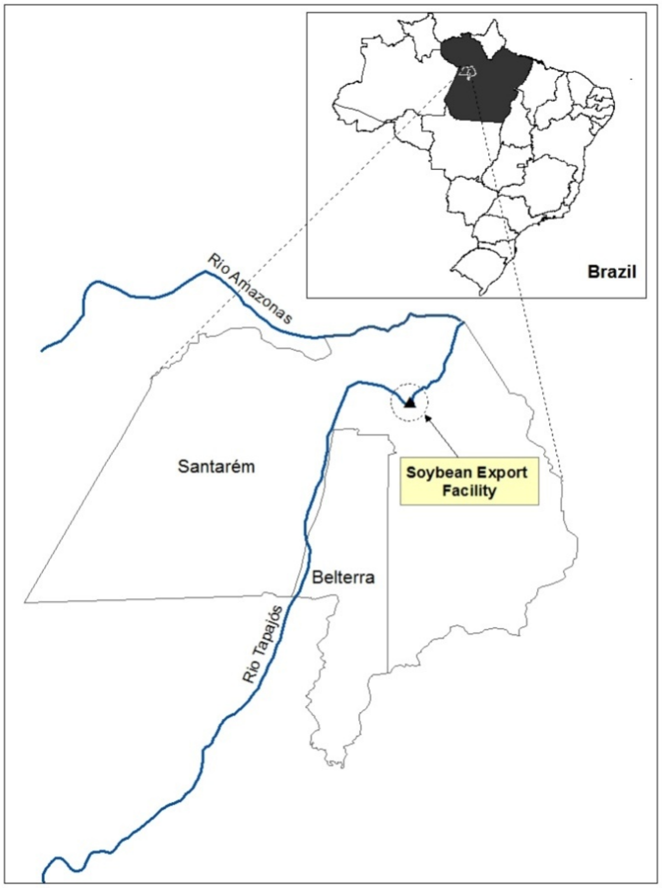


Fig. 1. The location of Cargill soybean export facility in Santarém near the confluence of the Amazon and Tapajós Rivers in northern Brazil

