Impact evaluation

of the Green Municipalities Program, and Imazon's support, in Pará, Brazil

Phase 2 Report
delivered to Mercy Corps

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Terms and acronyms

APP: Área de Preservação Permanente, or Area of Permanent Preservation, including riparian zones, steep slopes, and hilltops designated for forest protection per the Brazilian Forest Code

Blacklist: federal priority list, established in 2007, identifying municipalities with high levels of deforestation, administered by the MMA

CAR: Cadastro Ambiental Rural, or Rural Environmental Cadaster

DID: differences in differences

Gross deforestation: conversion of original mature forest to a non-forest land-use, not to be confused with net deforestation which is total change in forest cover

IBAMA: Brazilian Institute of Environment and Renewable Natural Resources, federal environmental agency

IBGE: Instituto Brasileiro de Geografia e Estatística, or the Brazilian Institute of Geography and Statistics

Imazon10: Ten municipalities receiving technical support from Imazon under the USAID/Skoll program, including Dom Eliseu, Tailândia, and Ulianópolis; Brasil Novo, Monte Alegre, Novo Progresso, Novo Repartimento, Santana do Araguaia and Santarém; and Moju (all are also participants in the PMV)

INPE deforestation year t: as monitored by INPE, from August 1 of year t-1 to July 31 of year t

LULCC: Land use / land cover change

MMA: Ministério do Meio Ambiente, or Ministry of the Environment

MPF: Ministerio Público Federal, or Public Prosecutor's Office

PMV: Programa Municípios Verdes (GMP in English)

PMV category: Categorization of municipalities in PA developed for prioritization and planning purposes, including (1) blacklisted, (2) consolidated or well developed old frontier, (3) forested or beyond the frontier, (4) deforestation monitored and under control, having exited the blacklist, and (5) under deforestation pressure or active frontier, at risk of entering the blacklist

PMV on paper: Indicator that municipality has signed agreement with the federal prosecutor in Pará (MPF, or *Ministério Público Federal*) and/or directly with the PMV, with year of treatment defined as earlier of these two possible agreements based on INPE definition of a deforestation year (August of previous year to July of current year) (Note that we exclude Paragominas, because it received assistance from Imazon although it was not part of the Imazon10, and the 11 municipalities that joined the program after 2011, because effects are not expected within such a short time frame.)

PMV implementation: Subset of municipalities in PMV on paper that have achieved at least three of the following steps identified by key informants as most important for active engagement with the program: celebrated a pact against deforestation, created a working group to combat deforestation, registered at least the median percent of land in the CAR, established at least minimum structure for municipal environmental governance

PA: State of Pará

Prefeitura/prefeito: municipal government/ mayor

PSDB: Partido da Social Democracia Brasileira, political party of current governor of Pará

SCM: Synthetic control methodology

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Executive Summary

This report documents an evaluation of the impacts on deforestation of two programs working in concert in the Brazilian Amazon state of Pará: (i) Programa Municípios Verdes (PMV); and (ii) an initiative by Imazon to provide technical assistance to 10 municipalities within the PMV (Imazon10). These programs were designed to help municipalities respond to federal mandates to reduce deforestation − including a 2007 policy that identifies and penalizes municipalities where the most deforestation has occurred (the 'blacklist'). The two programs are best considered as a bundle of complementary and interdependent activities – the Imazon10 serves to assist municipalities in their participation in the PMV. Both programs are on-going and expanding: municipalities continue enrolling in the PMV, and Imazon plans to expand their technical assistance to 40 more municipalities.

In preparation for this evaluation, we conducted an extensive review of applicable evaluation methodologies, and solicited insight from fellow investigators and key actors in Pará to inform the development of our approach and subsequently to inform interpretations of findings. Our team met with Imazon, PMV, and the municipal government of Paragominas during a visit to Brazil in October – November 2013, with Amintas Brandão of Imazon during his visit to North Carolina in October 2014, and with a larger group of stakeholders at a workshop in Belém in April 2015.

After identifying 519 municipalities in the Brazilian Amazon as the master "donor pool" of potential comparisons to the municipalities in the PMV and Imazon10, we compiled a large database on interventions, deforestation, and a wide range of geographic, biophysical, political, and economic factors (covariates) that influence both participation by and deforestation within these municipalities. Data were obtained from Imazon and Brazilian government sources such as the Instituto Brasileiro de Geografia e Estatística (IBGE) and the Instituto Nacional de Pesquisas Espacials (INPE). Prior to conducting this evaluation, we piloted and refined our approach by evaluating the deforestation impact of the Municipio Verde initiative in Paragominas that was one source of inspiration and a model for PMV. We then excluded Paragominas from this analysis (because it received technical assistance from Imazon similar to but separate from this program).

The selection bias inherent to intentionally-targeted and voluntary programs such as the PMV and Imazon10 can confound estimates of impacts, unless counterfactual outcomes are estimated using quasi-experimental methods. Based on our review of the literature and test in Paragominas, we identified the synthetic control method (SCM) as the most appropriate given our evaluation questions and available data. To evaluate the impact of the 'PMV', the PMV with assistance from Imazon ('bundled PMV + Imazon10'), and active engagement in the PMV, i.e. implementing key actions in addition to signing an agreement (all referred to hereafter as "treatments"), we ran over 700 separate analyses. From each analysis, we obtain an estimate of the impacts on annual rates of gross deforestation from the beginning of the interventions (in 2011, 2012 or 2013) through 2014 (using preliminary deforestation data for 2014). As robustness checks, we also estimate a panel regression and employ standard (covariate and kernel) matching approaches.

By applying SCM to our database of historical deforestation rates and characteristics of municipalities, we identify weighted combinations of municipalities (the 'synthetic control') that best represent what would have happened had the PMV or Imazon10 not been implemented. This is judged based on the match

between deforestation in the treated and synthetic control during the pre-treatment calibration period (from 2001 to beginning of treatment in 2011, 2012 or 2013), and we exclude municipalities for which we cannot obtain a good match during this time period. This revised report (1.3) includes appendices specifying the municipalities included in the synthetic controls and their weights. We also show that the weighted average of covariates in the synthetic control is generally a much better match for the 'treated' municipality in the IMAZON10 or PMV than a simple average of all municipalities in the donor pool. The municipalities in the synthetic control are drawn from donor pools that exclude all other municipalities in the program being evaluated and that include only municipalities in the same blacklist status (e.g., for black-listed treated municipalities, the donor pool for the counterfactual was restricted to similarly black-listed municipalities). We therefore estimate an impact of treatment that is conditional on blacklist status.

This impact of treatment is the difference between deforestation in the treated municipality and its matched counterfactual. To assess the significance of estimated impacts, we conducted "placebo tests" to establish the range of false "effects" in un-treated municipalities evaluated as if they were treated municipalities - estimated actual effects above the 95th or below the 5th percentile of this distribution are interpreted to be statistically significant. In municipalities where deforestation rates are already low (e.g., municipalities not on the blacklist), any possible reduction in deforestation is likely to fall within this distribution and thus not be statistically distinguishable from zero.

Synthetic controls were developed based on historic INPE data on deforestation available in 2014. Impact results reported here are based on INPE's estimates of deforestation in 2014 released in August of 2015. Averaging across five municipalities with good quality synthetic controls (Ulianopolis, Dom Eliseu, Tailandia, Novo Progresso and Santana do Araguaia), we found that the impact of the bundled PMV + Imazon10 treatment on blacklisted municipalities was to reduce annual deforestation by 0.3% or 21 km^2 in 2014 (and by 0.1% and 0.7 km^2 in 2013). Results using SCM and standard matching generally agreed, and we found that in most municipalities, both the bundled PMV+Imazon10 and the PMV alone significantly reduced deforestation in 2014 but did not in 2013. Municipalities with significant reductions in deforestation tended to be those that started treatment earliest (e.g. municipalities signing on to the PMV in 2010, the first year of the program), and those that had implemented the most steps in the PMV (as shown in this revised version 1.3). These findings are consistent with impacts emerging as various components of the programs are implemented. It also suggests the importance of longer-term evaluations to assess impacts that may take some time to be realized. While all but one of the blacklisted municipalities in the PMV are actively engaged in implementing the program, 85% of the non-blacklisted municipalities in the PMV have made little progress implementing the program. We detect no effect of the program on these non-blacklisted municipalities who are part of the PMV on paper only, while actively implementing the program appears to have caused very small reductions in deforestation in non-blacklisted municipalities.

Our findings suggest that the short-run impacts of these programs on deforestation are small or negligible. It is possible that these programs are having short-run impacts on outcomes that we have not analyzed. For example, it may be that in many municipalities, the blacklist alone is sufficient to effect reductions in deforestation, and that the additional impact of the PMV and Imazon10 programs is to reduce the cost of meeting the federal mandate, which may in turn help sustain the reduction in deforestation over the long run. Some consideration should be given to other potential impacts of the Imazon and PMV to frame subsequent evaluations planned for 2015 and 2016.

1.0 Introduction

The Programa Municípios Verdes (PMV) in the Brazilian state of Pará (PA) seeks to engage municipal governments in reducing deforestation and developing economic alternatives that do not require deforestation, thereby helping municipalities to comply with the environmental goals set by national climate change mitigation policies. As part of its support for this state-wide program, Imazon is providing additional technical assistance to 10 municipalities in the program (Imazon10), selected to represent the range of conditions influencing deforestation in PA. To date, PA is the only Brazilian state with a program like the PMV. In order to assess whether and how to scale up this type of intervention to other states in the Brazilian Amazon, we need a better understanding of its causal effects, or impacts. While Imazon and the PMV administration ultimately aim to generate sustainable economic development and stabilize forest cover, their immediate objective is to reduce gross deforestation rates. Thus, we have focused on estimating program impacts on gross deforestation, represented as the percent of the municipality deforested (as measured by INPE from August of previous year to July of current year). The challenges to evaluating impacts include that (1) municipalities were selected into these programs based on factors that also influence their future deforestation rates, (2) the number of treated units in the Imazon10 is very small, limiting the statistical power of most quasi-experimental methods, and (3) there is limited scope for observable impacts given that the programs have only been implemented for a few years and in the context of strong federal actions to reduce deforestation.

2.0 Framing the research question

2.1 Background and characterization of interventions ("treatments")

In 2008, Imazon began collaborating with the municipality of Paragominas to support their efforts to improve municipal environmental governance, develop economic alternatives, and reduce deforestation in order to get off the federal "blacklist" or priority list of the MMA, which had been established by the federal government in 2007 in order to focus enforcement efforts, restrict market access, and encourage better governance in municipalities where the most deforestation was occurring. A total of 48 municipalities have been blacklisted since 2007 (Figure 1). In 2010, Paragominas became the first municipality to be taken off the blacklist. Their success captured the attention of other municipalities in the same region and of the state government. As a result, Imazon sought funding to work with additional municipalities, obtaining a grant from the Amazon Fund that allowed them to expand collaboration to other municipalities in the same region in 2011. Subsequently, the governor established a special secretariat for a state-wide green municipalities program (Programa Municípios Verdes, hereafter "PMV"), also in 2011.

In March of 2011, the state government formally launched the PMV with the stated goals of promoting sustainable economic activities and reducing deforestation in the state. Imazon closely collaborates with the state government on this program, participating in the management council and the "environmental observatory" that tracks progress reducing deforestation and expanding registration in the CAR (rural

environmental cadaster), and providing deforestation alerts that the PMV passes on to the municipal governments. Municipalities can join the PMV by signing an agreement with the MPF (specifically, the federal prosecutor from the Ministério Público Federal assigned to Pará) and/or signing an agreement with the PMV.

When the PMV was established, it immediately incorporated 39 municipalities that had already signed agreements with the MPF in 2010. By July 2011 (the end of the 2011 INPE deforestation year), 91 municipalities (including Paragominas) had signed agreements with the MPF and thereby officially joined the PMV (Figure 1.1). Starting in 2012, the PMV also directly signed agreements with other municipalities, and by July 2014 (the end of the 2014 INPE deforestation year), another 11 joined by signing agreements with the MPF, the PMV, or both. Muncipalities with significant deforestation typically sign agreements with both the MPF and the PMV; municipalities without significant deforestation may sign agreements with the PMV in order to demonstrate support for the program, e.g. through initiatives to improve their urban environment. For our analysis, we consider municipalities that joined the program by 1 August 2011 as part of "PMV on paper," defined as a municipal government (*prefeitura*) signing up for the PMV (based on government records of the dates that prefeituras joined the PMV). We do not consider the eleven municipalities that have joined the program since that time, because the intervention has been applied too recently to expect impacts, and because they are also not valid 'controls' for estimating the counterfactual outcomes of municipalities that joined by August 2011. Likewise, we exclude Paragominas, because it neither underwent the same treatment as the rest of the Imazon10 nor serves as a valid control (see Figure 1.1).

In their agreements with the MPF and/or the PMV, the prefeituras commit to a series of specific actions (or steps), but they have made variable progress on implementing these steps, as tracked by the PMV in their on-line database. In order to identify the steps most indicative of active engagement with and implementation of the PMV, we elicited input from key informants including researchers at Imazon, consultants working with the PMV, municipal secretaries of the environment, and representatives of NGOs that collaborate with the PMV. Based on 11 responses, we identified four steps recorded in PMV's database as the best indicators that a municipality is implementing the program. "PMV implementation" is defined as having completed at least three out of the following four steps: celebrated a pact against deforestation, created a working group to combat deforestation, registered at least the median percent of land in the CAR, established at least a minimum structure for municipal environmental governance.[1]

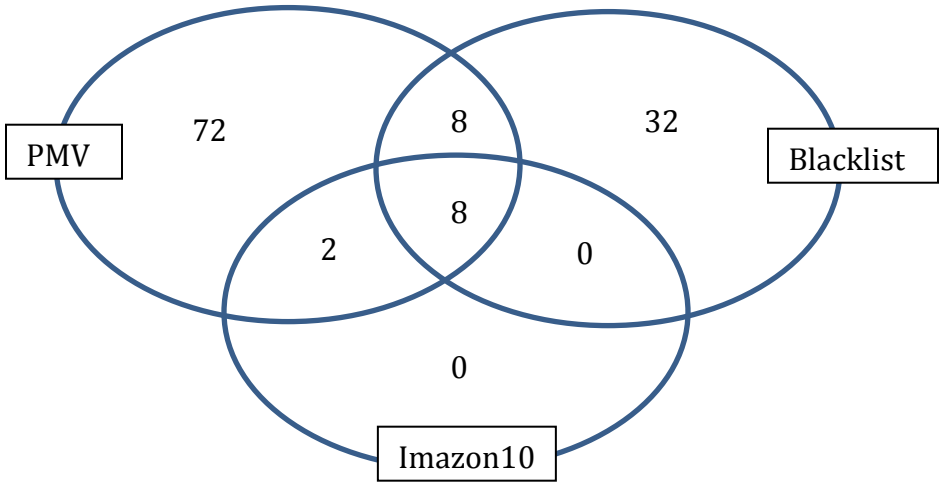
Against this backdrop of the PMV, Imazon, with funding from USAID-Skoll, is partnering with 3 of the municipalities where they established technical cooperation agreements in 2011 (Don Eliseu, Tailândia, and Ulianópolis), six municipalities that signed technical cooperation agreements with Imazon by the end of 2012, and Mojú, which replaced one of the originally selected municipalities that dropped out of the

[1] In Portuguese:

1. Possuir Acordo de Cooperação específico com o PMV
2. Pacto contra desmatamento celebrado
3. Grupo de combate ao desmatamento
4. % propriedades cadastradas no CAR
5. Habilitação para gestão ambiental municipal

program in 2013. All of these "Imazon10" are participants in the PMV on paper and implementation. Imazon's objective is essentially to replicate the "Paragominas model" with these municipalities (later to be scaled up to an additional 40 municipalities in the PMV), including developing detailed maps and municipal government capacity in order to facilitate the CAR and eventually environmental licensing. For actors in other states considering whether to implement this type of intervention (i.e., the target audience for scaling up), the most relevant question is the impact of implementing the PMV with the level of support provided by Imazon. Thus, we define one "treatment" of interest as joining the PMV with support from Imazon, or the "bundled" effect of the PMV and Imazon10 interventions. We consider the period up to 2010 as pre-treatment, and the period starting in 2013 as treatment, with variation in how we treat 2011 and 2012 across the different municipalities, given their staggered entry into the program.

Figure 1.1: Counts of municipalities considered in this analysis (excluding Paragominas and municipalities that joined the PMV between August 2011 and present)



2.2 Expected impacts ("outcomes")

While PMV and Imazon agree on the long-term goal of economic development with zero net deforestation in Pará (by 2020, according to Imazon's log frame for the USAID-Skoll project), they are equally clear that their short-term priority is to reduce *gross* deforestation. Since we are evaluating program impact over only a few years, we focus on gross deforestation: area of original mature forest in the municipality converted to other land uses. This does not distinguish illegal from legal deforestation (e.g. clearing up to 20% of private properties in municipalities not on the blacklist is legal), nor consider forest degradation, nor count plantations, restoration, or forest regeneration and potentially new clearing of that regeneration, nor distinguish areas of the municipality under the jurisdiction of different levels of government (e.g. federal protected areas vs. municipal land held under private titles).

In this version 1.3 of the report, we further consider whether the IMAZON10 and PMV have different impacts in areas under different land tenure, specifically considering deforestation outcomes in (i) the land eligible for registration in the CAR ("CAR I"), (ii) the land under municipal control ("CAR II"), and (iii) other land, comprised largely of federal protected areas, indigenous resources, and land reform settlements. We hypothesize that the effects are likely to be different in areas where the CAR is actively being implemented and areas where the municipal government has more direct control over land use, as compared to federally owned areas that may be subject to illegal activity more difficult for the municipal government to control. However, it is also possible that the PMV or the IMAZON10 is more effective in federal areas, as a result of better communication and coordination between different levels of government.

In any of these areas, annual gross deforestation can be represented by the (i) percent of the remaining original forest deforested, (ii) area deforested (in square kilometers), or (iii) share of the municipality deforested (square kilometers deforested divided by square kilometers of the municipality). The first option can be interpreted as the probability that any given area of forest is cleared in a year. From the perspective of modeling the behavior of deforestation agents, percentage deforestation is often the preferred outcome measure. However, for purposes of this impact evaluation, the third option is our preferred outcome measure for the impact evaluation, because it reflects the primary objective of the program, requires relatively little data manipulation (annual deforestation in square kilometers derived from shape files provided by INPE divided by constant area of municipality in square kilometers), and can be summed across years to calculate cumulative impacts. Nearly all of the municipalities in our sample were originally 100% covered in forest, and thus gross deforestation as a percent of the municipality also represents the percent of the *original* forest cover lost in a given year. Further, impacts on deforestation measured as a percent of the municipality can be easily converted to square kilometers of deforestation, which is also relevant in the context of the blacklist.

Once on the blacklist, a municipality can get off only by reducing gross deforestation below 40 square kilometers/year, regardless of the size of the municipality (apparently a deliberate effort to maximize pressure on large municipalities that are major contributors to Brazil's carbon emissions and generally considered "bad actors" in terms of overlooking blatant illegal activity by large holders). This has been incorporated into the PMV as a goal for all participating municipalities. If participation in the program means that municipalities target the goal of gross deforestation below 40 square kilometers/year, it suggests that the treatment is heterogeneous, because this generally requires large municipalities to reduce deforestation much more than small municipalities. To explore this, we examine variation in effects across municipalities of different sizes.

2.3 Selection into the Imazon and PMV interventions

It is important to place the PMV and Imazon's efforts in the context of recent changes at the federal level in Brazil. In 2007, a presidential decree established the legal basis for identifying priority municipalities for preventing, monitoring, and controlling deforestation, including increased enforcement effort by IBAMA, restrictions on commodity sales, and stricter requirements for land registration. In 2008, another presidential decree specified the administrative processes for dealing with environmental crimes, increasing

the clarity, speed, and likelihood of punishment through fines, seizure of production inputs, and/or embargoes, including the publication on the internet of a list of embargoed properties. Further, transporting, processing, trading or commercializing products from embargoed areas also become illegal. During 2009, the MPF reached various agreements with industry, producers, and state government in Pará requiring them to stop trade from embargoed areas and implement an environmental licensing system within 12 months. In the same year, Pará created a provisional version of the CAR, which allowed landowners to register before proving definitive title or having a field check of their APPs. However, the municipalities were not able to meet the MPF deadline for an environmental licensing system, and so in 2010 and 2011, the MPF signed another set of agreements with municipal governments (*prefeituras*) in Pará, as well as the state government, Ibama, and producers represented by FAEPA (Federação da Agricultura do Estado do Pará). These agreements postponed the requirement for environmental licensing, conditional on the prefeituras implementing a series of actions to combat deforestation, which in 2011 officially became the steps required to implement the PMV.

All municipalities in the state of PA are eligible to join the PMV. The administration of the program categorizes municipalities according to whether they are on the federal blacklist, previously but no longer on the blacklist (with deforestation "monitored and under control"), under strong deforestation pressure, already largely deforested ("consolidated"), or forested. They prioritize and actively encourage participation by municipalities that are on the federal blacklist and those under strong deforestation pressure. However, the prefeituras decide whether to participate. The federal blacklist is key to participation decisions, because prefeituras hope that the PMV will help them either avoid or get off the blacklist, thereby ensuring access to credit and markets for their agricultural producers. This motivation is strengthened by the connection between the PMV and the MPF, specifically the federal prosecutor's office in PA.

The MPF has demonstrated that it can effectively cut off credit and market access for producers in municipalities not complying with agreements to improve municipal environmental governance, in particular access to large beef and soy processors who not only purchase outputs but also finance production. By signing the agreement with the MPF and joining the PMV, prefeituras commit to developing a social pact to reduce deforestation, establishing a working group, monitoring deforestation, registering 80% of the municipality (outside of protected areas) in the CAR, and staying off the blacklist (by maintaining deforestation below 40 square kilometers per year, regardless of the size of the municipality). Failure to follow-through nullifies the extension of the deadline for environmental licensing. In the agreements with municipalities, the MPF agreed to take all possible measures to guarantee the municipality access to the government agencies necessary to register and license producers; work with INCRA to ensure that producers who comply also are able to register their land in the CCIR (Certificado de Cadastro de Imóvel Rural) system; work with financial institutions to guarantee producers access to financing and to assist the prefeituras with financing infrastructure; and work with the municipalities to help generate benefits in compensation for forest conservation. The federal environmental agency, IBAMA, also agreed not to embargo areas in municipalities that are making progress towards meeting these requirements.

The PMV and Imazon directly help municipalities comply with the requirements of their agreements with the MPF and the requirements of getting off the blacklist, for example, by facilitating the process of CAR registration, by helping establish GIS capacity in the prefeituras, encouraging NGOs to develop comprehensive base maps, and contracting firms to help smallholders register in the CAR. The PMV has

accomplished this largely by coordinating the actions and resource allocations of other state and federal agencies and NGOs, including both Imazon and others such as The Nature Conservancy (TNC). (Since July 2014, the PMV has also administered its own budget, including a large grant from the Amazon Fund.) The PMV has developed advertising campaigns to encourage registration in the CAR, and supported establishment of a new legal mechanism (COTP or Certificado de Ocupação de Terra Pública) to certify that land owners are in the process of obtaining title to state land, based on registration in the CAR. Further, PMV provides a communication channel between prefeituras and both the state police and IBAMA, who can in turn obtain support from the federal police for enforcement actions. Other municipalities in the forested and consolidated zones have a variety of motives for joining the PMV, including offering political support to the governor (if the prefeito and governor are from the same political party), obtaining technical assistance and supplies from the PMV (e.g. "kits" for monitoring deforestation, including motorcycles and financed through a World Bank loan to the state), attaining priority status for state assistance (e.g. from SEPOF), and other financial incentives beginning this year (such as allocation of the 25% of the VAT that is returned to municipalities).

Thus, the PMV offers a mix of incentives to participate, some appealing directly to prefeituras (access to the kits from Pará Rural, higher VAT allocation, and support for the governor when they are from the same political party) and some more appealing to agricultural producers (access to markets for beef and soy through CAR registration, liberation of subsidized agricultural credit from the government, provisional land titles). Partnership with Imazon basically provides technical assistance that allows more rapid progress towards the PMV's goals, including building the local government's capacity to take responsibility for environmental licensing, which in turn benefits producers who will not need to travel as far or wait as long for licenses. While PMV and Imazon tout the multiple benefits of the program to municipalities, there are clearly also costs, both on the administrative side and in terms of the opportunity cost to producers of not deforesting. In blacklisted municipalities, all deforestation is illegal, and hence these opportunity costs may not be a legitimate part of social cost accounting. Nonetheless, the demand for deforested land and the cost of foregoing that deforestation are likely to influence municipal decisions whether to join the PMV and/or partner with Imazon.

All municipalities in the PMV are supported by Imazon through its participation in the overall program, for example, providing monthly deforestation alerts, pursuing clarification on the division of environmental responsibilities between state and municipal governments, and setting standards for municipal environmental agencies. However, Imazon also selected 10 municipalities for more intensive support, seeking to replicate the "Paragominas model." Specifically, Imazon reports that they first selected municipalities that (1) were on the federal 'blacklist', (2) had a large area of forest remaining, and (3) had demonstrated interest in reducing deforestation (e.g., through signing agreement with the MPF or creating a "social pact" with stakeholders in the municipality to decrease deforestation). They then selected municipalities from this list, along with two other municipalities (Monte Alegre and Santarém), in order to obtain a set well distributed across regions of the state facing different deforestation pressures (i.e., speculation vs. colonization vs. expansion of commercial ranching and agriculture). For example, they picked Monte Alegre because it faces the most deforestation pressure in the Calha Norte region, although it does not have a high deforestation rate relative to the rest of the state and was not on the federal blacklist. Imazon had offered similar support to the municipality of Paragominas starting in 2008, and then expanded to nearby municipalities with financing from the Amazon Fund. Several of these nearby municipalities

were also selected for the USAID/Skoll project, although Paragominas is not among the ten (and is therefore excluded from our sample). Some of the municipalities that Imazon originally identified as potential participants in the program ultimately decided not to partner with Imazon. This decision of the prefeitura is likely related to both their level of interest in controlling deforestation and their support for the PMV, which is closely identified with both Imazon and the governor of PA (from the PSDB political party). Thus, both Imazon's selection rule and the prefeituras' choices about whether to participate are inherently – although not solely - related to deforestation. This creates a fundamental challenge for identifying the causal impact of these interventions.

2.4 Questions we seek to answer

Based on consultations with Imazon, PMV, Mercy Corps, Skoll and USAID, we identified a number of questions that are relevant for scaling programs to other states in the Brazilian Amazon and that reflect the inter-dependence of the Imazon10, PMV and federal blacklist:

1. What has been the impact on deforestation of joining PMV by signing a commitment with the MPF or PMV no later than July 2011 *and* receiving additional technical cooperation and support from Imazon? This bundled "PMV + Imazon10" intervention was fully implemented starting in 2011, 2012, or 2013, depending on the municipality.
2. What has been the impact on deforestation of joining PMV by signing a commitment with the MPF or PMV no later than July 2011 *without either* additional support of the Imazon10 intervention or necessarily implementing the PMV. In other words, what has been the effect of a local government committing to a low-deforestation development path by signing agreements with state and federal governments? We refer to this intervention simply as "PMV" (or "PMV on paper only" for municipalities that signed onto the PMV but did not implement core actions).
3. What has been the impact on deforestation of joining PMV by signing a commitment with the MPF or PMV no later than July 2011 *and* implementing a core set of actions required by the PMV? All of the municipalities in the Imazon10 and all but one of the blacklisted municipalities in the PMV have completed the core actions. We refer to this intervention as "PMV implementation." The municipalities in this intervention are a subset of the municipalities in the PMV intervention.

In sum, we considered how deforestation was affected by (i) the bundled PMV + Imazon10 intervention, and (ii) the PMV (without the Imazon10) – both on paper and implementation.

3.0 Data

We compiled a rich panel data set on a large pool of municipalities. In this section, we first explain how we defined our donor pool, or the sample of municipalities used to construct the counterfactual, and then

describe our outcome, treatment and moderator[2] variables. Detail on the covariates employed is provided in Annex 1.

3.1 Donor pool

The donor pool was defined as all municipalities in the Amazon forest biome. Specifically, a municipality was included in the donor pool if (i) it was fully contained within the Amazon Biome boundary published by IBGE, or (ii) if it crossed or bordered the Amazon Biome boundary and originally at least half of its area was under forest cover. We referenced municipal boundaries from the 2013 IBGE file[3], which we would further propose be held constant in future evaluations, to ensure that all future processing can be streamlined and will not require additional adjustments to historical boundaries. To define original, or historical, forest cover[4] we used the INPE PRODES data to map all areas that were ever categorized as forest (Figure 3.1). Based on these criteria, we identified an initial "master" donor pool of 519 municipalities (including treated and control) (Figure 3.2).

[2] In SCM, we use the moderator variables to identify patterns and interpret the heterogeneity of effects, e.g. across blacklist status and size.

[3] IBGE is the data source, but the shapefle was provided by Imazon.

[4] For historical forest cover, we used all areas that had been classified as forest (or deforested) in any year of the PRODES analysis from 1997 -; note that in 1997, the first year PRODES produced spatial data, areas that had been deforested prior to 1997 were also included in the deforestation category, thus allowing for a full reconstruction of historic forest cover.

Figure 3.1: Historical (Original) Forest Cover

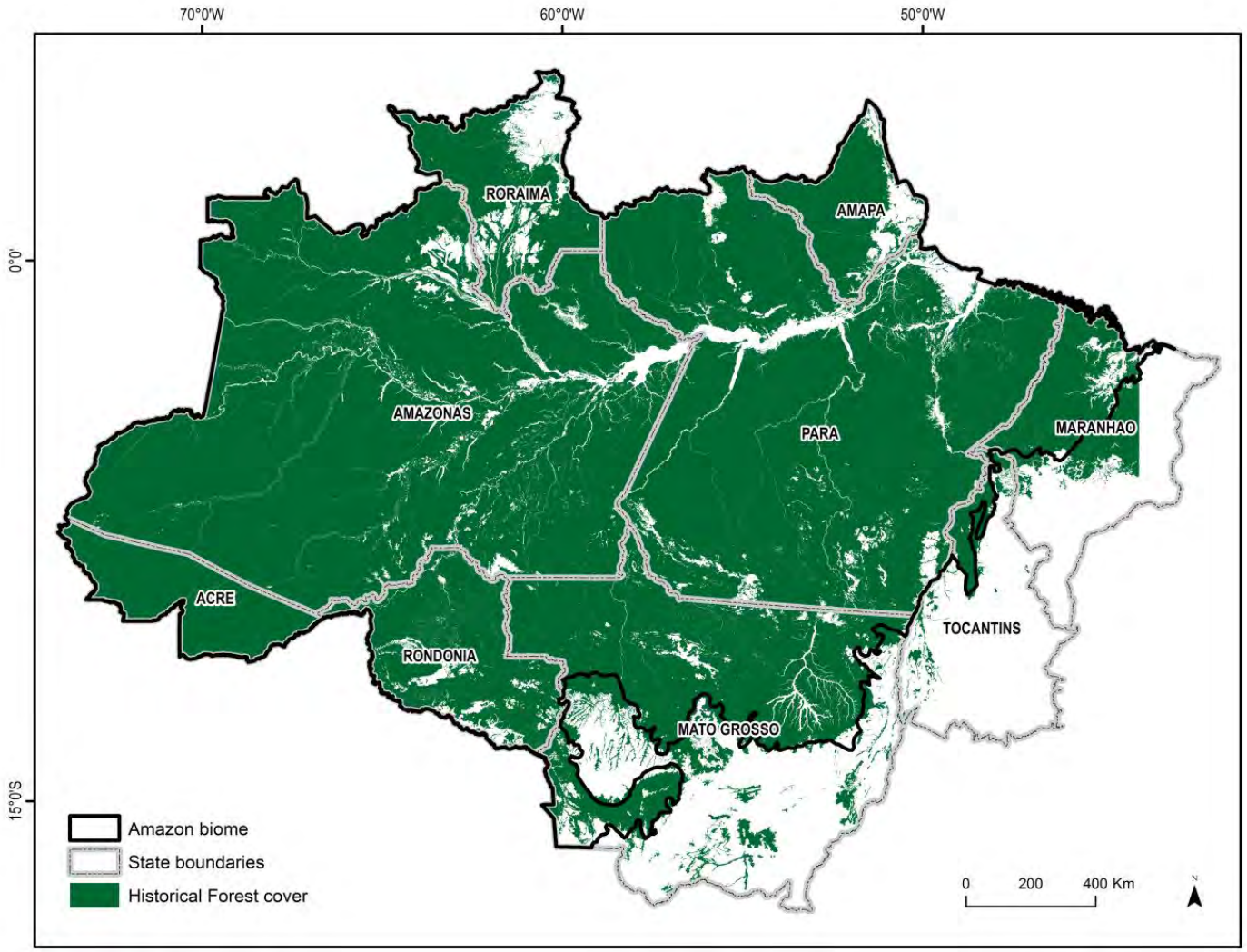
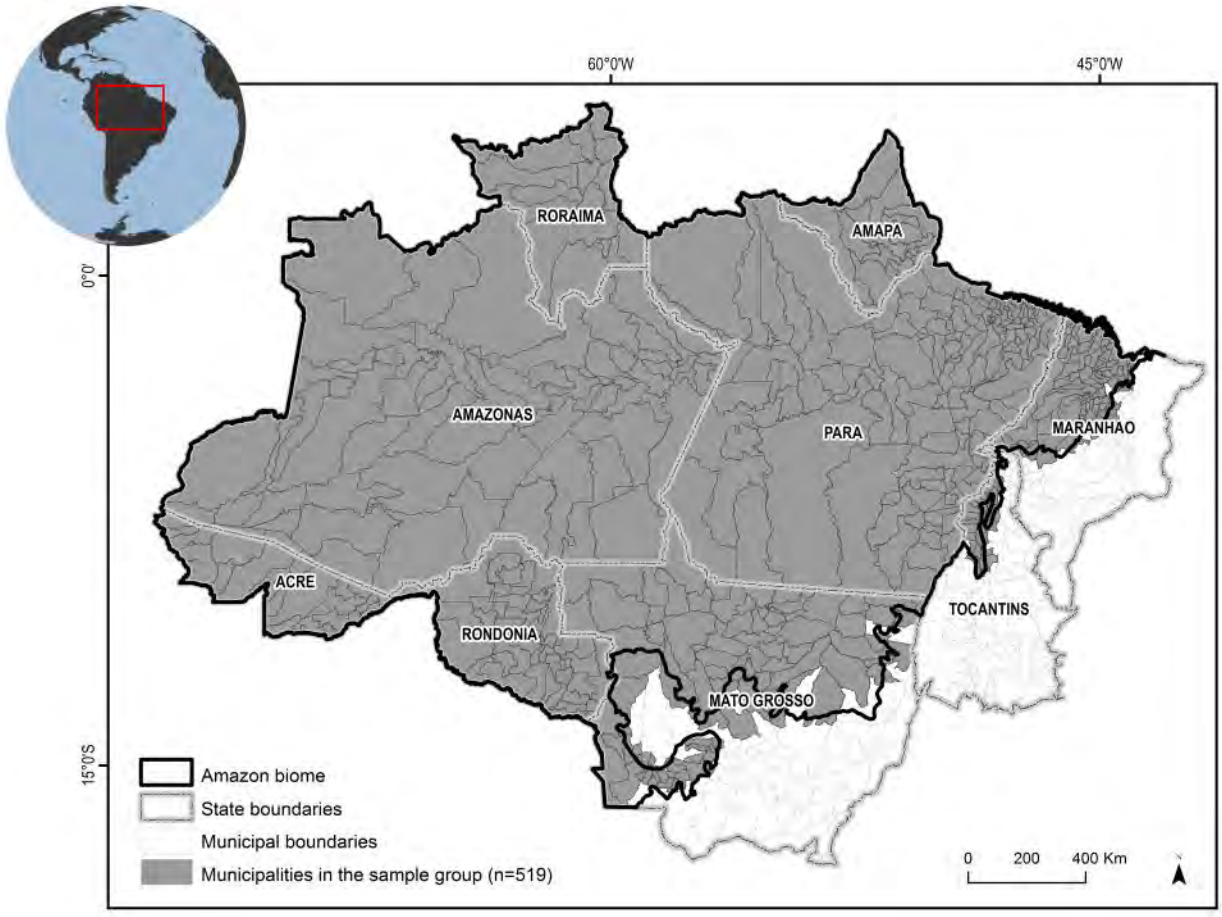
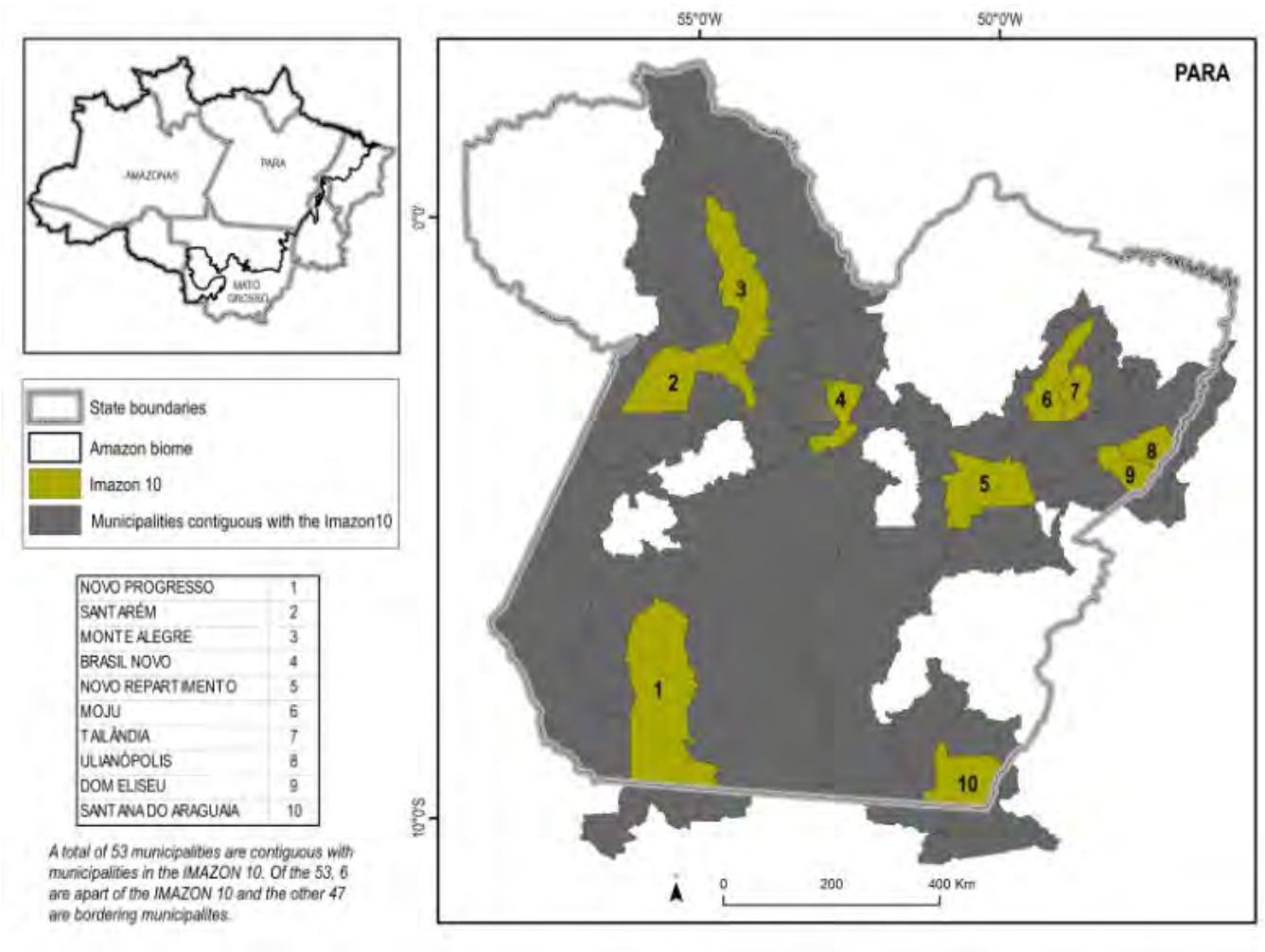


Figure 3.2: Sample (519 municipalities considered in analysis)



Bordering municipalities: To test for neighborhood effects (e.g. spillovers or leakages from the treatment), all municipalities contiguous with municipalities in the Imazon10 and in the PMV were identified. Six of the municipalities in the Imazon10 share borders with at least one other municipality in the Imazon10. In addition, there are 47 other municipalities contiguous with at least one of the Imazon10 (Figure 3.3). A total of 187 municipalities are contiguous with municipalities currently in the PMV (as of 2014). Of these 187, 100 are also part of the PMV and 87 are bordering municipalities. Excluding these municipalities from the donor pool essentially excludes all of Pará, as well as many municipalities in neighboring states, potentially including many of the best matches. This makes it difficult to test for neighborhood effects of the PMV. The direction of bias from any neighborhood effects is unknown, because they could either increase deforestation (e.g. through displaced land speculation) or decrease deforestation (e.g. through learning and demonstration effects).

Figure 3.3: Municipalities contiguous with the Imazon10



3.2 Outcomes – Deforestation

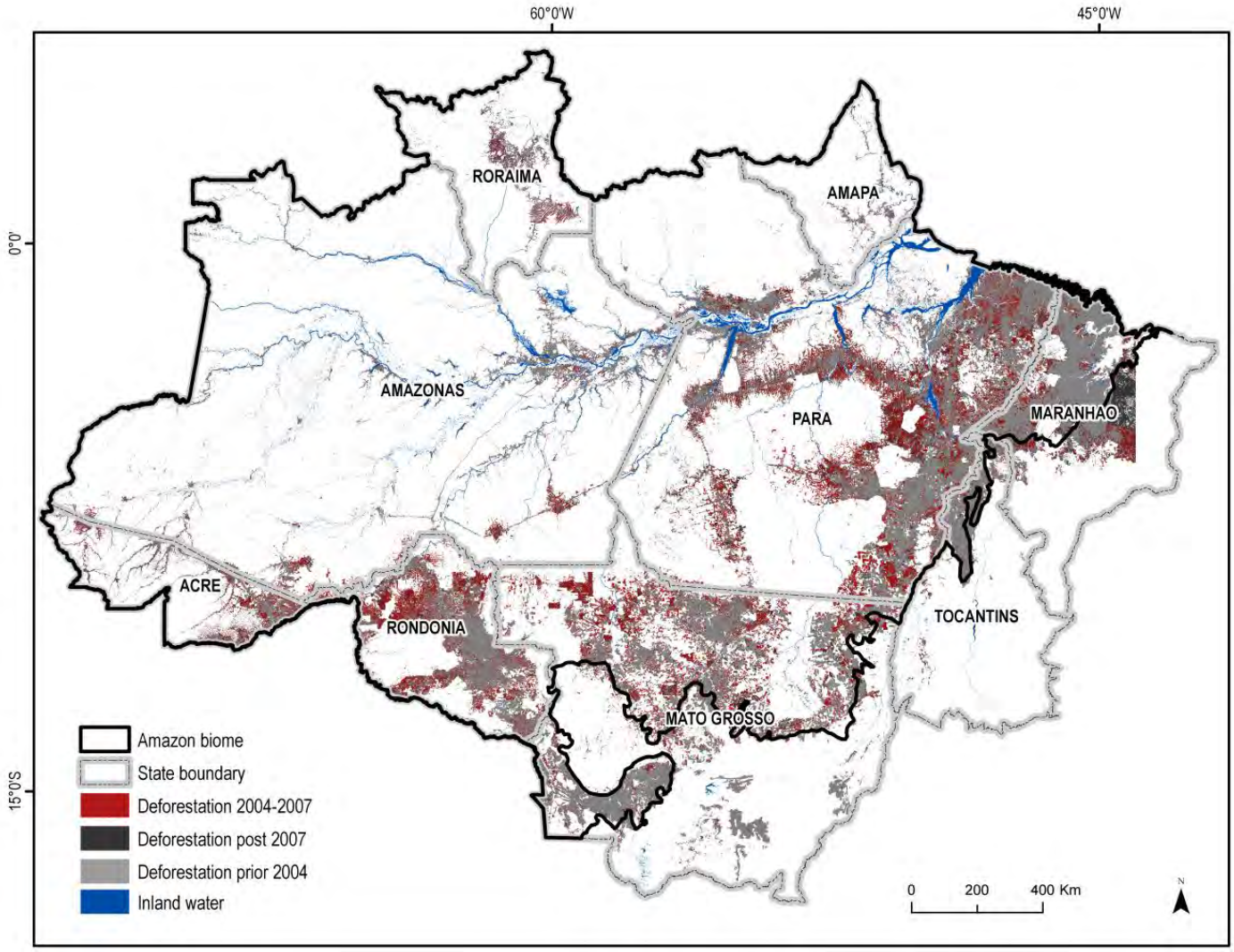
All deforestation data reported are from the INPE PRODES project. PRODES is the source of official deforestation information used by the Brazilian government, e.g. to determine which municipalities to include in the blacklist. Although the minimum mapping area of PRODES data is 6.25 hectares and higher resolution deforestation data are available, we used PRODES data to maintain consistency with officially reported deforestation rates. The PRODES record of deforestation begins in 1988, and spatially explicit information is available annually from 2000. Some of the early years of data suffer from poor image availability or quality because of clouds, but for most of the region annual data are available from 2000. Additional details about the PRODES project are available from INPE.[5]

PRODES deforestation data were extracted from shapefiles provided by Imazon, for 2000-2012, and downloaded directly from the PRODES website for 2013 and 2014. Data were processed independently for

[5] http://www.obt.inpe.br/prodes/index.php.

each state in ArcGIS and then combined after extraction in MS Excel (Figure 3.4). To manage for variability in perceived deforestation rates caused by cloud cover (i.e. due to non-continuous coverage), we used PRODES attribute data to identify deforestation polygons with previous cloud cover. We then distributed the area deforested evenly across the time period when clouds were present, following the approach developed by Imazon. Deforestation polygons coded by INPE as 'DSF_ANT" in the states of Amapá and Maranhão were treated as deforestation prior to 2000, following consultation with Imazon.[6] Finally, annual deforestation polygons were overlain on 2013 municipal boundaries.

Figure 3.4: Deforestation pre- and post- 2004



[6] http://www.dpi.inpe.br/gilberto/teses/dissertacao_mario.pdf

The final 2014 deforestation data were downloaded from the PRODES website in August of 2015 and compared to the preliminary shapefile downloaded earlier in the second phase of the IMAZON project. Differences were found in the number of deforestation polygons included in the dataset and total area of deforestation for the year. The new shapefile (PDigital2014_AMZ_pol) reports a total of 5111 sq km of deforestation for 2014 in 41729 records (including 537 sq km previously under cloud cover), while the preliminary shape file reported 4424 sq km. (See Figure 3.5 for example of additional deforestation polygons and area in the new data set.) The 537 sq km of deforestation under cloud cover were evenly distributed across the years that were obscured by clouds, following IMAZON's recommended approach. In comparison, the initial 2014 dataset had less information about cloud cover and there were residual records that were unclear.

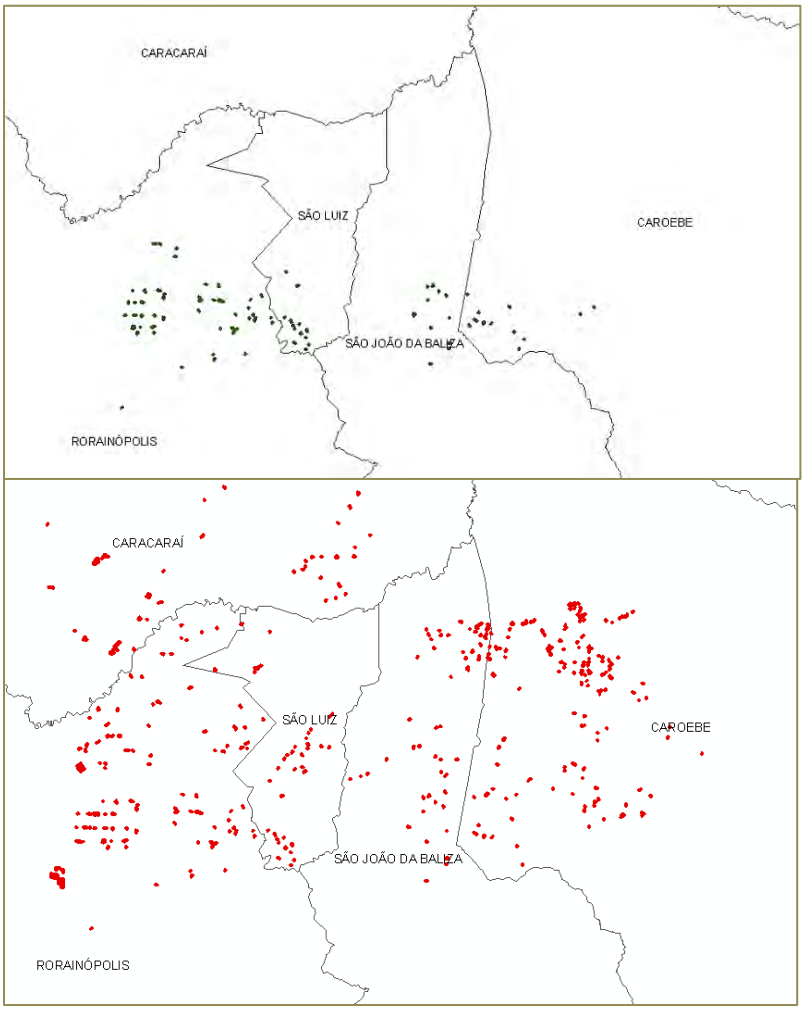


Figure 3.5 Revised Deforestation Estimates
Top: Previous PDigital2014_AMZ_pol file
Bottom: Recent PDigital2014_AMZ_pol

Processing of the new 2014 deforestation dataset followed the same approach applied in phase II of the project. The data was split based on the sprclasse column in the attribute table separating records that had cloud cover in previous years from those that did not. Calculation of total deforestation was a straightforward process for the no-cloud records where total deforestation was calculated in square kilometers. For the records with previous years of cloud cover, deforestation values were calculated through the "IMAZON approach", in which total deforested areas were averaged across the years that had been previously covered by clouds.

The deforestation shapefiles were clipped based on the CAR-eligible (CAR I[7]) and municipal land (CAR II [8]) extent and area of deforestation calculated for each year in the time series. For the 2012 to 2014 deforestation shapefiles, the field 'sprclasse' from the attribute table was used to separate records with previous years of cloud cover from those that had none. For the remaining years (1997-2011) the field classname was used. The same approach for calculating deforestation in municipalities was applied to CAR eligible areas.