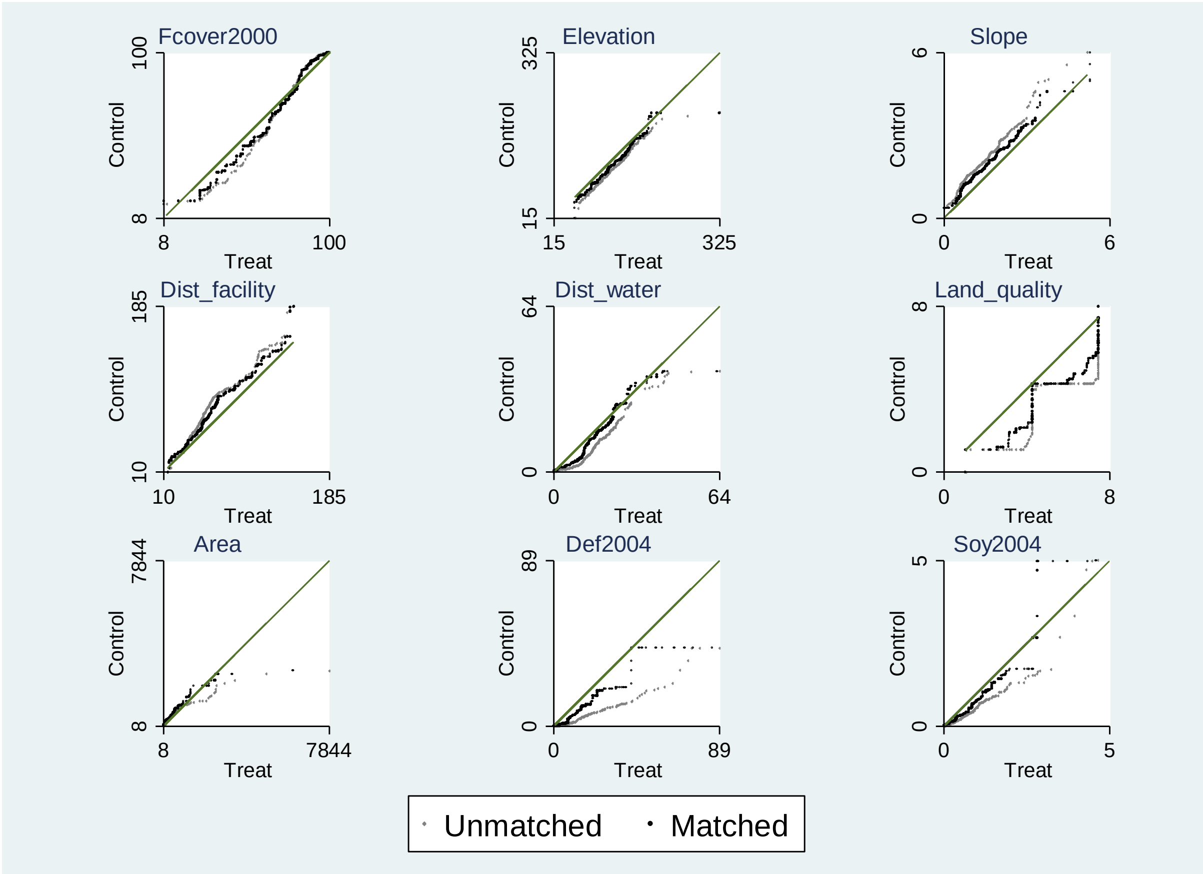
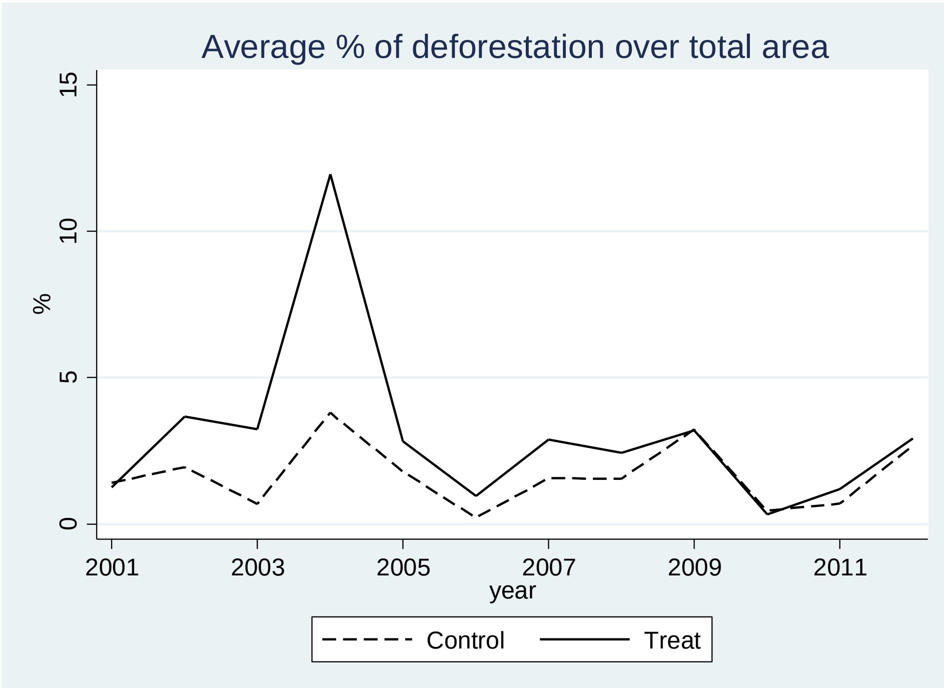


Fig. 2. Quantile-quantile plots of each covariate before and after matching in the evaluation of the impacts of the Responsible Soy Project