3.3 Treatment and moderator variables

We identified whether each municipality was participating in each of our treatments (PMV and Imazon10) and the year that they began participating. In addition, we determined whether the municipality had ever been on the federal blacklist, including year that entered and (if relevant) year that exited. We estimate all treatment impacts conditional on blacklist status, e.g. the impact of the PMV on a municipality given that it is on the blacklist (or not on the blacklist). Because reducing deforestation below 40 km2 is a more stringent requirement for larger municipalities, we also consider municipality size as another moderator variable.

Blacklisted
The official list of municipalities that have been blacklisted was obtained from the document *"Lista de Municipios Prioritarios da Amazonia and Lista de Municipios com Desmatamento Monitorado e Sob Controle"* [9] from the Ministério do Meio Ambiente. Those municipalities included on the list were identified in the database. Information on year entered and where relevant, year exited, was included in the database.

PMV
Participation in the PMV was extracted from *"Green Municipalities Program: Lessons Learned and Challenges for 2013/2014"* (Appendices: Situation of Para municipalities in relation to goals of the GMP – up to January 2013) and where necessary, confirmed and updated using the PMV's on-line database.[10] The year of treatment is the earlier of the "data de Assinatura do TC com MPF" or the "data de Assinatura do Termo de Cooperação com PMV" for each municipality (with years defined according to INPE's convention for deforestation: August of the previous year through July of the current year). The eleven municipalities that joined after our cut-off date for treatment (1 August 2011) and that are therefore excluded from the analysis are: Barcarena, Bragança, Bethlehem, Capitão Poço, Captain Wells, Melgação, Ourem, São Sebastião da Boa Vista, Terra Alta, Mojuí dos Campos and Cachoeira do Arari.

Municipalities were further categorized according to two levels of engagement in the PMV as explained in Section 2.1: "PMV on paper", i.e. signing agreement with the PMV/MPF, and "PMV implementation", i.e.

[7] CAR I is defined as: 2013 MUNICIPAL BOUNDARY - ALL CONSERVATION AREAS (STATE & FEDERAL)- INDIGENOUS AREAS- URBAN AREAS

[8] CAR II is defined as: 2013 BOUNDARY - ALL CONSERVATION AREAS (STATE & FEDERAL)- INDIGENOUS AREAS- URBAN AREAS- INCRA SETTLEMENTS- MILITARY AREAS - GLEBAS FEDERAIS

[9] Source: MMA (http://www.mma.gov.br/)

[10] Source: PMV http://www.municipiosverdes.com.br/

implementing three out of four identified key actions (celebrated a pact against deforestation, created a working group to combat deforestation, registered at least the median percent of land in the CAR, established at least a minimum structure for municipal environmental governance).

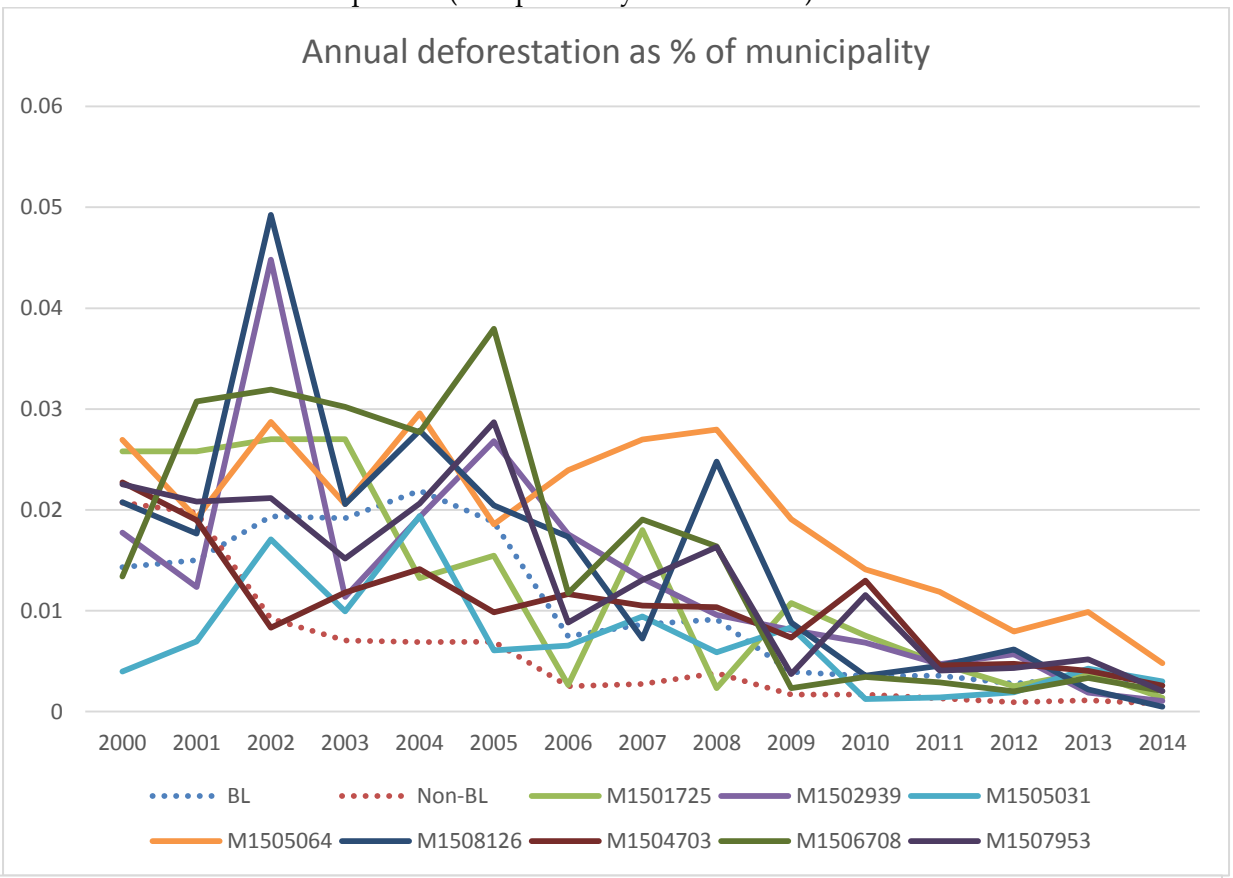
Imazon10
The treatment years for the ten municipalities in the Imazon10 are 2011 for Dom Eliseu, Tailândia, and Ulianópolis (based on the year that they started collaborating with Imazon under an initiative funded by the Amazon Fund); 2013 for Moju (when it substituted for another municipality); and 2012 for all others.

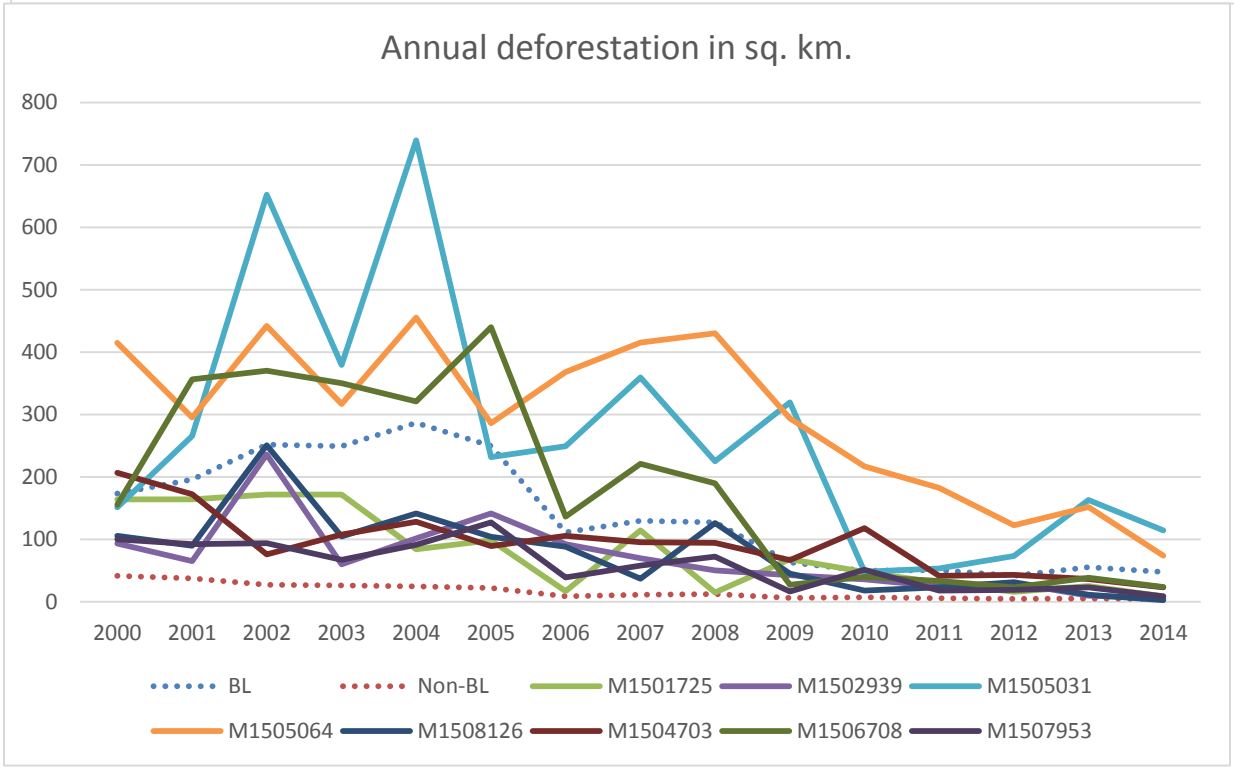
4. Methods

In this section, we draw on Sills et al. (2015), which was developed through initial work on this project to pilot test use of the synthetic control method to estimate impacts on land use/land cover change (LULCC) with a case study of the original green municipality initiative in Paragominas (Sills et al. 2014). There is a growing literature that applies various methods to improve estimation of causal impacts of conservation interventions, i.e., to discern if a particular intervention (treatment, project, program) actually caused a particular observed outcome – here that outcome being reduced deforestation. To assess the causal impacts of a program, we must establish what would have happened in areas exposed to the program if they had not been exposed (i.e., establish the 'counterfactual' scenario). This would be relatively easy if either the treated areas before treatment or all non-treated areas could be assumed similar in all aspects except treatment – justifying before/after or treated/not comparisons.
However, if temporal or spatial similarity cannot be assumed, then such comparisons are biased estimates of impacts. Temporal and spatial factors that differ systematically across treated and non-treated areas make it considerably harder to causally relate a program to any change in outcome, like a decrease in deforestation rates. These factors are impacts confounders when they are correlated both with the program (or its lack) and with outcomes of interest, such that their own impacts can be misinterpreted as a program-outcome link. One important feature of such confounders is that they may be observed (i.e., be variables in the dataset) or they may be unobserved by the analyst.

For observables, perhaps the most frequent approach for addressing such potential confounding is multivariate regressions that control for various factors while including a variable for the program being evaluated. As the workhorse of modern statistical inference, multivariate regressions are a logical starting point for any evaluation. When panel data are available, fixed effects can be employed to control for factor that are unobserved but time invariant. However, if selection processes strongly influence where a program is applied, it could be the case that the values for important characteristics included in regression specifications do not overlap a great deal between the program sites and comparison (or control) sites. When the program and comparison sites are different in terms of such characteristics, then regression can fail to separate the impacts of programs from the influences of these characteristics. This is clearly a potential problem with the 8 blacklisted municipalities in the Imazon10, which were selected because of the challenges they presented in terms of reducing their high rates of deforestation. Figures 4.1a and b show that deforestation rates (in km^2 and % of municipal area) in several of these eight municipalities were well above the mean deforestation rates (shown with blue dotted line) in all blacklisted municipalities prior to the PMV and all are above the mean deforestation rates in the rest of the municipalities in the sample.

Figure 4.1a and b. Annual deforestation (in square kilometers and as % of municipal area) in the eight Imazon10 blacklisted municipalities (as reported by INPE in 2015).





One solution could be to eliminate confounding through randomization in a traditional experimental design, but this is typically difficult to implement with conservation programs. Thus, these programs are most often evaluated with quasi-experimental methods – such as matching, instrumental variables and difference-in-differences – which combine sampling and estimation to control for selection on observables and unobservables. Matching methods have become the leading quasi-experimental approach, usually pairing LULCC treatment units (tracts, pixels or households) subject to interventions with 'very similar' comparison or control units in order to isolate impacts using statistical modeling. Various metrics of the similarity of control units to treated units can be employed, e.g., the Mahalanobis distance or probability of participation in a policy or program (the propensity score) as a summary statistic for the suite of ecological, socio-economic, institutional and geographic factors judged by the analyst to be relevant. By explicitly searching for greatest similarity, however that is defined, the analyst can compare treated units to similar control units with all of the characteristics – except the intervention of course - in common. This method can be powerful, especially when it is possible to match on all of the observed factors that are likely to influence selection into the treatment as well as the outcome. However, matching does not help address unobservable differences between the units. Further, establishing statistical similarity for observable factors typically relies upon quite large samples in order to find well-balanced sub-samples of treated and control units with similar distributions.

A potential solution for "low N" treatments is the 'synthetic control method' of SCM. When only a few units are treated, researchers often compare outcomes for a few selected 'similar' units to those for a 'treated' unit influenced by an intervention or exogenous event. Selecting similar units is critical to estimating impacts, because those units' outcomes are used to generate the counterfactual, i.e., the estimate of what would have happened within the treated unit had there not been any intervention. Thus, regardless of whether statistical or case study methods are employed, policy impact studies always involve judgments concerning similarity. For example, 'difference in difference' (DiD) estimates *assume* that comparison and treated units have similar time trends.

Like typical 'matching' approaches, which also search explicitly for similarity but only in terms of the observed characteristics of treated and control units, SCM searches for a weighted blend of control units that − for pre-treatment years − *actually did have a similar time trend* in terms of their outcomes. SCM makes explicit not only the weighting of those pre-intervention outcomes and units' characteristics − defining what is being minimized by searching for similarity − but also ultimately the definition of 'the synthetic control', i.e., the weights that are assigned to each of the potential comparison units.

This blended minimization, which identifies a combination of control units in terms of both observed characteristics and pre-treatment outcomes, blends the focus on characteristics from matching with the focus on unobservable trends from DiD approaches. For DiD, the analyst assembles a pool of comparison units assumed to have similar time trends and thus the treatment impact is estimated as the change in the outcome over time for the treated units minus the change over time for the controls (the latter identifying the common time trend to subtract it out). In SCM, the best fitting combination of units in terms of the pre-treatment trends in the outcomes − i.e., the synthetic control – is assumed to *continue to follow a time trend similar* to that of the treated unit but for the effect of the intervention. If the pre-treatment outcomes have been well-matched in the creation of the synthetic control, the impact estimate for each post-treatment year is simply the difference between the observed outcome for the treated unit and the synthetic's weighted outcome.

SCM's use of pre-treatment outcomes clearly can improve on matching only observed characteristics, thereby 'making up for' the limited cross-sectional sample size (due to few treated units) by employing intensive computation (feasible for each of a few treated units) to identify the optimal combination of controls. The observed characteristics in a data set will never include absolutely all of the factors that influence the outcome of interest, e.g., deforestation. The pre-treatment outcomes, in contrast, clearly do reflect all of the key factors (at least during the pre-treatment period). Thus, by matching on outcomes as well, we can in principle construct a more accurate counterfactual.

For example, consider a treated municipality whose deforestation is affected by its responsiveness to some exogenous factor − perhaps a price shock for a specific crop that can only be produced under particular agro-climatic conditions, or a regional shift in political power that has local effects through various political alliances. Thus, among a large set of control units, only some are sensitive to this factor. Looking at outcomes across pre-treatment years − most usefully years during which that factor shifted − and controlling for all of the observed characteristics of units that are believed to matter for deforestation, matching pre-treatment outcomes can identify which control units have the same sensitivities as the treatment unit.

In practical terms, we implement SCM using the Synth package in R. The steps include choosing an outcome variable for which there are time series data, e.g. deforestation. The next step is to define a 'donor pool', or a set of potential controls judged to have some underlying structural similarity in terms of the processes that generate the outcome of interest. For example, the pool might be units in the same region, or units with similar socio-economic characteristics and geography. When factors are expected to have non-linear influences, it becomes more important to select control units where those factors are within a reasonable range of the treatment unit's values in order to approximate linearity. One important set of factors to consider is interventions or treatments other than the one of interest, such as being on the federal blacklist. Another is historical conditions that constrain the range of the outcome, e.g. how much forest was still standing in a municipality at the start of the study period. Because the nested optimization process in Synth may fail to find a solution when the donor pool is too large, we narrow down large donor pools to the 80 most similar municipalities.

Given an outcome of interest and a donor pool, SCM selects weights (W) on potential control units to define a linear combination of controls' outcomes, i.e., 'the synthetic control'. These weights determine the impact estimate which, for any post-treatment time period, is the difference between the outcome for the treated unit and this weighted-average or synthetic outcome. W is chosen based on the core idea that the average of pre-treatment outcomes for control units − each weighted by its W value, perhaps zero − should be as close as possible to the pre-treatment outcome in the treated unit. Recall that the outcome (Y), here deforestation, is affected by both observed (Z) and unobserved (U) factors ($Y = \beta Z + U$). Were we to confirm only similarity in Y (i.e., search for low $WY_{control} - Y_{treated}$) for pre-treatment years, we might label as 'similar' units with higher Z and lower U. The innovation of SCM is to select units based on similar Y as well as similar Z, implying similar U (although they cannot be observed). Since one cannot minimize all differences at the same time, but only some combination of differences, another weighting vector V is required to assign weights to the variables in Z and to each year or averages of pre-treatment Y. In the Synth package for R that we use, V is selected to maximize predictive power for pre-treatment outcomes. (See Annex 3 for an example of W and V vectors generated by SCM.)

The quality of the synthetic control is measured by how closely the weighted synthetic outcomes match the outcomes for the treated unit in the years prior to the intervention in question. The goal is to minimize the difference, as measured by the mean squared prediction error (MSPE). A 'best' fit is always a matter of judgment and, in particular, one might go beyond MSPE to judge whether the synthetic cohort appears to mirror the treated unit in terms of the turning points in a plot of the outcomes across pre-treatment years. If the outcome plots look similar especially in the years immediately preceding treatment, it is more likely that the treated and synthetic control have similar responses – or similar sensitivity - to common factors. Another possible check is just the size of the error in the time periods immediately preceding treatment, since a persistent error here could easily be replicated in the estimated impacts.

A final step is to assess the statistical significance of any post-intervention divergence between the synthetic outcome and the treated outcome, i.e., the SCM estimate of impact. Standard statistical tests of the similarity between the treated unit and the constructed or weighted synthetic control − such as tests of 'balance' on covariates or of differences in outcomes − are not possible here due to the small number of treated units. Thus, other methods must be employed to characterize the 'noise' in such procedures, e.g. placebo tests for different years or municipalities, bootstrapping, or a combination of the two. Placebo effects are typically estimated for all units in the donor pool, i.e., by 'pretending' that they were treated and using SCM with a donor pool of all of the other control units to create synthetic controls for 'the treated' and calculate the resulting 'treatment effects'. As the units were not in fact treated, the effects should be zero and thus the false 'treatment effects' characterize the 'noise', indicating what can come out of SCM even where there is not really any effect. Estimated effects above the 95th percentile or below the 5th percentile of the placebo effects are significant at the 10% level.

However, because the optimization process in Synth works best with a donor pool of fewer than 100 units, we obtain fewer than 100 placebo effects, meaning that their distribution is not very smooth and the critical values for 5% and 95% often must be extrapolated from the nearest values. We therefore bootstrap the placebo tests, applying the procedure developed in Sills et al. (2015), by taking multiple random draws of their donor pool, ensuring that in each case we drop a proportional number of donors that received large and small weights in the original synthetic control. Annex 3 illustrates how the histogram of placebo effects is filled in, producing a smoother distribution, with increasing numbers of bootstraps. For this version of the report, we employed this approach to establish confidence intervals around our new estimated impacts using INPE's revised estimates for deforestation in 2013 and 2014.

5. Estimation and results

Results from the evaluations performed are detailed in this section, with a summary of evaluations and results provided in Table 5.4. We start with results from a fixed effects panel regression model, since that is the best known method and therefore the easiest to interpret. However, given that selection into the programs of interest was clearly based on deforestation and factors that influence deforestation, we focus on the results from quasi-experimental methods that are more robust to this selection bias.

5.1 Fixed effects panel regression

Our fixed effects model controls for time-invariant effects of spatial factors (municipality fixed effects) and space-invariant effects of temporal factors (year fixed effects). We estimate impacts with 2001-2014 data and judge significance using robust standard errors. Each coefficient represents the effect on annual deforestation of being in a program in any year (across all municipalities and all years in a program.) As expected, the blacklist has a robust, large and statistically significant effect reducing deforestation. Table 5.1 shows that both the PMV and the Imazon10 have statistically significant effects reducing deforestation as measured in square kilometers after controlling for both municipality and year fixed effects. However, once we control for blacklisted status, the Imazon10 no longer has a statistically significant effect (Table 5.1a). Further, in a model of annual deforestation as a percent of the municipality, we find that only the blacklist status has a statistically significant effect (Table 5.2b). These results suggest both that the PMV and Imazon10 are having some influence and that it is critically important to control for the blacklist in our impact estimates.

Table 5.1. Two-way-fixed-effects model, balanced panel (519 municipalities, 2001 – 2014), for annual square kilometers of deforestation based on estimates released by INPE in August 2015 (estimated coefficients on years all statistically significant at 5% level, not reported here).

Program	Coefficient	Robust Std Error	P-value
PMV	-25.9	10.97	0.019
Imazon10	-58.4	23.01	0.011

Table 5.1a. Two-way-fixed-effects model, balanced panel (519 municipalities, 2001 – 2014), for annual square kilometers of deforestation based on estimates released by INPE in August 2015 (estimated coefficients on years all statistically significant at 5% level, not reported here).

Program	Coefficient	Robust Std Error	P-value
Blacklisting	-122.62	16,49	0.000
PMV	-20.71	7.95	0.009

Table 5.1b. Two-way-fixed-effects model, balanced panel (519 municipalities, 2001 – 2014), for annual deforestation as percent of municipality based on estimates released by INPE in August 2015 (estimated coefficients on years all statistically significant at 5% level, not reported here).

Program	Coefficient	Robust Std Error	P-value
Blacklisting	-0.0035	0.0009	0.000
PMV	-0.0001	0.0006	0.875
Imazon10	-0.0025	0.0017	0.135

For some perspective on the size of the possible treatment effects suggested by the estimated coefficients in Table 5.1, in 2010-2011 the mean for annual km^2 of deforestation across all municipalities in our sample was only ~10 km^2, with a median of < 3 km^2. That reflects what we view as an important part of the context for any such consideration of treatment effects against a background of other influences, i.e., the declining trend in deforestation since 2004. These numbers reflect the fact that there are many municipalities with no or very

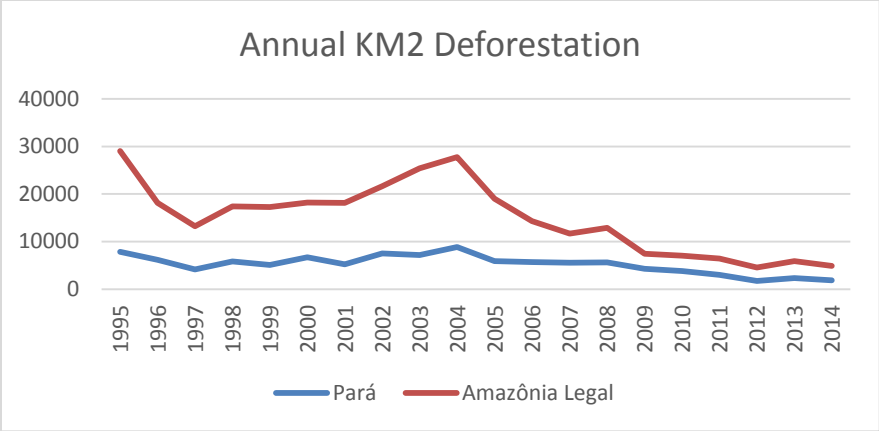
little deforestation − which greatly constrains the forest impacts of any forest conservation interventions. Even the 75th percentile of deforestation was less than 8 km^2 in both 2010 and 2011. Putting this in another light, though, the estimated impact from the fixed effects regressions on square kilometers of deforestation (5.1 and 5.1a) suggests that the PMV has reduced deforestation by more than the mean deforestation in the sample, and is thus substantively important as well as statistically significant.

One caveat on this analysis is that historical deforestation rates – and hence the underlying tendency towards deforestation – may be systematically different in the treated municipalities. This is clearly true for blacklisted municipalities, which are blacklisted precisely because of their high historical deforestation rates. While all the municipalities in Pará are eligible for the PMV, program administrators have focused on engaging those with high enough deforestation that they are at risk of blacklisting or already blacklisted. To obtain better estimates of the impact of the PMV, we should compare participating municipalities with municipalities that have similar (possibly unobserved) tendencies towards deforestation, since they will likely be better proxies for how much deforestation there would have been in participating municipalities if they had not become part of the PMV. We expect the best comparison municipalities (e.g., the municipalities given the highest weights in SCM) will be different for PMV municipalities that were recruited into the program because of their high deforestation (i.e. the blacklisted municipalities in the program), as compared to other municipalities that volunteered for unobservable reasons such as believing that they could easily meet program goals (i.e., non-blacklisted municipalities with low deforestation). Evaluating the impact of the PMV on municipalities at risk but not yet blacklisted is particularly challenging, as many of the natural comparison locations have been blacklisted and, therefore, are subject to other pressures to reduce deforestation rates.

5.2 Matching

The models of annual deforestation in Tables 5.1 are estimated over the full time period (2001 to 2014) with the full sample (519 municipalities), controlling for potential confounders only with blacklisted status and fixed effects, i.e., assuming that those fixed effects for municipalities and years capture the effect of any other potential covariates. For matching, we must identify specific covariates, the appropriate donor pool, and the appropriate time frame for evaluating outcomes. The choice of time frame should be informed by broader trends in deforestation in the Amazon. Figure 5.1 shows a rapid decline in annual deforestation following the federal government's policy shift in 2004, a resurgence of deforestation in 2008 before implementation of the blacklist, and an uptick of deforestation in 2013, making 2013 an interesting year to test impacts. We report estimated impacts for both 2013 and 2014, because all of the Imazon10 were in the program by 2013 and because those years allow the most time for impacts to emerge. The output from SCM would also allow impacts to be evaluated in terms of years since joining the program, rather than calendar years, or in terms of the sum or average across all of the years since joining the program. In developing our synthetic controls, we consider deforestation levels both before and after the 2004 regime change in federal policy, using the average annual deforestation 2001 – 2003 and 2004 – 2007 as covariates.

Figure 5.1 Total square kilometers of deforestation



For both SCM and traditional matching, the objective is to generate 'apples to apples baselines', i.e., controls that have the same outcome-relevant characteristics as treated units. In standard matching, characteristics that affect both the probability of participating in the program and the probability of deforestation are balanced. In synthetic control matching, the goal is to balance both those characteristics and historical deforestation. Though they emphasize different balances across control and treated, these two types of matching ultimately require the same characteristics data, in addition to data about the deforestation outcome.

Drawing on the literature and our understanding of the PMV and Imazon10, we identified factors that could drive deforestation and selection into these programs. Deforestation is largely a function of agricultural profitability, in turn related to both biophysical factors (soil quality, slope, rainfall) and market access (percent of municipality within 5KM of a road, quarantine for hoof-and-mouth disease). Given the strong spatio-temporal correlation of deforestation within the Brazilian Amazon, historical deforestation trends are correlated with current deforestation. Selection into the PMV was also related to historical deforestation, because program administrators prioritized municipalities already on or at risk of being added to the blacklist. Imazon sought to engage with municipalities representing a range of frontier conditions with local governments interested in collaborating. Participation in each program is voluntary, likely driven by: (i) concern about sanctions imposed by the federal government (including the blacklist, embargos and equipment seizures by IBAMA, and restrictions on market access imposed by the MPF); (ii) perception that outside assistance is needed to control deforestation; and (iii) personal and political relationships. Concern about sanctions could vary with whether a municipality sells to national and international commodity markets (proxied by presence of large slaughterhouses that must comply with MPF requirements) and any prior enforcement action (number of properties embargoed by IBAMA). Perceived need for outside assistance could be related to both costs (e.g., distance from municipal seat to border of municipality and the difficulty of enforcement and compliance with the law in irregular shaped municipalities; count of farms, which affects the cost of achieving 80% CAR coverage). One indicator of political relationships is whether the prefeito is from the same political party as the governor who created the PMV. Some factors fit into more than one category. The importance of agriculture for the municipality (% PIB from agriculture) is likely to both drive deforestation and interest in maintaining access to agricultural credits and markets. In summary, we sought variables that could represent the following categories of drivers:

1. Factors in agricultural profitability, including slope, elevation and market access (e.g., % of

municipality that is within 5 km of a road)

2. Descriptors of land tenure, including % under federal control, in protected areas, indigenous territories, and agricultural settlements
3. Indicators of social welfare and structure, such as education levels, per capita income, and income distribution
4. Indicators of demand for agricultural production: in sanitary zone free of hoof and mouth disease, whether slaughterhouses present
5. Political indicators such as party of the prefeito, and percent of municipal income generated by agricultural sector
6. Indicators of pressure for land speculation and invasion, including land tenure and # of conflicts recorded by the Catholic Church
7. Indicators of cost to implement the CAR, such as count of farms and furthest distance from municipal seat to municipal boundary
8. Other deforestation drivers like population density, cattle density, and possibly mine density

The initial sample for matching is the same as for the fixed effects regression: the 519 municipalities either fully inside the Amazon Biome or adjacent/crossing the boundary of the biome and with more than 50% historical forest cover. Recall, we are interested in the following effects: PMV (on paper and implementation) versus all other influences and the bundled Imazon10 + PMV versus those other influences. For both, the donor pool is all 519 municipalities except those in the PMV. Because the blacklist is a critical contemporaneous influence on deforestation, we split the pool according to blacklist status, and we drop Paragominas because while not part of the Imazon10 it received a similar level of support from Imazon (Sills et al. 2015). This still leaves a large donor pool of 388 non-blacklisted municipalities. For constructing the synthetic controls, we narrow this pool down to fewer than 80 municipalities in two ways: (i) selecting donor municipalities with the most similar percent forest cover in 2000; or (ii) selecting those with the most similar propensity to participate in the intervention (Imazon10 or PMV) in a model estimated with the same covariates used to construct synthetic controls. We found that results were reasonably robust to the choice between these two options for lowering the size of the donor pool, although it is clear that for any specific location the quality of the matching and its implications for impact can vary by approach. We also constructed synthetic controls after dropping all municipalities contiguous with treatments (Imazon10 or PMV) but not surprisingly, we found those fits to generally be much worse and thus not very informative about leakages or spillovers; we therefore do not report them here.

5.2.1 Impact of the bundled PMV + Imazon10 estimated with SCM

The bundled PMV + Imazon10 does not provide a large enough sample of treated units for traditional matching, especially after subdivided into the 8 municipalities on the blacklist and 2 municipalities not on the blacklist. Tests of balancing would tend to show no statistically significant differences across treated and controls simply because of the small sample size. Likewise, estimated treatment effects would be hard to distinguish from zero due to sample size. The synthetic control method is thus clearly the preferred option to evaluate this treatment. We construct synthetic controls for each PMV + Imazon10 municipality using municipalities not in the PMV. Given the potentially important effects of blacklisting, we draw from a pool of blacklisted municipalities to construct the synthetic control for the 8 municipalities that are in the blacklist, the PMV, and the Imazon10 and a donor pool of non-blacklisted municipalities for the 2 municipalities in the Imazon10 that are not blacklisted.

For each of the PMV + Imazon10, we plot deforestation over time in the municipality and in a constructed synthetic control, showing the year of treatment as a vertical dashed line. In addition, Annex 2 includes a table for each of the Imazon10, specifying the value of the covariates for that municipality, the value of the covariates as weighted for the synthetic control, and the mean and individual covariate values for all municipalities in the donor pool. These tables show that the synthetic control is always more similar to the treated municipality than the mean of the donor pool in terms of the covariates. We further assess the quality of the synthetic controls based on the historical deforestation plots. Based on the plots, we sort the municipalities into three categories:

(i) poor synthetic control, i.e., unable to identify a linear combination of donor municipalities with similar historical deforestation, in particular in the final pre-treatment years for which errors in fitting appear to imply correlated errors in impact estimates;

(ii) deforestation always low or, even if not, then low immediately pre-treatment, implying little potential for the intervention to reduce deforestation beyond the influences represented in the donor pool that have already maintained low deforestation; or

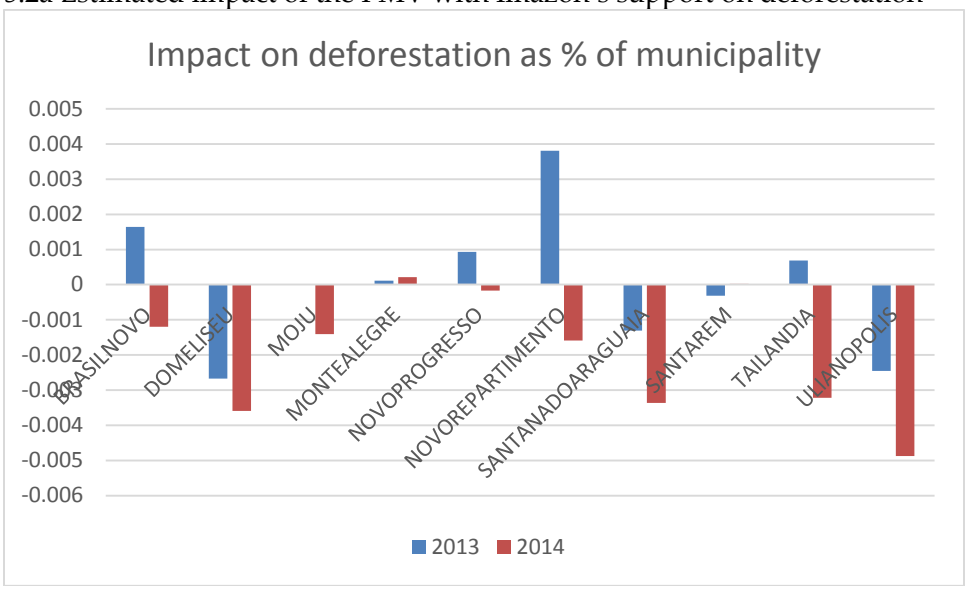
(iii) synthetic controls with low MSPE (mean square prediction error) that are closely matched to the treated unit in the years immediately preceding treatment.

We follow the SCM literature and drop group (i), although below we also explore the possibility of correcting for pre-treatment error using a DiD-type approach. For low-pressure locations (ii), synthetic controls appear to match well, although there is really not enough variation pre-treatment to assess the fit. They also generally show no impact of the program. Because we find many such municipalities, that category matters for overall impacts of interventions. For locations facing more pressure and where the synthetic control is a reasonable match (iii), we calculate treatment impacts as the treated's percent deforestation minus the synthetic's percent deforestation (implying that the goal is a value below zero).

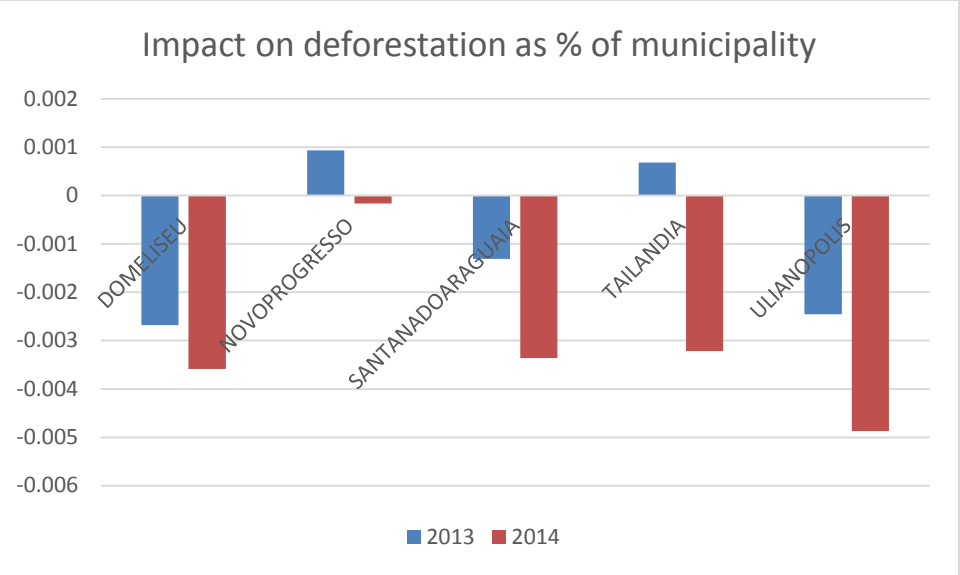
For the bundled PMV and Imazon, we find that: (i) three municipalities have poorly fit synthetic controls: Brasil Novo, Moju, and Novo Repartimento; (ii) the deforestation rate has been low and steady in Monte Alegre and Santarém and this not surprisingly leads to low estimated impacts, but also makes it difficult to evaluate the quality of the synthetic control; and (iii) the synthetic control closely matches historical deforestation in Novo Progresso and Santana do Araguaia, and matches reasonably well in Dom Eliseu, Tailandia, and Ulianopolis. It is always a judgment call whether the match quality is "sufficiently good." In all cases, the construction of the synthetic control improves the match, or "balance," of the covariates. However, the heart of SCM is use of historical data on the outcome to match on unobservables as well as observables, and thus we ultimately judge quality based on the plots of historical deforestation. The plots are provided in Annex 2. As an illustration of the underlying process and the intermediate outputs from the SCM software package, Annex 3 also shows the vector of weights assigned to the different covariates (V) and to the different municipalities (W) for a case study municipality. We picked this case study because the results are fairly typical, in that fewer than 10 municipalities receive positive weights in W. In this case, two-thirds of the weight is on Vila Rica in MT and Nova Mamore in RO, with the remaining third distributed across 3 other municipalities. This pattern of concentrated weight on a few municipalities would facilitate the process of obtaining local and expert input. In V, two-thirds of the weight is placed on just two covariates: municipal GDP per capita, and percent of GDP from agriculture. However, in this case, the remaining third is distributed across all of the other covariates. Again, these vectors are just an example from one municipality, provided to illustrate the estimation output from SCM.

As can be seen by comparing the solid and dotted lines in the plots, the estimated effects range from increasing deforestation to decreasing deforestation relative to the counterfactual. In particular, several treated municipalities appear to have higher deforestation than their counterfactuals in 2013 and lower deforestation in 2014 (e.g. see plots for Novo Repartimento, Brasil Novo, Moju and Tailândia). However, some of the apparent increased deforestation effects in 2013 are for municipalities with the poorest fitting synthetic controls (e.g. Novo Repartimento and Brasil Novo). And one of the municipalities (Moju) only joined the Imazon10 in 2013. As shown in Figure 5.2a, for the blacklisted municipalities, all point estimates in 2014 were of decreased deforestation. It is worth noting that some of the largest effects on reducing deforestation are in the three municipalities judged to have "sufficiently good" synthetic controls (see Figure 5.2b), despite the fact that deforestation in those synthetic controls was below actual deforestation in the years immediately prior to treatment, which would lead to downward bias in the impact estimate if that difference persisted into the treatment period.

5.2a Estimated impact of the PMV with Imazon's support on deforestation



5.2a Estimated impact of the PMV with Imazon's support on deforestation in municipalities with good quality synthetic controls



Averaging across the five municipalities with good quality synthetic controls, we find that the bundled PMV and Imazon on average reduced deforestation as a percent of the municipality by 0.3% or 21 km^2 in 2014 (and by <0.1% or <0.7 km^2 in 2013). This leaves the critical question of whether these impacts will continue into the future.

The next question is whether these effects are statistically different from zero. To assess this, we turn to four sets of placebo tests to establish the range of estimates around zero that could be expected due purely to noise. The four placebo tests are for treatment in 2011, 2012, and 2013 for the blacklisted municipalities and in 2012 for the non-blacklisted municipalities. The annex provides histograms of the estimated placebo effects, showing the empirical 90% confidence interval around zero. The tick marks at the top of those histograms indicate the actual estimated effects in the treated municipalities. Any that fall outside of the 90% confidence interval (i.e., below – or more negative – than the fifth percentile of placebo effects) indicate a statistically significant effect of the Imazon10 on reducing deforestation. Table 5.2 summarizes results for the ten municipalities in the IMAZON10.

Table 5.2. Effect of bundled Imazon10 + PMV intervention, estimated with SCM: first symbol (+ or -) indicates whether the point estimate is positive or negative, and second symbol indicates its statistical significance based on placebo tests: significantly different from zero in the positive (+) or negative (-) direction or no different from zero (0):

'0' - zero (within the 90% confidence interval around zero established by the placebos)

'-' -reduces deforestation (more negative than at least 95% of the estimated placebo effects)

'+' - increases deforestation (more positive than at least 95% of the estimated placebo effects).

Municipality	Year joined	Quality of Synth Control	Sign and significance of effect of Imazon10+PMV		
			2012	2013	2014
Blacklist					
Brasil Novo	2012	Unacceptable			
Dom Eliseu	2011	Good	+ 0	- -	- -
Moju	2013	Unacceptable			
Novo Progresso	2012	Excellent	- 0	+ 0	- 0
Novo Repartimento	2012	Unacceptable			
Santana do Araguaia	2012	Excellent	- 0	- 0	- -
Tailandia	2011	Good	+ 0	+ 0	- -
Ulianopolis	2011	Good	+ 0	- 0	- -
Non-blacklist					
Monte Alegre	2012	Unknown‡	+ 0	- 0	+ 0
Santarem	2012	Unknown‡	- 0	- 0	+ 0

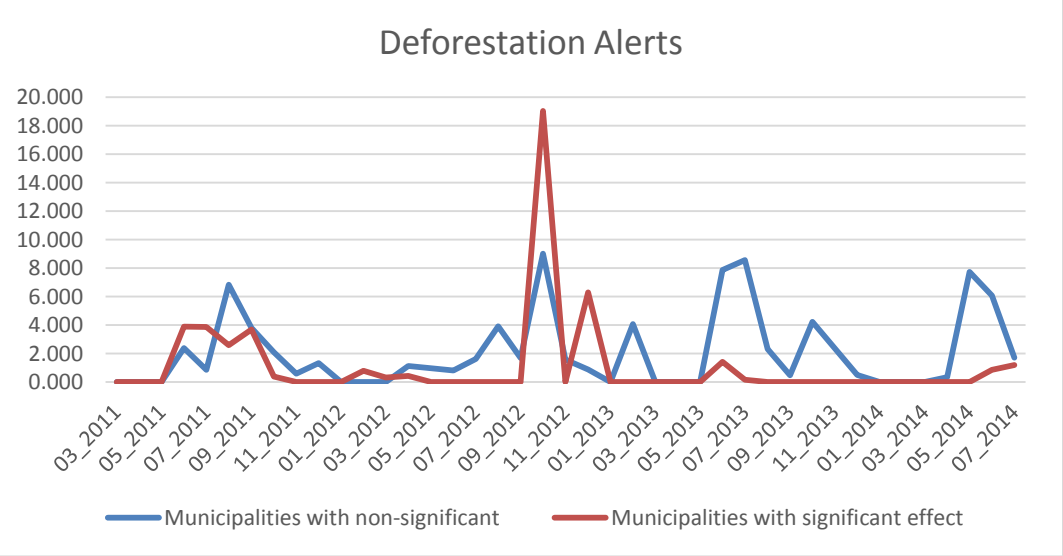
‡While the synthetic controls match annual deforestation in these municipalities prior to 2012, this is not a good test of whether they are valid counterfactuals, because annual deforestation was consistently very low and therefore very easy to match by simply picking other municipalities outside the active deforestation frontier.

The placebo plots and table show that the only consistently significant effects on reducing deforestation occur in blacklisted municipalities three years after they start working with Imazon, i.e. in 2014 in the blacklisted municipalities that started working with Imazon in 2011. In the other municipalities that started working with Imazon in 2012 or 2013 (except for Santana do Araguaia), none of the estimated effects are significantly different from zero. In particular, the last placebo plot makes clear that there is no significant effect in the two municipalities not on the blacklist, Monte Alegre and Santarem. Pending confirmation with future years of deforestation data, it appears that the Imazon10 has a lagged effect, only reducing deforestation after several years in the program. All of the municipalities in the Imazon10 are implementing the PMV, in the sense defined earlier. But they have not all accomplished every goal of the program. For example, the PMV sets a goal for all municipalities to register in the CAR at least 80% of the land eligible for registration (the CAR1 zone). The four municipalities where the program had a significant impact in 2014 (Dom Eliseu, Santana do Araguaia, Tailandia, and Ulianopolis) had all registered more than 80% of their eligible land in the CAR, while none of the other municipalities in the Imazon10 had reached that goal. In future phases of this work, we will assess the impact of registering land in the CAR, both on the registered land and on the rest of the municipality.

Another metric for evaluating the impact of the Imazon10 and PMV is the number of deforestation alerts issued by Imazon for each municipality and whether/how the municipal government responded. Figure 5.3 compares the number of deforestation alerts issued on average to the four municipalities in the Imazon10 where the Imazon10 had statistically significant and negative impacts (lower deforestation relative to the

synthetic control) to the number of alerts in the two municipalities where there was no impact (excluding the four municipalities where we could not construct or could not effectively judge the quality of the synthetic control). As with deforestation, this figure shows that since the first quarter of 2013, there have been consistently fewer alerts in the four municipalities where we estimated significant impacts.

Figure 5.3: Average number of deforestation alerts per municipality where Imazon 10 was estimated to have a significant effect (in red) and municipalities where not found to have a significant effect (in blue)



The findings from SCM highlight an important consideration when thinking about impacts. On the one hand, where the blacklist is imposed, there are other forces working to lower deforestation, thus constraining the impacts of the PMV + Imazon10 treatment. On the other hand, the blacklist was not randomly imposed and where it was not imposed there is a good chance that deforestation pressure is low, which also bounds impacts very close to zero, because the maximum possible reduction in deforestation is the total amount of deforestation under the counterfactual. As long as there is very little deforestation under the counterfactual, then there can be very little reduction under treatment. Of course, counterfactual deforestation can grow over time, and thus effects may only become evident after a number of years. While on the topic of selection, we also emphasize a dual selection issue with the PMV, which we evaluate next. Among places where the blacklist is not imposed, some will be known locally to have higher pressure and greater chances of being placed on the blacklist. PMV likely targeted those. If so, it may be difficult to find good matches for them, e.g., they may have higher deforestation than other non-blacklisted locations on average. That could lead to spurious estimates of PMV increasing deforestation, such as the point estimate of a positive effect of the bundled Imazon10 and PMV on deforestation in Monte Alegre (see appendix).

5.2.2 Impact of the PMV estimated with SCM

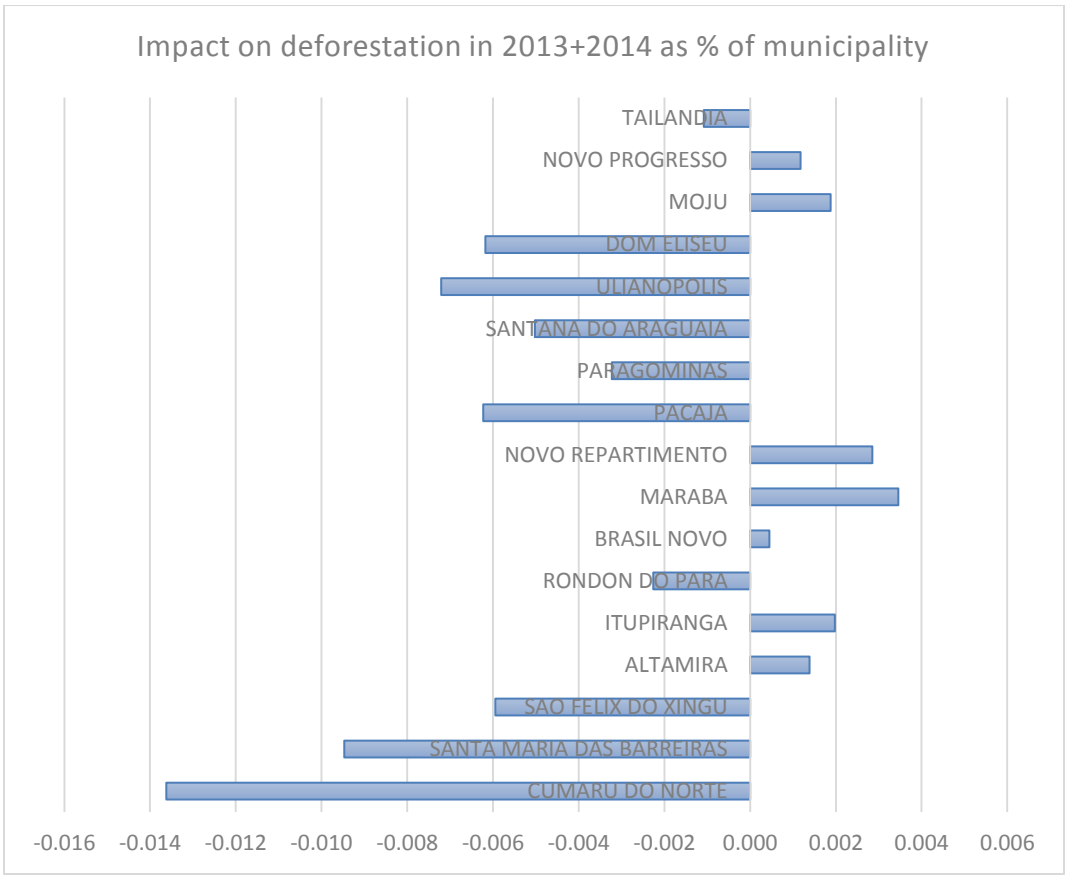
As with the bundled PMV and Imazon10 intervention, we examine effects of the PMV on blacklisted municipalities and non-blacklisted municipalities separately, recognizing different deforestation histories (creating different opportunities to reduce deforestation) as well as different sets of interventions designed to reduce deforestation. Plots for all municipalities referenced as examples here are provided in Annex 2. In general, the PMV has more impact in the blacklisted municipalities, as shown clearly by the donor plots for Cumaru do Norte, Rondon do Pará, and Santa Maria da Barreira. More specifically, in the 10 blacklisted

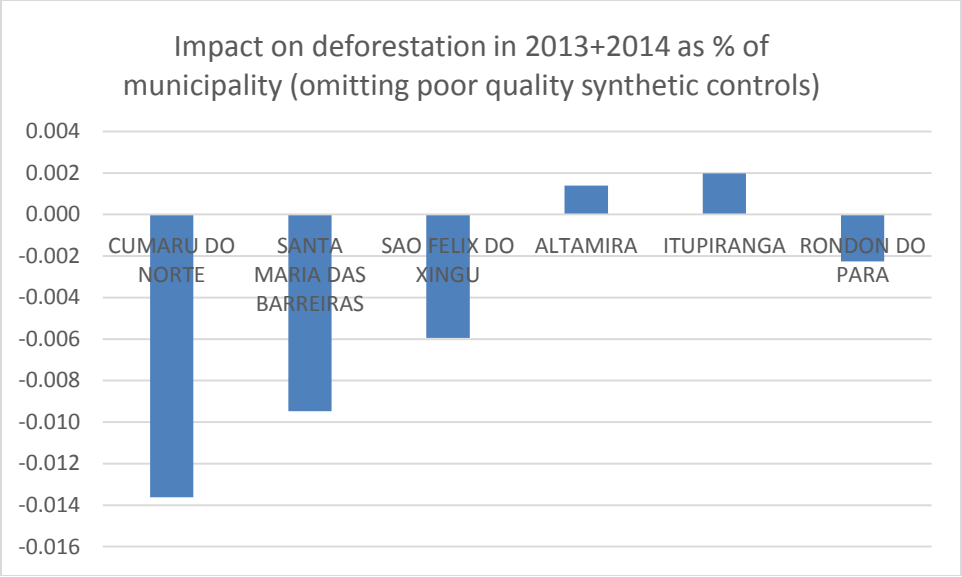
municipalities that joined the PMV in 2010, the treatment appeared to reduce 2014 deforestation in all but one, and it significantly reduced deforestation (below the noise observed in the placebos) in five of the municipalities. This was only observed in one out of the seven blacklisted municipalities that joined the PMV in 2011.