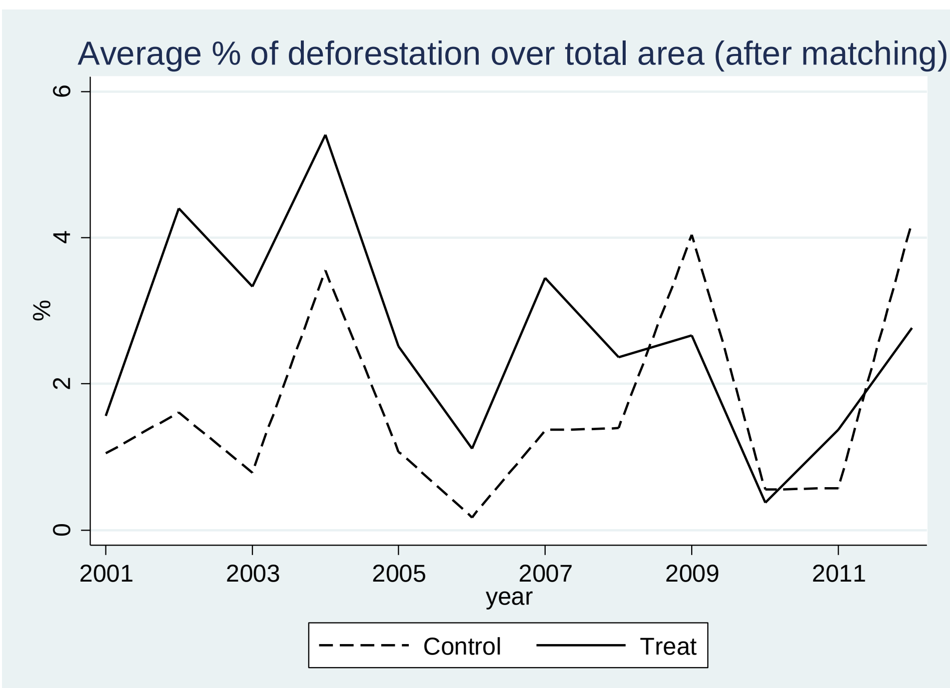


Fig. 3. Comparison of the average percentage of deforested land over the total area in the control group and in the treatment group by year before (above) and after (below) matching of control and treatment observations based on biophysical characteristics

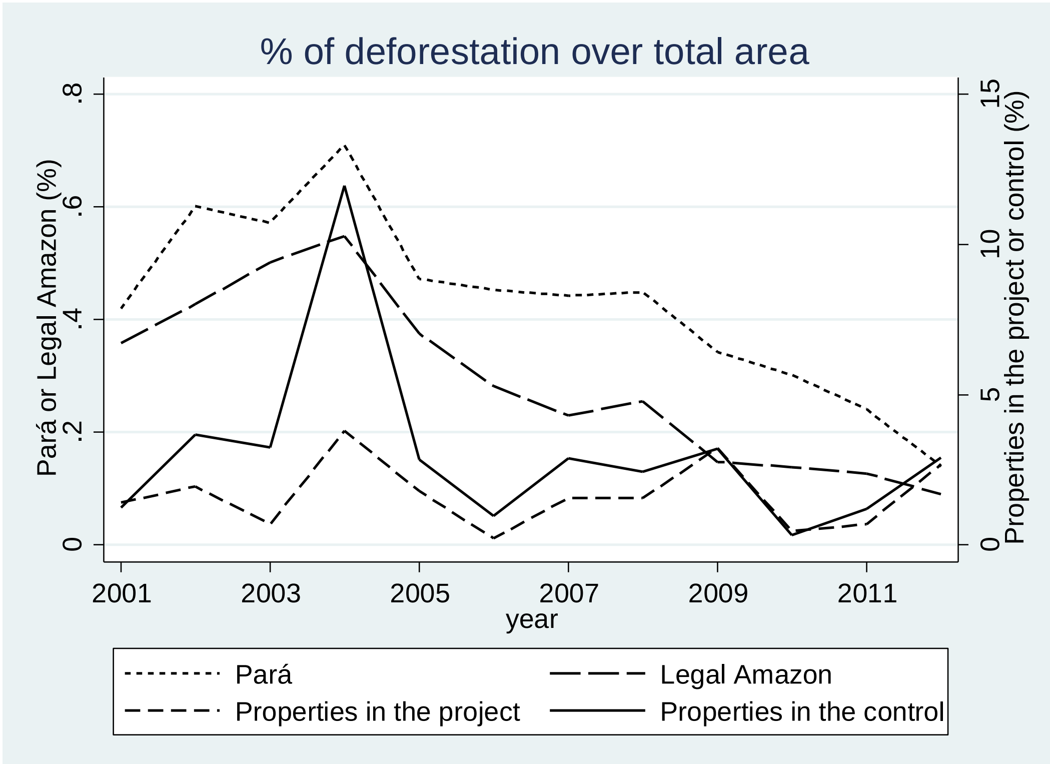


Fig. 4. Comparison of the percentage of deforested land over the total area in the state of Pará, Legal Amazon (INPE 2015), and in the treatment group by year.