For the larger pool of municipalities in the PMV but not on the blacklist (Figure 1.1), we follow the same approach of categorizing municipalities based on their donor plots, finding that only about 20% have synthetic controls that clearly match their historical deforestation (illustrated by Bannach and Tucuma), another 20% have clearly poor quality synthetic controls (illustrated by Picarra and Ruropolis), with the remaining 60% having very low deforestation always or in recent years, meaning that there is not much variation to test the quality of the match and that there is little scope for impact (illustrated by Chaves and Redenção).

We summarize the effects by summing percentage deforestation in the most recent years observed: 2013 and 2014 (using preliminary deforestation figures for 2014). Figure 5.4 suggests that the PMV had the most success reducing deforestation in Cumaru do Norte and the most perverse effect in Marabá. Both of these have reasonable MSPE, but the plots of the synthetic controls (Annex 2) show that the synthetic for Cumaru do Norte is much better quality than for Marabá in the years immediately before treatment, thus we have low confidence in the apparent perverse effect in Marabá.

Figure 5.4. Summary of estimated effects of the PMV on deforestation as percent of municipal area across 2013 and 2014 (sum of deforestation in these two years).





Following the literature, our summary results omit impact estimates for municipalities with poor quality synthetic controls (indicated by high MSPE or large systematic error in the three years before treatment). For example, Novo Repartimento has had among the highest deforestation rates in the Amazon, making it difficult to construct a synthetic control. While not true in general, we suspect for this evaluation, poor quality synthetics most often underestimate true impact (with exceptions, e.g., Mae do Rio). However, in some cases, although there is a large error in fit just before treatment that would appear to generate what are likely to be spurious estimated impacts, there could still be a real impact, which is perhaps understated due to the error (see plot for Pacaja).

Therefore, we also speculate about ways to adjust for imbalance between such synthetic controls and treated municipalities, motivated by the concern that simply omitting these is throwing out important information (in either direction, depending on the sign of the imbalance). We believe that a logical next step to generate more policy relevant information could be to net out any persistent residual error in the synthetic controls, similar to estimating DiD within a matched sample. Specifically, this would mean subtracting the persistent error in the years immediately prior to treatment from the estimated impact. However, unlike DiD, it is not obvious which year's error should be netted out. To illustrate the idea and some potential challenges in its implementation, we calculate the error by averaging the difference between the actual and the synthetic in the year of entry into the PMV and the two preceding years (2008–2010) for Marabá and Cumaru do Norte. After adjusting effects in 2013 and 2014 by subtracting this error, the effect of the PMV appears even larger in Marabá than in Cumaru do Norte, as shown in Table 5.3. However, this result is sensitive to the construction of the pre-treatment error, just as DiD is sensitive to the assumed baseline year. For example, if we net out the average error in 2009 and 2010, then it still appears that PMV reduces deforestation in Marabá but to a lesser degree than in Cumaru do Norte. Thus, we do not make this adjustment to the estimates reported here.

Table 5.3: Illustration of the effects of adjusting for average pre-treatment error

Effect in 2013 + 2014	Maraba	Cumaru do Norte

SCM estimate	0.0033	-0.0136
After adjustment	-0.0158	-0.0074

As shown by Table 5.3, even if we did adjust impact estimates for residual error, there would still be great heterogeneity in the estimated effects. In addition to blacklist status, another possible driver of this heterogeneity is the size of the municipality, because the requirement to reduce deforestation below 40 km^2 in order to exit the blacklist is much more binding on large municipalities. The municipalities in the PMV vary greatly in size, with 27 above the mean (with an average size of 32,000 km^2) and 63 below the mean (with an average size of 3,300 km^2). As predicted, among blacklisted municipalities, the effect of the PMV on percent deforestation is substantially larger in 2013, although no different in 2014, among municipalities larger than the mean.

5.2.3 Impact of the "PMV on paper only" vs "PMV implementation" estimated with SCM

We examine differences between municipalities that are part of the PMV on paper only vs. those that are actively engaged in implementing the program (based on our simple categorization described above[11]). All but one of the blacklisted municipalities in the PMV are actively implementing the program. Thus, we focus on non-blacklisted municipalities, comparing the effect of joining the PMV on paper only vs. implementing the PMV. We find that the PMV has essentially a zero effect (< |0.0001|) on percent deforestation in 2013 and 2014 in the municipalities participating on paper only, and a small effect on percent deforestation in 2013 (mean of -0.0006) and 2014 (mean of -0.0002) in the municipalities implementing the program. Comparing effects estimated for (a) different years and (b) different non-blacklisted municipalities, the PMV has the largest effect on reducing deforestation (a) in 2013 and (b) in municipalities that were actively engaged in implementing the program. Because all but one of the blacklisted municipalities in the PMV are actively engaged in implementation of the program, the estimated effects of "PMV on paper" and "PMV implementation" are nearly identical for blacklisted municipalities. The average effect on blacklisted municipalities is largest in 2014 (the most recent year of data). Patterns such as these are only suggestive, we should stress, but nonetheless it is at least interesting to speculate that perhaps outside of the blacklist the overall background pressure for deforestation drives impact (resulting in a higher counterfactual and therefore larger impact in 2013) while municipalities on the blacklist (but not in the PMV) might be allowing deforestation to slowly rise over time to accommodate economic activity (resulting in a higher counterfactual in 2014).

5.2.4 Impact of PMV estimated with Standard Matching

To place our findings using SCM in context, we also conducted more conventional matching to evaluate if the PMV reduced (or avoided) deforestation in 2013 and 2014. We only applied matching to the PMV (on paper and implementation), which has a large enough sample of treated for conventional statistical tests of balance and significant effects. We employed two of the most widely used forms of matching: covariate

[11] Note that we consider a municipality to have been implementing the PMV from the date on which they signed the agreement as long as they achieved at least three out of four key steps by the time of this evaluation. That is, this treatment is defined as active municipal engagement in the program, as measured by eventual accomplishment of these steps. We do not have data on when each step was completed, and therefore we cannot measure the effect of having accomplished each step.

(using the Mahalanobis metric) and propensity score (kernel) matching (Pattanayak, 2009). Even prior to running the matching estimator, the initial set-up for conventional matching differs from SCM in the following steps:

1. Define a list of outcomes, which unlike SCM requires specifying the year of interest. With conventional matching, we can use the same matched sample to examine impacts on several different outcomes (because the matches are not constructed in order to match the lagged values of a particular outcome). Thus, in addition to percentage deforestation (***anodeflorpct2014 anodeflorpct2013)***, we consider the level of deforestation or 'absolute deforestation' ***(kmdefor2014 kmdefor2013)*** in a municipality in 2013 or 2014.
2. Define a list of treatments, which unlike SCM requires defining the year of interest. We decided to examine the impact of signing onto PMV in 2010, signing on to PMV in 2011, signing on to PMV in either 2010 or 2011, and engaging in the implementation of PMV as defined above (***pmv2010, pmv2011, pmv2010+11, pmv-implementation***).
3. Define a list of covariates, with a greater focus on covariates that affect participation as well as deforestation, as opposed to the deforestation determinants used in SCM. We decided on: ***everblacklisted sharedefor2000 roadclassR2010 pctindigmuni2011 pctpamuni2011 incrapctR2010 polpartyR2008 cattleR2004 numberofagR2011 fmdR2011 incR2000 pibpcR2003 popdenR2000 pibagpctR2003 eduhdiR2011 pctembargoR2011*** (see appendix for a full description of the variables).
4. Identify two alternate sub-samples corresponding to: (a) excluding treatments if they were part of the ***imazon10***, and (b) excluding potential controls if the municipality was contiguous to a treatment to avoid spillover biases.

Given the supplementary nature of this standard matching analysis, we do not report all of the results from each of these many model runs or re-estimate effects with the revised deforestation estimates for 2013 and 2014. Results can be summarized as follows. First, compared to the covariate matching, the kernel matching is better at matching treatment and control municipalities, presumably because it has more degrees of freedom (i.e., all potential controls are potentially contributing to the match). This is relevant to SCM as a strategy because kernel matching is similar in spirit to what SCM is attempting. Second, unlike SCM, most of our conventional matching analyses show that the treatment does not statistically significantly reduce annual deforestation (in percent or absolute terms). This may be because conventional matching estimates an average effect across all treated municipalities, including the municipalities that are excluded from the summaries of SCM results because of poor matches. There is one exception: conventional matching (covariate and kernel) shows that municipalities that joined the PMV in 2010 have lower deforestation in 2014 (both percent and absolute) compared to their matched controls. This is consistent with the finding from SCM and suggests that more impacts may emerge over time.

Table 5.4: Summary of evaluations and results. All evaluations are conditional on blacklist status.

Intervention	Evaluation approach	Evaluation timeframe (all use data from 2001 to 2014)	Outcome variable	Results

Imazon10 + PMV	SCM	Impact observed starting 2011 to 2013 depending on municipality; focus on 2013-2014	Annual area deforested / municipal area	Reasonable matches achieved with five out of 8 blacklisted municipalities. Significant reductions in 2014 deforestation (outside 90% confidence interval around zero based on placebos) in black-listed municipalities that started with Imazon in 2011 (Dom Eliseu, Tailandia, Ulianopolis), and in two municipalities in the third year of collaboration with Imazon (Dom Eliseu in 2013, and Santana do Araguaia in 2014). Not enough deforestation to judge quality of synthetic or to observe substantial impact on deforestation in two municipalities not blacklisted.
PMV (all)	Panel regression	Impact observed starting 2011 to 2014 depending on municipality	Annual sq km deforestation	Significant reduction in deforestation
	SCM	Impact observed starting 2011 or 2012 depending on municipality; focus on 2013-2014	Annual area deforested / municipal area	Substantial reductions in deforestation in black-listed municipalities in 2014 (statistically significant among 5 municipalities that joined in 2010 and 1 municipality that joined in 2011)

	Matching (covariate and kernel)	Impact tested in 2013-2014	Annual area deforested / municipal area and annual area deforested (km^2)	Significant reduction in 2014 deforestation in municipalities signing on to PMV in 2010 (earliest year).
PMV (paper only)	SCM	Impact observed starting 2011 or 2012 depending on municipality; focus on 2013-2014	Annual area deforested / municipal area	Small reductions in deforestation for blacklisted (no impact on non-blacklisted)
PMV (implementation)	SCM	Impact observed starting 2011 or 2012 depending on municipality; focus on 2013-2014	Annual area deforested / municipal area	Small reductions in 2013 and very small reductions in 2014 deforestation for non-blacklisted (blacklisted same as PMV on paper)
	Matching (covariate and kernel)	Impact tested in 2013-2014	Annual area deforested and Annual area deforested / municipal area	Same as PMV (all)

5.2.5 Estimated Effects by Tenure Status (local, eligible for CAR, and other)

Results are presented in Annex 3. We summarize here by comparing the estimated effects on deforestation in the entire municipality (as reported above), to deforestation in the area most directly under local governance (prefeitura's area), and in the areas eligible and not eligible for the CAR. We only estimated effects in a particular tenure zone if that zone comprised at least 5% of a municipality.

Summary

Test group	**Whole Municipality**	**Prefeitura's Area (CAR E2), excluding federal areas**	**CAR Eligible Area (CAR E1)**	**Not eligible for CAR**
8 municipalities that are blacklisted, in the PMV, and in the IMAZON10	4 negative and significant, 1 zero, 3 poor fits in 2014. Only Dom Eliseu significant and negative in 2013.	Negative effect across all treated and those with significant results. Average reduction in deforestation of -0.27% in 2014.	Average negative effect on deforestation across all 8 treated only in 2014 (-0.19%) Average negative effect in the ones with statistically significant effects in both years (-0.15% for 2014).	Negative in Brasil Novo; insignificant in Novo Progresso and Novo Repartimento; area too small in other municipalities
2 municipalities that are not blacklisted but are in the PMV and Imazon10	Zero impact in 2012-2014	Only Santarem has a negative effect on deforestation (impact in 2014 is -0.003%)	Negative effect only for Santarem. This municipality's impact on 2014 is -0.04%.	Both municipalities with a negative effect in 2014 (-0008%)
17 municipalities that are blacklisted and in the PMV	Negative effect on deforestation. Average impact in 2014 -0.19%	Negative effect on deforestation. Average impact in 2014 of -0.50%.	Average negative effect of treatment equal to -0.22% in 2014. Also negative effect for 2013.	Negative average effect on deforestation in the treated municipalities for 2013 and 2014. Impact for 2014 is -0.11%
70 municipalities that are not blacklisted but are in the PMV	Negative effect on deforestation in 2013-14		43 out of 70 treated municipalities with negative effects on deforestation in 2014	22 out of 39 treated have a negative effect on deforestation

6. DISCUSSION

Consistent with our expectations that the federal blacklist is a key moderating variable, we found that the impacts of Imazon10 and PMV differed for blacklisted and non-blacklisted municipalities. This is probably due to some combination of selection into the blacklist (i.e., municipalities with more prior deforestation were blacklisted) and implementation of the blacklist (e.g., economic incentives, such as restoring access to farm credit, to reduce deforestation). Among municipalities on the blacklist (and at risk of being placed on it), the influence of the PMV and Imazon10 interventions on deforestation depends on how they interact with the blacklist:

(a) They could complement federal (blacklist) incentives by helping to build governance capacity and the social capital required to limit deforestation sufficiently to avoid or to exit the blacklist;
(b) They could be "forest redundant" given federal (blacklist) incentives, not having any additional impact on deforestation but rather helping reduce the cost of meeting federal mandates; or
(c) They could to some extent substitute for lower deforestation in demonstrating local capacity to control deforestation and meet federal mandates, thereby potentially reducing onerous federal oversight and potentially even allowing more deforestation.

Among municipalities with low deforestation that are not at risk of being blacklisted, the programs are unlikely to reduce deforestation (because there is not much deforestation to be reduced). However, they could conceivably substitute for deforestation outcomes in assuring regulators about the local capacity to control deforestation, allowing deforestation to rise. Thus, for both blacklisted and non-blacklisted municipalities, we have no a priori prediction about the effect of the PMV and Imazon10 programs, which could plausible be negative, zero, or positive.

Our analysis suggests that these programs' impacts on deforestation are often quite small, especially in non-blacklisted but also in blacklisted municipalities. Impacts more often emerge towards the end of the post-treatment period, perhaps due to increasing deforestation pressure or increasing effectiveness of the program. To fully evaluate program benefits, the scope of the evaluation should be expanded to include costs (perhaps proxied by local economic activity) and long-term impacts on net forest cover. These are potentially complementary, as lowering the local costs of meeting federal deforestation targets may be the best way to sustain reductions in deforestation and build local support for conservation and restoration of forest.

The PMV and Imazon10 programs were designed to help municipalities respond to the federal blacklist. In this context, the programs could help municipalities to [1] satisfy that mandate sooner and/or [2] lower the local costs of meeting the federal mandates. Doing [1] means reducing deforestation and demonstrating the capacity to control deforestation. Doing [2] means reducing the transactions costs of complying with environmental regulations, as well as increasing the profitability of economic activities compatible with reduced deforestation.

Consistent with their first role, the stated short-term goal of the programs is to reduce gross deforestation. Yet that is feasible only if there is deforestation pressure to be blocked, e.g., in the municipalities that have been blacklisted or are at risk of being blacklisted. Where pressures are low, there can be little avoided deforestation. Thus, where federal actions have already reduced deforestation to low levels, we are unlikely to detect short-run program impacts on deforestation. Where deforestation pressure is high, the estimated effect depends on the counterfactual, as in any impact evaluation.

The stated immediate goal of the interventions is to bring gross deforestation completely under control, which is considered a pre-requisite for pursuing other objectives, such as developing economic alternatives that do not depend on deforestation and restoring riparian forest zones (as required under the federal Forest Code). The argument is that this 'closes the frontier', both increasing the scarcity and hence the value of forest, and reducing the sense of lawlessness and unrestricted access to forest resources. Reducing gross deforestation below 40 km^2 per year is one of the specific requirements for getting off the blacklist, which is another explicit goal set by both the PMV and Imazon10 for blacklisted municipalities. However, while reducing gross deforestation is the immediate goal of program administrators, it seems likely that local governments have other immediate goals, like maintaining economic activity including agricultural production. Thus, from the local perspective, it would make sense to also consider economic outcomes, and from a long-term perspective, it would make sense to also assess impacts on other outcomes, such as net deforestation and measures of local well-being such as the human development index, or HDI.

7. Costs of the Imazon10 and PMV interventions

In order to place the impacts of interventions in context, it is important to assess the costs of those interventions. To that end, we collected budget data to estimate the cost to date of the Imazon10, independently and bundled with the PMV. There are numerous limitations on our ability to estimate costs, including (1) the interventions are on-going and costs may decline over time reflecting up-front investments in capacity building and operating systems, (2) both Imazon and the state government are engaged in many related activities, making it difficult to disaggregate and attribute costs to these individual programs, and (3) the federal and municipal governments incur costs for activities that complement but are not clearly part of these programs. Despite these limitations, we have developed rough budget estimates that show Imazon's spending per municipality is quite significant in the context of the PMV, which in turn is quite significant in the context of municipal government spending on the rural environment.

We focused on quantifying the costs of the two interventions to their primary administrators: the state government in the case of the PMV and Imazon in the case of the Imazon10. We also gathered information on the related expenditures of three municipal governments. While these budgets provide important information on the costs of the program, they are far from complete because they exclude contributions by the federal government (e.g. activities of the MPF) and by other NGOs (e.g. The Nature Conservancy – TNC, Instituto de Pesquisa Ambiental da Amazônia – IPAM, Instituto Socioambiental – ISA, and Instituto Internacional de Educação do Brasil - IEB). Further, we have not estimated costs borne by landowners or other private individuals, such as the opportunity costs of foregone deforestation or transactions costs of registering in the CAR. The PMV and the Imazon10 both seek to lower these costs to private individuals, and any such cost savings represent an important additional benefit of the interventions.

All costs are reported in Brazilian reais. The exchange rate has fluctuated from a high of USD 0.6 per BRL in March 2011 (when the PMV was launched) to an exchange rate of roughly USD 0.35 per BRL four years later. However, during most of the time period considered, the exchange rate was around USD 0.5 per BRL, and we therefore recommend using that as a rough conversion rate.

Budget data for the PMV were obtained from an on-line budget portal for the state government called SIAFEM (Sistema Integrado de Administração Financeira para Estados e Municípios), using the expenditures ("liquido final") associated with implementation of the PMV. During most of the period that we consider (through June 2014), the budget for the PMV was managed through (a) the governor's office, which paid the salaries and travel expenses of a small program staff, and (b) other units of the state government, which actually implemented program activities.[12] In the state government's budget, there are earmarked funds for the PMV in the budgets of the following units:

1. Instituto de Desenvolvimento Florestal do Estado do Pará – IDEFLOR;
2. Instituto de Desenvolvimento Econômico, Social e Ambiental do Estado do Pará – IDESP;
3. Instituto de Terras do Estado do Pará – ITERPA;
4. Secretaria de Estado de Indústria, Comércio e Mineração – SEICOM;
5. Empresa de Assistência Técnica e Extensão Rural – EMATER;
6. Secretaria de Meio Ambiente do Estado do Pará – SEMA.

In 2011, only SEMA had a budget allocated to the PMV, making 2012 the first year of program implementation. We focus on 2013 and 2014, when the program was fully operational and incurring costs through several units of state government. By the beginning of that time period, 100 municipalities had signed onto the PMV, and we therefore divide costs by 100 to obtain a conservation back-of-the-envelope estimate of costs per municipality.

Imazon has been funded by USAID and Skoll to provide support for 10 municipalities in the PMV since May of 2013. They provided budget information on this program, to place estimated impacts in 2013 and 2014 in context. While we have budget information for this specific program, there are two important caveats:

- Imazon actually began collaborating with 9 out of 10 of the municipalities earlier (in 2011 or 2012), and our impact evaluation assumes those earlier treatment dates in order to avoid contaminating the pre-treatment period used to construct the synthetic controls. Imazon's budget for the program in 2013 and 2014 thus clearly underestimates the budget that would be required to launch a similar program in a different state, without all of the prior investments that had been made by Imazon.
- The expenditures were for (i) activities conducted in the Imazon10, (ii) activities that both benefit the Imazon10 and lay the groundwork for rolling out the program to another 40 municipalities, and (iii) operating and administrative costs of Imazon. The first of these underestimates the true cost, while the sum of the three overestimates especially the cost per municipality, which will fall as more municipalities are added to the program. For a back-of-the-envelope estimate of costs, we distribute the cost of the activities conducted in the Imazon10 across those 10 municipalities, and the rest of the costs across those 10

[12] When we update our cost estimates next year, we will need to account for a new budget structure. Starting in June of 2014, the PMV is administering its own budget, including R$ 83 million allocated by the Amazon Fund.

municipalities plus half the number that Imazon plans to add to the program (i.e., we divide total costs by 30 municipalities).

We also collected data on municipal spending in three municipalities, selected as follows. Based on the characteristics of the municipalities participating in the Imazon10, we clustered them into three groups of similar municipalities based on their "blacklist" status: on the blacklist, previously blacklisted but with deforestation now monitoring and under control, and never blacklisted. We then selected one municipality in each group, based on our assessment of the likelihood that the prefeitura would respond positively to our request for budget data. The three selected municipalities were Dom Eliseu (previously on blacklist, now deforestation monitored and under control), Novo Repartimento (blacklisted), and Santarém (never blacklisted).[13] We obtained information on expenditures from the secretary of the environment in each of these municipalities. They were not able to identify expenditures associated specifically with the PMV. Instead, Santarém provided information on their budget for combating deforestation. Dom Eliseu provided the total budget for their SEMMA and indicated that about 80% was for rural areas. Novo Repartimento also provided the total budget and indicated that about 50% was for rural areas. However, within the budget for rural areas, it proved difficult for the municipalities to clearly separate the costs of implementing the PMV and of collaborating with Imazon from other costs that are part of normal operations. We therefore report these costs separately to provide additional context.

Clearly, quantifying the administrative costs of the bundled Imazon and PMV intervention requires making numerous assumptions. Nonetheless, we present a rough back-of-the-envelope calculation below (Table 7.1). These costs are potentially over-estimated because of misidentification of costs, e.g. state agencies may have re-characterized some of their on-going activities as for the PMV in the state budget system. Equally important is the issue of whether and for how long any impacts induced by these expenditures will last. Many of the program costs in these initial years are for training personnel and establishing systems of municipal environmental governance that are expected to last for years.

Table 7.1: Administrative cost per municipality (current year BRL)

Category	**2013**	**2014**
Imazon focused on 10	3,438	17,706

[13] The bundled Imazon10 and PMV reduced deforestation in each of these municipalities by between 0.02% to 0.4% of municipal area in 2014. However, considering all years since they joined the program, the cumulative impact ranges from reduction of 0.6% to an increase of 1%. As discussed above, the initial increase in deforestation may reflect a compensatory effect in that engagement in the PMV may deflect or postpone federal enforcement action by demonstrating local commitment to reducing deforestation. Yet an equally likely explanation is that this estimated positive effect on deforestation reflects a poor quality synthetic control (high MSPE and poor match in years immediately before treatment between synthetic control and actual deforestation in Novo Repartimento). The changing effects over time, and the difficulty of constructing the counterfactual for high-deforestation municipalities like Novo Repartimento, are additional challenges to calculating cost-effectiveness ratios.

Imazon general program	42,530	43,291
PMV central administration	9,886	9,655
PMV activities	54,930	12,238
Sum	110,784	82,890

The three municipalities from which we sought budget information provided very different estimates for their costs of managing environmental issues in rural areas, including deforestation (Table 7.2). These include all costs, not limited to additional activities undertaken for the PMV. Nonetheless, they provide important context: for their combined intervention (Imazon10 + PMV), the state government and Imazon together spend somewhere between a quarter and half as much as the municipal governments spend on rural environmental issues (not limited to but dominated by regulation of deforestation). This indicates that municipal governments bear significant costs, which could potentially be reduced through efficiencies introduced by the Imazon10 + PMV intervention. At the same time, this also shows that the intervention is quite significant in terms of the level of spending relative to what the municipal governments spend.

Table 7.2: Municipal costs of rural environmental governance

Municipality	2013	2014
Santarem	16,773	95,813
Dom Eliseu	310,438	188,322
Novo Repartimento	431,384	355,190

ANNEX 1. Variable definitions

The covariates used in the analysis are described below, including information on the processing steps.

ENVIRONMENTAL VARIABLES

Slope and DEM
Information on elevation and slope were calculated from a raster image of the shuttle radar topography mission (SRTM) which provides free high quality digital elevation maps at a spatial resolution of 90 m. The file was provided by Imazon. Zonal statistics were used to derive the min, max, range and mean for the slope and DEM for each municipality.

SOCIO-ECONOMIC

Roads
Imazon provided us with a map of roads that they had manually digitized from satellite imagery. The data include information on unofficial roads in 2003, 2007, 2008 and 2010 across the Amazon Biome, excluding the states of Maranhão and Tocantins. The Estrada shapefile contained classes 1, 2 and 3 corresponding to the type of roads. Class 1 is for official roads, class 2 for unofficial roads (not in federal or state maps) and class 3 are roads in human settlements. The classes were split by year (2003, 2007, 2008 and 2010) and area was calculated as a 5 km buffer around all roads.

INCRA Settlements
Imazon provided us with data on INCRA settlements. The INCRA shapefile contained information regarding the capacity for the number of families and the actual number of families resettled. They are contained in the attribute table under CAPAC and Benef. To calculate the capacity and benefit totals, the INCRA polygons were converted to points. This was done to reduce error and retain the count information from the polygons that crossed two or more municipalities. The information on number of families was assigned to the municipality identified in the attribute table. The area of INCRA settlements was calculated based on the area within each municipality using the 2013 boundaries. A total of 985 INCRA settlements crossed municipal boundaries and are also included in the database.

Indigenous Areas
The shapefile with polygons for indigenous territories was intersected with the municipalities shapefile to derive the name of the municipality each indigenous polygon fell in. The shapefile was dissolved by the municipalities to calculate the area in sq.km for each municipality.

Protected Areas
The shapefile with polygons for state and federal protected areas (including APAs) was intersected with the municipalities shapefile to derive the name of municipality each protected area polygon fell in. The shapefile was dissolved by the municipalities to calculate the area in sq.km for each municipality. All years were used in the calculations

CAR Registration

Data on properties in the state of Pará that are CAR APPROVED and CAR PROVISIONAL were provided by Imazon. These files were intersected with the 2013 municipal boundary shapefile and the area in both categories was calculated in sq. km. for each municipality. To calculate the total CAR eligible area, the total municipal area in 2013 without the areas in federal and state protected areas, indigenous territories, or urban areas was calculated.

Embargoed Areas

The area under embargo in each municipality was calculated. Only embargo areas from the years 2000-2012 were included, although the data included a range of dates from 1963-2013. This embargo shapefile was intersected with the municipality shapefile and dissolved by municipality and date. The resulting shapefile was broken down by year, from 2000 to 2012 and all other years including missing years in one shapefile. The area under embargo was calculated in sq km.

INDUSTRIES

Mines

A shapefile of the point location of mines was obtained from Imazon. The data had no information on quantity or type of extraction, so the count of total mines within each municipality was extracted.

Frigorificos (slaughterhouses)

This shapefile shows the location of slaughter houses for cattle. The shapefile was spatially joined with the municipality shapefile to derive the count of slaughter houses per municipality and sum of cattle head. A scale from 1-10 was created to provide some information on the size of the plant using the cattle head field. The scale was produced using the same logic as the polos madeireiro scale.

We also drew on a database compiled by Imazon to accompany the series O Estado da Amazônia, extracting the following variables for the year 2005 or 2006:

Cattle	Density of cattle in municipality (heads / km^2).
Income10	Percentage share of income going to top 10% of earners (percent of total income).
PctHomesWithLand	Percent of homes with own land and settled (percent).
PIB_AG_PC	Per capita PIB (Produto Interno Bruto, or GNP) sourced from agricultural enterprises ($R million).
PIBPC	PIB (Produto Interno Bruto, or GNP) per capita ($R)
PopDen	Population density (people / km^2).
PIB_PCT_AG	Percent of PIB (Produto Interno Bruto, or GNP) sourced from agricultural enterprises (percent).
CONFLICT.PCT	Percent of municipality identified as in conflict (percent).
EDUCATIONHDI	HDI for education using new methodology (HDI).

Finally, we gathered additional data from Brazilian government sources (including the Ministry of Agriculture and the Electoral Commission or Tribunal Superior Eleitoral) on the political party of the prefeito elected in 2008 (coded as binary variable indicating whether the same party as state governor, or PSDB); the density of rural properties (count of properties per km^2); and whether the municipality was quarantined for foot and mouth disease (summarized as number of years free of foot and mouth disease in the decade of the 2000s).

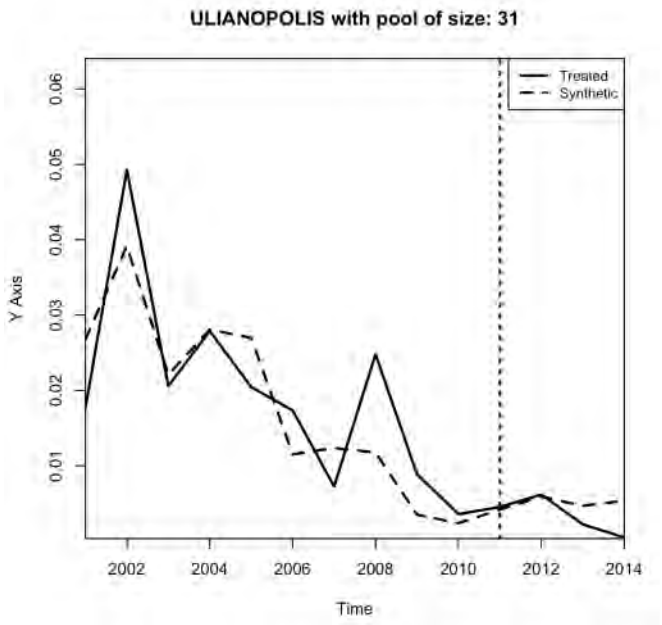
All variables used in analysis are listed in the table below:

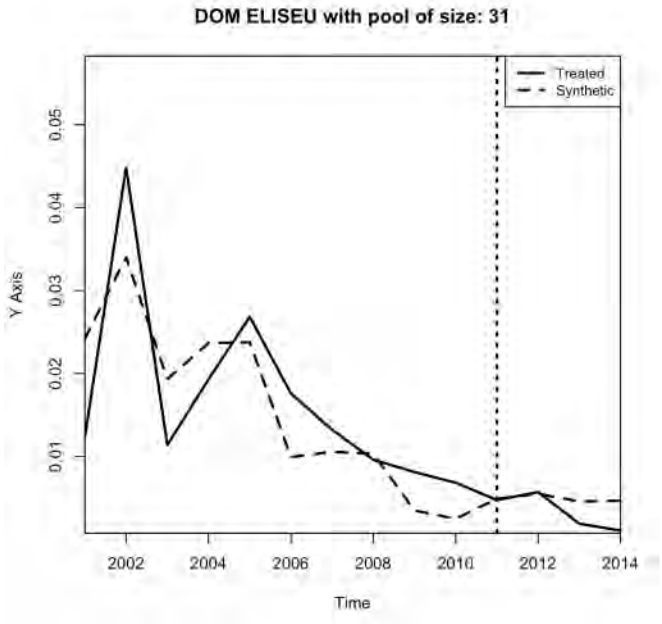
Variable Name	Description	Years
MEANSLOPE	Average slope (degrees).	N/A
MEANDEM	Mean elevation (meters).	N/A
ROAD.class12.PCT	Percent municipality area within 5km buffered area of class 1(official roads) and class 2 (unofficial roads) (percent of municipality).	2003, 2007, 2008, 2010
PCT.INDIG.MUNI	Percent of municipality designated as an indigenous area (percent).	
PCT.PA.MUNI	Percent of municipality designated as a protected area (percent).	
INCRA.PCT	Percent of municipality designated an INCRA area of resettlement	2000 - 2012
PCT.CAR.PRO	Percent of municipality provisionally designated CAR	
POLITICAL.PARTY	Political party affiliation of preferito election winner (1 is PSDB, 0 is all other)	2008, 2012
SLAUGHTERHOUSE	One or more slaughterhouses are present in municipality (0 = none, 1 = one or more)	2005
MINES	Density of mines in municipality (mines / km^2).	
Cattle	Density of cattle in municipality (heads / km^2).	2000-2004
NUMBER.OF.AG	Density of rural properties in municipality (properties / km^2).	2006
FMD	Number of years out of previous decade municipality was Foot and Mouth Disease-free (years).	2000 - 2012
Income10	Percentage share of income going to top 10% of earners (percent of total income).	2000

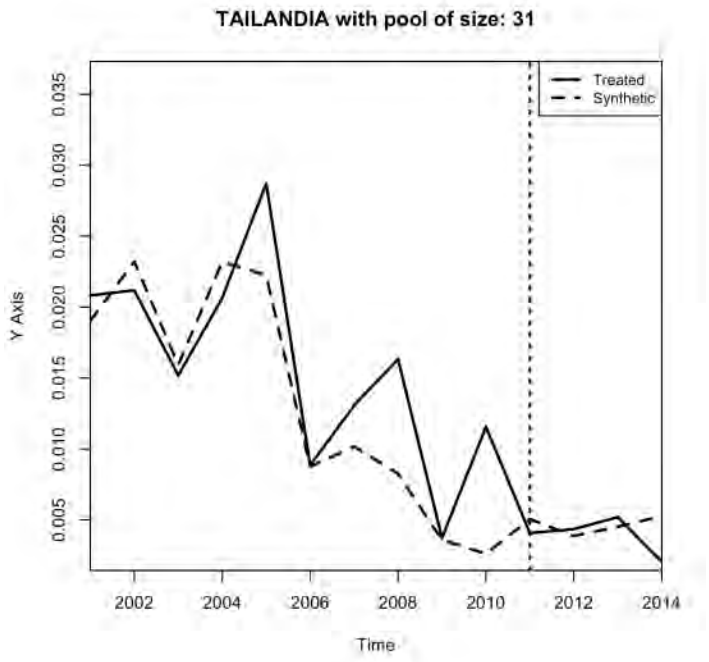
PctHomesWithLand	Percent of homes with own land and settled (percent).	2000
PIB_AG_PC	Per capita PIB (Produto Interno Bruto, or GNP) sourced from agricultural enterprises ($R million).	2000 - 2003
PIBPC	PIB (Produto Interno Bruto, or GNP) per capita ($R)	2000 - 2003
PopDen	Population density (people / km^2).	2000
PIB_PCT_AG	Percent of PIB (Produto Interno Bruto, or GNP) sourced from agricultural enterprises (percent).	2000 - 2003
CONFLICT.PCT	Percent of municipality identified as in conflict (percent).	2005
EDUCATIONHDI	HDI for education using new methodology (HDI).	2000
PCT.EMBARGO	Percentage of municipality area under IBAMA embargo (percent).	2000 - 2012

ANNEX 2 SCM Results

Donor plots show actual deforestation in the 'treated' municipality (in solid black) and synthetic deforestation estimate based on the synthetic control (dotted line). For example, in the first 8 figures, treated are part of the Imazon10 and synthetic controls are constructed from the 31 municipalities blacklisted but not in the PMV. Vertical dotted line is the year of treatment.






TAILANDIA with pool of size: 31
Treated
Synthetic
Y Axis
0.005
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0.015
0.020
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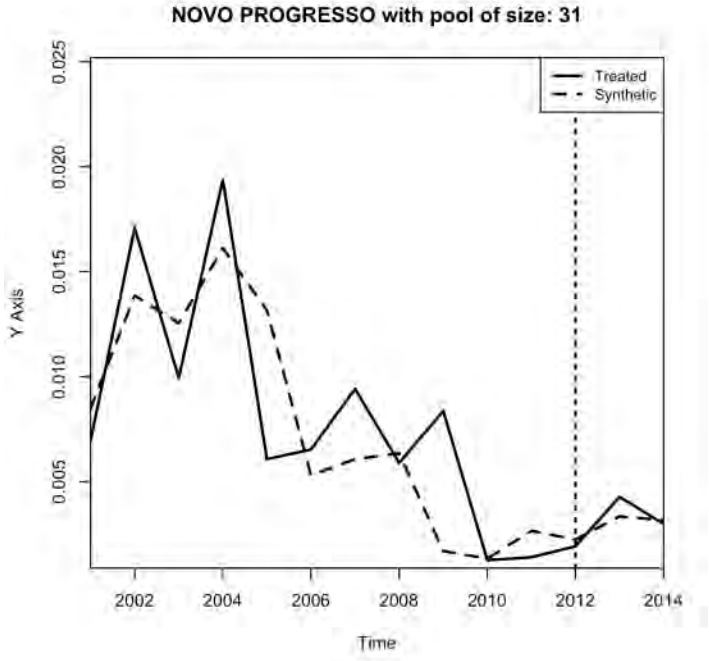
2002
2004
2006
2008
2010
2012
2014
Time


NOVO PROGRESSO with pool of size: 31
Treated
Synthetic
Y Axis
0.005
0.010
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2002
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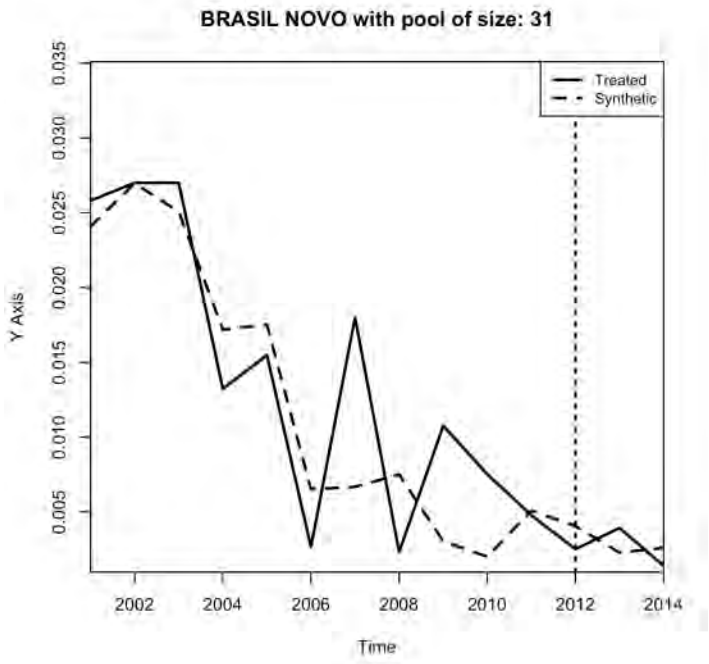
2012
2014
Time


BRASIL NOVO with pool of size: 31
Treated
Synthetic
Y Axis
0.005
0.010
0.015
0.020
0.025
0.030
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2002
2004
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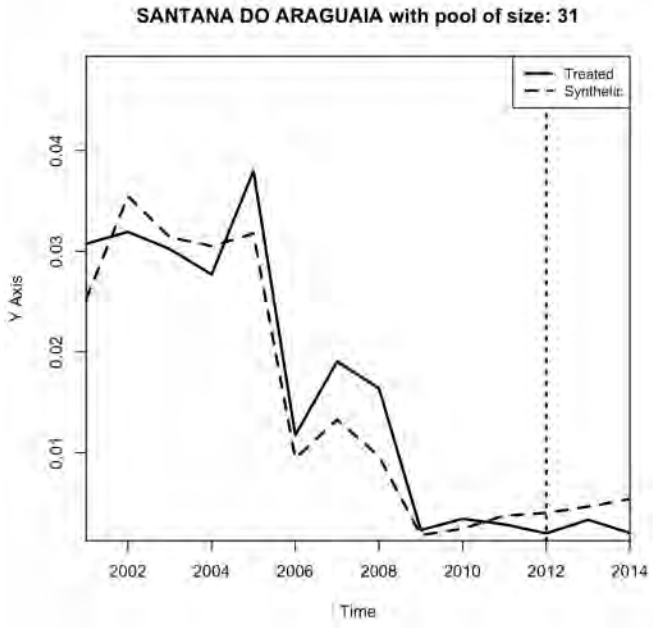
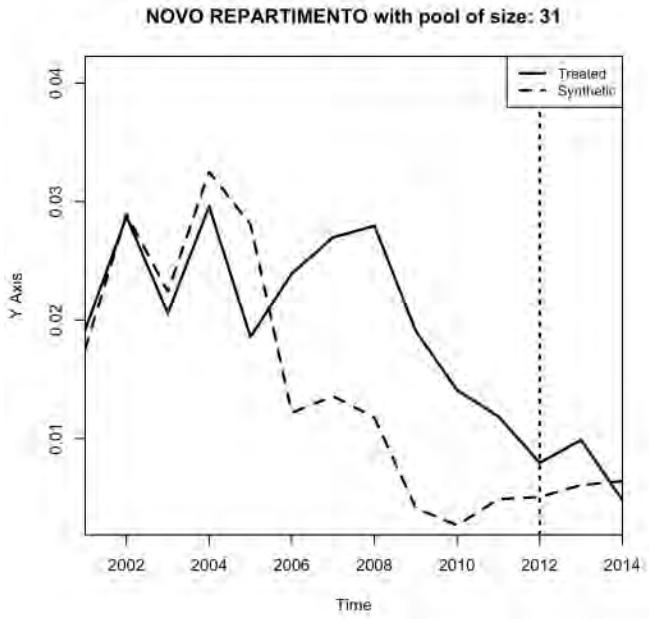
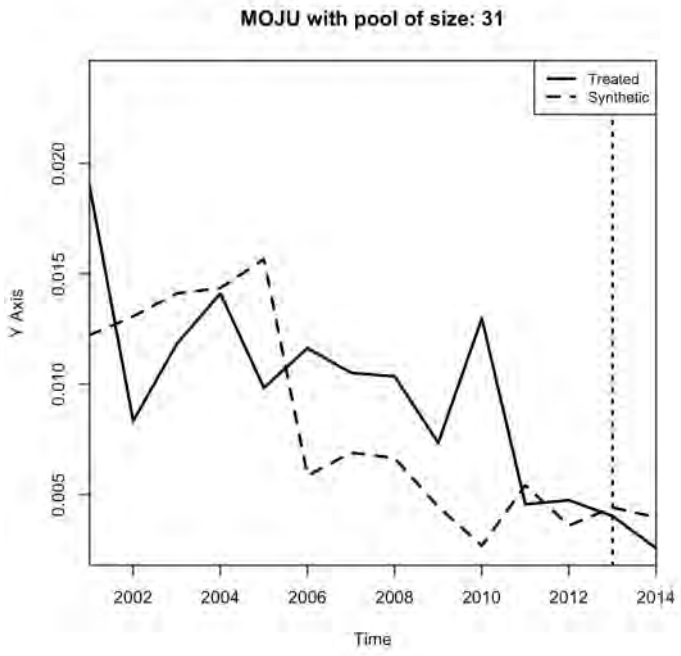
2012
2014
Time


SANTANA DO ARAGUAIA with pool of size: 31
Treated
Synthetic
Y Axis
0.01
0.02
0.03
0.04
2002
2004
2006
2008
2010
2012
2014
Time


NOVO REPARTIMENTO with pool of size: 31
Treated
Synthetic
Y Axis
0.01
0.02
0.03
0.04
2002
2004
2006
2008
2010
2012
2014
Time


MOJU with pool of size: 31
Treated
Synthetic
Y Axis
0.005
0.010
0.015
0.020
2002
2004
2006
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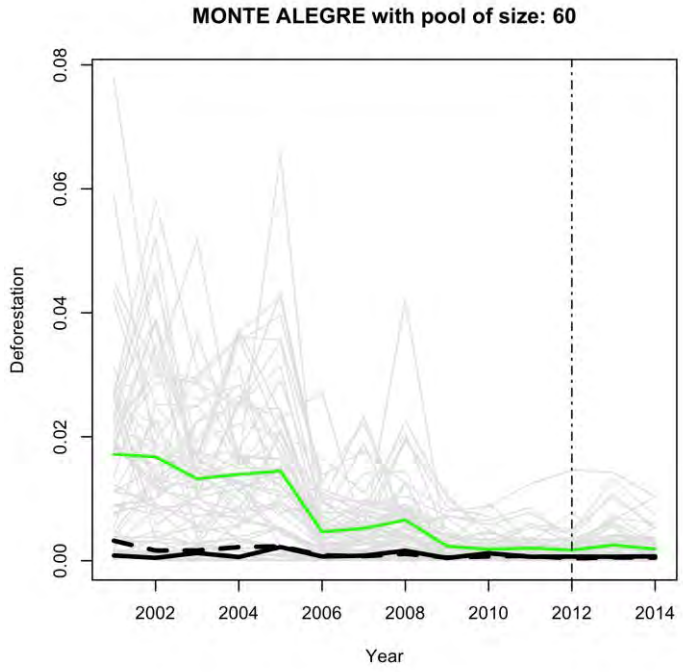
2010
2012
2014
Time


MONTE ALEGRE with pool of size: 60
Deforestation
0.00
0.02
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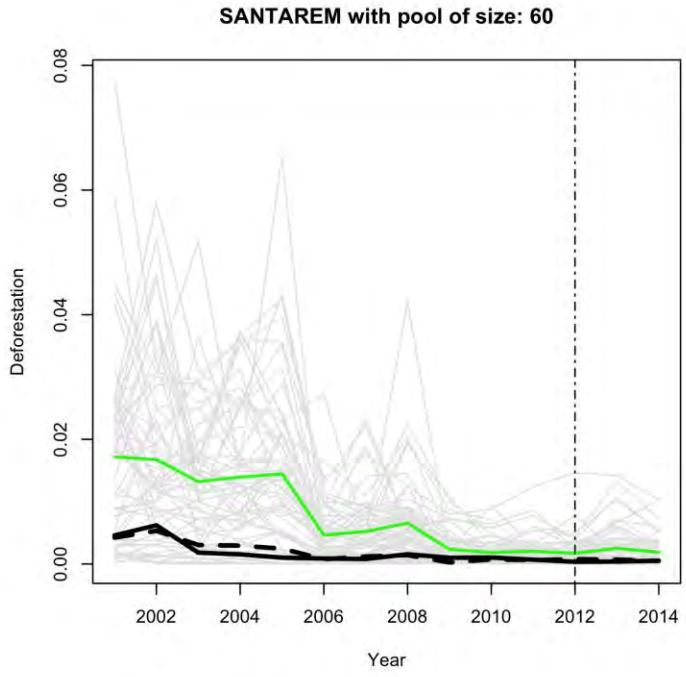
0.06
0.08
2002
2004
2006
2008
2010
2012
2014
Year


SANTAREM with pool of size: 60
Deforestation
0.00
0.02
0.04
0.06
0.08
2002
2004
2006
2008
2010
2012
2014
Year

We have generated tables describing the municipalities in the Imazon10, the synthetic control, and the donor pool (including all municipalities with a weight greater than 0.0005 in the synthetic control) in terms of the covariates used to construct the synthetic control. These are archived in CSV format, and illustrated here with the two municipalities in the Imazon10 that are not blacklisted. Variables are defined in Annex 1.

These tables demonstrate that even for the non-blacklisted municipalities, on most (but not all) characteristics, the synthetic control is more similar than the mean of the donor pool to the treated municipality. The characteristics that do not match well are likely to be those given lower weights, because matching on them did not help match historical trends in deforestation.

In future work, we anticipate reviewing these tables with Imazon to identify any municipalities that should be removed from the donor pool.