Appendix

Table A1. Estimation of overall treatment impacts using difference-in-differences (DID) regression method after matching by dividing years into pre- and post- periods, where their impacts vary by municipality

	Dependent variable: Deforestation rate (%)							
	Using all observations				Without observations in 2003 and 2004			
Treat	1.20***	1.27***	1.45***	1.25**	0.98*	1.04*	1.34**	1.06
	(0.42)	(0.41)	(0.42)	(0.57)	(0.59)	(0.59)	(0.63)	(0.71)
Post-2005	-0.62	-0.61	0.61	0.61	0.0059	0.011	1.73**	1.73**
	(0.39)	(0.39)	(0.58)	(0.58)	(0.47)	(0.47)	(0.68)	(0.68)
Treat × Post-2005	-1.55***	-1.55***	-1.81***	-1.81***	-1.27**	-1.28**	-1.65**	-1.65**
	(0.50)	(0.50)	(0.52)	(0.52)	(0.64)	(0.64)	(0.70)	(0.70)
Santarém	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Santarém × Post-2005	No	No	Yes	Yes	No	No	Yes	Yes
Santarém × Treat	No	No	No	Yes	No	No	No	Yes
Observations	3034	3034	3034	3034	2520	2520	2520	2520
R^2	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03

Notes: Control variables include forest cover in 2000 (%), elevation, slope, dist. Facility (km), dist. Water (km), soil quality, total area, and price of soybeans. ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively.

Table A2. Estimation of overall treatment impacts using difference-in-differences (DID) regression method after matching by dividing years into pre- and post- periods with year-fixed effects that vary by municipality

	Dependent variable: Deforestation rate (%)							
	Using all observations				Without observations in 2003 and 2004			
Treat	1.20***	1.27***	1.45***	1.24**	0.98	1.04*	1.34**	1.05
	(0.42)	(0.41)	(0.42)	(0.56)	(0.59)	(0.59)	(0.63)	(0.71)
Post-2005	-0.07	-0.07	-0.21	-0.21	0.35	0.35	1.96**	1.96**
	(0.37)	(0.37)	(0.93)	(0.93)	(0.44)	(0.44)	(0.90)	(0.90)
Treat × Post-2005	-1.55***	-1.56***	-1.81***	-1.81***	-1.28**	-1.28**	-1.65**	-1.65**
	(0.50)	(0.50)	(0.52)	(0.52)	(0.64)	(0.64)	(0.70)	(0.70)
Santarém	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Santarém × Year	No	No	Yes	Yes	No	No	Yes	Yes
Santarém × Treat	No	No	No	Yes	No	No	No	Yes
Observations	3034	3034	3034	3034	2520	2520	2520	2520
R^2	0.04	0.04	0.08	0.08	0.03	0.03	0.07	0.07

Notes: Control variables include forest cover in 2000 (%), elevation, slope, dist. facility (km), dist. water (km), soil quality, total area, and year fixed effects. ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively.

Table A3. Estimation of overall treatment impacts using difference-in-differences (DID) regression method after matching by dividing years into pre- and post- periods with year-fixed effects, where their impacts vary by municipality and year, after excluding treated observations paired with control observations that have been used over 5 times

	Dependent variable: Deforestation rate (%)			
	Using all observations	Without 2003 and 2004	Using all observations	Without 2003 and 2004
Treat	1.13*	1.36	1.12*	1.35
	(0.62)	(0.84)	(0.62)	(0.84)
Post-2005	0.48	1.73**	-2.15	-1.85
	(0.70)	(0.83)	(5.98)	(6.01)
Treat × Post-2005	-1.34**	-1.72**	-1.34**	-1.72**
	(0.61)	(0.85)	(0.62)	(0.85)
Santarém	Yes	Yes	Yes	Yes
Santarém × Treat	Yes	Yes	Yes	Yes
Santarém × Post-2005	Yes	Yes		
Santarém × Each Year			Yes	Yes
Observations	2382	1978	2382	1978

R^2	0.03	0.04	0.06	0.06

Notes: Control variables include forest cover in 2000 (%), elevation, slope, dist. Facility (km), dist. Water (km), soil quality, total area, and price of soybeans. ***, **, and * indicate 1%, 5%, and 10% level of significance, respectively.