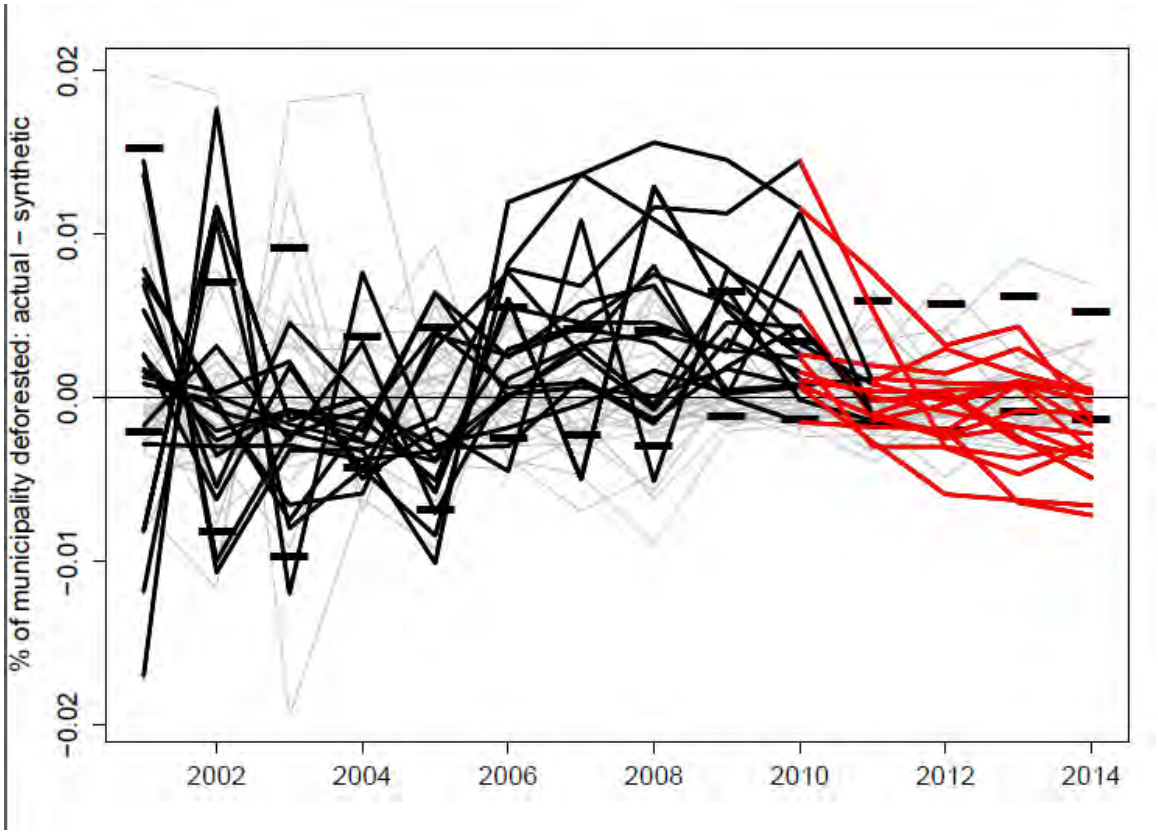
	Monte Alegre	Synthetic Control	Mean of donor pool	MUANA	MANCIOLIMA	ITAPIRANGA	MACAPA	CANDEIASDOJAMARI	JOAOLISBOA	ALTOALEGRE	BOMJESUSDASSELVAS
SC weights				0.444	0.256	0.121	0.048	0.047	0.045	0.037	0.001
meanslope	2.220	0.719	1.309	0.299	0.840	1.314	0.386	0.472	1.797	2.380	2.282
meandem	282.870	112.565	234.016	10.361	256.425	74.946	16.517	101.886	244.545	444.447	221.479
roadclass12pct	0.080	0.106	0.351	0.067	0.116	0.060	0.303	0.448	0.000	0.094	0.000
pctindigmuni	0.029	0.054	0.084	0.000	0.104	0.000	0.000	0.000	0.000	0.738	0.045
pctpamuni	0.596	0.712	0.222	1.000	0.645	0.392	0.038	0.516	0.010	0.800	0.045
incrapct	0.008	0.007	0.002	0.008	0.009	0.000	0.001	0.019	0.000	0.000	0.007
pctcarpro	0.166	0.077	0.019	0.173	0.000	0.000	0.000	0.000	0.000	0.000	0.000
politicalparty	0.000	0.037	0.067	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
mines	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
cattle	7.356	5.679	32.334	2.638	1.607	2.270	2.374	15.858	63.253	2.417	26.870
numberofag	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
fmd	0.000	0.200	0.574	0.000	0.583	0.000	0.000	1.083	0.000	0.000	0.000
income10	45.960	46.644	47.251	47.040	51.400	41.910	48.570	39.890	41.740	37.740	47.500
pcthomeswithland	78.170	73.753	72.478	61.730	86.500	80.930	74.320	76.710	85.180	89.960	73.980
pib_ag_pc	1414.325	451.932	1451.439	534.775	128.701	404.812	75.739	2266.740	259.083	267.796	822.930

pibpc	2408.524	2027.570	3964.195	1363.224	1843.972	2192.854	5116.898	6036.541	1227.503	2666.659	1673.973
popden	3.000	7.033	12.518	6.700	2.400	1.700	43.100	1.900	23.300	0.700	5.800
pib_pct_ag	0.585	0.241	0.328	0.393	0.069	0.168	0.015	0.310	0.190	0.103	0.479
conflictpct	0.001	0.000	0.001	0.000	0.000	0.000	0.003	0.004	0.000	0.000	0.000
educationhdi	0.784	0.757	0.774	0.734	0.708	0.867	0.904	0.789	0.737	0.831	0.658
pctembargo	0.218	0.198	0.711	0.000	0.229	0.000	0.031	2.857	0.007	0.088	0.012

	Santarem	Synthetic Control	Mean of Donor Pool	SILVES	SERRADONAVIO	SAOJOSEDERIBAMAR	MONTENEGRO	AMAJARI	MANCIOLIMA	PORTOGRANDE	CASTANHAL	ALTOALEGRE
SC Weights				0.7640	0.0640	0.0510	0.0340	0.0300	0.0190	0.0140	0.0130	0.0120
meanslope	0.9816	1.1275	1.3009	1.0640	0.9080	0.3901	1.8858	3.5022	0.8404	1.2143	0.4492	2.3801
meandem	66.8304	91.9977	229.0289	64.1720	175.7670	10.1102	200.9870	404.7740	256.4250	108.7510	38.5267	444.4470
roadclass12pct	0.1842	0.1908	0.3454	0.2121	0.0104	0.0000	0.2272	0.1025	0.1164	0.2469	0.8062	0.0936
pctindigmuni	0.0000	0.0307	0.0818	0.0000	0.0000	0.0000	0.0554	0.5999	0.1040	0.0000	0.0000	0.7382
pctpamuni	0.2581	0.1567	0.2214	0.0000	0.9570	0.9175	0.0554	0.6350	0.6446	0.4225	0.0000	0.7995
incrapct	0.0200	0.0002	0.0019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0094	0.0000	0.0017	0.0000
pctcarpro	0.3215	0.0039	0.0237	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3027	0.0000
politicalparty	0.0000	0.8400	0.0781	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000	0.0000	0.0000	1.0000
mines	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0005	0.0000	0.0000	0.0007	0.0000	0.0000
cattle	6.2525	7.6213	31.5144	5.9455	0.0810	1.0892	73.8694	2.0581	1.6066	0.3296	29.2912	2.4172
numberofag	0.0000	0.0002	0.0003	0.0000	0.0000	0.0027	0.0004	0.0000	0.0000	0.0000	0.0010	0.0000
fmd	0.0000	0.0479	0.5559	0.0000	0.0000	0.0000	1.0833	0.0000	0.5833	0.0000	0.0000	0.0000
income10	50.3100	44.2240	47.2518	42.2900	54.9600	50.0200	44.3500	54.0800	51.4000	47.9600	47.2900	37.7400
pcthomeswithland	80.8300	77.0522	72.6865	76.8300	65.7600	86.0300	77.0700	75.9800	86.5000	76.9000	81.4200	89.9600
pib_ag_pc	518.68	769.58	1425.40	878.61	505.57	45.79	878.16	426.54	128.70	935.85	170.45	267.80
pibpc	2367.06	2843.10	3920.35	2647.22	6535.32	888.38	3227.72	2777.36	1843.97	4532.40	2577.28	2666.66

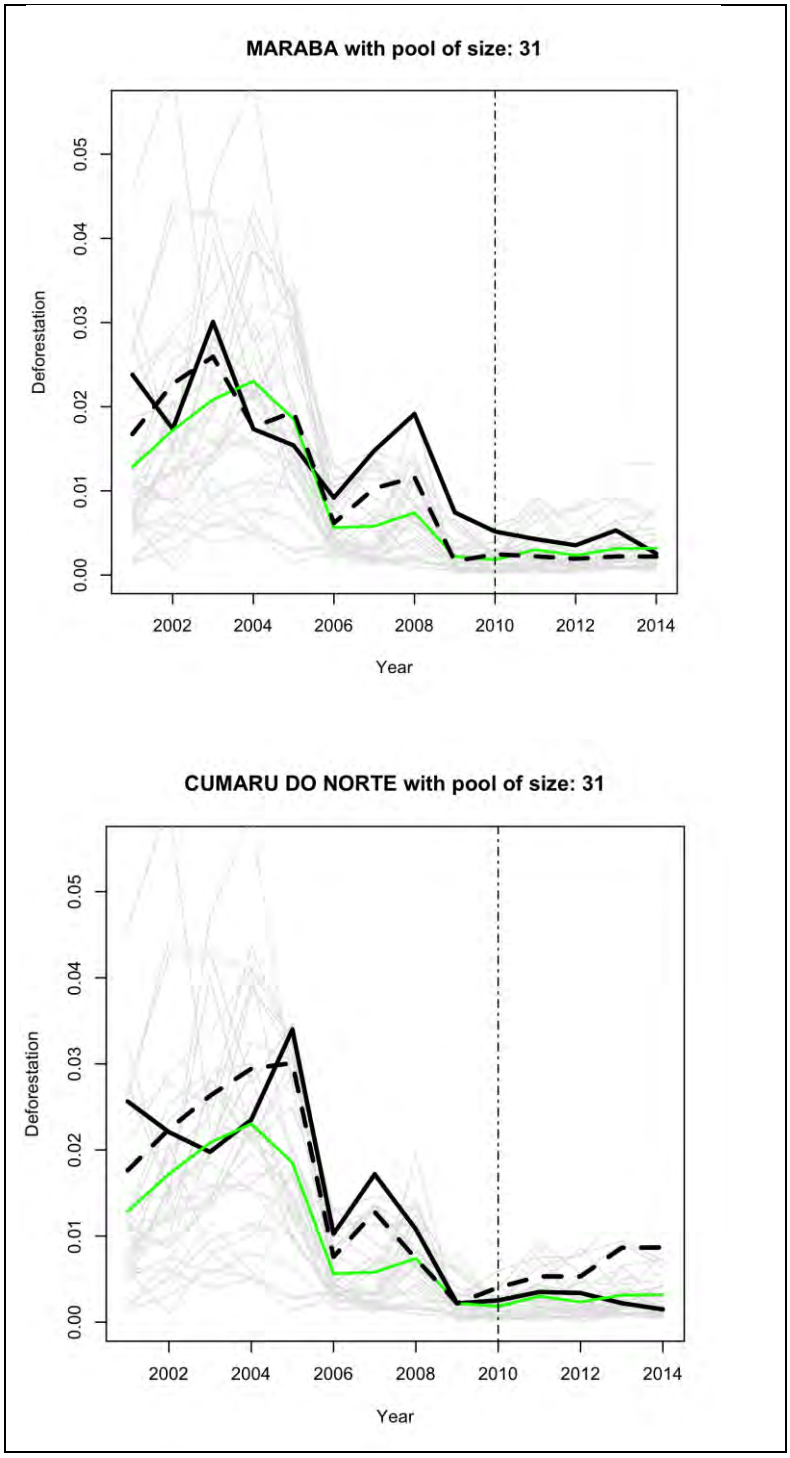
popden	10.8000	16.2765	12.5512	2.1000	0.4000	246.1000	8.9000	0.2000	2.4000	2.5000	130.6000	0.7000
pib_pct_ag	0.2024	0.2736	0.3247	0.3221	0.0770	0.0522	0.2606	0.1569	0.0686	0.2098	0.0658	0.1026
conflictpct	0.0000	0.0001	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0040	0.0000	0.0000
educationhdi	0.8840	0.8474	0.7767	0.8560	0.8970	0.8510	0.7450	0.7070	0.7080	0.8230	0.8540	0.8310
pctembargo	0.4039	0.0140	0.6947	0.0024	0.0355	0.0024	0.0147	0.0564	0.2290	0.1547	0.0000	0.0877

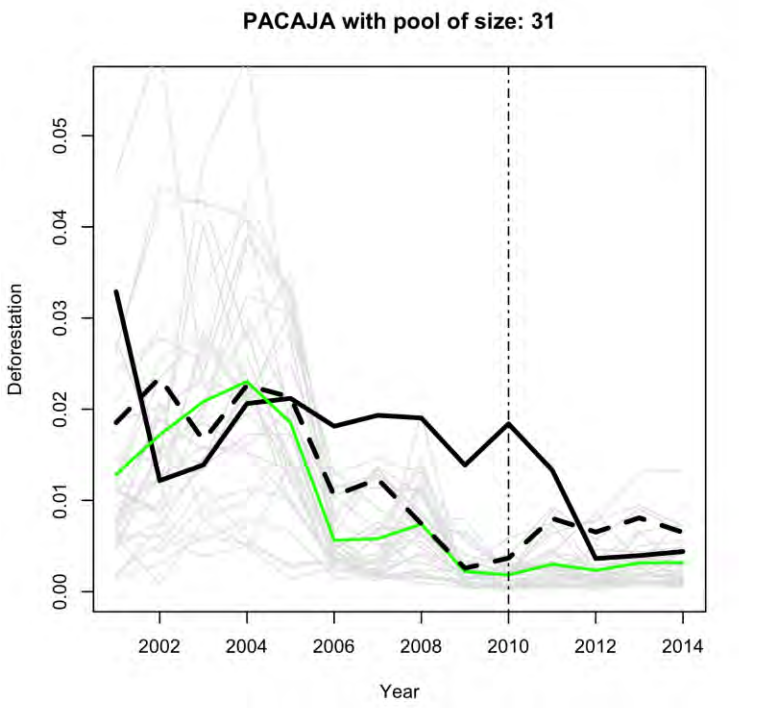
Placebo plot for PMV (effect on blacklisted municipalities, red indicates year joined the PMV)

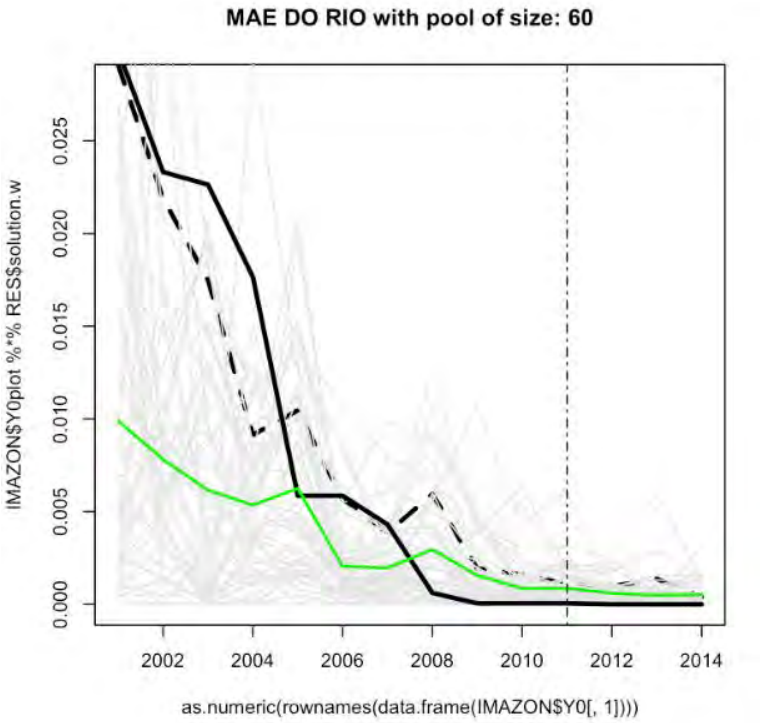


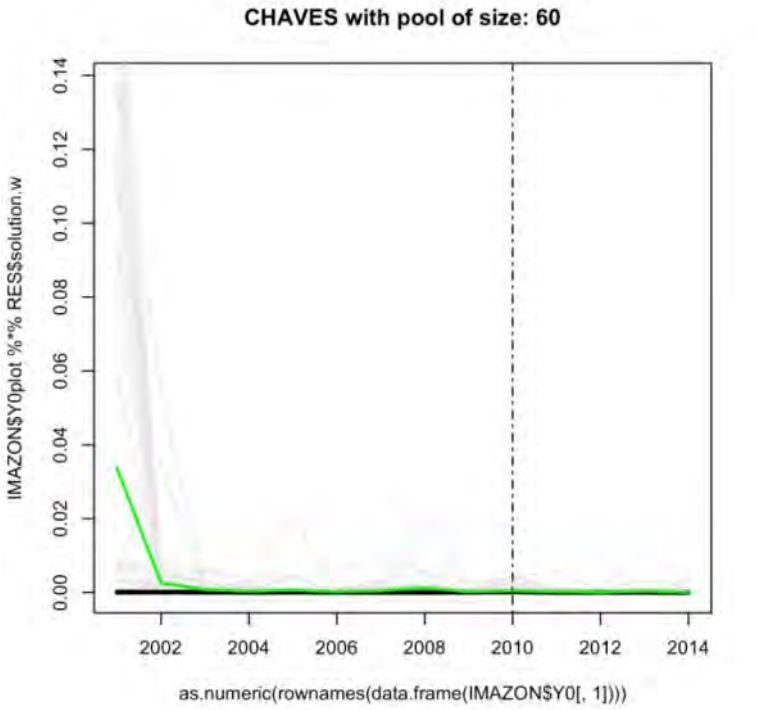
Plots of SCM results for evaluation of the PMV

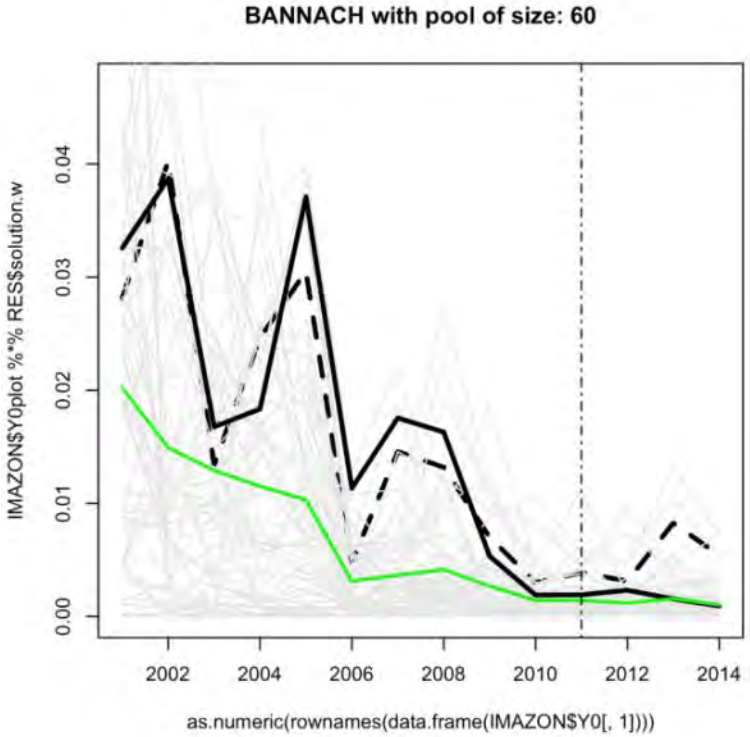
Only the municipalities referenced in the text are included here. Dark black line shows deforestation in the treated unit; dotted black line shows deforestation in the synthetic control; light gray lines show deforestation in the municipalities in the donor pool; green line shows mean deforestation in the donor pool; vertical dotted line shows year of treatment.

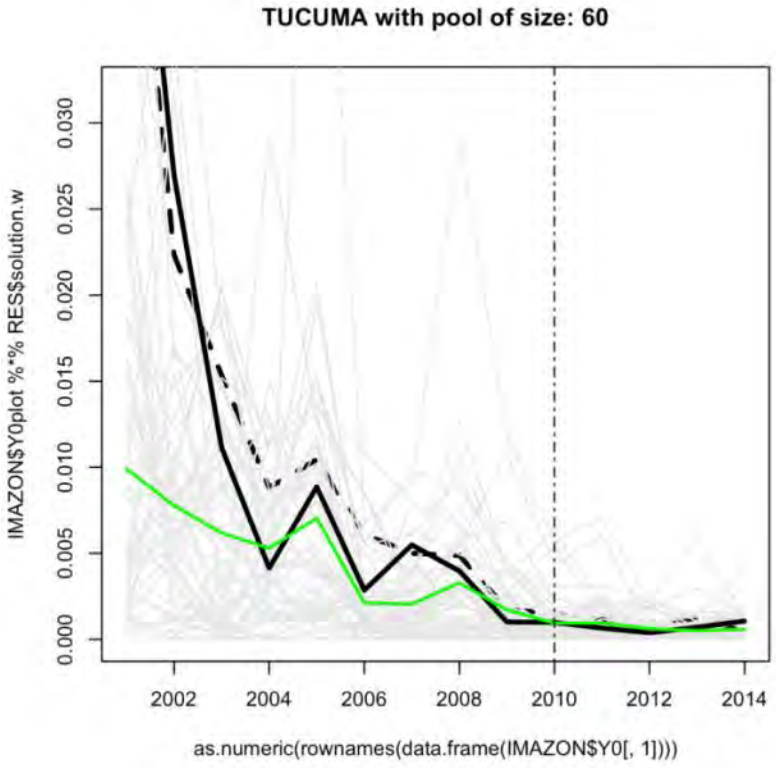

MARABA with pool of size: 31
Deforestation
0.00
0.01
0.02
0.03
0.04
0.05
2002
2004
2006
2008
2010
2012
2014
Year
CUMARU DO NORTE with pool of size: 31
Deforestation
0.00
0.01
0.02
0.03
0.04
0.05
2002
2004
2006
2008
2010
2012
2014
Year

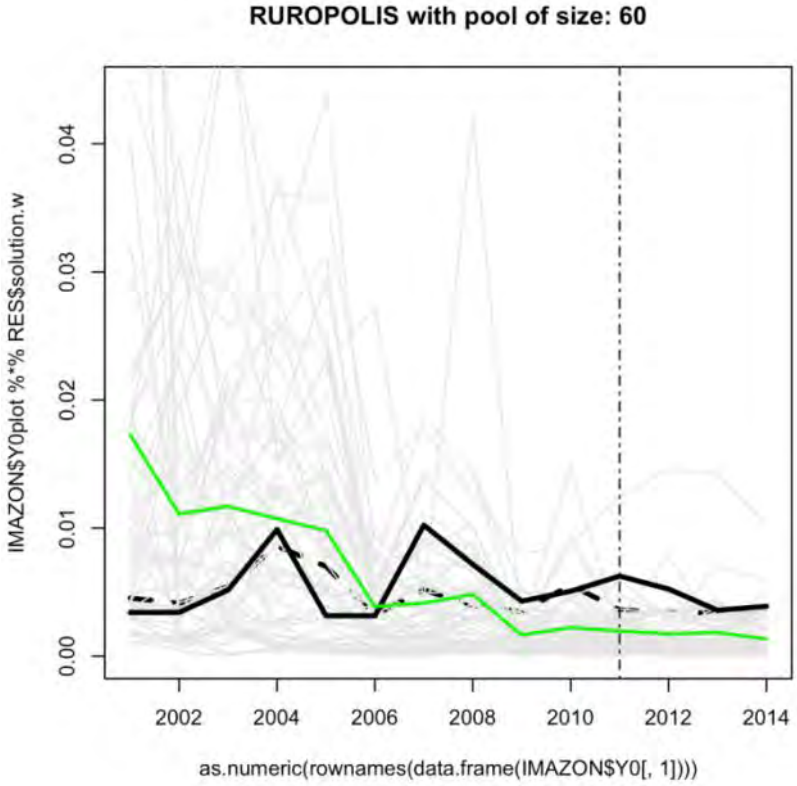

PACAJA with pool of size: 31
Deforestation
0.00
0.01
0.02
0.03
0.04
0.05
2002
2004
2006
2008
2010
2012
2014
Year

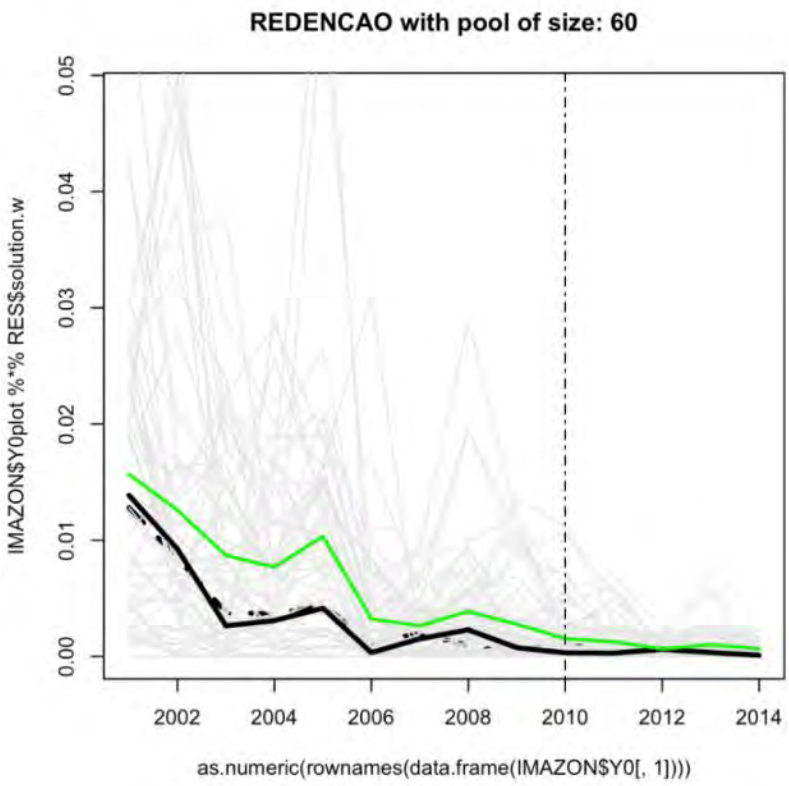

MAE DO RIO with pool of size: 60
IMAZON$Y0plot %*% RES$solution.w
0.000
0.005
0.010
0.015
0.020
0.025
2002
2004
2006
2008
2010
2012
2014
as.numeric(rownames(data.frame(IMAZON$Y0[, 1])))

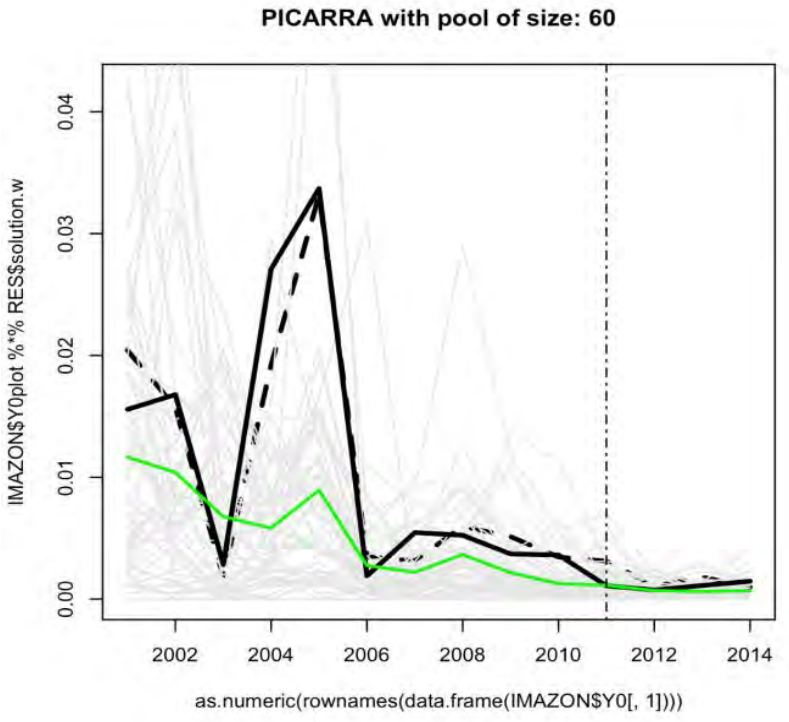

CHAVES with pool of size: 60
IMAZON$Y0plot %*% RES$solution.w
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
2002
2004
2006
2008
2010
2012
2014
as.numeric(rownames(data.frame(IMAZON$Y0[, 1])))

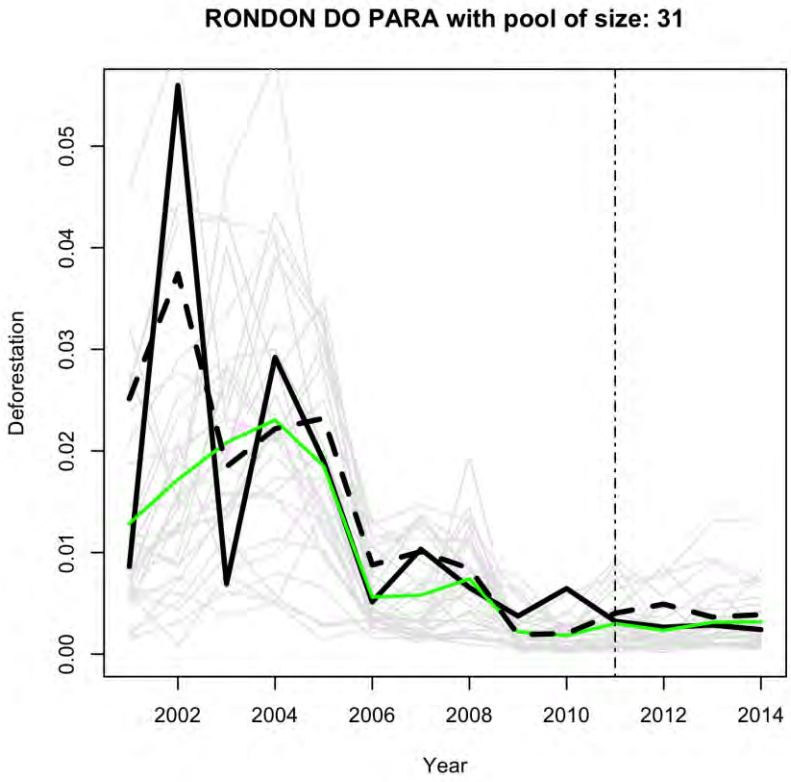

BANNACH with pool of size: 60
IMAZON$Y0plot %*% RES$solution.w
0.00
0.01
0.02
0.03
0.04
2002
2004
2006
2008
2010
2012
2014
as.numeric(rownames(data.frame(IMAZON$Y0[, 1])))

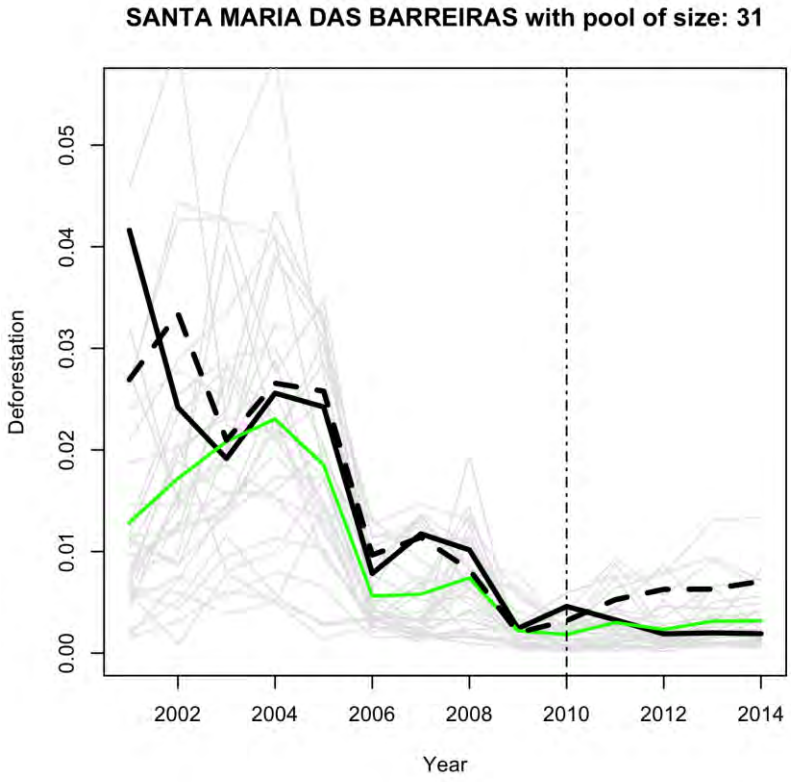

TUCUMA with pool of size: 60
IMAZON$Y0plot %*% RES$solution.w
0.000
0.005
0.010
0.015
0.020
0.025
0.030
2002
2004
2006
2008
2010
2012
2014
as.numeric(rownames(data.frame(IMAZON$Y0[, 1])))


RUROPOLIS with pool of size: 60
IMAZON$Y0plot %*% RES$solution.w
0.00
0.01
0.02
0.03
0.04
2002
2004
2006
2008
2010
2012
2014
as.numeric(rownames(data.frame(IMAZON$Y0[, 1])))


REDENCAO with pool of size: 60
IMAZON$Y0plot %*% RES$solution.w
0.00
0.01
0.02
0.03
0.04
0.05
2002
2004
2006
2008
2010
2012
2014
as.numeric(rownames(data.frame(IMAZON$Y0[, 1])))


PICARRA with pool of size: 60
IMAZON$Y0plot %*% RES$solution.w
0.00
0.01
0.02
0.03
0.04
2002
2004
2006
2008
2010
2012
2014
as.numeric(rownames(data.frame(IMAZON$Y0[, 1])))

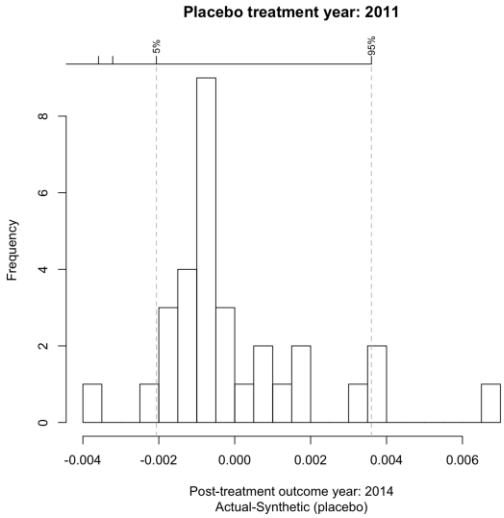

RONDON DO PARA with pool of size: 31
Deforestation
0.00
0.01
0.02
0.03
0.04
0.05
2002
2004
2006
2008
2010
2012
2014
Year

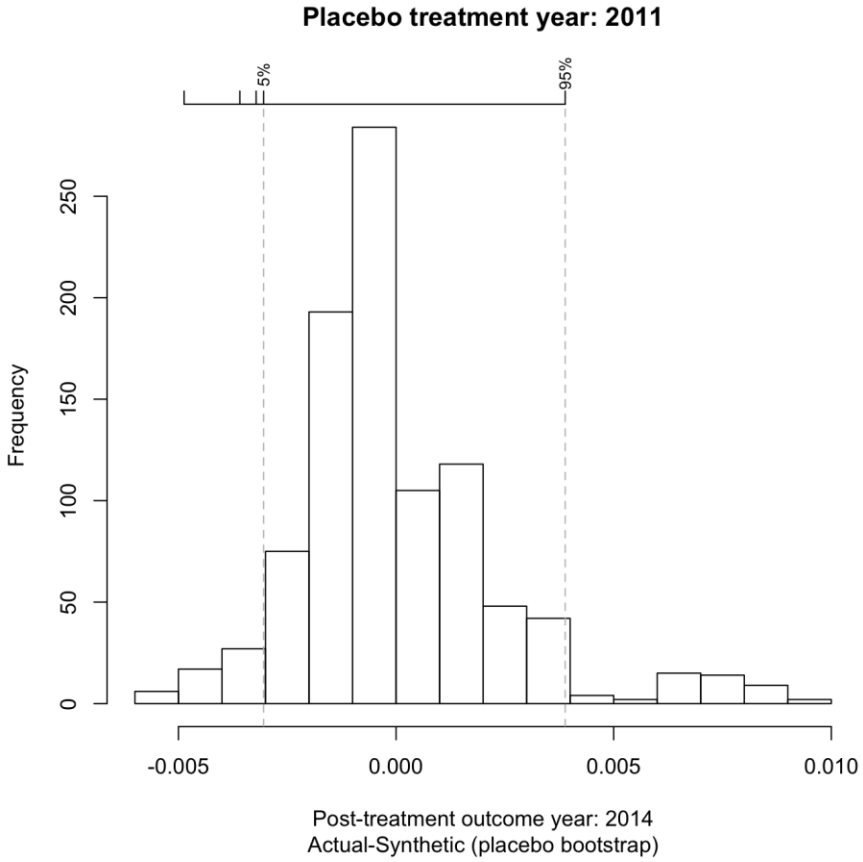

SANTA MARIA DAS BARREIRAS with pool of size: 31
Deforestation
0.00
0.01
0.02
0.03
0.04
0.05
2002
2004
2006
2008
2010
2012
2014
Year

Annex 3 SCM Methodology

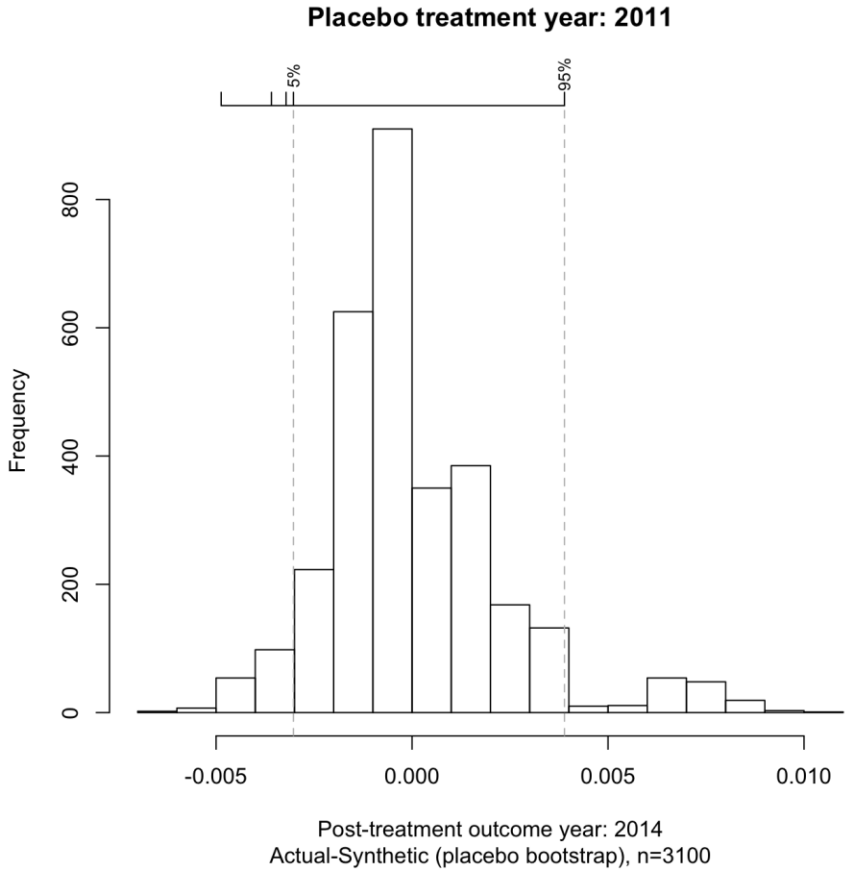
A) 'Bootcebos'

The following histograms show placebo effects on deforestation in 2014 of a 2011 treatment, first with just the 31 placebo effects estimated for blacklisted municipalities not in the PMV, then with each of those effects re-estimated 30 times by bootstrapping the donor pool, and then with each of those effects re-estimated 100 times by bootstrapping the donor pool.





Each placebo bootstrapped 31 times for N = 961



B) Output from Synth package for SCM

The following tables provide examples of the vectors of weights on municipalities that comprise each synthetic control and on covariates used to construct each synthetic control, illustrating the type of intermediate output provided by the SCM package. The examples presented here are for Santana do Araguaia compared to other blacklisted municipalities not in the PMV. We have archived these vectors for all synthetic controls, as an input to facilitate discussion about the method and understanding of the synthetic controls. For example, in this case, we see that the largest weights are placed economic factors (total and agricultural municipal GDP) and on municipalities in MT and RO. Given local knowledge of Santana do Araguaia, we could assess whether these weights are sensible.

Municipality	State	Weight
VILA RICA	MT	0.439
NOVA MAMORE	RO	0.226
CONFRESA	MT	0.145
PARANAITA	MT	0.13
NOVA BANDEIRANTES	MT	0.061
MACHADINHO D'OESTE	RO	0

PIMENTA BUENO	RO	0
PORTO VELHO	RO	0
BOCA DO ACRE	AM	0
LABREA	AM	0
MUCAJAI	RR	0
AMARANTE DO MARANHAO	MA	0
ALTA FLORESTA	MT	0
ALTO BOA VISTA	MT	0
ARIPUANA	MT	0
BRASNORTE	MT	0
CLAUDIA	MT	0
COTRIGUACU	MT	0
FELIZ NATAL	MT	0
GAUCHA DO NORTE	MT	0
JUARA	MT	0
JUINA	MT	0
MARCELANDIA	MT	0
NOVA UBIRATA	MT	0
PEIXOTO DE AZEVEDO	MT	0
PORTO DOS GAUCHOS	MT	0
QUERENCIA	MT	0
SANTA CARMEM	MT	0
SAO FELIX DO ARAGUAIA	MT	0
TAPURAH	MT	0
NOVA MARINGA	MT	0

Covariate	Weight
pib_ag_pc	0.3456
pibpc	0.3327
avg % defor 2001 - 2003	0.0933
educationhdi	0.0376
avg % defor 2004 - 2007	0.0335
pib_pct_ag	0.0253
mines	0.0202
popden	0.018
roadclass12pct	0.0169
income10	0.0126
fmd	0.0109
pctindigmuni	0.0106
meanslope	0.0102
numberofag	0.0086
meandem	0.0076
pcthomeswithland	0.0059
pctcarpro	0.0055

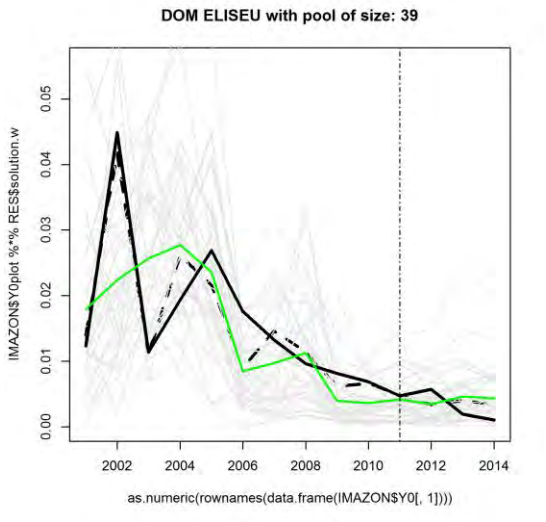
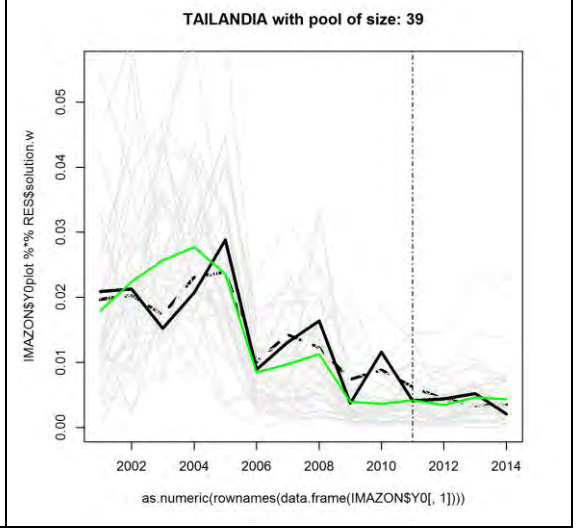
cattle	0.0041
pctpamuni	0.0005
incrapct	0.0002
politicalparty	0.0001
conflictpct	0.0001
pctembargo	0

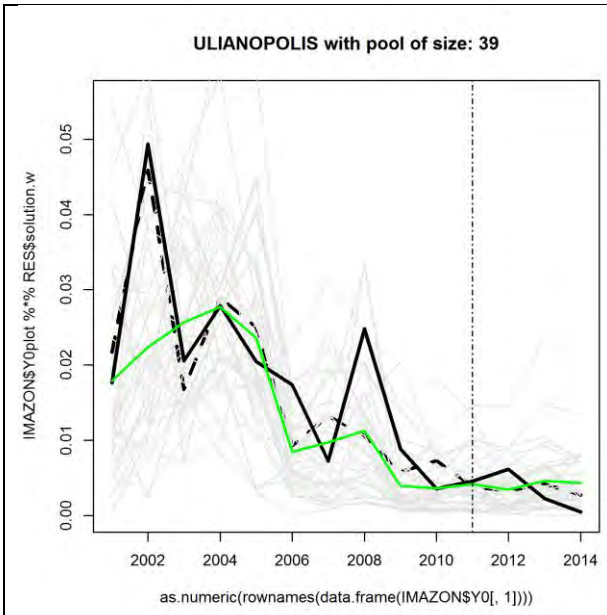
Annex 4 Impacts by Tenure Zone (local, eligible for CAR, other)

SCM Plots by Tenure Zone for the IMAZON10

Municipality	Year joined
Blacklist	
Brasil Novo	2012
Dom Eliseu	2011
Moju	2013
Novo Progresso	2012
Novo Repartimento	2012
Santana do Araguaia	2012
Tailandia	2011
Ulianopolis	2011
Non-blacklist	
Monte Alegre	2012
Santarem	2012

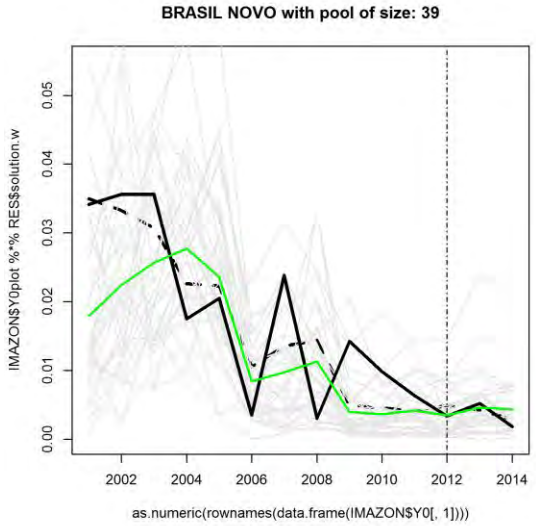
Deforestation in CAR eligible area (CAR I) of blacklisted municipalities

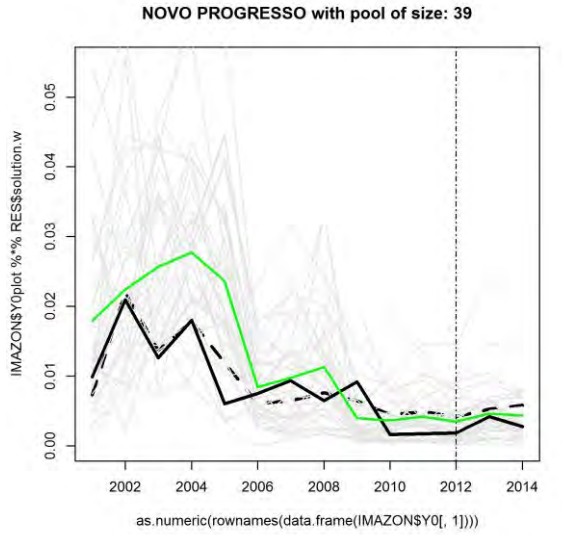
Joined IMAZON10 in 2011:	
	

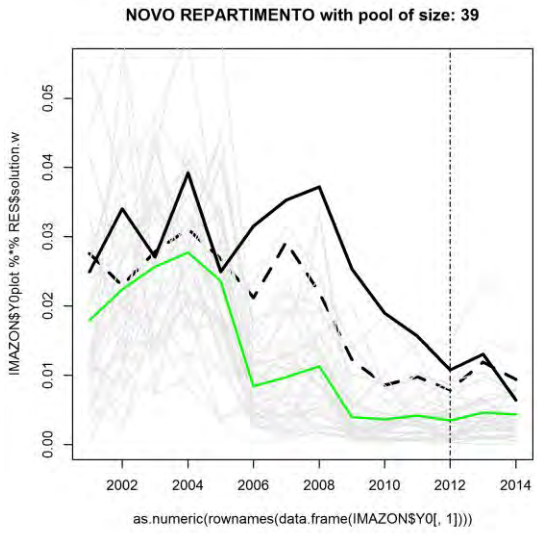


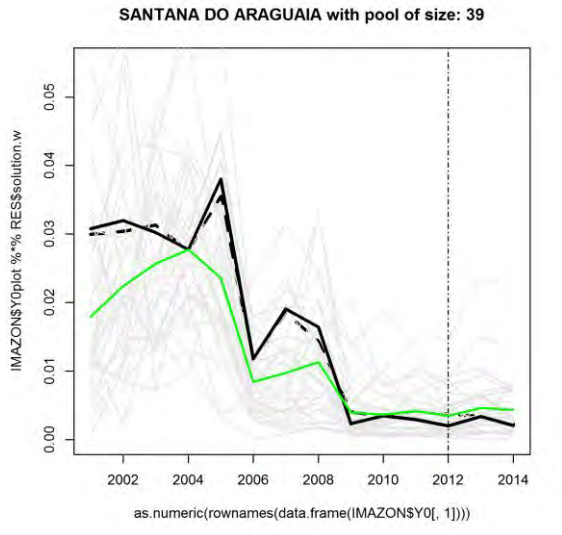
For treatment in 2011, the empirical 90% confidence interval is from -0.00488 to 0.002786 for 2013 and from -0.0032 to 0.003529 for 2014. None of the estimated effects are more negative than the 5th percentile of the placebo tests and thus none can be considered significantly different than zero.

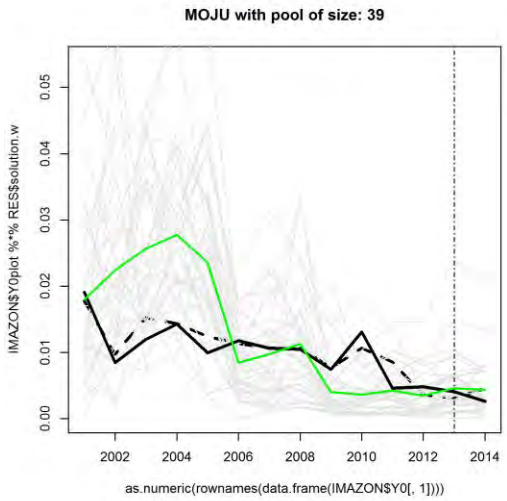
Joined IMAZON10 in 2012









Joined IMAZON10 in 2013:	
	For treatment inn 2013, empirical 90% confidence interval in 2013 is from -0.00327 to 0.00289 and in 2014 is from -0.0029 to 0.00315. Impact estimates for Moju fall within that range and are thus not significantly different from zero.