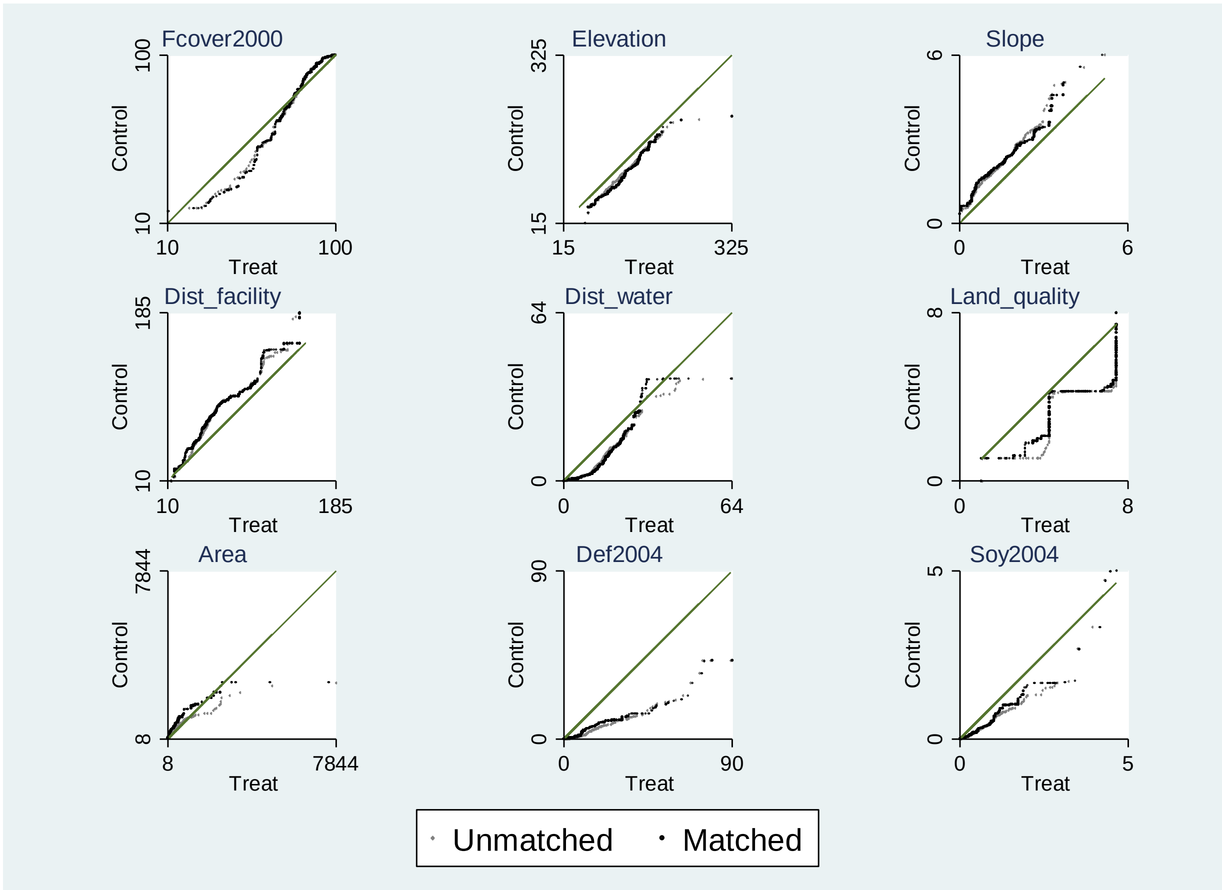


Fig. A1. Quantile-quantile plots of each covariate before and after matching in the evaluation of the impacts of adherence to the Forest Code (corresponding to Table 6 in the manuscript)